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AFRPL-TR-67-144

HYDROGEN PEROXIDE HANDBOOK

AD819081

By

Chemical and Material Sciences Department
Research Division
Rocketdyne, a Division of North American Aviation, Inc.
Canoga Park, California

Technical Report AFRPL-TR-67-144

July 1967

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Air Force Rocket Propulsion Laboratory
Research and Technology Division
Edwards Air Force Base, California
Air Force Systems Command
United States Air Force

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Air Force Rocket Propulsion Laboratory
Research and Technology Division
Edwards Air Force Base, California
Air Force Systems Command
United States Air Force

FOREWORD

This handbook is submitted as the final report under Rocketdyne G.O. 7108 in compliance with Contract AF04(611)-11397, Part I, Para. B.1, and line items 2 and 3 of DD 1423. The effort under this contract was sponsored by the Air Force Rocket Propulsion Laboratory, Research and Technology Division, Air Force Systems Command, USAF, Edwards, California, with 1/Lt. Ralph Fargnoli acting as the Air Force Project Officer.

This program was conducted by the Propellant Technology function of the Rocketdyne Research Division, with Dr. E. F. C. Cain serving as Program Manager and Mr. M. T. Constantine serving as Responsible Project Scientist. Technical personnel who contributed to the compilation and analysis of the data and information in this handbook include M. M. Williams and K. J. Youel.

This handbook has been assigned the Rocketdyne identification number R-6931.

This report has been reviewed and is approved.

W. H. EBELKE, Colonel, USAF
Chief, Propellant Division

ABSTRACT

This handbook is a compilation of the engineering properties and handling characteristics of propellant-grade hydrogen peroxide. The handbook includes data and information on hydrogen peroxide physicochemical properties, production, storability, materials compatibility, materials treatment and passivation, facilities and equipment, disposal, transportation, safety, and decomposition.

ACKNOWLEDGMENT

This handbook includes data and information generated through experimental and analytical studies conducted at many different organizations. Although every effort has been made to reference these studies, a great number of individuals responsible for these data have been neglected. These individual contributions as well as the contributions of the industry and government organizations are gratefully acknowledged.

Appreciation is also gratefully extended to the various organizations who responded to a request for data and information during an industry survey. These organizations (with the responding individual noted) are as follows:

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D. Coucl

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SECTION 1: INTRODUCTION

1.1 GENERAL

The discovery of hydrogen peroxide was reported to the Paris Academy of Sciences in July 1818 by Louis-Jacques Thenard and was initially described as oxidized water. The discovery was a result of government-subsidized research on the preparation of voltaic cells. Thenard, in working with alkaline earth oxides, discovered that the reaction of barium peroxide with cold nitric acid resulted in the formation of "oxygenated water." Thenard then conducted a fairly extensive study of hydrogen peroxide, which included catalytic decomposition studies, density determinations, measurements of the volume of oxygen released, etc. He noted extensive supercooling and the inability to achieve appreciable concentration increases with crystallization techniques. Thenard also reported that vacuum distillation could continue to complete dryness in the reservoir without appreciable decomposition, although the determination of normal boiling points was impossible because of decomposition of the hydrogen peroxide. His work led to the publication of several papers, which are extensively summarized in Ref. 1.1.

In his work, Thenard cites reactions with some 130 elements, oxides, salts, acids, and bases with frequent notations of decomposition of the hydrogen peroxide. These decomposition reactions were sometimes accompanied with the note that "in these decompositions, chemical action is evidently missing; it is necessary then, to attribute these actions to a physical cause; but the actions are dependent on neither heat nor light, whence it follows that they are probably due to electricity" (Ref. 1.1). These "unexplained" reactions were later recognized by Berzelius (Ref. 1.2) in 1836 in the first notation of catalysts and catalytic activity.

Although Thenard's only noted uses for hydrogen peroxide were in removing sulfide deposits on oil paintings and as a skin irritant for medicinal purposes, hydrogen peroxide and its aqueous solutions have found a number of commercial applications since its discovery. The primary bulk of this commercial use is limited to hydrogen peroxide grades of less than 52 percent H_2O_2 by weight; these "industrial grades" have been used for many years in textile and pulp bleaching, synthesis of chemical derivatives, the manufacture of foam rubber, the oxidation of dyes, the purification of metal salt solutions, the treatment of metal surfaces, etc. The requirement for higher concentrations and their subsequent commercial development was based primarily on the establishment of hydrogen peroxide as a source of energy.

Hydrogen peroxide (in a 60 w/o aqueous solution) was first utilized as an energy source for underwater propulsion in Germany in 1934; this work led to its subsequent application (in higher concentrations) during World War II for auxiliary propulsion and gas generation concepts in aircraft and rockets. Its use in these areas resulted from its thermally or catalytically initiated exothermic decomposition (with substantial heat release) to yield a gaseous mixture of oxygen and superheated steam. Although its advantages as a monopropellant include a 47 w/o available oxygen content, high density, high boiling point, unlimited availability, and nontoxic exhaust gases, the initial areas of application for hydrogen peroxide were limited because of its questionable storage stability.

The use of hydrogen peroxide has been expanded with improvements in its stability, through stabilization additives and increased purification. Currently, hydrogen peroxide is the primary monopropellant used for underwater propulsion, aerospace propulsion, and auxiliary power concepts. Hydrogen peroxide/water solutions can now be stored for extended periods without significant decomposition (i.e., decomposition rates of < 0.1 percent/year

are readily attainable). Reaction control systems using hydrogen peroxide have already demonstrated space storability in excess of 2 years (with an estimated storability of 5 years).

The use of hydrogen peroxide as a monopropellant in the aerospace industry has been widespread in the areas of station maintenance, space maneuvering, thrust vector control, power generation, etc. Some examples of systems which have used or are presently utilizing hydrogen peroxide include the V-2 (gas generator), Redstone (gas generator), Mercury Spacecraft (reaction control system), Scout (reaction control system--2nd and 3rd stages), Little Joe II (reaction control system), Burner II (reaction control system), SATAR (reaction control system), ASSET (reaction control system), 122Y (attitude control system), Lunar Landing Simulator (main propulsion and attitude control systems), Astronaut Maneuvering Unit (main propulsion), SYNCOM (reaction control system), COMSAT (reaction control system), HS-303A "Blue Bird" (reaction control system), ATS (reaction control system), Personnel Rocket Belt, and X-15 (gas generator, reaction control, and auxiliary power systems). Although the use of hydrogen peroxide in operational bipropellant systems has been limited thus far to extremely high-performance aircraft rockets, hydrogen peroxide is potentially applicable to a variety of liquid bipropellant and hybrid propellant systems.

This widespread application potential of hydrogen peroxide has led to the requirement for a comprehensive and definitive compilation of physical, chemical, and handling properties of this important oxidizer. As a result of this interest, this handbook represents a current summary of the engineering properties of propellant-grade hydrogen peroxide. Propellant-grade hydrogen peroxide is defined in this report as high-purity hydrogen peroxide/water solutions in which the hydrogen peroxide concentration is $\geq$ 70 percent by weight. Within this concentration

range of interest, solutions containing 70, 75, 90, 95, 98, and 100 percent by weight hydrogen peroxide have been designated as concentrations of special interest.

1.2 HANDBOOK FORMAT

The material contained in this handbook has been organized into sections. These are:

Section 1: Introduction

Section 2: Physico-Chemical Properties

Section 3: Production

Section 4: Storage and Handling

Section 5: Transportation

Section 6: Safety

Section 7: Decomposition, Stabilization, and Catalysts

Section 8: Bibliography

Each section is subdivided further to permit the user of this handbook to obtain specific information expeditiously. The material is arranged in such a manner as to permit convenient updating of various sections as data are generated from additional studies in these areas.

The interest of each individual user may be limited to specific aspects of the subject material; however, it is recommended that personnel involved in H_2O_2 handling be thoroughly familiar with all of the engineering properties contained in this report. Although every effort has been made to provide presently available information on H_2O_2 in sufficient detail for most of the potential users of the handbook, size limitations of the handbook obviously preclude inclusion of every conceivable detail.

Thus, for those users who desire additional details on specific items, consultation of the many referenced publications is recommended.

Wherever a series of reports or papers has been utilized to report the progress in a particular study, the data and information referenced are from final reports, whenever applicable. This was done to eliminate confusion in efforts where progress reports included incomplete experimentation and/or analysis of the data. In those efforts where a final report has not been issued or does not contain sufficient detail of the item, the data were taken from the latest progress report containing the pertinent results.

The tables figures, and references noted in each section are contained in that section for convenience. Each table, figure, and reference number is preceded by the section number (i.e., Table 1.3 is the third table in Section 1, etc.).

Because the major portion of this handbook is related to areas of engineering interest, all of the data ar presented in engineering terminology (i.e., English units). However, as a convenience to all of the users, data in certain sections (notably, the physical properties section) of the handbook are presented in both metric and English units. Where data are presented in both units, the attendant discussion indicates the units of the referenced work.

As a further convenience to the user, physical constants and conversion factors are presented in Tables 1.1 through 1.3 to enable the user to convert the values to his particular needs. Also, because these constants are presented to the known degree of significance, they can be rounded to fit particular needs.

1.3 REFERENCES

1.1 Schumb, W. C., C. N. Satterfield, and R. L. Wentworth, Hydrogen Peroxide, A.C.S. Monograph 128, Reinhold Publishing Corporation, New York, New York, 1955.

1.2 Berzelius, J. J., Jahresber. Chem., 15, 237 (1836), as presented in Ref. 1.1.

TABLE 1.1

PHYSICAL CONSTANTS

Unit	Remarks	Value
g_c	Standard gravitational acceleration	32.1740 ft/sec^2 980.665 cm/sec^2
1 atm	Standard atmosphere	1,013,250 dynes/sq cm
1 mm Hg	Standard millimeter Hg	1333.2237 dynes/sq cm
1 cal	Thermochemical calorie	4.1840 abs joules 41.2929 ±0.0020 cu cm-atm
1 cal (I. T.)	International Stream Tables calorie	1.000654 thermochemical calories
T_0 C	Ice Point	491.6880 ±0.018 R 273.160 ±0.010 K
$(pV)^{P=0}_{0\ C} - (RT)_{0\ C}$	Pressure-Volume product for ideal gas at 0 C	22,414.6 ±0.4 cu cm-atm/g mole 2271.16 ±0.04 abs joules/g mole
R	Molar gas constant	8.31439 ±0.00034 abs joules/K-g mole 1.98719 ±0.00013 cal/K-g mole 82.0567 ±0.0034 cu cm-atm/K-g mole 59.47 cu ft-atm/R-lb mole 10.73 cu ft-psia/R-lb mole
1 Btu		1055.040 abs joules 252.161 thermochemical calories 251.996 I. T. calories
1 in.	United States unit	2.54000508 cm
1 ft	United States unit	30.4800610 cm
1 lb	Avoirdupois	453.5924277 g
1 gal	United States unit	0.133680555 cu ft 3785.43449 cu cm

Note: Compiled by Rossini, F. D. et al., American Petroleum Institute Research Project 44, U.S. Department of Commerce, Natl. Bur. Standards, Circular 461, U.S. Government Printing Office, Washington, D. C., 1947.

CONVERSION FACTORS

Temperature

C + 273.16 = K

F + 459.69 = R

(C x 1.8) + 32 = F

(F - 32)/1.8 = C

K(1.8) = R

Pressure

atm x 14.69618 = psi

mm Hg x 0.00131579 = atm

mm Hg x 0.019337 = psi

g/sq cm x 0.00096784 = atm

g/sq cm x 0.0142234 = psi

bars x 0.98692 = atm

bars x 14.504 = psi

megabaryes x 1 = bars

Mass

grams (mass) x 0.002204622 = pounds (mass)

Length

centimeters x 0.393700 = inches

centimeters x 0.032808 = feet

Area

square centimeters x 0.15500 = square inches

square centimeters x 0.0010764 = square feet

square feet x 144 = square inches

TABLE 1.2

(Concluded)

Viscosity

centipoises x 0.672×10^{-3} = lb_f/ft-sec

centistokes x 1.076×10^{-5} = sq ft/sec

(kinematic viscosity) x (density) = (absolute) viscosity

Thermal Conductivity

(cal/cm-sec-C) x 241.8588 = Btu/ft-hr-F

Velocity of Sound

(m/sec) x 3.28083 = ft/sec

Compressibility

(sq cm/dyne) x 1.01325×10^{6} = atm^{-1}

(sq cm/dyne) x 6.8947×10^{4} = psi^{-1}

TABLE 1.2
(Continued)

Volume

cubic centimeters x 0.061023 = cubic inches
cubic centimeters x 3.531445×10^{-5} = cubic feet
cubic inches (U.S.) x 5.78704×10^{-4} = cubic feet

Time

seconds/60 = minutes
seconds/3600 = hours
seconds/86,400 = days

Force

dynes x 0.00101972 = grams (force)
grams (force) x 0.00220462 = pounds (force)

Density and Specific Volume

(g/cu cm) x 62.43 = lb/cu ft
(cu cm/g) x 0.016018 = cu ft/lb

Surface Tension

(dynes/cm) x 6.8523×10^{-5} = lb_f/ft

Thermodynamic Properties

(cal/g mole) x 1.8 = Btu/lb mole
(cal/g mole- K) x 1 = Btu/lb mole - R
(Btu/lb mole)/mol. wt = Btu/lb
(Btu/lb mole- R)/mol. wt = Btu/lb - R
(Cal/g) x 1.8 = Btu/lb

TABLE 1.3

TEMPERATURE CONVERSION

Interpolation Factors		
C	X	F
0.56	1	1.8
1.11	2	3.6
1.67	3	5.4
2.22	4	7.2
2.78	5	9.0
3.33	6	10.8
3.89	7	12.6
4.44	8	14.4
5.00	9	16.2
5.56	10	18.0

Temperature Range																							
-459 to 0			0 to 50			50 to 100			100 to 490			500 to 1000			1000 to 1490			1500 to 2000					
C	Y	F	C	Y	F	C	Y	F	C	Y	F	C	Y	F	C	Y	F	C	Y	F			
-273	-459		-17.8	0	32.0	10.0	50	122.0	38	100	212	260	500	932	538	1000	1832	816	1500	2732			
-268	-450		-17.2	1	33.8	10.6	51	123.8	43	110	230	266	510	950	543	1010	1850	821	1510	2750			
-262	-440		-16.7	2	35.6	11.1	52	125.6	49	120	248	271	520	968	549	1020	1868	827	1520	2768			
-257	-430		-16.1	3	37.4	11.7	53	127.4	54	130	266	277	530	986	554	1030	1886	832	1530	2786			
-251	-420		-15.6	4	39.2	12.2	54	129.2	60	140	284	282	540	1004	560	1040	1904	838	1540	2804			
-246	-412		-15.0	5	41.0	12.8	55	131.0	66	150	302	288	550	1022	566	1050	1922	843	1550	2822			
-240	-400		-14.4	6	42.8	13.3	56	132.8	71	160	320	293	560	1040	571	1060	1940	849	1560	2840			
-234	-390		-13.9	7	44.6	13.9	57	134.6	77	170	338	299	570	1058	577	1070	1958	854	1570	2858			
-229	-380		-13.3	8	46.4	14.4	58	136.4	82	180	356	304	580	1076	582	1080	1976	860	1580	2876			
-223	-370		-12.8	9	48.2	15.0	59	138.2	88	190	374	310	590	1094	588	1090	1994	866	1590	2894			
-218	-360		-12.2	10	50.0	15.6	60	140.0	93	200	392	316	600	1112	593	1100	2012	871	1600	2912			
-212	-350		-11.7	11	51.8	16.1	61	141.8	99	210	410	321	610	1130	599	1110	2030	877	1610	2930			
-207	-340		-11.1	12	53.6	16.7	62	143.6	100	212	414	327	620	1148	604	1120	2048	882	1620	2948			
-201	-330		-10.6	13	55.4	17.2	63	145.4	104	220	428	332	630	1166	610	1130	2066	888	1630	2966			
-196	-320		-10.0	14	57.2	17.8	64	147.2	110	230	446	338	640	1184	616	1140	2084	893	1640	2984			
-190	-310		- 9.44	15	59.0	18.3	65	149.0	116	240	464	343	650	1202	621	1150	2102	899	1650	3002			
-184	-300		- 8.89	16	60.8	18.9	66	150.8	121	250	482	349	660	1220	627	1160	2120	904	1660	3020			
-179	-290		- 8.33	17	62.6	19.4	67	152.6	127	260	500	354	670	1238	632	1170	2138	910	1670	3038			
-173	-280		- 7.78	18	64.4	20.0	68	154.4	132	270	518	360	680	1256	638	1180	2156	916	1680	3056			
-169	-273	-459	- 7.22	19	66.2	20.6	69	156.2	138	280	536	366	690	1274	643	1190	2174	921	1690	3074			
-168	-270	-454	- 6.67	20	68.0	21.1	70	158.0	143	290	554	371	700	1292	649	1200	2192	927	1700	3092			
-162	-260	-436	- 6.11	21	69.8	21.7	71	159.8	149	300	572	377	710	1310	654	1210	2210	932	1710	3110			
-157	-250	-418	- 5.56	22	71.6	22.2	72	161.6	154	310	590	382	720	1328	660	1220	2228	938	1720	3128			
-151	-240	-400	- 5.00	23	73.4	22.8	73	163.4	160	320	608	388	730	1346	666	1230	2246	943	1730	3146			
-146	-230	-382	- 4.44	24	75.2	23.3	74	165.2	166	330	626	393	740	1364	671	1240	2264	949	1740	3164			
-140	-220	-364	- 3.89	25	77.0	23.9	75	167.0	171	340	644	399	750	1382	677	1250	2282	954	1750	3182			
-134	-210	-346	- 3.33	26	78.8	24.4	76	168.8	177	350	662	404	760	1400	682	1260	2300	960	1760	3200			
-129	-200	-328	- 2.78	27	80.6	25.0	77	170.6	182	360	680	410	770	1418	688	1270	2318	966	1770	3218			
-123	-190	-310	- 2.22	28	82.4	25.6	78	172.4	188	370	698	416	780	1436	693	1280	2336	971	1780	3236			
-118	-180	-292	- 1.67	29	84.2	26.1	79	174.2	193	380	716	421	790	1454	699	1290	2354	977	1790	3254			
-112	-170	-274	- 1.11	30	86.0	26.7	80	176.0	199	390	734	427	800	1472	704	1300	2372	982	1800	3272			
-107	-160	-256	- 0.56	31	87.8	27.2	81	177.8	204	400	752	432	810	1490	710	1310	2390	988	1810	3290			
-101	-150	-238	0	32	89.6	27.8	82	179.6	210	410	770	438	820	1508	716	1320	2408	993	1820	3308			
- 95.6	-140	-220	0.56	33	91.4	28.3	83	181.4	216	420	788	443	830	1526	721	1330	2426	999	1830	3326			
- 90.0	-130	-202	1.11	34	93.2	28.9	84	183.2	221	430	806	449	840	1544	727	1340	2444	1004	1840	3344			
- 84.4	-120	-184	1.67	35	95.0	29.4	85	185.0	227	440	824	454	850	1562	732	1350	2462	1010	1850	3362			
- 78.9	-110	-166	2.22	36	96.8	30.0	86	186.8	232	450	842	460	860	1580	738	1360	2480	1016	1860	3380			
- 73.3	-100	-148	2.78	37	98.6	30.6	87	188.6	238	460	860	466	870	1598	743	1370	2498	1021	1870	3398			
- 67.8	- 90	-130	3.33	38	100.4	31.1	88	190.4	243	470	878	471	880	1616	749	1380	2516	1027	1880	3416			
- 62.2	- 80	-112	3.89	39	102.2	31.7	89	192.2	249	480	896	477	890	1634	754	1390	2534	1032	1890	3434			
- 56.7	- 70	- 94	4.44	40	104.0	32.2	90	194.0	254	490	914	482	900	1652	760	1400	2552	1038	1900	3452			
- 51.1	- 60	- 76	5.00	41	105.8	32.8	91	195.8				488	910	1670	766	1410	2570	1043	1910	3470			
- 45.6	- 50	- 58	5.56	42	107.6	33.3	92	197.6				493	920	1688	771	1420	2588	1049	1920	3488			
- 40.0	- 40	- 40	6.11	43	109.4	33.9	93	199.4				499	930	1706	777	1430	2606	1054	1930	3506			
- 34.4	- 30	- 22	6.67	44	111.2	34.4	94	201.2				504	940	1724	782	1440	2624	1060	1940	3524			
- 28.9	- 20	- 4	7.22	45	113.0	35.0	95	203.0				510	950	1742	788	1450	2642	1066	1950	3542			
- 23.3	- 10	14	7.78	46	114.8	35.6	96	204.8				516	960	1760	793	1460	2660	1071	1960	3560			
- 17.8	0	32	8.33	47	116.6	36.1	97	206.6				521	970	1778	799	1470	2678	1077	1970	3578			
			8.89	48	118.4	36.7	98	208.4				527	980	1796	804	1480	2696	1082	1980	3596			
			9.44	49	120.2	37.2	99	210.2				532	990	1814	810	1490	2714	1088	1990	3614			
			10.00	50	122.0	37.8	100	212.0				538	1000	1832				1093	2000	3632			

SECTION 2: PHYSICO-CHEMICAL PROPERTIES

2.1 GENERAL DESCRIPTION

Hydrogen peroxide is a chemical compound with the empirical formula H_2O_2. Because of the compound's complete miscibility with water above 32 F, hydrogen peroxide is commercially available in aqueous solutions at concentrations to ~98 percent by weight H_2O_2. Propellant-grade hydrogen peroxide has generally been limited to aqueous solutions ≥ 70 w/o H_2O_2 with regulation of the concentrations and impurity levels of the more frequently applied propellant grades by government procurement specifications.

Hydrogen peroxide and its aqueous solutions are water-like in appearance in both the liquid and solid states. Although hydrogen peroxide is generally considered odorless, the odor of high vapor concentrations has been described as sweet and comparable to the odor of weak concentrations of ozone and the halogens. Aqueous hydrogen peroxide solutions are more dense, slightly more viscous, and have higher boiling and lower freezing points than water.

Although hydrogen peroxide solutions are normally insensitive to shock and impact and are nonflammable, they are active oxidizing materials and can decompose exothermally to yield water and oxygen. Because of their strong oxidizing nature and the liberation of oxygen and heat during their decomposition, propellant-grade solutions can initiate the vigorous combustion of many common organic materials such as clothing, wood, wastes, etc. In the absence of contamination, propellant-grade hydrogen peroxide solutions are relatively stable (nominal decomposition rates are 0.1 percent per year) over ambient temperature ranges. However, in the presence of higher temperatures and/or various contaminants (including many inorganic materials), the decomposition rate is

drastically increased. Rapid decomposition can occur in situations where extreme temperature levels and/or mass contamination are present. As the decomposition rate increases, the attendant heat release causes additional decomposition; this bootstrap effect can lead to a runaway reaction.

Hydrogen peroxide is normally stored, shipped, and handled as a liquid under its own vapor pressure with provisions for relief of pressure buildup. When stored and/or transferred in clean, passivated, compatible systems by properly educated and trained personnel, hydrogen peroxide does not present a serious storage or handling problem.

2.2 PHYSICAL PROPERTIES

A majority of the physical properties of propellant-grade solutions of hydrogen peroxide have been experimentally characterized (or analytically extrapolated) with a reasonable degree of accuracy over ambient temperature ranges. However, because of the increasing decomposition rates of these propellant solutions with increase in temperature, very few measurements have been conducted above 200 F. In addition, the accuracy of data is questionable in temperature ranges where decomposition rates are relatively high. This is evident in the discontinuity of some of the data at the higher temperature ranges.

It should also be noted that the data reported for "pure" (or 100 w/o) H_2O_2 is questionable since there is some doubt as to the existence of H_2O_2 concentrations above 99.7 to 99.8 w/o. Some of the data reported for 100 w/o H_2O_2 were obtained by extrapolation of property data of H_2O_2 solutions of lower concentration, while other experimental measurements reported on "100 w/o" H_2O_2 indicated propellant assays of "99+ percent," "99 ±0.5 percent," etc. Even for most of those studies which report the H_2O_2 concentrations,

the methods of determining these concentrations are not reported or are based on an assumption of purity related to the purification technique.

Although it is suspected (because of discontinuities in the data) that many of the measurements on the "100 w/o" H_2O_2 represent, in reality, measurements on H_2O_2 of lower concentrations, properties are reported for 100 w/o H_2O_2 wherever an extrapolation (from lower concentrations) seems reasonable. This characterization is of academic interest only because ~ 98 w/o H_2O_2 is the highest concentration presently available commercially. Future aerospace industry utilization of higher concentrations appears unlikely because of practical and economical considerations.

Nominal values for physical property data that are recommended as the most representative of the existing data are summarized for the "100", 98, 95, 90, 75, and 70 w/o hydrogen peroxide grades in Table 2.1. All of the data presented are direct experimental determinations or are derived from curve-fits of the experimental data, except for those data referenced with an asterisk; the data referenced with an asterisk were a result of calculations made during the referenced work and based on standard analytical correlations and physical relationships. The absence of data on a particular property is denoted by blank spaces in the tables.

Properties for which property-temperature relationships have been established are noted in Table 2.1 with a figure or another table number; the corresponding property-temperature relationships are shown in Fig. 2.1 through 2.23a and Tables 2.2 through 2.17. The graphical illustrations represent either curve-fits of the best available experimental data or analytical estimations of the property; curve-fits of experimental data are noted with a solid line, while a dashed line designates calculated data. Equations

resulting from computer curve-fits of some of the data are presented in attendant discussions.

The origin of the selected data is referenced in each table and figure. A brief discussion of the available data for each property is presented in the following paragraphs.

2.2.1 General Identification

The physical classifications under general identification are those properties that are used to identify hydrogen peroxide and its physical state.

2.2.1.1 Molecular Weight. The molecular weight of hydrogen peroxide was experimentally determined by freezing point depression (Ref. 2.1 and 2.2) and vapor density (Ref. 2.3) measurements. The results of these studies are comparable to the value of 34.016 calculated from the International Atomic Weights. The mole percent and apparent molecular weight as a function of weight percent H_2O_2 for various aqueous solutions of H_2O_2, as shown in Fig. 2.1, were calculated from the molecular weights of H_2O and H_2O_2 based on the International Atomic Weights.

2.2.1.2 Freezing Point. The determination of freezing and melting points of H_2O_2-H_2O solutions is relatively difficult because of the large degree of supercooling possible with these solutions. In addition, phase equilibrium measurements (Ref. 2.2) have indicated that solid solutions are not formed in the solidification of concentrated (greater than 65 w/o H_2O_2) aqueous solutions of H_2O_2; instead, the solid consists of crystals of H_2O_2 with occluded mother liquid. Thus, the range of temperatures over which the material melts or freezes is a function of the crystallization pattern of the H_2O_2.

The freezing point of "100 percent" H_2O_2 has been reported as -0.461 C (31.17 F), -0.43 C (31.23 F), and -0.41 C (31.26 F) in Ref. 2.2, 2.4, and 2.5, respectively. Based on a reported sample purity of 99.97 m/o H_2O_2, the freezing point determination of Ref. 2.4 was selected as representative of 100 percent H_2O_2. Measurements of the freezing points of aqueous solutions of H_2O_2 (Ref. 2.2) indicate eutectics at 45.2 w/o H_2O_2 and -52.4 C (-62.3 F), and at 61.2 w/o H_2O_2 and -56.5 C (-69.7 F). The results of these measurements, which are graphically illustrated in Fig. 2.2 and 2.2a, represent the temperatures at which 20 to 30 percent of the liquid had solidified. Experimental melting point studies (Ref. 2.6), based on observation of the temperature at which melting was complete, resulted in slightly higher melting temperatures for concentrations above 60 w/o H_2O_2.

A variety of experimental studies have produced no significantly effective freezing point depressants for propellant-grade H_2O_2 solutions. These studies, described in detail in Ref. 2.3 and 2.6 through 2.9, have shown that many additives will form unstable or shock-sensitive mixtures with H_2O_2.

2.2.1.3 Triple Point. The triple point of 99.97 m/o H_2O_2 was estimated as 272.74 K (-0.42 C or 31.24 F) from experimental heat of fusion studies (Ref. 2.5). Although no vapor pressure measurements have been made on solid H_2O_2, the vapor pressure at the triple point has been calculated (Ref. 2.10) as 0.26 mm Hg (0.005 psia).

2.2.1.4 Normal Boiling Point. The normal boiling points of propellant-grade H_2O_2 solutions have not been experimentally determined by conventional means since these points are in a temperature region where thermal decomposition of the H_2O_2 is significant. The normal boiling points listed in Table 2.1 and Fig. 2.3

for propellant-grade H_2O_2-H_2O solutions represent extrapolations of the vapor pressure data of Section 2.2.2.4 to 1 atmosphere of pressure. Other references (i.e., Ref. 2.11 and 2.12) give very similar boiling points even though these temperatures were calculated from extrapolations of different individual sets of vapor pressure data. The correlation of these individual sets of data, which results in the newly calculated normal boiling points, is discussed in Section 2.2.2.4.

2.2.1.5 Critical Properties. There has been no experimental determinations of critical properties of H_2O_2 since the compound undergoes extensive decomposition before the critical temperature is achieved. However, because this property is of academic interest, the critical temperature has been estimated by assuming that the critical temperature/boiling point ratio of H_2O_2 is equal to that of water. Based on this technique, a critical temperature (T_c) of 458.8 C (857.8 F) has been reported for 100 w/o H_2O_2 (Ref. 2.11); another T_c value of 457 C (855 F) for 100 w/o H_2O_2, which was alluded to in Ref. 2.12, was reported in Ref. 2.10. Using a vapor pressure equation established in Ref. 2.12, the critical pressure, P_c, was calculated (Ref. 2.10) as 214 atmospheres (3140 psia) at the latter T_c.

Using the estimated boiling point given in Table 2.1 and correlation technique described above, a T_c of 733 K (460 C, 860 F) is recommended for 100 w/o H_2O_2. An estimation technique suggested in Ref. 2.12 (P_c/T_c is equivalent for both H_2O_2 and H_2O) resulted in a calculated and recommended P_c of 247 atmospheres (3630 psia) for 100 w/o H_2O_2 using the T_c value of 733 K. Pseudocritical constants were calculated for the propellant-grade H_2O_2-H_2O solutions through the use of Kay's method (Ref. 2.13); the results of these calculations are shown in Table 2.1 and in Fig. 2.3.

2.2.2 Phase Properties

Those properties of hydrogen peroxide, which are associated with one particular phase (either solid, liquid, or gas) have been grouped as phase properties.

2.2.2.1 Density. A density of 1.70 gm/cc (106.76 lb/cu ft) was computed for solid 100-percent H_2O_2 from X-ray diffraction measurements (Ref. 2.14) at -20 C (-4 F). Density measurements on H_2O_2-H_2O solutions during cooling and freezing (Ref. 2.15) indicated that true solid solutions of H_2O_2 and H_2O were not formed; this was later verified in Ref. 2.2. Since the occlusion of the mother liquor occurred in freezing, the measured densities were a function of the freezing technique. However, it was noted (Ref. 2.15) that solutions containing < 45 w/o H_2O_2 expand during freezing and solutions > 65 w/o H_2O_2 contract during freezing.

Experimental determinations of the liquid densities of various H_2O_2-H_2O solutions were reported as a function of composition in Ref. 2.6 (at 0 and 18 C), Ref. 2.15 (at 0 C), Ref. 2.16 (at 20 C), and Ref. 2.17 (at 0, 10, 25, 50, and 96 C). In addition, experimental studies have determined the density of 90 w/o H_2O_2 from 76 to 193 C (Ref. 2.18), and the density of 98 w/o H_2O_2 from 27 to 105 C (Ref. 2.19). The data from these six studies were simultaneously curve fitted by a least-squares computer program, and the following equation was found to adequately (actual deviation for each experimental point was < 0.002 gm/cc) describe the data from 0 to 193 C (32 to 379 F) over a concentration range of 60 to 100 w/o H_2O_2.

$$\rho_{(gm/cc)} = 1.0479 + 2.455 \times 10^{-3}W + 1.781 \times 10^{-5}W^2 - 6.76 \times 10^{-4}T_{(C)} - 2.4 \times 10^{-7}T_{(C)}^2 - 3.98 \times 10^{-6}WT_{(C)}$$

where W is weight percent H_2O_2.

Converting to English units, this equation becomes:

$$\rho_{(lb/cu\ ft)} = 66.166 + 1.577 \times 10^{-1}W + 1.112 \times 10^{-3}W^2 - 2.31 \times 10^{-2}T_{(F)} - 4.7 \times 10^{-6}T_{(F)}^2 - 1.38 \times 10^{-4}WT_{(F)}$$

The curves described by these equations are graphically illustrated for propellant-grade H_2O_2 solutions in Fig. 2.4 and 2.4a, respectively.

Experimental vapor density measurements (Ref. 2.3) at 92 C (165.6 F) show that H_2O_2 is not associated in the vapor state. If it is assumed that no decomposition occurs, the vapor density may be calculated through use of the perfect gas law.

2.2.2.2 Coefficient of Thermal Expansion. Using the curve fits of the density data, the coefficients (cubical) of thermal expansion were calculated for propellant-grade H_2O_2-H_2O solutions from 0 to 100 C (32 to 212 F) through the following relationship:

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial t}\right)_P$$

Curve fits of these calculations are presented in Fig. 2.5 and 2.5a.

2.2.2.3 Compressibility. The adiabatic compressibilities of H_2O_2 solutions were calculated (Ref. 2.16) from experimental density and sonic velocity data covering a temperature range of 3.5 to 33.5 C (38.3 to 92.3 F) and a concentration range of 0 to 93.4 m/o (0 to 96.5 w/o). These data were used to plot the adiabatic compressibilities of propellant-grade H_2O_2 solutions shown in Fig. 2.6 and 2.6a.

Although no experimental data have been reported on the isothermal compressibility of H_2O_2, the adiabatic compressibility, density, and heat capacity data were used to calculate (Ref.2.16) an isothermal compressibility of 26.514×10^{-12} $cm^2/dyne$ (26.865×10^{-6} atm^{-1}, 18.281×10^{-5} $psia^{-1}$) for 100 w/o H_2O_2 at 20 C (68 F).

2.2.2.4 Vapor Pressure. The vapor pressure data resulting from four different experimental measurements (Ref. 2.11, 2.12, 2.20, and 2.21) on various aqueous solutions of H_2O_2 over temperature ranges of 0 to 90 C (32 to 194 F) have been correlated. Using a least squares curve-fit computer program, these data were curve-fitted with the following equations (in the metric system):

$$\underline{100 \text{ w/o } H_2O_2} \quad \log P_{(mm\ Hg)} = 8.92536 - \frac{2482.60}{T_{(K)}} - \frac{24675}{T_{(K)}^2}$$

$$\underline{98 \text{ w/o } H_2O_2} \quad \log P_{(mm\ Hg)} = 7.89728 - \frac{1797.84}{T_{(K)}} - \frac{134089}{T_{(K)}^2}$$

$$\underline{95\ w/o\ H_2O_2}\ \log P_{(mm\ Hg)} = 7.68235 - \frac{1647.17}{T_{(K)}} - \frac{154665}{T_{(K)}^2}$$

$$\underline{90\ w/o\ H_2O_2}\ \log P_{(mm\ Hg)} = 7.67297 - \frac{1606.47}{T_{(K)}} - \frac{157563}{T_{(K)}^2}$$

$$\underline{75\ w/o\ H_2O_2}\ \log P_{(mm\ Hg)} = 7.39108 - \frac{1351.86}{T_{(K)}} - \frac{185863}{T_{(K)}^2}$$

$$\underline{70\ w/o\ H_2O_2}\ \log P_{(mm\ Hg)} = 7.42560 - \frac{1354.10}{T_{(K)}} - \frac{181798}{T_{(K)}^2}$$

Converting these equations to English units resulted in the following:

$$\underline{100\ w/o\ H_2O_2}\ \log P_{(psia)} = 7.21175 - \frac{4468.68}{T_{(R)}} - \frac{79947}{T_{(R)}^2}$$

$$\underline{98\ w/o\ H_2O_2}\ \log P_{(psia)} = 6.18367 - \frac{3236.11}{T_{(R)}} - \frac{434448}{T_{(R)}^2}$$

$$\underline{95\ w/o\ H_2O_2}\ \log P_{(psia)} = 5.96874 - \frac{2964.91}{T_{(R)}} - \frac{501115}{T_{(R)}^2}$$

$$\underline{90\ w/o\ H_2O_2}\ \log P_{(psia)} = 5.95936 - \frac{2891.65}{T_{(R)}} - \frac{510504}{T_{(R)}^2}$$

$$75\ w/o\ H_2O_2\ \log P_{(psia)} = 5.67747 - \frac{2433.35}{T_{(R)}} - \frac{602196}{T_{(R)}^2}$$

$$\underline{70\ w/o\ H_2O_2}\ \log P_{(psia)} = 5.71199 - \frac{2437.38}{T_{(R)}} - \frac{589026}{T_{(R)}^2}$$

The equations are illustrated graphically in Fig. 2.7 and 2.7a, where the data are extrapolated to temperatures above 90 C (194 F) by assuming a linear relationship between the temperatures for which H_2O_2 solutions and water have the same vapor pressures. These extrapolations were used to determine the pseudo-boiling points (the temperatures where the pressures are equivalent to 760 mm Hg) of the propellant-grade H_2O_2 mixtures.

2.2.2.5 Vapor-Liquid Equilibrium. Vapor-liquid equilibrium compositions of H_2O_2-H_2O solutions were determined experimentally in two different studies (Ref. 2.12 and 2.21). Although comparable, there are slight differences in the data at some of the temperatures. The data of Ref. 2.12 were used in Ref. 2.22 to plot vapor composition and vapor-liquid equilibrium, and to calculate and plot activity coefficients for the system. These plots are shown in Fig. 2.8 through 2.10.

Calculations (Ref. 2.23) of saturation pressure, activity coefficients, and vapor compositions have been made for three different H_2O_2-H_2O solutions (90, 81.5, and 65.4 w/o) at high temperatures and pressures. The computation of these data, which are shown in Table 2.2, are described in detail in Ref. 2.23. Although these computations were based on assumptions of H_2O_2 critical constants that are different (critical temperature = 457 C, critical pressure = 215 atmospheres) from the values recommended in this handbook, corrections to Table 2.2 are slight.

2.2.2.6 Surface Tension. The surface tensions of H_2O_2-H_2O solutions have been experimentally determined (Ref. 2.24) as a function of composition at 0 C (32 F) and 20 C (68 F). Graphical representations of the data are shown in Fig. 2.11 and 2.11a.

2.2.3 Thermodynamic Properties

The H_2O_2 properties which define energy changes in the physical transitions through the various solid, liquid, and gas states, as well as in chemical changes, have been listed under thermodynamic properties.

2.2.3.1 Heat of Formation. The heats of formation (ΔH_F) of propellant-grade H_2O_2 solutions were calculated in this study from heat of dissociation data given in Ref. 2.25. Heat of fusion, heat of vaporization, heat of mixing, and heat capacity data used to characterize the heat of formation over a range of temperatures, phases, and concentrations are given in subsequent sections. Data for the aqueous solutions are presented as heats of formation of the solution (which includes the heat of formation contributions of both H_2O and H_2O_2, and the heat of mixing).

The ΔH_F data for the liquid and solid phases of propellant-grade H_2O_2 solutions are given in Tables 2.3 through 2.8 and Fig. 2.12 and 2.12a. Figures 2.13 and 2.13a illustrate the ΔH_F of the liquid at 25 C (77 F) as a function of composition. The heats of formation of the vapor of propellant-grade H_2O_2-H_2O solutions are given in Tables 2.9 through 2.14.

2.2.3.2 Heat of Fusion. The heats of fusion of propellant-grade H_2O_2 solutions were taken from the experimental studies of Ref. 2.2; these data are shown in Tables 2.3 through 2.8 as the change in enthalpy at the freezing point.

2.2.3.3 Heat of Vaporization. The experimental data of Ref. 2.26 were used to plot the heats of vaporization of H_2O_2-H_2O solutions as a function of temperature; curve-fits of the data at 0, 25, 45, and 60 C (32, 77, 113, and 140 F) are shown in Fig. 2.14

and 2.14a. Heats of vaporization of propellant-grade H_2O_2 solutions at other temperatures can be obtained by computing the difference in the heats of formation of the liquid (Tables 2.3 through 2.8) and vapor (Tables 2.9 through 2.14) phases of the H_2O_2-H_2O solutions at the corresponding temperatures and H_2O_2 concentrations.

2.2.3.4. Heat of Sublimation. The heat of sublimation of 100 w/o H_2O_2 has been calculated (Ref. 2.10) from the heats of fusion and vaporization as 457.8 cal/gm (824 Btu/lb).

2.2.3.5 Heat of Mixing. Graphical representations of the heats of mixing of propellant-grade H_2O_2-H_2O solutions, shown in Fig. 2.15 and 2.15a, were plotted from smoothed data given in Ref. 2.26. These data represent experimental data of the referenced work, previous experimental studies (Ref. 2.25), and their extrapolation to higher temperatures for comparison with the experimental data of Ref. 2.12. Excellent agreement is noted between the data of Ref. 2.26 and Ref. 2.12 except in the 20 to 30 w/o H_2O_2 concentration range.

2.2.3.6 Heat of Decomposition. The heats of decomposition, graphically represented in Fig. 2.16 and 2.16a, were converted from smoothed data from the experimental studies of Ref. 2.25. The figures illustrate the heats of decomposition of propellant-grade H_2O_2-H_2O solutions with decomposition to either liquid water or water vapor.

2.2.3.7 Heat Capacity. The heat capacities of solid and liquid propellant-grade H_2O_2-H_2O solutions are shown in Tables 2.8 through 2.13 and in Fig. 2.17 and 2.17a from 0 to 400 K (0 to 720 R). The

heat capacities of solid H_2O_2 were taken from the data of Ref. 2.5. Since solid solutions of H_2O_2 and H_2O are not formed in the concentration region of interest, the heat capacities of the solid phases of propellant-grade H_2O_2-H_2O solutions were assumed to be the sum of the individual heat capacity contributions of solid H_2O and solid H_2O_2.

The liquid heat capacities were curve-fitted from the experimental data of Ref. 2.25 and 2.26; these studies indicated that the change in heat capacity of an H_2O_2-H_2O solution of constant composition over the indicated temperature range was of the order of the accuracy of the experimental data. Experimental measurements of liquid heat capacity were not conducted below 0 C (32 F); therefore, the heat capacity was estimated in this region using the heat capacity of supercooled H_2O and the extrapolated heat capacity contribution of the H_2O_2.

During experimental heat transfer studies at relatively high temperatures (Ref. 2.18), the heat capacities of 90 w/o H_2O_2 were indirectly determined from heat transfer data over a temperature range of 240 to 380 F. An equation was developed for the data which indicated an increasing deviation of the experimental data from the curve fit of the data with increasing temperature. The differences in these data from extrapolations of the data presented in Fig. 2.17 and 2.17a, which are $\leq$0.01 Btu/lb-F (cal/gm-C), are assumed to be the result of H_2O_2 decomposition in the experimental study.

The heat capacities of the vapor phase of propellant-grade H_2O_2 solutions are given in Tables 2.9 through 2.14. The origin of these data is discussed in Section 2.2.3.9.

2.2.3.8 Enthropy and Enthalpy. The entropy and enthalpy of the solid and liquid phases of propellant-grade H_2O_2 solutions were calculated from the other thermodynamic functions given in Tables 2.3

through 2.8. The basis for the vapor-phase entropy and enthalpy data on propellant-grade H_2O_2 solutions, given in Tables 2.9 through 2.14 is discussed in Section 2.2.3.9.

2.2.3.9 Vapor-Phase Thermodynamic Properties. The thermodynamic properties of hydrogen peroxide vapor were calculated (Ref. 2.27) from structural data. These data, which replaced earlier reported data (Ref. 2.28), were based on new spectroscopic measurements (Ref. 2.29) and new calorimetric data (Ref. 2.5 and 2.25). The primary difference in the presently accepted values and those reported earlier are in the internal rotation values.

The structural values used by Ref. 2.27 in the computation of the vapor-phase thermodynamic properties, given in Tables 2.9 through 2.14, are:

r O-H = 0.965 Å	υ_1 = 3610 cm^{-1}
r O-O = 1.49 Å	υ_2 = 1350 cm^{-1}
α OOH = 100 degrees	υ_3 = 880 cm^{-1}
φ = 95 degrees	υ_4 = 520 cm^{-1}
I_A = 2.785 x 10^{-40} $gm\text{-}cm^2$	υ_5 = 3610 cm^{-1}
I_B = 34.0 x 10^{-40} $gm\text{-}cm^2$	υ_6 = 1266 cm^{-1}
I_C = 33.8 x 10^{-40} $gm\text{-}cm^2$	σ = 2
I_{Red} = 0.696 x 10^{-40} $gm\text{-}cm^2$	

2.2.4 Transport Properties

All properties of propellant-grade solutions of H_2O_2 that involve the transfer of mass or energy at the molecular level are presented in the following paragraphs.

2.2.4.1 Viscosity. Experimental determinations of the viscosity of liquid H_2O_2-H_2O solutions ranging in composition from 0 to 100 w/o H_2O_2, have been reported in Ref. 2.6 (0 and 18 C), Ref. 2.24 (0 and 20 C), and Ref. 2.22 (0, 25, and 50 C). Curve-fits of these data at 0, 20, 25, and 50 C (32, 68, 77, and 122 F) are graphically illustrated as a function of w/o H_2O_2 (from 50 to 100 w/o) in Fig. 2.18 and 2.18a. In addition, viscosity measurements have been conducted on 98 w/o H_2O_2 (Ref. 2.19) from 20 to 85 C (68 to 185 F) and on 90 w/o H_2O_2 (Ref. 2.18) from 77 to 325 F (25 to 162.8 C). The data for 98 and 70 w/o H_2O_2 from the various sources has been plotted as a function of temperature and compared to the viscosity of water in Fig. 2.19 and 2.19a.

The viscosity of the vapor phase of H_2O_2-H_2O solutions at 1 atmosphere has been calculated (from experimentally determined data) as reported in Ref. 2.30. An equation (Ref. 2.30) representing these data from 100 to 300 C (212 to 540 F) with an estimated precision of ±2 percent is given as:

$$\mu \text{ (micropoises)} = 134 + 0.35\,[T_{(C)} - 100] - 14\,Y$$

where

Y = mole fraction H_2O_2 in vapor

This equation, comparing the vapor viscosity of water with 100 w/o H_2O_2, is graphically represented in Fig. 2.20.

2.2.4.2 Thermal Conductivity. Experimental measurements of the thermal conductivity of H_2O_2-H_2O solutions have been limited to determinations (Ref. 2.22) on 98.2 w/o H_2O_2 at 0 C (32 F) and 25 C (77 F) and on 50 w/o H_2O_2 at 25 C; resulting thermal conductivities were 0.321, 0.339, and 0.347 Btu/hr-ft-F, respectively.

Using the two experimental data points, the thermal conductivity of 98.2 w/o H_2O_2 was extrapolated to the critical point (Ref. 2.31). This extrapolation, shown in Fig. 2.21, used H_2O as a reference substance and assumed no decomposition and a thermal conductivity of 0.100 Btu/hr-ft-F at the critical point.

Experimental heat transfer studies (Ref. 2.19) indicated that the estimated thermal conductivities reported in Ref. 2.31 agree reasonably well with those calculated from the experimental heat transfer data.

2.2.4.3 Coefficient of Diffusion. The experimental determination of the diffusion coefficient of liquid H_2O_2 into water has been reported (Ref. 2.32) for 0.17 w/o H_2O_2 from 0 to 40 C (32 to 104 F) and for 0.019, 1.44, and 7.92 w/o H_2O_2 at 20 C (68 F). At 20 C (68 F), the diffusion coefficients were <1.2 cm^2/day for the concentrations studied.

The diffusion coefficient of H_2O_2 vapor into air was experimentally determined (Ref. 2.33) in a vertical tube as 0.188 cm^2/sec at 60 C (140 F) and 1-atmosphere pressure. This can be compared to a diffusion coefficient of 0.320 cm^2/sec reported (Ref. 2.34) for water vapor under identical conditions.

2.2.4.4 Sonic Velocity. The velocity of sound was experimentally measured (Ref. 2.16) in H_2O_2-H_2O solutions from 3.5 to 33.5 C (38.3 to 92.3 F). These data are plotted for propellant-grade H_2O_2 solutions in Fig. 2.22 and 2.22a.

2.2.5 Electromagnetic Properties

The electrical, magnetic, and electromagnetic (optical) properties of H_2O_2 have been grouped as electromagnetic properties.

These properties generally are related to the electronic structure of the atoms in contrast to the transport properties which involve only molecular movement.

2.2.5.1 Index of Refraction. The refractive indexes of H_2O_2-H_2O solutions were experimentally determined (Ref. 2.15) using the sodium D line. The data for propellant-grade H_2O_2-H_2O solutions are presented in Table 2.15 at 25 C (77 F) with a temperature correction guide.

2.2.5.2 Dipole Moment. Calculated dipole moments of H_2O_2 were reported as 2.22 Debye (or 2.22×10^{-18} esu-cm) and 2.05 Debye in Ref. 2.35 and 2.36, respectively. In addition, a value of 2.26 Debye was estimated (Ref. 2.37) from the Stark effect, and a value of 2.13 Debye was determined (Ref. 2.38) for H_2O_2 in dioxane. The latter value was selected as the representative dipole moment for H_2O_2.

2.2.5.3 Dielectric Constant. Figures 2.23 and 2.23a show the dielectric constants of propellant-grade H_2O_2-H_2O solutions as a function of temperature. These data were interpolated from the experimental studies reported in Ref. 2.39, in which the dielectric constants were determined as a function of composition at constant temperatures from -40 to 30 C (-40 to 86 F). Because of the supercooling of the H_2O_2-H_2O solutions, measurements were obtained on the liquid below the freezing point. The data from the measurements on 100 w/o H_2O_2 were curve-fitted from -60 to 30 C (-76 to 86 F) to the following equation (Ref. 2.40):

$$\epsilon = 84.2 - 0.62\, T_{(C)} + 0.0032 T_{(C)}^2$$

2.2.5.4 Electrical Conductivity. The conductivity of "pure" H_2O_2 has been reported by several investigators with values ranging from 2 to 0.39 micromhos (microohms^{-1}). Experimental studies (Ref. 2.41) of the conductivity of unstabilized H_2O_2 were conducted as a possible means of determining its purity. The results of this study are summarized as follows:

1. Fractional crystallization reduced the conductivity of commercial 90 w/o H_2O_2 (11.5 microohms^{-1} at 25 C) to approximately one-half (5.0 microohms^{-1} at 25 C) of its initial value, while increasing its concentration to 98+ w/o H_2O_2.
2. Distillation of the crystallized H_2O_2 reduced its specific conductance to ~2 micromhos. This value compared with that reported in earlier studies (Ref. 2.42).
3. A second distillation of the crystallized and once-distilled H_2O_2 reduced its specific conductance to 1.2 micromhos; this value was still greater than that reported in Ref. 2.43 and 2.44.
4. The specific conductance of both 98 w/o H_2O_2 and deionized water increased on storage in contact with Pyrex glass. A conclusion of these studies indicated that only a rough correlation between low electrical conductivity and high stability was found (or that electrical conductivity per se is not a reliable indicator of stability).

The electrical conductivity of both water and hydrogen peroxide is increased by the addition of one to the other.

2.2.5.5 Magnetic-Optic Rotation (Verdet Constant). Although not optically active, H_2O_2, when placed in a magnetic field, will

to rotate the plane of polarized light. This is expressed as:

$$\alpha = k_v \ell H$$

where

α = degree of rotation

ℓ = path length

H = field strength

k_v = Verdet constant

The Verdet constant, k_v, as reported in Ref. 2.45 at 10 C (50 F), is shown for various H_2O_2-H_2O solutions in Table 2.16.

2.2.5.6 Magnetic Susceptibility. Hydrogen peroxide is diamagnetic. The magnetic susceptibility of liquid H_2O_2 has been summarized in Ref. 2.10.

Values of -0.73×10^{-6} cgs-emu/cc at 10 C, -0.50×10^{-6} cgs-emu/g, -17×10^{-6} cgs-emu/g mol, and 0.9999908 are reported for the volume susceptibility (K), mass susceptibility (X_g), molar susceptibility (Xm), and permeability (P), respectively. In addition, an equation expressing the mass susceptibility of H_2O_2-H_2O solutions at 10 C (50 F) is given as:

$$X_g \times 10^6 = -0.720 + 0.218\ w$$

where

w = weight fraction H_2O_2

The susceptibility of the solid becomes more positive upon freezing, while the susceptibility of the vapor is assumed to be the same as the liquid.

2.2.5.7 Other Molecular and Electromagnetic Properties. A number of miscellaneous molecular and electromagnetic properties have been summarized for H_2O_2 in Table 2.17. The origin of these data is referenced in the table.

2.2.6 Structure and Spectra

The equilibrium geometry of hydrogen peroxide was established by an electron diffraction study (Ref. 2.48). This was supported by an X-ray study (Ref. 2.14) with limited least-squares data reduction, an infrared study (Ref. 2.49 and 2.50), and a microwave study (Ref. 2.37 and 2.51). The results of these studies are summarized in Table 2.18. The infrared study may be regarded as definitive, although the structure of the solid, as determined by X-ray, may be appreciably different from the gas phase. The X-ray study may be questioned, however, because the data analysis used visual intensity estimation and primitive numerical machines. The rotational constants measured in the infrared are $A' = 10.356\ cm^{-1}$, $B' = 0.8656\ cm^{-1}$, $C' = 0.8270\ cm^{-1}$, $D_J = 4.5 \times 10^{-6}\ cm^{-1}$, $D_K = 7.5 \times 10^{-4}\ cm^{-1}$, and $D_{JK} = -2 \times 10^{-5}\ cm^{-1}$. Dipole moments of 3.15 ±0.05 D and 3.24 ±0.05 D were measured (Ref. 2.51) for each of the two potential minima. A far infrared study (Ref. 2.50) showed the angle τ has two equilibrium values (with the lowest at 111.5 degrees ±0.5) and determined an accurate hindered-rotation potential function. The best geometric parameters are those underlined in Table 2.18.

Hydrogen peroxide forms tetragonal crystals, space group $D_4^4 - P4_12_1$, upon freezing (Ref. 2.14). There are four molecules in the unit cell of dimensions a = 4.06 Å and c = 8.00 Å. The crystal structure has been completely determined, and the volume of the unit cell is 131.9 $Å^3$ (Ref. 2.14). This gives a crystal density of 1.70 gm/cc.

Hydrogen peroxide is the simplest molecule having an internal rotation motion, and, therefore, has had fairly extensive study with respect to absorption spectra. Hindered internal rotation effects are observed in all regions of the spectrum. Extensive studies have been conducted on the vapor, the crystalline solid, and dilute solutions. Less work has been spent on the concentrated liquid solutions, because of decomposition effects and the difficulty in finding suitable window materials. Since the spectrum as a whole is very complicated, it is considered beyond the scope of this handbook; thus, references to H_2O_2 spectrum characterization are provided as a guide for interested individuals.

The infrared absorption by H_2O_2 is not very useful for chemical analysis because the spectrum is quite similar to that of water and since suitable window materials are not widely available. Ultraviolet absorption by H_2O_2 is quite strong, and (although Beer's law does not hold strictly) if the solution is clear and transparent to ultraviolet, direct spectrophotometry measurements are suitable for analysis of dilute solutions. The ultraviolet spectrum of concentrated hydrogen peroxide has been reported for 50 and 90 w/o solutions in Ref. 2.39, and for 55 and 99 w/o hydrogen peroxide solutions in Ref. 2.24. The infrared absorption spectrum of H_2O_2 has been reported in Ref. 2.50, 2.52, and 2.53. The Raman spectrum of concentrated hydrogen peroxide (99+ percent) is probably covered best in Ref. 2.39.

2.3 CHEMICAL PROPERTIES

Hydrogen peroxide is a strong oxidizing agent in either acid or alkaline solutions; however, with a very strong oxidizing agent such as MnO_4^{--}, it will also behave as a reducing agent.

Hydrogen ion concentration (pH), the presence and nature of catalysts, and temperature are important controlling parameters in hydrogen peroxide reactions. By proper choice of reaction conditions, it is possible to modify the oxidizing action of concentrated hydrogen peroxide solutions. As an oxidizing agent, hydrogen peroxide has the distinct advantage of producing only water as a by-product. Hydrogen peroxide also forms simple addition complexes, forming compounds similar to hydrates. These compounds are normally called hydroperoxidates. These are generally accepted as hydrogen-bonded compounds, which are analogous to anion water compounds. Hydroperoxidates are readily formed with highly electronegative atoms such as nitrogen, oxygen, and fluorine. Amino groups form stronger bonds with peroxide than carboxyl or hydroxyl groups.

Compilations of typical hydrogen peroxide reactions have been reported in Ref. 2.10 and 2.55. These compilations were combined and are presented in Table 2.19 along with references to the original work.

2.4 SOLUBILITY AND MISCIBILITY

Because of hydrogen peroxide's chemical and thermodynamic activity (as noted in Section 2.3), precautions should be observed when considering solutions of H_2O_2 with various organic and inorganic compounds. Although violent reactions upon mixing are the exception, such reactions have been observed. Many H_2O_2 solutions may be fairly stable when undisturbed but are subject to violent detonation under certain conditions. The addition of any material which may be oxidized or reduced should be suspect, particularly as the relative concentrations approach stoichiometric proportions. For these reasons, it is suggested that appropriate references be consulted in detail to define the

chemical nature of the proposed solution as well as the solubility of the solute before solutions of H_2O_2 with other materials are attempted.

The solubility and miscibility of hydrogen peroxide and its aqueous solutions with a number of organic and inorganic compounds are referenced in detail in Ref. 2.10. In general, concentrated H_2O_2 solutions are completely miscible with most organic liquids (including ethanol, isopropanol, acetone, ethyl cellosolve, pyridine, etc.) that are miscible with water in all proportions. In addition, hydrogen peroxide is more miscible than water in a number of organic materials, such as methyl methacrylate, dimethyl and diethyl phthalate, ethyl acetate, and aniline. Compounds with which hydrogen peroxide is nearly immiscible include petroleum ether, toluene, styrene, carbon tetrachloride, chloroform, kerosene, fuel oil, and gasoline.

Hydrogen peroxide and its aqueous solutions also possess, in general, solvent or solute relationships that are similar to water. The results of several experiments show that sodium fluoride, potassium nitrate, various potassium or sodium phosphates, potassium chloride, and sodium or potassium sulfate are more soluble in H_2O_2 than in water. Sodium nitrate, sodium chloride, silver nitrate, lead nitrate, and lithium nitrate and sulfate are less soluble in H_2O_2 than in water. Chlorine and iodine are only slightly soluble in anhydrous H_2O_2.

In consideration of the materials compatibilities of various lubricants with H_2O_2, the solubilities of several organic compounds in propellant-grade H_2O_2 are discussed in Table 4.14a, Section 4.

2.5 GELATION

Results of gel studies on hydrogen peroxide are given in detail in Ref. 2.99 and 2.100.

2.6 HEAT TRANSFER PROPERTIES

Since heat transfer involves a combination of phase, thermodynamic, and transport properties, as well as some consideration of chemical kinetics, this section on heat transfer properties has been included as part of the physico-chemical properties. This section is designed as a reference guide and summary of the various experimental heat transfer studies that have been conducted on propellant-grade hydrogen peroxide solutions.

Experimental heat transfer studies on 90 w/o H_2O_2 solutions (reported in Ref. 2.101) indicated that a high flux heat transfer, usually associated with boiling, was obtained from a 347 stainless-steel surface to liquid 90 w/o H_2O_2 as a result of the H_2O_2 decomposition mechanism. This decomposition, which simulates boiling by the liberation of gas bubbles at the heat transfer surface, is accelerated with temperature increase of the surface. Figure 2.24 illustrates the magnitude of this effect, as well as the lesser effect of pressure and liquid temperature, in terms of heat flux. Because of these effects, the study showed that the temperature difference between the surface and liquid was not significant.

An extension of these studies to high fluid velocities and moderately high temperature differences was reported in Ref. 2.102. At high flowrates and high Reynolds numbers (where decomposition is limited by the short liquid residence time), the resultant heat transfer data agreed with that expected for

forced convective heat transfer. It was found that heat fluxes as high as 11.75 Btu/sq in.-sec (at liquid velocities of ~ 80 ft/sec) could be obtained with 90 w/o H_2O_2 without complication by decomposition of the hydrogen peroxide. A least-squares fit of the heat transfer data obtained on 90 w/o H_2O_2 resulted in the following expression:

$$(N_{Nu})_f = 0.0287\ (N_{Re})_f^{0.8} (N_{Pr})_f^{1/3}$$

The standard deviation of the experimental data from this equation was 10.2 percent.

Heat transfer studies in the forced convective region of both 90 w/o and 98 w/o H_2O_2 were reported in Ref. 2.103. Peak heat fluxes of 7.80 Btu/sq in.-sec were measured for 90 w/o H_2O_2 at fluid velocities of 41.3 ft/sec. The results obtained for peak heat flux of 98 w/o H_2O_2 at the conditions investigated are shown in Fig. 2.25. The correlation of the data on 98 w/o H_2O_2 with the Dittus-Boelter, Colburn, and Sieder-Tate equations (Fig. 2.26 through 2.28, respectively) indicated better agreement of the data with the Dittus-Boelter relationship. It has been suggested, however, that some of the apparently low heat transfer coefficients, indicated by the correlations of Fig. 2.26 through 2.28, may be due to slight scaling (oxidation) of heat transfer surfaces.

A current study on the use of 98 w/o hydrogen peroxide for regeneratively cooled rocket engines has reported (Ref. 2.104) that during 18 experimental tests (with fluid velocities from 25 to 198 ft/sec, pressures from 2000 to 4700 psia, and feed temperatures from 60 to 240 F), heat fluxes up to 48.2 Btu/sq in.-sec were achieved. It was found that the heat flux at burnout (under the conditions tested) was directly proportional

to the fluid velocity by the relationship: heat $flux_{BO}$ = 0.21 x velocity. These results indicated good correlation of heat flux and fluid velocity with the studies of Ref. 2.102 and 2.103. During these tests, no appreciable difference in heat transfer could be associated with feed temperature, and no detectable decomposition was evident. Four similar tests with 90 w/o hydrogen peroxide indicated no discernible differences from the results of the 98 w/o hydrogen peroxide tests. As in the studies of Ref. 2.103, the Dittus-Boelter correlation was found to represent the data more closely than either the Colburn or Sieder-Tate relationships.

The results of all of these studies have shown that hydrogen peroxide has coolant properties comparable to those of water. Of course, the difficulty in its use as a regenerative coolant lies in the limited stability of the H_2O_2 at higher temperatures. As a result, various bulk liquid temperature limits have been suggested and established in the use of H_2O_2 as a regenerative coolant. These limits range from established (Ref. 2.105) maximum allowable temperatures of 225 F (with a 105 F rise over inlet temperature) to suggested operating limits (Ref. 2.106) of 250 F (with red line conditions at 275 F). More detailed analysis of minimum safe design criteria of H_2O_2 regenerative-cooling systems, based on the available data from various sources, is presented in terms of ultimate heat flux and fluid velocity in Ref. 2.107. Additional analysis of transient heat transfer for an H_2O_2 regeneratively cooled engine model are given in Ref. 2.108.

2.7 IGNITION CHARACTERISTICS

Although ignition characteristics are system-related parameters, they are also a direct indication of chemical reactivity and/or stability. As such, these characteristics have been included as a part of the Physico-Chemical Properties Section of this

handbook. However, because a detailed characterization of these parameters would involve a discussion of system design variables (such as configuration, intended use environment, operating sequence, etc.) that are beyond the intended scope of this handbook, this review of hydrogen peroxide ignition characteristics is limited to a general and brief summary and reference guide to various ignition studies previously conducted. In addition, this summary is limited further by the security classification of many of these studies as opposed to the unclassified nature of this handbook. For the purpose of clarity, the characterization of hydrogen peroxide ignition is presented in terms of its two primary application areas: monopropellant systems and bipropellant systems.

2.7.1 Monopropellant Systems

Studies of the controlled decomposition process, that characterize hydrogen peroxide's use as a monopropellant, are given in Section 7.2. As a result of these studies, which are detailed and referenced in Section 7.2, the initiation period for hydrogen peroxide decomposition in a monopropellant chamber are fairly well-defined for all propellant-grade concentrations. As expected, all the studies demonstrate the effect of many variables, such as the initiating source and type (catalyst or thermal bed), injection technique, chamber configuration, hydrogen peroxide concentration, hydrogen peroxide inlet temperature, initial chamber temperature, exit pressure, etc., on the start transient. (The start transient is defined in these efforts as the time period from injection of hydrogen peroxide into the decomposition chamber to the achievement of 90-percent of the operating chamber pressure.)

In general, the start transient for a hydrogen peroxide catalytic monopropellant decomposition chamber normally ranges from 50 to 150 ms. This start transient is typical of all of the

catalysts used in the decomposition of hydrogen peroxide concentrations ranging from 76 w/o (Ref. 2.109) to 98 w/o (Ref. 2.18, 2.110 and 2.111).

The greatest effect on this typical start transient is caused by variation in the hydrogen peroxide and/or catalyst bed temperature. Laboratory studies (Ref. 2.41) have demonstrated the lack of reaction between solid or super-cooled hydrogen peroxide and a typical catalytic material, while studies with actual engine catalyst beds (Ref. 2.110) have shown limited initiation of decomposition and excessive start transient periods when the temperature approaches the propellant's freezing point. However, the low temperature start characteristics of various catalyst beds have been improved through special design of the catalyst chamber and special treatment of the catalyst bed (Ref. 2.18, 2.110, and 2.111). Conversely, an increase in propellant or catalyst bed temperature (such as experienced in pulsing or other heat feedback operations) has resulted in start transients as low as 10 ms (Ref. 2.18, 2.104, 2.109, 2.110, and 2.111).

Although exit pressure has a slight effect on the start transient, this effect is usually within the ranges noted above and controlled by the temperature effects. Of course the start transients are affected by the catalyst life and generally are the best indication of the decline in catalytic effectiveness.

The start transients in a hydrogen peroxide thermal decomposition chamber are entirely related to the technique and configuration employed. Since this concept depends on the initial heating of a thermal pack (see Section 7.2.2) prior to injection of the hydrogen peroxide, the start transient of the main hydrogen peroxide stream should approach the hot bed start transients ($\sim$ 10 ms) noted above. However, studies with both 90 w/o (Ref. 2.18) and 98 w/o (Ref. 2.113) have indicated that adequate heating of the thermal pack may require periods ranging

500 ms to several minutes depending on the technique employed. Hypergolic slugs of hydrazine containing mixed cyanide salts (Ref. 2.18) have produced initial start transients (i.e., the period measured from injection of the hypergol) of 10 to 20 ms, but this technique required 300 ms hydrogen peroxide leads and 500 ms hypergol injection periods.

2.7.2 Bipropellant Systems

Although some studies have indicated that 90 w/o and 98 w/o hydrogen peroxide solutions are hypergolic (i.e., ignites without producing damaging overpressures to the system) with the hydrazine and 50 w/o N_2H_4-50 w/o $(CH_3)_2N_2H_2$ fuels (Ref. 2.111), other studies (Ref. 2.18) have indicated that the hypergolicity of 90 w/o hydrogen perioxide with both hydrazine and $(CH_3)_2N_2H_2$ is questionable. Ignition delays (e.g., the time period from injection of the second propellant into the combustion chamber to 90 percent of the designed chamber pressure) of ~ 5 to 25 ms were reported for H_2O_2/N_2H_4 systems in Ref. 2.111; however, large overpressures (e.g., the peak pressure to chamber pressure ratio) and erratic chamber pressure fluctuations were demonstrated in these systems. In the studies reported in Ref. 2.18, which demonstrated ignition delays for this system of 10 to 109 ms (with average delays of 35 to 52 ms recorded for various mixture ratios), it was concluded that hypergolicity was marginal and unreliable.

As a result of these and similar studies of other hydrogen peroxide bipropellant systems, including the $H_2O_2/CH_3N_2H_3$ (Ref. 2.111) and H_2O_2/B_5H_9 (Ref. 2.113) systems, it is concluded that the hypergolicity of hydrogen peroxide with various fuels is, at best, marginal. For this reason many hydrogen peroxide bipropellant systems utilize hydrogen peroxide decomposition gases (resulting from injection of the hydrogen

peroxide in a catalyst chamber upstream of the main combustion chamber) as the ignition source. Through the use of this concept, successful system ignition has been demonstrated with various liquid (including those noted above, as well as with JP-5 in the AR-2 system), solid (Ref. 2.114) and heterogeneous (Ref. 2.104) fuels. Ignition delays between the hot decomposition gases and the fuels are minimal (5 to 10 ms), although the system design controls the overall start transient period (i.e., from injection of the hydrogen peroxide into the catalyst chamber to the achievement of main chamber combu tion). Many system designs employ only a small "pilot light" catalyst chamber with subsequent main stream liquid injection (which bypasses the catalyst chamber), while other systems utilize prior decomposition of all of the hydrogen peroxide throughout the operation of the bipropellant system.

The use of hypergols in the ignition of hydrogen peroxide-oxidized bipropellant systems has been studied (Ref. 2.18) with the hydrazine, $(CH_3)_2N_2H_2$ (UDMH), and JP-5 fuels. In these studies, which were designed to demonstrate the feasibility of direct liquid injection of 90-percent hydrogen peroxide into bipropellant chambers, relatively smooth and rapid ignition was achieved with all three fuels using nitrogen tetroxide as the hypergol for the first two fuels and aluminum triethyl with the latter fuel. In addition, the use of mixed cyanide salts as an ignition aid to the H_2O_2/N_2H_4 system is noted in Ref. 2.18.

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TABLE 2.1

PHYSICAL PROPERTIES OF HYDROGEN PEROXIDE AT

Property	Units		100 Percent H_2O_2		90 Percent H_2O_2		85 Percent H_2O_2	
	Metric	English	Metric	English	Metric	English	Metric	English
General Identification								
Identification			Hydrogen Peroxide		Hydrogen Peroxide		Hydrogen Peroxide	
Molecular Formula			H_2O_2		(H_2O_2) 0.9088 + (H_2O) 0.0372		(H_2O_2) 0.9096 + (H_2O) 0.0904	
Molecular Weight	g-mole	lb-mole	34.016	34.016	33.484	33.484	32.571	32.571
Freezing Point	C	F	-0.5	31.1	-2.1	28.2	-5.1	22.8
Triple Point	C	F	-0.43	31.24				
Normal Boiling Point	C	F	150.2	302.0	148.7	299.6	146.8	296.3
Critical Properties								
Temperature	C	F	460	860	456.5	854	452	846
Pressure	atm	psia	247	3630	246	3615	244.5	3591
Density	g/cc							
Phase Properties								
Density								
Solid	g/cc	lb/cu ft	1.71 at -80 C	106.76 at -4 F				
Liquid	g/cc	lb/cu ft	1.444	90.1	1.432	89.4	1.415	88.3
Gas	g/cc	lb/cu ft	See Section 2.2.2.1		See Section 2.2.2.1		See Section 2.2.2.1	
Thermal Expansion	C^{-1}	F^{-1}	7.502×10^{-4}	4.165×10^{-4}	7.508×10^{-4}	4.165×10^{-4}	7.508×10^{-4}	4.168×10^{-4}
Compressibility (cubic)								
Adiabatic	atm^{-1}	$psia^{-1}$	2.411×10^{-5}	1.640×10^{-6}	2.445×10^{-5}	1.665×10^{-6}	2.490×10^{-5}	1.699×10^{-6}
Isothermal	atm^{-1}	$psia^{-1}$	2.617×10^{-5} at 20 C	3.840×10^{-4} at 68 F				
Vapor Pressure	mm Hg	psia	2.08	0.042	2.30	0.045	2.43	0.053
Surface Tension	dyne/cm	lb/ft	80.15 at 20 C	5.490 at 68 F	79.95 at 20 C	5.477 at 68 F	79.64 at 20 C	5.456 at 68 F

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TABLE 2.1
(Continued)

Property	Units		100 Percent H_2O_2		98 Percent H_2O_2		95 Percent H_2O_2	
	Metric	English	Metric	English	Metric	English	Metric	English
Thermodynamic Properties								
Heats of								
Formation	cal/g	Btu/lb	-1320	-2376	-1369	-2464	-1445	-2601
Fusion	cal/g	Btu/lb	86	155	87	157	85	153
Vaporization	cal/g	Btu/lb	364	654.5	368	661.5	376	677
Sublimation	cal/g	Btu/lb	457.8	824				
Mixing	cal/g (solution)	Btu/lb (solution)	0	0	1.0	1.8	2.4	4.2
Decomposition	cal/g	Btu/lb						See Fig. 2.16 and
Heat Capacity								
Solid	cal/g-C	Btu/lb-F	0.461 at melting point	0.461 at melting point	0.461 at melting point	0.461 at melting point	0.414 at melting point	0.414 at melting poi
Liquid	cal/g-C	Btu/lb-F	0.625	0.626	0.633	0.633	0.645	0.645
Gas								
C_p	cal/g-C	Btu/lb-F	0.303	0.303	0.306	0.306	0.310	0.310
C_v	cal/g-C	Btu/lb-F						
Entropy	cal/g-C	Btu/lb-F						See Section 2.2
Enthalpy	cal/g	Btu/lb						See Section 2.2
Transport Properties								
Viscosity								
Liquid	Centipoises	lb/ft-sec	1.153	0.770×10^{-3}	1.158	0.772×10^{-3}	1.160	0.775×10^{-3}
Gas	Centipoises	lb/ft-sec	1.91×10^{-2}	1.283×10^{-5}				
Thermal Conductivity								
Liquid	cal/cm-sec-C	Btu/ft-hr-F			1.40×10^{-3}	0.34		
Gas	cal/cm-sec-C	Btu/ft-hr-F						
Coefficient of Diffusion	cm^2/sec	$in.^2$/sec						
Sonic Velocity								
Liquid	m/sec	ft/sec	1781.0	5843	1774.6	5821	1767.0	5794
Gas	m/sec	ft/sec						

TABLE 2.1
(Continued)

H_2O_2 fish	95 Percent H_2O_2		90 Percent H_2O_2		75 Percent H_2O_2		70 Percent H_2O_2		Figure and Table Number	Reference Number
	Metric	English	Metric	English	Metric	English	Metric	English		
	-1445	-2601	-1571	-2828	-1946	-3503	-2070	-3726	T2.3-2.14, F2.12-2.13a	2.25, 2.34
	85	153	82	148	77	138	72	129	T2.3-2.8	2.2
	376	677	389	700	427	768	438	789	T2.3-2.14 F2.14, F2.14a	2.26
										2.10
	2.4	4.2	4.3	7.6	8.15	14.65	9.0	16.03	F2.15, F2.15a	2.26
	See Fig. 2.10 and 2.16a								F2.16, F2.16a	2.25
at ng point	0.414 at melting point	0.414 at melting point	0.417 at melting point	0.417 at melting point	0.377 at melting point	0.377 at melting point	0.415 at melting point	0.415 at melting point	T2.3-2.8 F2.17, F2.17a	2.5
	0.645	0.645	0.663	0.663	0.720	0.720	0.738	0.738	T2.3-2.8 F2.17, F2.17a	2.18, 2.25, 2.26
	0.310	0.310	0.317	0.317	0.338	0.338	0.346	0.346	T2.9-T2.14	2.27
	See Section 2.2.3.6								T2.3-T2.14	2.34
	See Section 2.2.3.8								T2.3-T2.14	2.34
2×10^{-3}	1.160	0.775×10^{-3}	1.158	0.777×10^{-3}	1.136	0.769×10^{-3}	1.123	0.758×10^{-3}	F2.18, F2.18a F2.19, F2.19a	2.5, 2.22, 2.24
									F2.20	2.30
									F2.21	2.31
	1767.0	5794	1752.5	5745	1706.9	5598	1690.3	5543	F2.22, F2.22a	2.16

TABLE 2.1
(Concluded)

Property	Units		100 Percent H_2O_2		98 Percent H_2O_2		95 Percent H_2O_2	
	Metric	English	Metric	English	Metric	English	Metric	English
Electromagnetic Properties								
Index of Refraction	(Sodium D-Line)							
Solid								
Liquid			1.4067		1.4049		1.4083	
Gas								
Dipole Moment	Debye Units		2.13					
Dielectric Constant			70.5		71.6		73.0	
Liquid								
Gas								
Electrical Conductivity	micro-ohms^{-1}							See Section 5
Verdet Constant								See Table 2.
Magnetic Susceptibility	cgs-emu/g		-0.50 x 10^{-6} at 10 C (50 F)					

TABLE 2.1
(Concluded)

95 Percent H_2O_2		90 Percent H_2O_2		75 Percent H_2O_2		70 Percent H_2O_2		Figure and Table Number	Reference Number
Metric	English	Metric	English	Metric	English	Metric	English		
1.4083		1.3880		1.3854		1.3814		T2.15	2.15
73.0		75.0		78.8		79.5		F2.25	2.38 2.39
See Section 2.2.5.4									2.41, 2.42, 2.43 2.44
See Table 2.16								T2.16	2.45 2.10

TABLE 2.2

CALCULATED SATURATION PRESSURE, ACTIVITY COEFFICIENTS, AND VAPOR COMPOSITIONS FOR HYDROGEN PEROXIDE-WATER SOLUTIONS AT HIGH TEMPERATURES AND PRESSURES

H_2O_2 Concentration, w/o	System Pressure, psia	Mole Fraction H_2O in Liquid	Temperature C	Temperature F	Vapor Pressure H_2O_2*, psia	Vapor Pressure H_2O, psia	Activity Coefficient, H_2O_2	Activity Coefficient, H_2O	$\theta_{H_2O_2}$	θ_{H_2O}	Mole Fraction H_2O_2 in Vapor	Mole Fraction H_2O in Vapor	Partial Pressure H_2O_2, psia	Partial Pressure H_2O, psia
90	37.4**	0.1734	175	347	30.7	129.5	0.5835	0.5782	0.9948	1.0454	0.6706	0.3294	25.1	12.3
	64.7								0.9803	1.0322	0.5921	0.1927	25.4	12.5
	114.7								0.9502	1.0125	0.2290	0.1112	26.2	12.7
	314.7								0.8161	0.9258	0.0971	0.0443	30.6	13.9
	514.7								0.6958	0.8427	0.0696	0.0298	35.9	15.3
	1014.7								0.4650	0.6642	0.0528	0.0191	53.7	19.4
	2014.7								0.2075	0.4122	0.0597	0.0156	120.2	30.4
81.5	44.7**	0.3000	175				0.9470	0.6526	0.9893	1.0414	0.4592	0.5408	20.5	24.2
	64.7								0.9785	1.0316	0.3203	0.3766	20.8	24.4
	114.7								0.9487	1.0116	0.1870	0.2174	21.4	24.9
	314.7								0.8155	0.9254	0.0792	0.0865	24.9	27.2
	514.7								0.6955	0.8424	0.0568	0.0581	29.2	29.8
	1014.7								0.4650	0.6641	0.0431	0.0374	43.7	38.0
	2014.7								0.2075	0.4123	0.0487	0.0304	97.8	61.2
65.4	61.7**	0.5000	17				0.8402	0.7790	0.9769	1.0326	0.2136	0.7864	13.1	48.6
	64.7								0.9751	1.0310	0.2037	0.7496	13.2	48.6
	114.7								0.9452	1.0096	0.1190	0.4334	13.6	49.6
	314.7								0.8140	0.9242	0.0503	0.1723	15.8	54.2
	514.7								0.6946	0.8417	0.0360	0.1157	18.5	59.5
	1014.7								0.4646	0.6638	0.0273	0.0744	27.7	75.4
	2014.7								0.2075	0.4122	0.0309	0.0604	62.0	121.6
90	69.6**	0.1734	200	392	58.9	226	0.9847	0.5922	0.9935	1.0624	0.6928	0.3072	48.2	21.4
	114.7								0.9734	1.0440	0.4297	0.1906	49.2	21.8
	314.7								0.8724	0.9755	0.1745	0.0742	54.8	23.5
	514.7								0.7712	0.9055	0.1207	0.0489	62.0	25.2
	1014.7								0.5612	0.7470	0.0842	0.0301	85.4	30.5
	2014.7								0.2955	0.5064	0.0906	0.0224	162	45.0
81.5	81.5**	0.3000					0.9504	0.6634	0.9863	1.0570	0.4872	0.5128	39.7	41.8
	114.7								0.9715	1.0433	0.3519	0.3696	40.3	42.3
	314.7								0.8713	0.9747	0.1428	0.1440	44.8	45.3
	514.7								0.7706	0.9050	0.0988	0.0948	50.8	48.8
	1014.7								0.5610	0.7468	0.0688	0.0583	69.8	59.1
	2014.7								0.2955	0.5064	0.0659	0.0434	132	87.1

*Saturated vapor pressure at the temperature and liquid composition indicated.
**Bleck's imperfection term (AIChE Journal, 5, 249, 1959)

TABLE 2.2 (Concluded)

H_2O_2 Concentration, w/o	System Pressure, psia	Fraction H_2O in Liquid	Temperature C	Temperature F	Vapor Pressure H_2O_2, psia	Vapor Pressure H_2O, psia	Activity Coefficient, H_2O_2	Activity Coefficient, H_2O	$\phi_{H_2O_2}$	ϕ_{H_2O}	Mole Fraction H_2O_2 in Vapor	Mole Fraction H_2O in Vapor	Partial Pressure H_2O_2, psia	Partial Pressure H_2O, psia
65.4	109.0*	0.5000	200	392	58.9	226	0.8482	0.7848	0.9705	1.0452	0.2360	0.7640	25.7	83.3
	114.7								0.9677	1.0429	0.2252	0.7290	25.8	83.4
	314.7								0.8683	0.9726	0.0914	0.2845	28.7	89.4
	514.7								0.7687	0.9035	0.0651	0.1873	32.5	96.4
	1014.7								0.5602	0.7461	0.0439	0.1150	44.5	116.4
	2014.7								0.2954	0.5062	0.0420	0.0855	84.5	172
90	198.1*	0.1734	250	482	177	578	0.9867	0.6170	0.9908	1.1038	0.7527	0.2673	145	51.1
	314.7								0.9534	1.0682	0.4792	0.1744	150	54.8
	514.7								0.8889	1.0188	0.3143	0.1118	161	57.4
	1014.7								0.7270	0.8964	0.1949	0.0645	197	65.4
	2014.7								0.4740	0.6836	0.1508	0.0426	234	85.6
81.5	222.5*	0.3000					0.9562	0.6823	0.9809	1.0955	0.5463	0.4597	120.1	102.4
	314.7								0.9516	1.0675	0.3941	0.3358	124	105
	514.7								0.8873	1.0177	0.2584	0.2141	133	110
	1014.7								0.7262	0.8958	0.1601	0.1234	162	125
	2014.7								0.4739	0.6935	0.1238	0.0816	249	164
65.4	281.3*	0.5000					0.8621	0.7848	0.9578	1.0769	0.2818	0.7182	79.2	202.1
	314.7								0.9483	1.0668	0.2546	0.6465	80	203
	514.7								0.8841	1.0157	0.1679	0.4165	86	214
	1014.7								0.7246	0.8945	0.1034	0.2399	105	244
	2014.7								0.4736	0.6832	0.0798	0.1585	160	319
90	461.0*	0.1734	300	572	429	1254	0.988	0.658	0.9901	1.1515	0.7678	0.2327	354	107
	514.7								0.9750	1.1365	0.6983	0.2112	359	108
	1014.7								0.8495	1.0277	0.4065	0.1185	412	120
	2014.7								0.6293	0.8417	0.2768	0.0730	556	147
81.5	499.7*	0.3000					0.961	0.698	0.9787	1.1408	0.5898	0.4102	295	204.7
	1014.7								0.8695	1.0337	0.3271	0.2238	322	226
	2014.7								0.6570	0.8563	0.2184	0.1358	434	273
65.4	598.8*	0.5000					0.874	0.803	0.9504	1.1158	0.3291	0.6709	197.2	401.6
	1014.7								0.8634	1.0301	0.2140	0.4299	217	435
	2014.7								0.6542	0.8549	0.1425	0.2610	286	525

*Saturated vapor pressure at the temperature and liquid composition indicated.
**Black's imperfection term (AIChE Journal, 5, 249, 1959)

TABLE 2.3

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES OF 100 w/o H_2O_2*

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-160.2	-288.4	-1359	-2446	Solid
20	36	0.000	0.00	-160.2	-288.4	-1368	-2462	
40	72	0.05	0.02	-159.7	-287.5	-1374	-2473	
60	108	0.100	0.050	-158.2	-284.8	-1383	-2489	
80	144	0.144	0.085	-155.7	-280.3	-1389	-2500	
100	180	0.181	0.121	-152.5	-274.5	-1395	-2511	
120	216	0.210	0.157	-148.6	-267.5	-1398	-2516	
140	252	0.236	0.192	-144.1	-259.4	-1401	-2522	
160	288	0.259	0.225	-139.5	-251.1	-1404	-2527	
180	324	0.281	0.257	-134.7	-242.5	-1407	-2533	
200	360	0.302	0.287	-128.9	-232.0	-1409	-2536	
220	396	0.325	0.311	-122.6	-220.7	-1411	-2540	
240	432	0.349	0.346	-115.9	-208.6	-1412	-2542	
260	468	0.382	0.376	-108.6	-195.5	-1413	-2543	
272.7	490.8	0.461	0.394	-103.2	-185.8	-1412	-2542	

*Refer to Section 2.2.3

TABLE 2.3

(Concluded)

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
272.7	490.8	0.626	0.716	-17.4	-31.3	-1326	-2387	Liquid
280	504	0.626	0.734	-11.4	-20.5	-1324	-2383	
298.1	536.7	0.626	0.774	0.0	0.0	-1320	-2376	
300	540	0.626	0.777	1.11	2.0	-1319	-2374	
310	558	0.626	0.798	7.40	13.32	-1317	-2371	
320	576	0.626	0.819	13.68	24.62	-1314	-2365	
330	594	0.627	0.838	19.96	35.93	-1312	-2362	
340	612	0.627	0.857	26.23	47.21	-1310	-2358	
350	630	0.627	0.876	32.51	58.52	-1308	-2354	
360	648	0.627	0.894	38.73	69.71	-1306	-2351	
370	666	0.628	0.911	45.07	81.13	-1304	-2347	
380	684	0.628	0.928	51.34	92.41	-1301	-2342	
390	702	0.628	0.945	57.60	103.72	-1299	-2338	
400	720	0.628	0.961	63.90	115.02	-1298	-2336	

TABLE 2.4

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES
OF 98 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-160.44	-288.79	-1402	-2524	Solid
20	36	0.00	0.017	-160.40	-288.72	-1408	-2534	
40	72	0.05	0.031	-159.92	-287.86	-1425	-2565	
60	108	0.100	0.072	-158.82	-285.87	-1430	-2574	
80	144	0.144	0.108	-156.38	-281.45	-1439	-2590	
100	180	0.181	0.138	-153.14	-275.65	-1445	-2601	
120	216	0.210	0.168	-143.72	-258.70	-1443	-2597	
140	252	0.236	0.197	-144.74	-260.53	-1452	-2614	
160	288	0.260	0.225	-139.78	-251.60	-1454	-2617	
180	324	0.282	0.253	-134.63	-242.33	-1456	-2621	
200	360	0.303	0.281	-128.50	-231.30	-1458	-2624	
220	396	0.326	0.310	-122.20	-219.96	-1460	-2628	
240	432	0.351	0.338	-115.42	-207.76	-1461	-2630	
260	468	0.384	0.366	-108.08	-194.54	-1463	-2633	
271.1	488	0.461	0.357	-103.51	-186.32	-1462	-2632	

*Refer to Section 2.2.3

TABLE 2.4

(Concluded)

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
271.1	488	0.633	0.682	-17.14	-30.85	-1375	-2475	Liquid
280	504	0.633	0.699	-11.49	-20.68	-1374	-2473	
290	522	0.633	0.720	-5.16	-9.29	-1371	-2468	
298.1	536.7	0.633	0.739	0.0	0.0	-1369	-2464	
300	540	0.633	0.743	1.17	2.11	-1369	-2464	
310	558	0.633	0.764	7.50	13.50	-1367	-2461	
320	576	0.633	0.784	13.83	24.89	-1365	-2457	
330	594	0.633	0.803	20.16	36.29	-1362	-2452	
340	612	0.634	0.820	26.49	47.68	-1360	-2448	
350	630	0.634	0.836	32.83	59.09	-1358	-2444	
360	648	0.635	0.854	39.17	70.51	-1357	-2443	
370	666	0.635	0.872	45.51	81.92	-1354	-2437	
380	684	0.635	0.889	51.86	93.35	-1352	-2434	
390	702	0.636	0.907	58.22	104.80	-1350	-2430	
400	720	0.636	0.925	64.58	116.24	-1347	-2425	

TABLE 2.5

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES OF 95 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-160.19	-288.34	-1483	-2669	Solid
20	36	0.001	0.017	-160.15	-288.27	-1492	-2686	
40	72	0.051	0.037	-159.65	-287.37	-1500	-2700	
60	108	0.101	0.072	-158.13	-284.63	-1508	-2714	
80	144	0.145	0.108	-155.67	-280.21	-1513	-2723	
100	180	0.182	0.138	-152.35	-274.23	-1519	-2734	
120	216	0.211	0.168	-148.49	-267.28	-1523	-2741	
140	252	0.238	0.197	-143.99	-259.18	-1526	-2747	
160	288	0.261	0.225	-139.01	-250.22	-1529	-2752	
180	324	0.284	0.253	-133.555	-240.39	-1531	-2756	
200	360	0.305	0.281	-127.67	-229.81	-1533	-2759	
220	396	0.329	0.310	-121.33	-218.39	-1535	-2763	
240	432	0.354	0.338	-114.49	-206.08	-1536	-2765	
260	468	0.387	0.366	-107.02	-192.64	-1536	-2765	
268.1	482.6	0.414	0.368	-103.85	-186.93	-1537	-2767	

*Refer to Section 2.2.3

TABLE 2.5
(Concluded)

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
268.1	482.6	0.645	0.683	-19.38	-34.88	-1452	-2614	Liquid
280	504	0.645	0.702	-11.71	-21.08	-1450	-2610	
290	522	0.645	0.723	-5.30	-9.54	-1448	-2606	
298.1	536.7	0.645	0.742	-0.0	0.0	-1445	-2601	
300	540	0.645	0.746	1.19	2.14	-1445	-2601	
310	558	0.645	0.767	7.63	13.73	-1443	-2597	
320	576	0.645	0.787	14.07	25.33	-1441	-2594	
330	594	0.645	0.809	20.51	36.92	-1439	-2590	
340	612	0.645	0.826	26.95	48.51	-1436	-2585	
350	630	0.645	0.845	33.40	60.12	-1434	-2581	
360	648	0.645	0.863	39.85	71.73	-1432	-2578	
370	666	0.646	0.880	46.30	83.34	-1430	-2574	
380	684	0.646	0.897	52.76	94.97	-1427	-2569	
390	702	0.647	0.914	59.22	106.60	-1425	-2565	
400	720	0.648	0.930	65.69	118.24	-1423	-2561	↓

TABLE 2.6

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES OF 90 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-160.62	-289.12	-1606	-2891	Solid
20	36	0.003	0.004	-160.58	-289.04	-1615	-2907	
40	72	0.053	0.023	-160.08	-288.14	-1624	-2923	
60	108	0.103	0.054	-158.52	-285.34	-1631	-2936	
80	144	0.147	0.090	-156.02	-280.84	-1638	-2948	
100	180	0.184	0.127	-152.72	-274.90	-1644	-2959	
120	216	0.213	0.163	-148.74	-267.73	-1647	-2965	
140	252	0.240	0.193	-144.20	-259.56	-1651	-2972	
160	288	0.264	0.223	-139.16	-250.49	-1654	-2977	
180	324	0.287	0.252	-133.66	-240.59	-1656	-2981	
200	360	0.309	0.281	-127.70	-229.86	-1658	-2984	
220	396	0.333	0.309	-121.28	-218.30	-1660	-2988	
240	432	0.358	0.338	-114.38	-205.88	-1662	-2992	
260	468	0.392	0.366	-106.92	-192.46	-1663	-2993	
263.3	473.9	0.417	0.368	-105.59	-190.06	-1662	-2992	

*Refer to Section 2.2.3

TABLE 2.6

(Concluded)

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
263.3	473.9	0.664	0.680	-23.11	-41.59	-1580	-2844	Liquid
280	504	0.664	0.714	-12.03	-21.65	-1575	-2835	
290	522	0.663	0.735	-5.40	-9.72	-1573	-2831	
298.1	536.7	0.663	0.755	0.0	0	-1571	-2828	
300	540	0.663	0.759	1.22	2.20	-1571	-2828	
310	558	0.663	0.781	7.86	14.15	-1568	-2822	
320	576	0.663	0.802	14.48	26.06	-1566	-2819	
330	594	0.663	0.822	21.11	38.00	-1564	-2815	
340	612	0.664	0.842	27.74	49.93	-1561	-2810	
350	630	0.664	0.861	34.38	61.88	-1559	-2806	
360	648	0.664	0.880	41.02	73.84	-1557	-2803	
370	666	0.664	0.898	47.66	85.79	-1555	-2799	
380	684	0.665	0.916	54.31	97.76	-1552	-2794	
390	702	0.666	0.933	60.96	109.73	-1550	-2790	
400	720	0.667	0.950	67.62	121.72	-1548	-2786	

TABLE 2.7

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES

of 75 w/o H_2O_2 SOLUTIONS *

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-164.94	-296.89	-1975	-3555	Solid
20	36	0.007	0.010	-164.91	-296.84	-1987	-3577	
40	72	0.057	0.032	-164.27	-295.68	-1996	-3593	
60	108	0.107	0.065	-162.63	-292.73	-2004	-3607	
80	144	0.152	0.102	-160.07	-288.13	-2010	-3618	
100	180	0.188	0.140	-156.67	-282.01	-2017	-3631	
120	216	0.218	0.171	-152.61	-274.70	-2021	-3638	
140	252	0.245	0.202	-147.99	-266.38	-2025	-3645	
160	288	0.271	0.232	-142.83	-257.09	-2028	-3650	
180	324	0.296	0.262	-137.15	-246.87	-2030	-3654	
200	360	0.319	0.292	-131.01	-235.82	-2033	-3659	
220	396	0.345	0.321	-124.35	-233.83	-2035	-3663	
240	432	0.372	0.350	-117.19	-210.94	-2037	-3667	
241.1	444	0.377	0.355	-116.78	-210.20	-2038	-3668	

*Refer to Section 2.2.3

TABLE 2.7

(Conclud[illegible])

Temperature		Heat Capacity, cal g-K (Btu lb-R)	Entropy, cal/g-K (Btu lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
241.1	444	0.736	0.662	-41.54	-74.77	-1961	-3530	Liquid
260	468	0.736	0.717	-27.63	-49.73	-1956	-3521	
280	504	0.726	0.771	-13.07	-23.53	-1950	-3510	
290	522	0.720	0.794	-6.31	-11.3	-1948	-3506	
298.1	536.7	0.720	0.816	0.0	0	-1946	-3503	
300	540	0.720	0.820	1.33	2.39	-1945	-3501	
310	558	0.720	0.844	8.52	15.34	-1943	-3497	
320	576	0.720	0.866	15.71	28.28	-1940	-3492	
330	594	0.720	0.889	22.90	41.22	-1938	-3488	
340	612	0.720	0.910	30.09	54.16	-1935	-3483	
350	630	0.720	0.931	37.28	67.10	-1932	-3478	
360	648	0.721	0.952	44.48	80.06	-1930	-3474	
370	666	0.721	0.972	51.69	93.04	-1927	-3469	
380	684	0.722	0.992	58.91	106.04	-1925	-3465	
390	702	0.723	1.011	66.16	119.09	-1922	-3460	
400	720	0.726	1.030	73.43	132.17	-1919	-3454	

TABLE 2.8

SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES OF 70 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/g-K (Btu/lb-R)	Entropy, cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation		Phase
K	R			cal/g	Btu/lb	cal/g	Btu/lb	
0	0	0	0	-174.66	-314.39	-2109	-3796	Solid
20	36	0.009	0.013	-174.58	-314.24	-2119	-3814	
40	72	0.059	0.036	-173.94	-313.09	-2129	-3832	
60	108	0.109	0.070	-172.22	-310.00	-2136	-3845	
80	144	0.153	0.107	-169.60	-305.28	-2143	-3857	
100	180	0.189	0.145	-166.18	-299.12	-2150	-3870	
120	216	0.220	0.176	-162.10	-291.78	-2154	-3877	
140	252	0.248	0.207	-157.42	-283.36	-2157	-3883	
160	288	0.273	0.237	-152.22	-274.00	-2161	-3890	
180	324	0.299	0.267	-146.50	-263.70	-2164	-3895	
200	360	0.323	0.297	-140.26	-252.47	-2166	-3899	
220	396	0.349	0.326	-133.54	-240.37	-2168	-3902	
233.1	419.6	0.415	0.345	-128.55	-231.39	-2164	-3895	

*Refer to Section 2.2.3

TABLE 2.8

(Concluded)

Temperature		Heat Capacity, cal/gm-K (Btu/lb-R)	Entropy, cal/gm-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation		Phase
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb	
233.1	419.6	0.746	0.649	-55.81	-100.46	-2092	-3766	Liquid
240	432	0.757	0.670	-43.25	-77.85	-2087	-3757	
260	468	0.745	0.730	-28.23	-50.81	-2081	-3746	
280	504	0.739	0.785	-13.39	-24.10	-2075	-3735	
290	522	0.739	0.810	-6.00	-10.80	-2073	-3731	
298.1	536.7	0.738	0.831	0.0	0	-2070	-3726	
300	540	0.738	0.836	1.36	2.45	-2069	-3724	
310	558	0.738	0.860	8.74	15.73	-2067	-3721	
320	576	0.738	0.883	16.12	29.02	-2064	-3715	
330	594	0.738	0.906	23.50	42.30	-2061	-3710	
340	612	0.738	0.928	30.90	55.62	-2059	-3706	
350	630	0.739	0.949	38.26	68.87	-2056	-3701	
360	648	0.739	0.970	45.64	82.15	-2053	-3695	
370	666	0.740	0.991	53.05	95.45	-2051	-3692	
380	684	0.742	1.010	60.43	108.77	-2047	-3685	
390	702	0.746	1.030	67.85	122.13	-2045	-3681	
400	720	0.749	1.048	75.32	135.58	-2042	-3676	↓

TABLE 2.9

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
100 w/o H_2O_2*

Temperature		Heat Capacity, cal/gm-K (Btu/lb-R)	Entropy, cal/gm-K (Btu/lb-R)	Enthalpy ($H_T - H_{298}$)		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0	-76.26	-137.27	-912.08	-1641.74
100	180	0.235	1.310	-52.86	-95.15	-931.45	-1676.61
200	360	0.259	1.479	-25.78	-46.40	-942.56	-1696.61
298	536.4	0.303	1.636	0.0	0	-956.38	-1721.48
300	540	0.304	1.638	0.56	1.01	-956.86	-1722.35
400	720	0.340	1.743	32.81	59.06	-965.61	-1738.10
500	900	0.369	1.810	68.35	123.03	-972.11	-1749.80
600	1080	0.391	1.879	106.46	191.63	-976.81	1758.26
700	1260	0.407	1.941	146.41	263.54	-980.34	-1764.61
800	1440	0.420	1.996	187.83	338.09	-983.13	-1769.63
900	1620	0.432	2.046	230.47	414.85	-985.37	-1773.67
1000	1800	0.441	2.092	270.15	486.27	-987.13	-1776.83
1100	1980	0.451	2.135	318.78	573.80	-988.48	-1779.26
1200	2160	0.459	2.175	364.27	655.69	-989.54	-1781.17
1300	2340	0.466	2.211	410.42	738.76	-990.31	-1782.56
1400	2520	0.474	2.246	457.55	823.59	-990.87	-1783.57
1500	2700	0.480	2.279	505.18	909.32	-991.31	-1784.36

*Refer to Section 2.2.3

TABLE 2.10

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
98 w/o H_2O_2 SOLUTIONS *

Temperature		Heat Capacity cal/g-K (Btu/lb-R)	Entropy cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0	-77.36	-139.25	-957.2	-1723.0
100	180	0.239	1.32	-53.55	-96.39	-976.6	-1757.9
200	360	0.262	1.49	-26.13	-47.03	-987.6	-1777.7
298	536.4	0.306	1.65	0.0	0	-1001.4	-1802.5
300	540	0.307	1.65	0.56	1.01	-2001.9	-1803.4
400	720	0.342	1.74	33.07	59.53	-1010.7	-1819.3
500	900	0.370	1.83	68.82	123.88	-1017.3	-1831.1
600	1080	0.393	1.90	107.11	192.80	-1022.2	-1840.0
700	1260	0.409	1.96	147.25	265.05	-1025.9	-1846.6
800	1440	0.422	2.01	188.84	339.91	-1028.8	-1851.8
900	1620	0.434	2.06	231.67	417.01	-1031.2	-1856.2
1000	1800	0.443	2.11	271.64	488.95	-1033.2	-1859.8
1100	1980	0.453	2.15	320.41	576.74	-1034.6	-1862.3
1200	2160	0.461	2.19	366.13	659.03	-1035.8	-1864.4
1300	2340	0.469	2.23	412.53	742.55	-1036.7	-1866.1
1400	2520	0.477	2.25	449.55	809.19	-1037.4	-1867.3

*Refer to Section 2.2.3

TABLE 2.11

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
95 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity cal/g-K (Btu/lb-R)	Entropy cal/g-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0	-79.0	-142.2	-1024.9	-1844.8
100	180	0.245	1.345	-55.1	-99.2	-1044.2	-1879.6
200	360	0.268	1.52	-26.7	-48.1	-1055.2	-1899.4
298	536.4	0.310	1.68	0.0	0	-1068.9	-1924.0
300	540	0.311	1.68	0.6	1.1	-1069.4	-1924.9
400	720	0.346	1.75	33.5	60.3	-1078.4	-1941.1
500	900	0.374	1.80	69.5	125.1	-1085.2	-1953.4
600	1080	0.395	1.86	108.1	194.6	-1090.3	-1962.5
700	1260	0.411	1.92	148.5	267.3	-1094.2	-1969.6
800	1440	0.425	2.05	190.4	342.7	-1097.4	-1975.3
900	1620	0.437	2.09	233.5	420.3	-1100.0	-1980.0
1000	1800	0.446	2.14	273.9	493.0	-1102.2	-1984.0
1100	1980	0.457	2.18	322.8	581.0	-1103.9	-1987.0
1200	2160	0.465	2.22	368.9	664.0	-1105.2	-1989.4
1300	2340	0.472	2.26	415.6	748.1	-1106.3	-1991.3
1400	2520	0.481	2.32	463.5	834.3	-1107.0	-1992.6

*Refer to Section 2.2.3

TABLE 2.12

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
90 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/gm-K (Btu/lb-R)	Entropy, cal/gm-K (Btu/lb-R)	Enthalpy $(H_T - H_{298})$		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0.0	-81.76	-147.17	-1137.8	-2048.0
100	180	0.256	1.38	-56.34	-101.41	-1157.0	-2082.6
200	360	0.277	1.56	-27.55	- 49.59	-1167.9	-2102.2
298	536.4	0.317	1.72	0.0	0	-1181.5	-2126.7
300	540	0.318	1.72	0.58	1.04	-1182.0	-2127.6
400	720	0.351	1.81	34.11	61.40	-1191.2	-2144.2
500	900	0.379	1.90	70.69	127.24	-1198.3	-2156.9
600	1080	0.400	1.96	109.73	197.51	-1203.8	-2166.8
700	1260	0.416	2.03	151.53	272.75	-1208.1	-2174.6
800	1440	0.429	2.09	192.91	347.24	-1211.7	-2181.1
900	1620	0.442	2.15	236.50	425.70	-1214.7	-2186.5
1000	1800	0.452	2.19	277.59	499.66	-1217.2	-2191.0
1100	1980	0.462	2.23	326.92	588.46	-1219.2	-2194.6
1200	2160	0.471	2.27	373.57	672.43	-1220.9	-2197.6
1300	2340	0.479	2.31	420.97	757.75	-1222.2	-2200.0
1400	2520	0.488	2.39	469.42	844.96	-1223.3	-2201.9

*Refer to Section 2.2.3

TABLE 2.13

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
75 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/gm-K (Btu/lb-R)	Entropy, cal/gm-K (Btu/lb-R)	Enthalpy (H_T-H_{298})		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0	-90.02	-162.04	-1476.4	-2657.5
100	180	0.287	0.98	-61.57	-110.83	-1495.5	-2691.9
200	360	0.305	1.64	-30.21	-54.38	-1505.8	-2710.4
298	536.4	0.338	1.80	0.0	0	-1519.2	-2734.6
300	540	0.339	1.80	0.62	1.12	-1519.6	-2735.3
400	720	0.368	1.90	36.06	64.91	-1529.5	-2753.1
500	900	0.393	1.99	74.21	133.58	-1537.7	-2767.9
600	1080	0.413	2.06	114.64	206.35	-1544.2	-2779.6
700	1260	0.429	2.13	156.83	282.29	-1549.8	-2789.6
800	1440	0.443	2.19	200.52	360.94	-1554.6	-2798.3
900	1620	0.456	2.24	245.55	441.99	-1558.8	-2805.8
1000	1800	0.467	2.29	288.76	519.77	-1562.4	-2812.3
1100	1980	0.479	2.33	339.13	610.43	-1565.4	-2817.7
1200	2160	0.489	2.37	387.53	697.55	-1568.0	-2822.4
1300	2340	0.498	2.41	436.81	786.26	-1570.2	-2826.4
1400	2520	0.508	2.58	487.24	877.03	-1572.0	-2829.6
1500	2700						

*Refer to Section 2.2.3

TABLE 2.14

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF
70 w/o H_2O_2 SOLUTIONS*

Temperature		Heat Capacity, cal/gm-K (Btu/lb-R)	Entropy, cal/gm-K (Btu/lb-R)	Enthalpy (H_T-H_{298})		Heat of Formation	
K	R			cal/gm	Btu/lb	cal/gm	Btu/lb
0	0	0	0	-92.8	-167.0	-1589.2	-2860.6
100	180	0.297	1.52	-63.3	-113.9	-1608.3	-2894.9
200	360	0.314	1.75	-31.1	-56.0	-1618.5	-2913.3
298	536.4	0.346	1.89	0.0	0	-1631.8	-2937.2
300	540	0.346	1.90	0.63	1.13	-1632.2	-2938.0
400	720	0.374	1.99	36.7	66.1	-1642.3	-2956.1
500	900	0.398	2.09	75.4	135.7	-1650.8	-2971.4
600	1080	0.418	2.16	116.2	209.2	-1657.8	-2984.0
700	1260	0.434	2.23	158.9	286.0	-1663.8	-2994.8
800	1440	0.448	2.28	203.1	365.6	-1668.9	-3004.0
900	1620	0.461	2.34	248.6	447.5	-1673.4	-3012.1
1000	1800	0.473	2.39	292.5	526.5	-1677.4	-3019.3
1100	1980	0.485	2.40	343.2	617.8	-1680.8	-3025.4
1200	2160	0.495	2.50	392.2	706.0	-1683.7	-3030.7
1300	2340	0.505	2.52	442.1	795.8	-1686.1	-3035.0
1400	2520	0.515	2.71	493.2	887.6	-1688.2	-3038.8

*Refer to Section 2.2.3

TABLE 2.15

REFRACTIVE INDEX (SODIUM D-LINE) OF PROPELLANT-GRADE H_2O_2-H_2O SOLUTIONS AT 25 C*

H_2O_2, w/o	0.3, percent	0.2, percent	0.4, percent	0.6, percent	0.8, percent
66	1.3782	1.3784	1.3785	1.3787	1.3788
67	790	792	793	796	796
68	798	800	801	803	804
69	806	808	809	811	812
70	1.3814	1.3816	1.3817	1.3819	1.3820
71	822	824	825	827	828
72	830	832	833	835	836
73	838	840	841	843	844
74	846	848	849	851	852
75	854	856	857	859	860
76	862	864	865	867	868
77	870	872	873	875	876
78	878	880	881	883	884
79	886	888	889	891	892
80	1.3894	1.3896	1.3897	1.3899	1.3901
81	903	904	906	908	909
82	911	913	915	916	918
83	920	921	923	925	927
84	928	930	932	933	935
85	937	939	940	942	944
86	945	947	949	950	952
87	954	956	957	959	961
88	962	964	966	968	969
89	971	973	974	976	978

*Refer to Section 2.2.5.1

NOTE: Temperature correction is -0.34×10^{-5}/C from 15 to 25 C.

TABLE 2.15

(Concluded)

H_2O_2, w/o	0.3, percent	0.2, percent	0.4, percent	0.6, percent	0.8, percent
90	1.3880	1.3981	1.3983	1.3985	1.3986
91	988	990	992	993	995
92	997	999	1.4000	1.4002	1.4004
93	1.4006	1.4007	009	011	013
94	014	016	018	020	021
95	023	025	027	028	030
96	032	034	035	037	039
97	041	042	044	046	048
98	049	051	053	055	056
99	058	060	062	063	065
100	1.4067				

TABLE 2.16

VERDET CONSTANT OF HYDROGEN PEROXIDE-WATER SOLUTIONS AT 10 C*

H_2O_2, w/o	$-k_v$, min/gauss-cm x 10^3			
	5893 Å	5780 Å	5461 Å	4358 Å
100	11.48	11.90	13.52	22.65
96	11.60	12.03	13.64	22.70
78.5	11.98	12.45	14.07	23.45
62.0	12.30	12.80	14.43	24.11
50.9	12.53	12.98	14.60	24.22
38.1	12.69	13.15	14.86	24.47
18.1	12.91	13.38	15.13	25.00
0	13.09	13.64	15.40	25.21

*Refer tc Section 2.2.5.5

TABLE 2.17

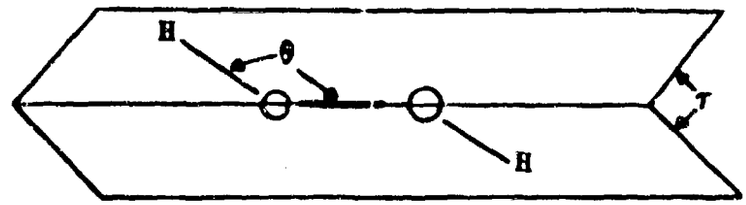
MISCELLANEOUS MOLECULAR AND ELECTROMAGNETIC PROPERTIES OF HYDROGEN PEROXIDE

Property	Value	Temperature	Reference
Specific Refraction	0.1705 cm^3/gm	25 C	2.15
Molar Refraction	5.801 $cm^3/mole$	25 C	2.15
Polarizability	2.30×10^{-24} $cm^3/mole$	25 C	2.45
Molar Dispersion	1.3576 $cm^3/mole$	--	2.45
Dispersion Constant	8.479×10^{30} sec^{-2}	--	2.45
Characteristic Frequency	2.979×10^{15} sec^{-1}	--	2.45
Molecular Radius	1.32 Å	--	2.45
Molecular Susceptibility	-21.0 ±4	25 C	2.46
Molecular Diamagnetism	16.73 ±0.20	25 C	2.47

TABLE 2.18

STRUCTURE AND STRUCTURAL PARAMETERS
OF HYDROGEN PEROXIDE

Structure



Structural Parameters

	R(O-O), Å	R(O-H), Å	θ(OOH), degrees	τ (HOOH), degrees
Electron Diffraction	1.47			
Crystal Diffraction	1.49		97	94
Far Infrared	1.475 ±0.004	0.950 ±0.005	94.8 ±2	(119.8 ±3)
Microwave				111.5

TABLE 2.19

REACTIONS OF HYDROGEN PEROXIDE

	Reference
INORGANIC COMPOUNDS	
$Ag + H_2O_2 \xrightarrow{acid}$ dissolves (Ag^+)	2.56
$Al + H_2O_2 \longrightarrow Al(OH)_3$	2.10
$As + H_2O_2 \longrightarrow H_3AsO_4$	2.10
$AsO_3^{-3} + H_2O_2 \longrightarrow AsO_4^{-3}$	2.57
$As(OH)_3 + H_2O_2 \longrightarrow H_3AsO_4$	2.10
$Au + H_2O_2 \xrightarrow{HCl}$ dissolves	2.58
Oxide of gold $+ H_2O_2 \xrightarrow{alkaline}$ reduction	2.58
B (colloidal) $+ H_2O_2 \longrightarrow H_3BO_3$	2.59
$Ba(OH)_2 + H_2O_2 \longrightarrow BaO_2 + H_2O$	2.10
$Bi_2O_3 + H_2O_2 \longrightarrow Bi_2O_4$	2.60
$Bi(NO_3)_3 + H_2O_2 \xrightarrow{alkaline} Bi(OH)_3$	2.61
$BrO_3^{-1} + H_2O_2 \longrightarrow Br^{-1} + Br_2$	2.10
$CN^{-1} + H_2O_2 \longrightarrow CO_3^{-2} + CNO^{-1}$	2.62
$CNS^{-1} + H_2O_2 \longrightarrow NH_3 \xrightarrow{H_2O_2} NO_3^{-1}$	2.63

TABLE 2.19
(Continued)

	Reference
INORGANIC COMPOUNDS (cont.)	
$Cl_2 + H_2O_2 \longrightarrow Cl^{-1}$	2.64
$ClO_3^{-1} + H_2O_2 \xrightarrow{\text{alkaline or neutral}}$ no reaction	2.65
$ClO_3^{-1} + H_2O_2 \xrightarrow{\text{acid}} Cl_2 + ClO_2$	2.65
$HClO_4 + H_2O_2 \longrightarrow$ no reaction	2.10
$HOCl + H_2O_2 \longrightarrow Cl^{-1}$	2.64
$Co + H_2O_2 \longrightarrow$ dissolves	2.66
$Co + H_2O_2 \xrightarrow{\text{alkaline}} Co(HO)_3$	2.10
$Cr + H_2O_2 \longrightarrow$ slow solution	2.10
$CrO_3 + H_2O_2 \longrightarrow Cr^{+3}$	2.67
$Cu + H_2O_2 \xrightarrow{\text{acid}}$ dissolves	2.68
$CuO + H_2O_2 \longrightarrow CuO_2 + H_2O$	2.69
$CuO_2 + H_2O_2 \longrightarrow CuO + H_2O + O_2$	2.69
$Fe + H_2O_2 \longrightarrow Fe^{+2} \xrightarrow{H_2O_2} Fe^{+3}$	2.10
$Fe(CN)_6^{-4} + H_2O_2 \xrightarrow{\text{acid}} Fe(CN)_6^{-3}$	2.70

TABLE 2.19
(Continued)

	Reference
INORGANIC COMPOUNDS (cont.)	
$Fe(CN)_6^{-3} + H_2O_2 \xrightarrow{\text{alkaline}} Fe(CN)_6^{-4}$	2.70
$Hg + H_2O_2 \xrightarrow{\text{acid}}$ dissolves	2.10
$Hg + H_2O_2 \xrightarrow{\text{alkaline}}$ oxides of mercury	2.10
$I_2 + H_2O_2 \longrightarrow I^{-1} \xrightarrow{pH=1} IO_3^{-1}$	2.71
$HI + H_2O_2 \longrightarrow I_2 + H_2O$	2.10
$Li^{+1} + H_2O_2 \longrightarrow Li_2O_2$	2.10
$Mg + H_2O_2 \longrightarrow Mg(OH)_2$	2.10
$MnO_4^{-1} + H_2O_2 \xrightarrow{\text{acid}} Mn^{+2} + H_2O + O_2$	2.10
$MnO_4^{-1} + H_2O_2 \xrightarrow{\text{alkaline}} MnO_2$	2.10
$MoS_2 + H_2O_2 \longrightarrow SO_4^{-2}$	2.10
$Ni + H_2O_2 \xrightarrow[H_2SO_4]{HCl \text{ or}}$ dissolves	2.10
$NiSO_4 + H_2O_2 \xrightarrow{H^+}$ no reaction	2.72
$N_2H_4 + H_2O_2 \longrightarrow$ various products depending upon conditions	2.73
$HONH_2 + H_2O_2 \longrightarrow NO_3^{-1}$	2.74

TABLE 2.19
(Continued)

	Reference
INORGANIC COMPOUNDS (cont.)	
$NO_2^{-1} + H_2O_2 \longrightarrow NO_3^{-1}$	2.75
$NO_3^{-1} + H_2O_2 \longrightarrow$ no reaction	2.10
$O_3 + H_2O_2 \longrightarrow H_2O + O_2$	2.76
$P + H_2O_2 \longrightarrow PH_3 + H_3PO_4$	2.77
$P_2O_5 + H_2O_2 + H_2O \longrightarrow H_3PO_5$	2.78
$PO_4^{-3} + H_2O_2 \longrightarrow$ no reaction	2.10
$PO_3^{-3} + H_2O_2 \longrightarrow PO_4^{-3}$	2.79
$Pb + H_2O_2 \xrightarrow{H^+}$ dissolves	2.80
$Pb + H_2O_2 \xrightarrow{\text{alkaline}} PbO_2$	2.80
$Po + H_2O_2 \longrightarrow$ dissolves	2.81
$Pt + H_2O_2 \longrightarrow$ no reaction	2.82
$S + H_2O_2 \longrightarrow$ no reaction	2.10
H_2S (aq.) $+ H_2O_2 \xrightarrow{\text{acid}} S^\circ$	2.83
H_2S (aq.) $+ H_2O_2 \xrightarrow{\text{alkaline}} SO_4^{-2}$	2.84
$M_2S + H_2O_2 \longrightarrow SO_4^{-2}$ plus various products depending upon metal	2.84

TABLE 2.19
(Continued

	Reference
INORGANIC COMPOUNDS (cont.)	
$SO_3^{-2} + H_2O_2 \longrightarrow SO_4^{-2} + S_2O_6^{-2}$	2.85
$Sb + H_2O_2 \longrightarrow$ no reaction	2.10
$Sb_2S_3 + H_2O_2 \xrightarrow{NH_3}$ antimoniate	2.86
$Se + H_2O_2 \longrightarrow SeO_2$	2.87
$Se + H_2O_2 \longrightarrow H_2SeO_4$	2.10
$H_2Se + H_2O_2 \longrightarrow$ rapidly attacked	2.10
$SeO_3^{-2} + H_2O_2 \longrightarrow SeO_4^{-2}$	2.88
$Sn^{+2} + H_2O_2 \longrightarrow Sn^{+4}$	2.89
$SnO_2 + H_2O_2 \longrightarrow$ no reaction	2.10
$Te + H_2O_2 \longrightarrow H_6TeO_6$	2.90
$Ti^{+3} + H_2O_2 \longrightarrow TiO_3$	2.91
$TiO_2^{+2} + H_2O_2 \longrightarrow Ti(O_2)_4^{-4}$	2.92
$Tl + H_2O_2 \longrightarrow TlOH$	2.10
$TlO_2 + H_2O_2 \longrightarrow Tl_2O_3$	2.10
$W + H_2O_2 \longrightarrow H_2WO_4$	2.10

TABLE 2.19
(Continued)

	Reference
INORGANIC COMPOUNDS (cont.)	
$Zn + H_2O_2 \longrightarrow ZnO$	2.10
$Zn + H_2O_2 \xrightarrow[\text{alcoholic}]{\text{alkaline}}$ dissolves	2.93
$Zr + H_2O_2 \longrightarrow$ no reaction	2.94
$Zr(SO_4)_2 + H_2O_2 \longrightarrow$ no reaction	2.94
ORGANIC COMPOUNDS	
Alkanes:	
Saturated paraffins + $H_2O_2 \xrightarrow[\text{catalysts}]{\text{with and without}}$ no reaction	2.55
Cyclic alkanes + $H_2O_2 \xrightarrow[\text{catalysts}]{\text{with and without}}$ no reaction	2.55
Grignard reagent (RMgX) + $H_2O_2 \longrightarrow$ alcohol	2.95
Alkenes:	
RCH = CHR' + $H_2O_2 \xrightarrow[\text{catalysts}]{\text{with and without}}$ no reaction	2.55
RCH = CHR' + $H_2O_2 \xrightarrow[40^\circ C]{RCOOOH}$ RCH – CHR' (epoxy) $\longrightarrow$ RHC – CHR' (OH OH, glycol)	2.10, 2.55

TABLE 2.19

(Continued)

	Reference
ORGANIC COMPOUNDS (cont.)	
Alcohols:	
$ROH + H_2O_2 \xrightarrow[\text{no catalyst}]{\text{cold}}$ no reaction	2.55
$RCH_2OH + H_2O_2 \xrightarrow{Fe^{+3}} RCOOH \longrightarrow CO_2$	2.55
Carboxylic Acids:	
$RCOOH + H_2O_2 \xrightarrow{1\%\ H_2SO_4} \underset{\text{peroxy acid}}{RCOOOH} + H_2O$	2.55
Aldehydes:	
$R\text{-}CHO + H_2O_2 \xrightarrow[H^+]{80\ C} RCOOH$	2.55
Aromatics:	
Benzene or toluene $+ H_2O_2 \xrightarrow{\text{no catalyst}}$ no reaction	2.10
Benzene $+ H_2O_2 \xrightarrow[\text{Al strips}]{Fe^{++}\ \text{catalyst}}$ phenol	2.55
β-naphthol $+ H_2O_2$ (in acetic acid) $\xrightarrow{RCOOOH}$ o-carboxycinnamic acid	2.96, 2.98
Hydrazobenzene $+ H_2O_2 \xrightarrow{22\text{-}23C}$ azobenzene	2.55
Azobenzene $+ H_2O_2$ (in acetic acid) $\xrightarrow[RCOOOH]{1\%\ H_2SO_4}$ azoxybenzene	2.55

TABLE 2.19
(Concluded)

	Reference
ORGANIC COMPOUNDS (cont.)	
Aromatics:	
Aniline + H_2O_2 $\xrightarrow{22\text{-}23C}$ aniline black products	2.55
Aniline + H_2O_2 (in acetic acid) $\xrightarrow[\text{added to water slurry of aniline containing Na bicarbonate}]{22\text{-}23C;\ \text{oxidant}}$ nitrobenzene + azoxybenzene	2.96
Benzaldehyde + H_2O_2 (in acetic acid) $\xrightarrow[1\%\ H_2SO_4,\ RCOOOH]{22\text{-}23C}$ benzoic acid	2.97
Anthracene + H_2O_2 (in acetic acid) $\xrightarrow{RCOOOH}$ anthraquinone	2.96
Primary Amines:	
$RNH_2 + H_2O_2 \longrightarrow$ vigorous decomposition of peroxide; reaction difficult to control; no products isolated	2.55
Secondary Amines:	
$(R)_2NH + H_2O_2 \longrightarrow (R)_2NOH$ hydroxylamine	2.55
Tertiary Amines:	
$(R)_3N + H_2O_2 \longrightarrow R_3NO$ amineoxide	2.55

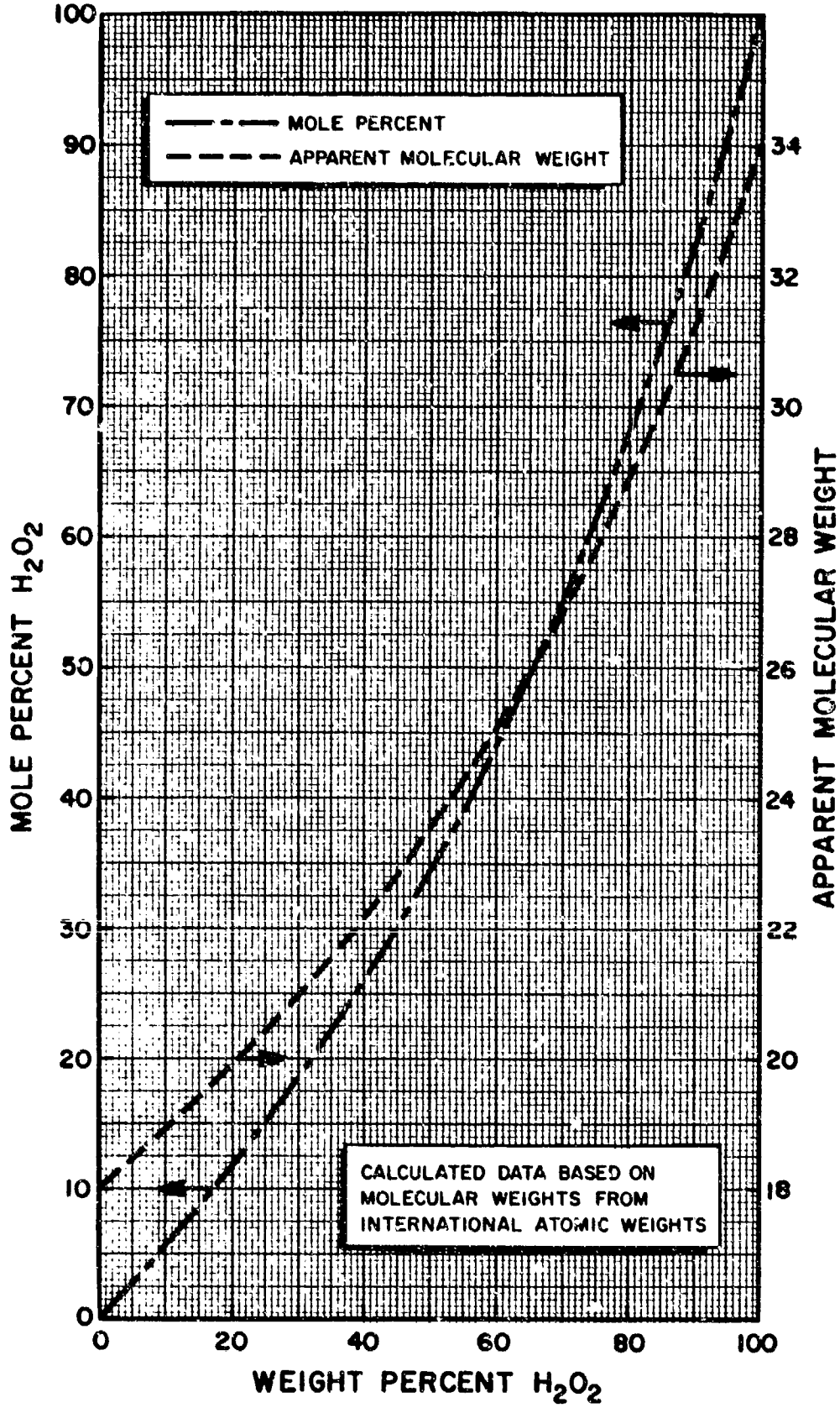


Figure 2.1. Concentration and Apparent Molecular Weight of Aqueous Hydrogen Peroxide Solutions

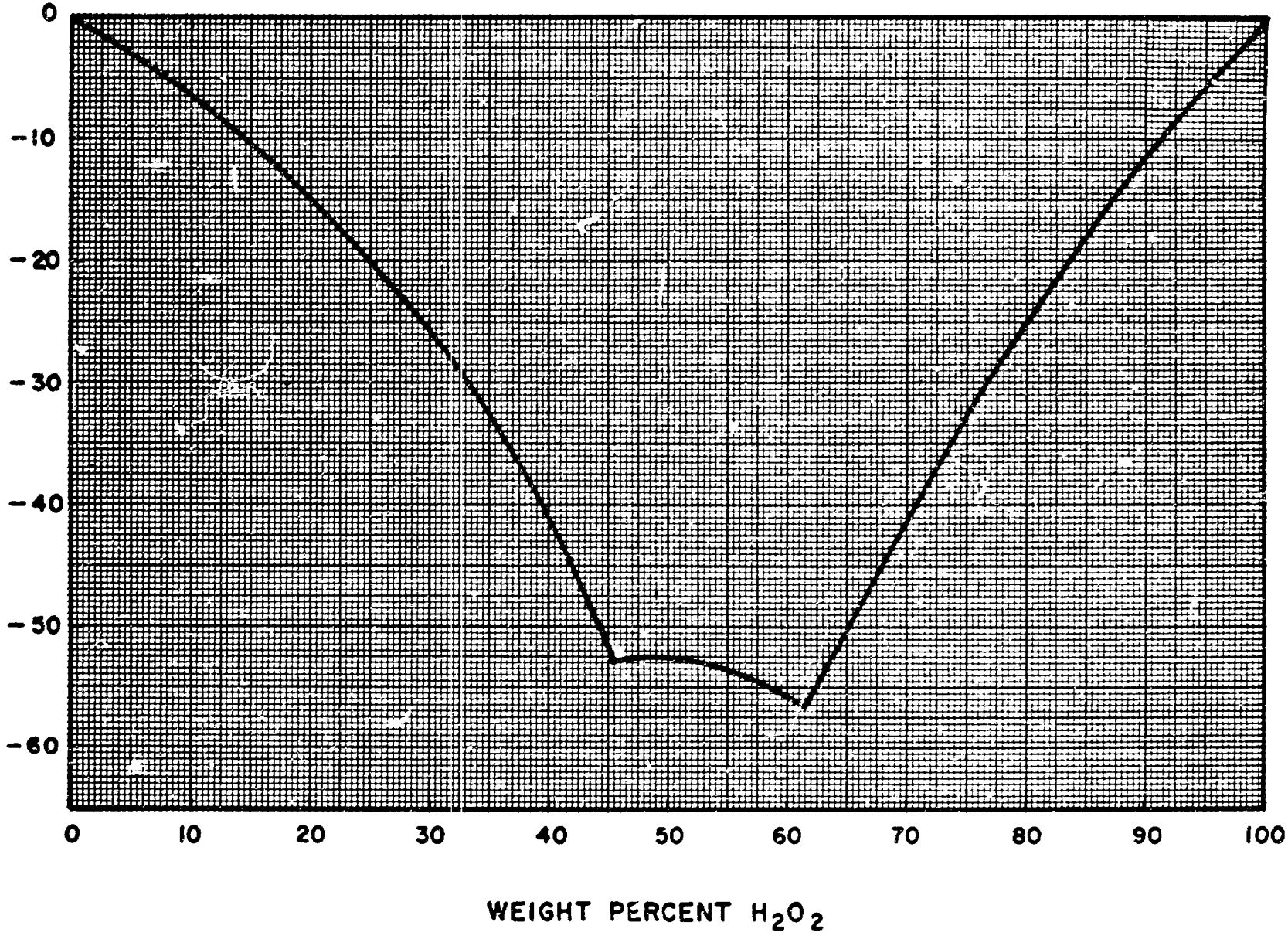


Figure 2.2. Freezing Points of Hydrogen Peroxide-Water Solutions (Ref. 2.2)

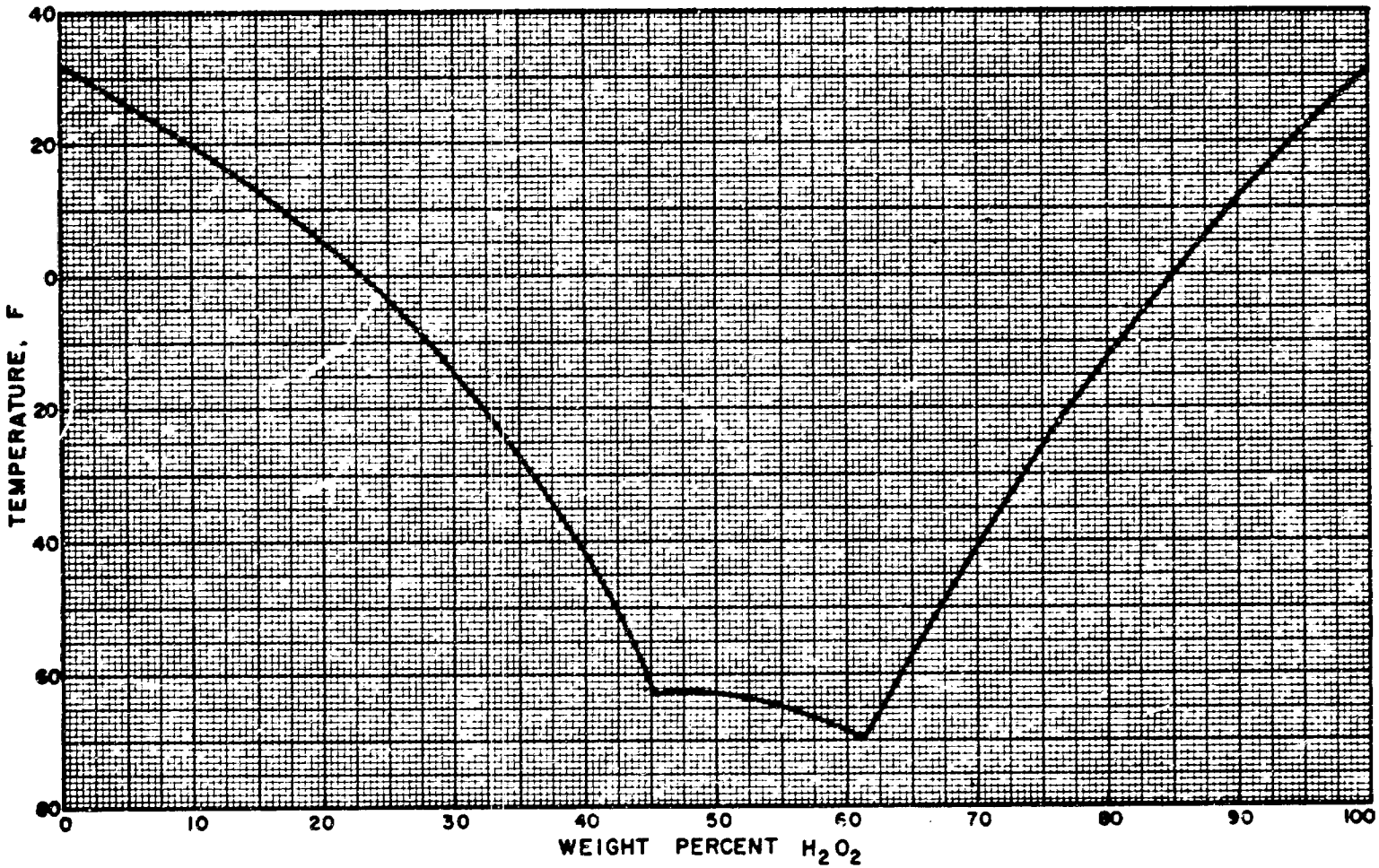


Figure 2.2a. Freezing Points of Hydrogen Peroxide-Water Solutions (Ref. 2.2)

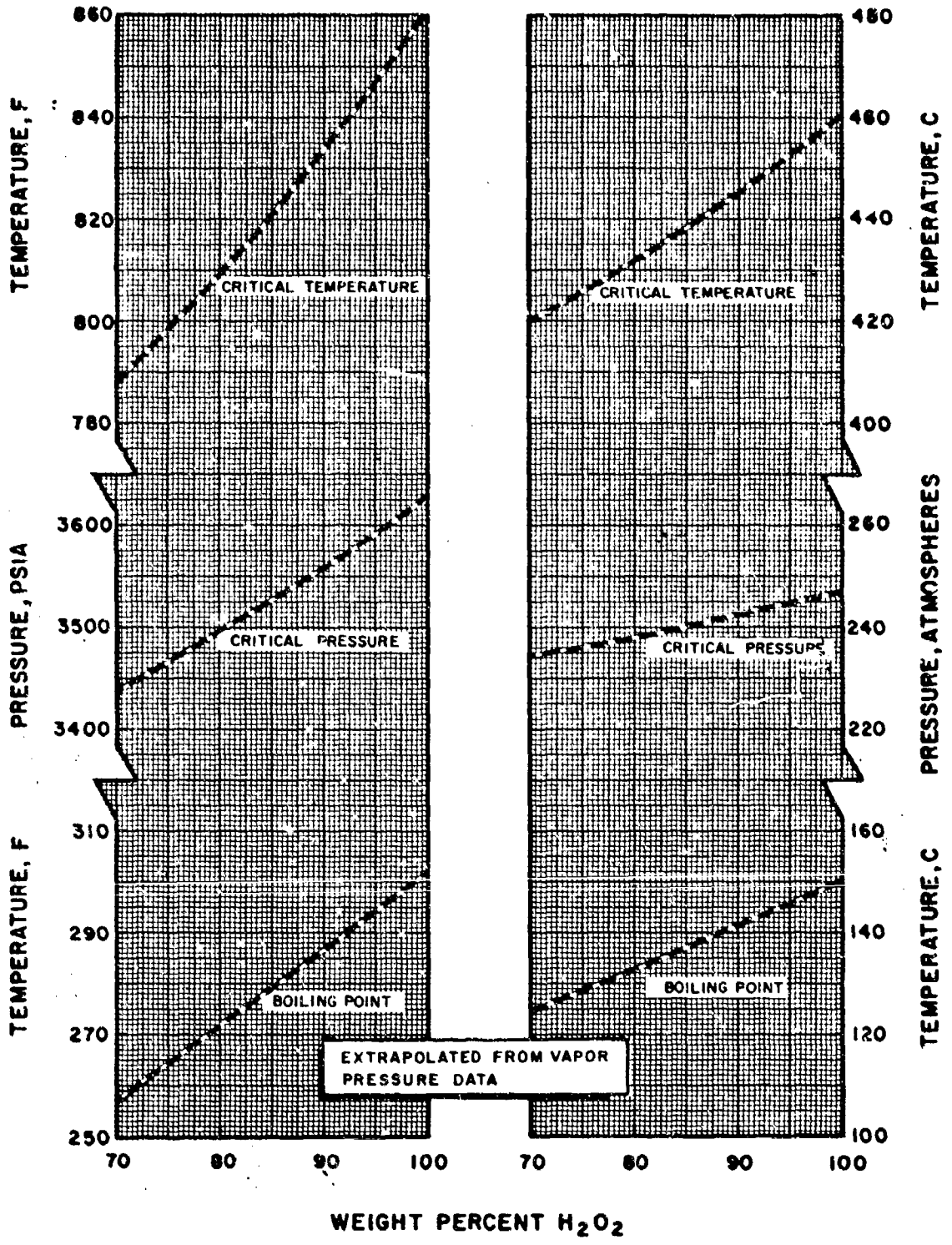


Figure 2.3. Critical Temperature, Critical Pressure, and Boiling Point of Propellant-Grade Hydrogen Peroxide-Water Solutions

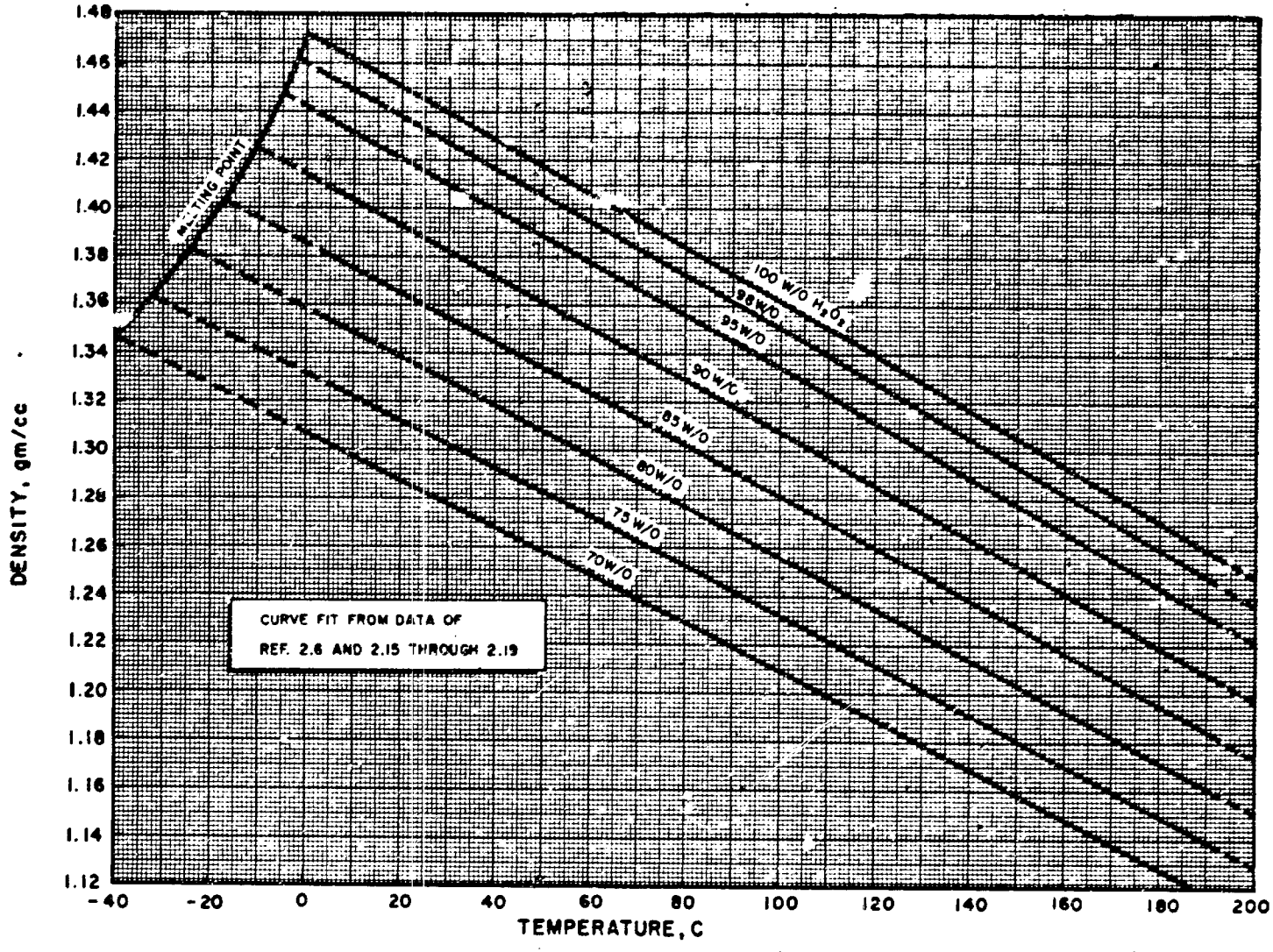


Figure 2.4. Density of Propellant-Grade Hydrogen Peroxide-Water Solutions

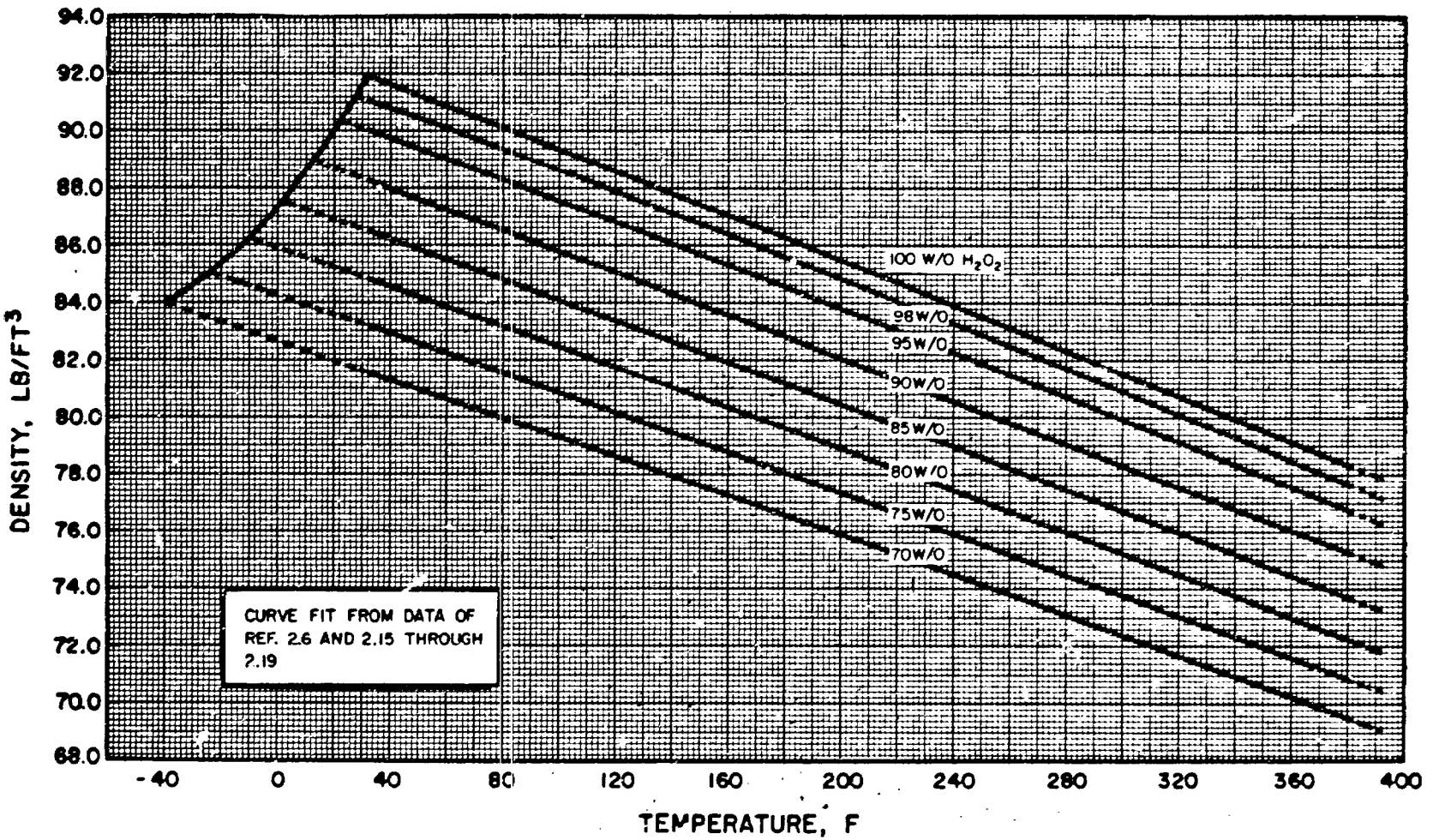


Figure 2.4a. Density of Propellant-Grade Hydrogen Peroxide-Water Solutions

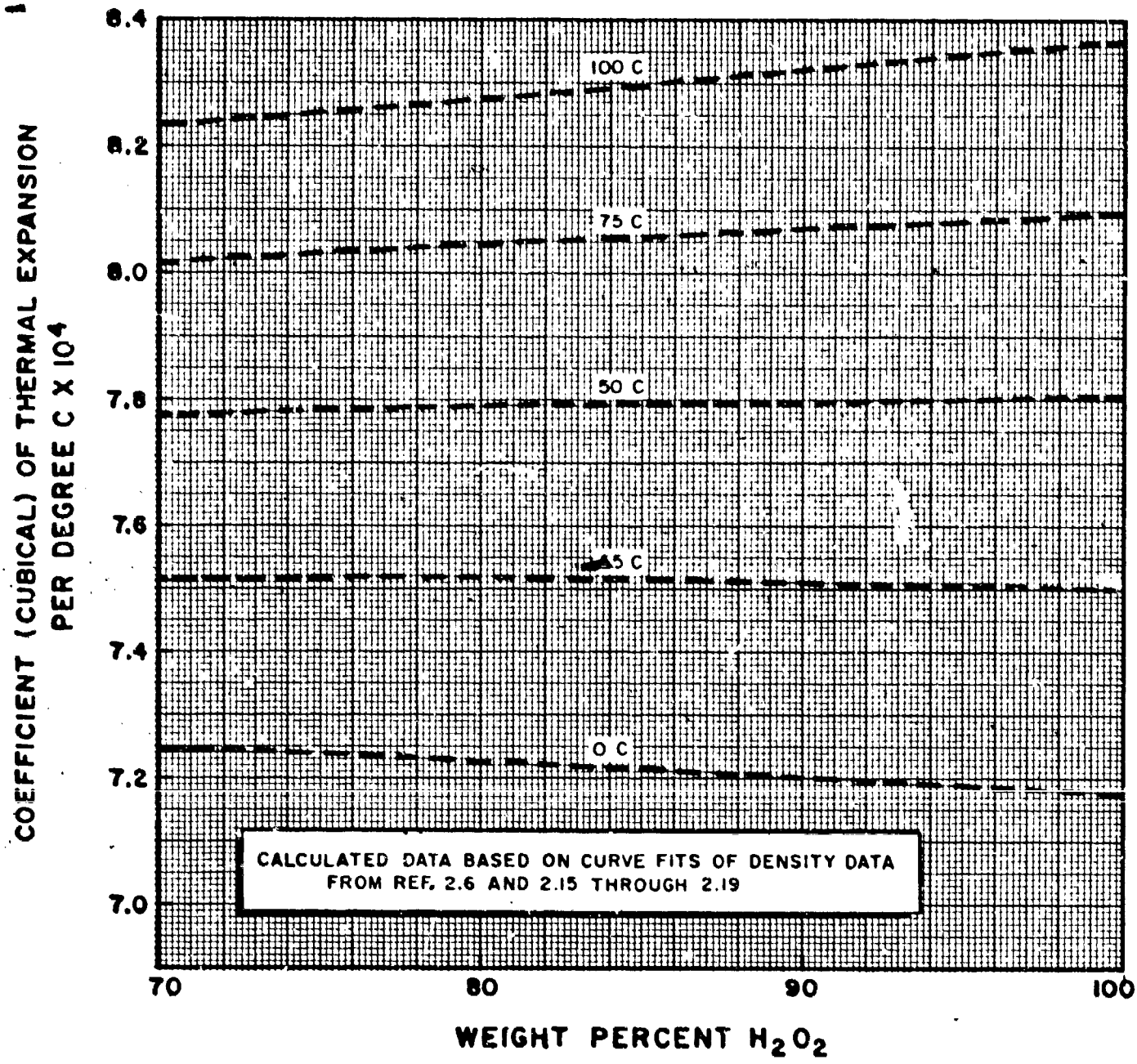


Figure 2.5. Coefficients (Cubical) of Thermal Expansion for Propellant-Grade Hydrogen Peroxide-Water Solutions

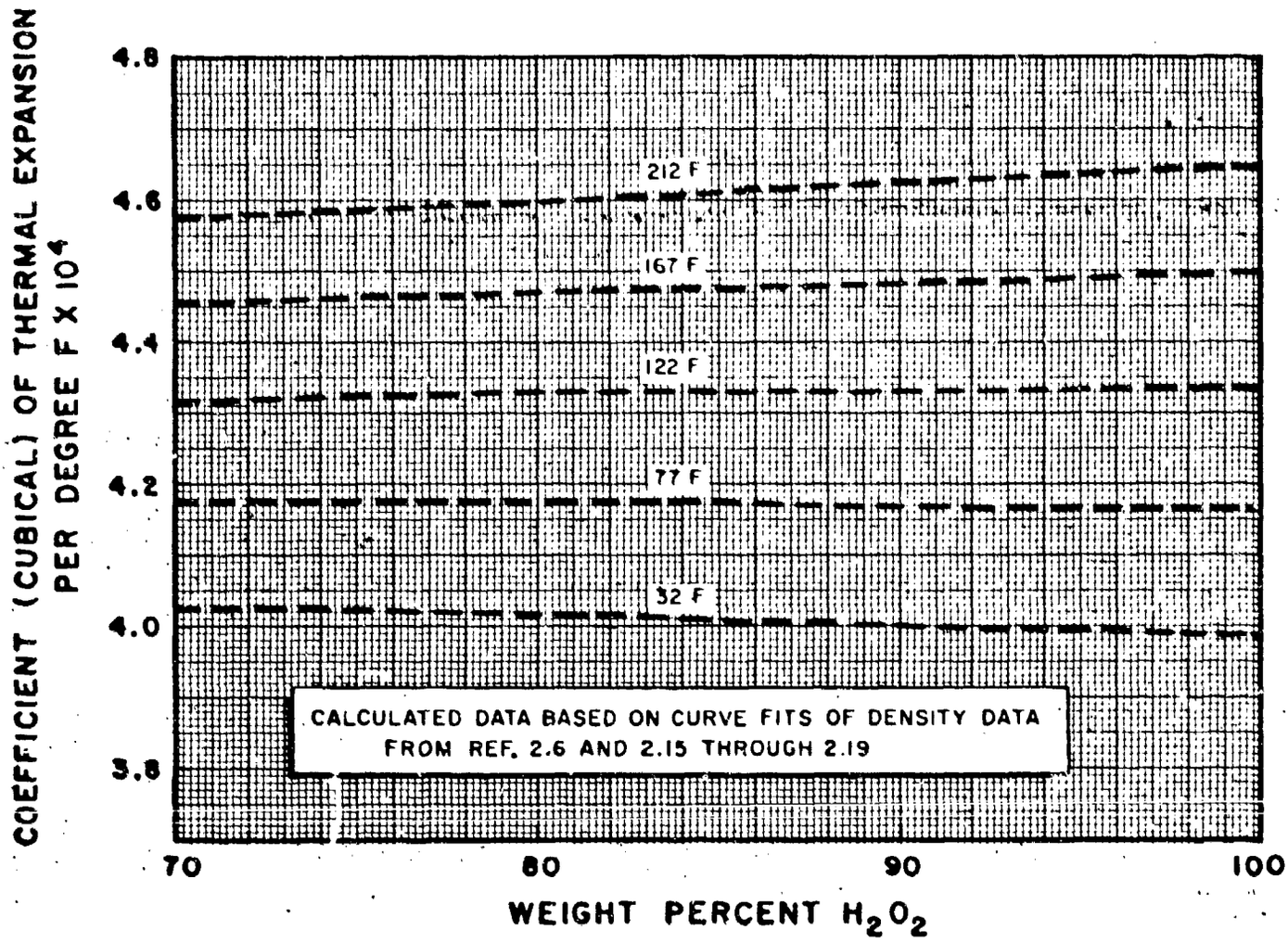


Figure 2.5a. Coefficients (Cubical) of Thermal Expansion for Propellant-Grade Hydrogen Peroxide-Water Solutions

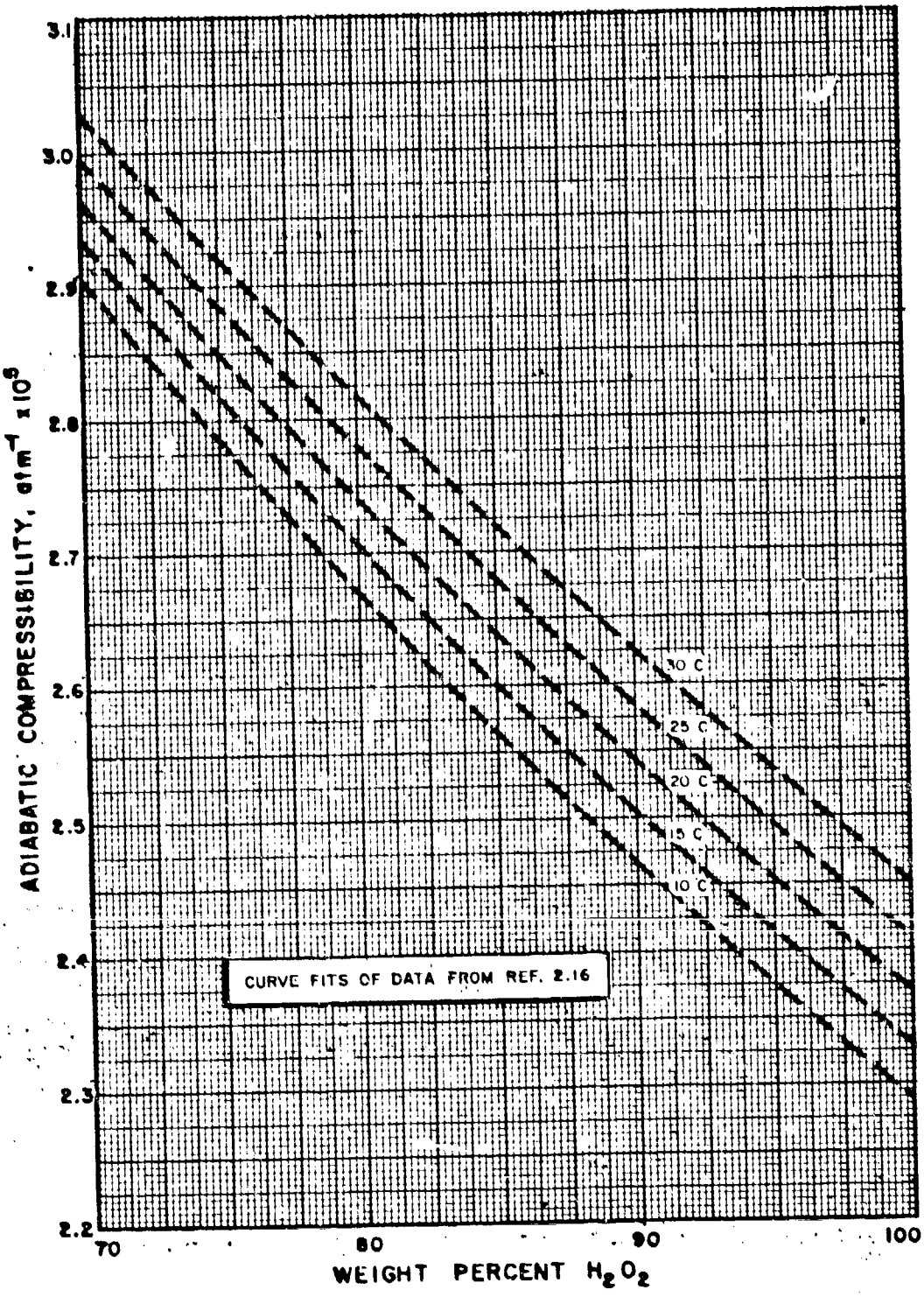


Figure 2.6. Adiabatic Compressibility of Propellant-Grade Hydrogen Peroxide-Water Solutions

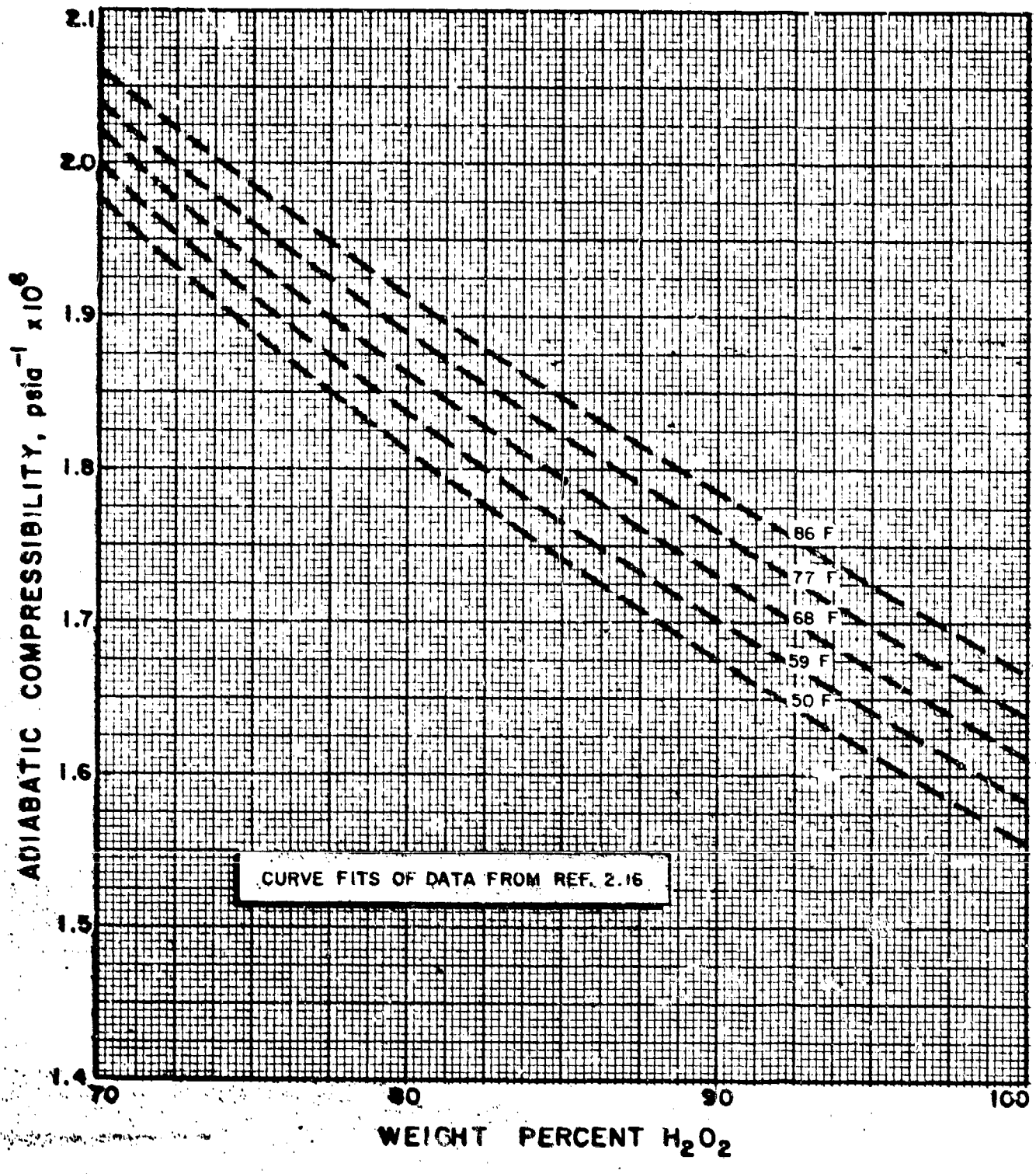


Figure 2.6a. Adiabatic Compressibility of Propellant-Grade Hydrogen Peroxide-Water Solutions

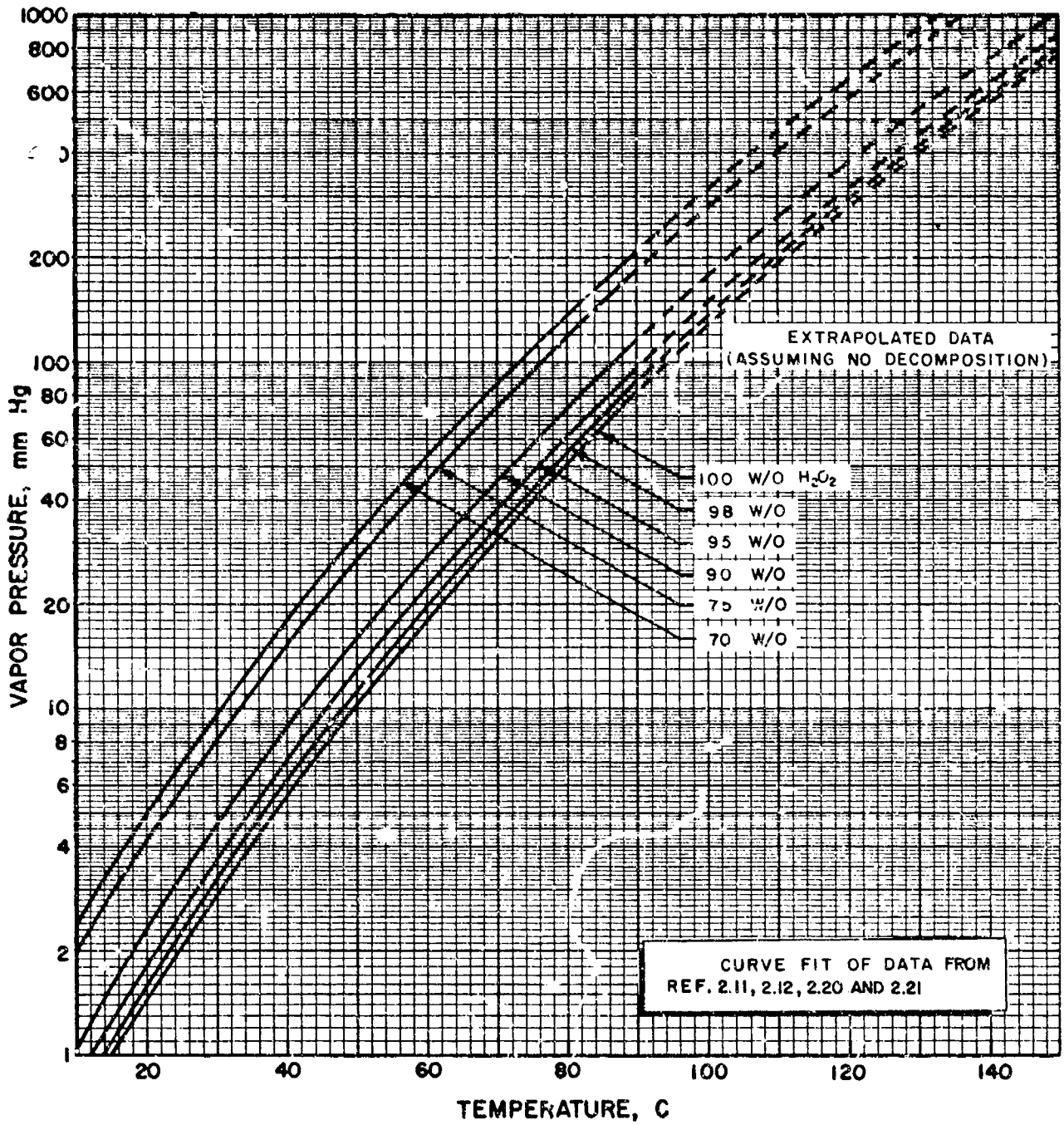


Figure 2.7. Vapor Pressure of Propellant-Grade Hydrogen Peroxide-Water Solutions

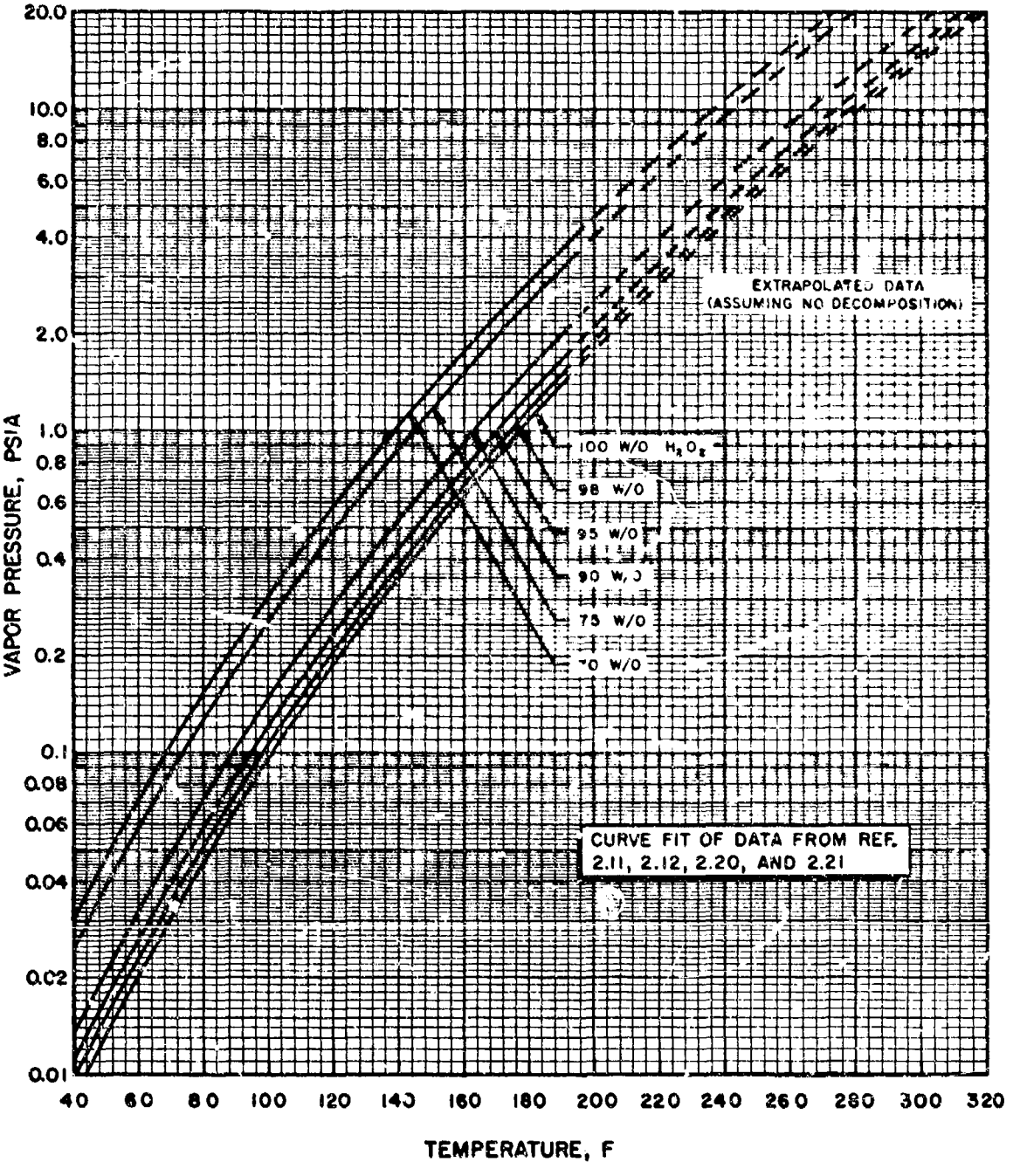


Figure 2.7a. Vapor Pressure of Propellant-Grade Hydrogen Peroxide-Water Solutions

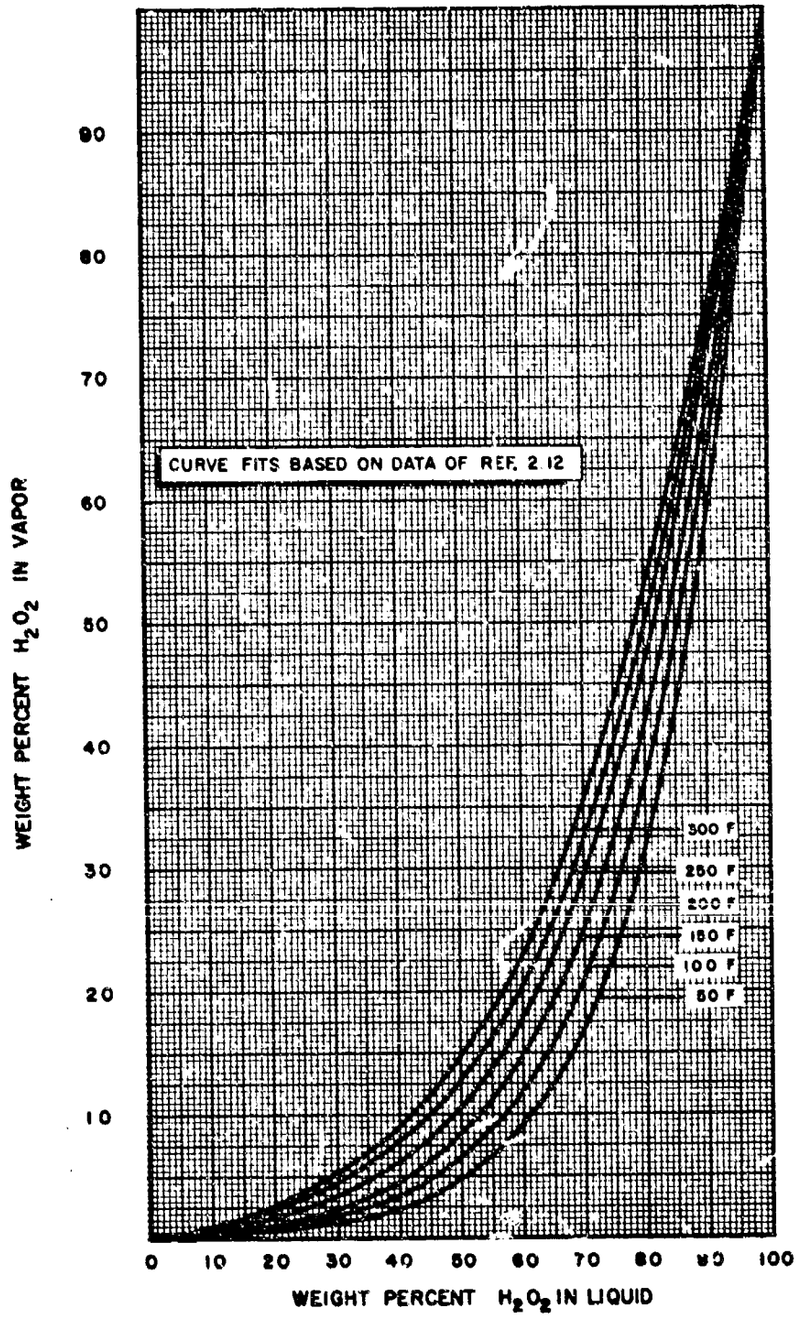


Figure 2.8. Vapor Composition Over Hydrogen Peroxide-Water Solutions (Ref. 2.22)

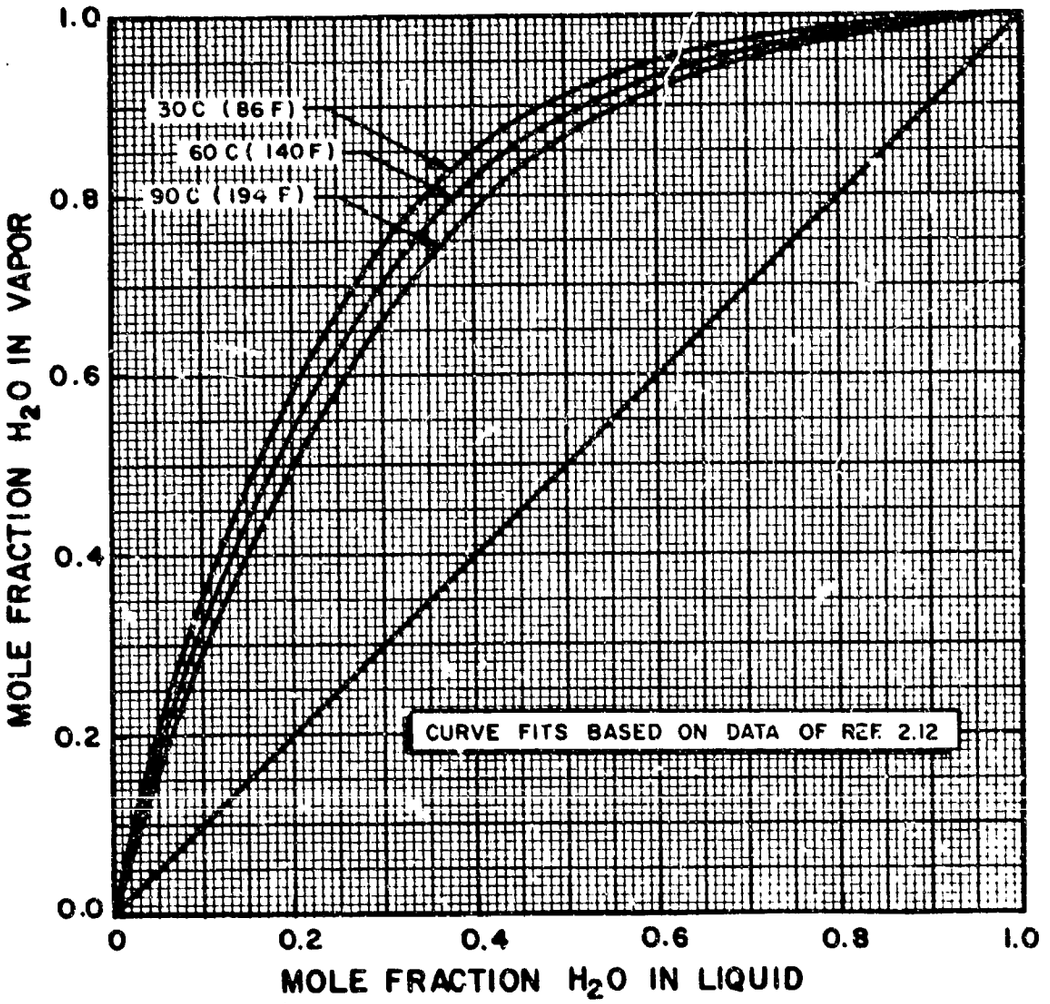


Figure 2.9. Vapor-Liquid Equilibrium for the Hydrogen Peroxide-Water System (Ref. 2.22)

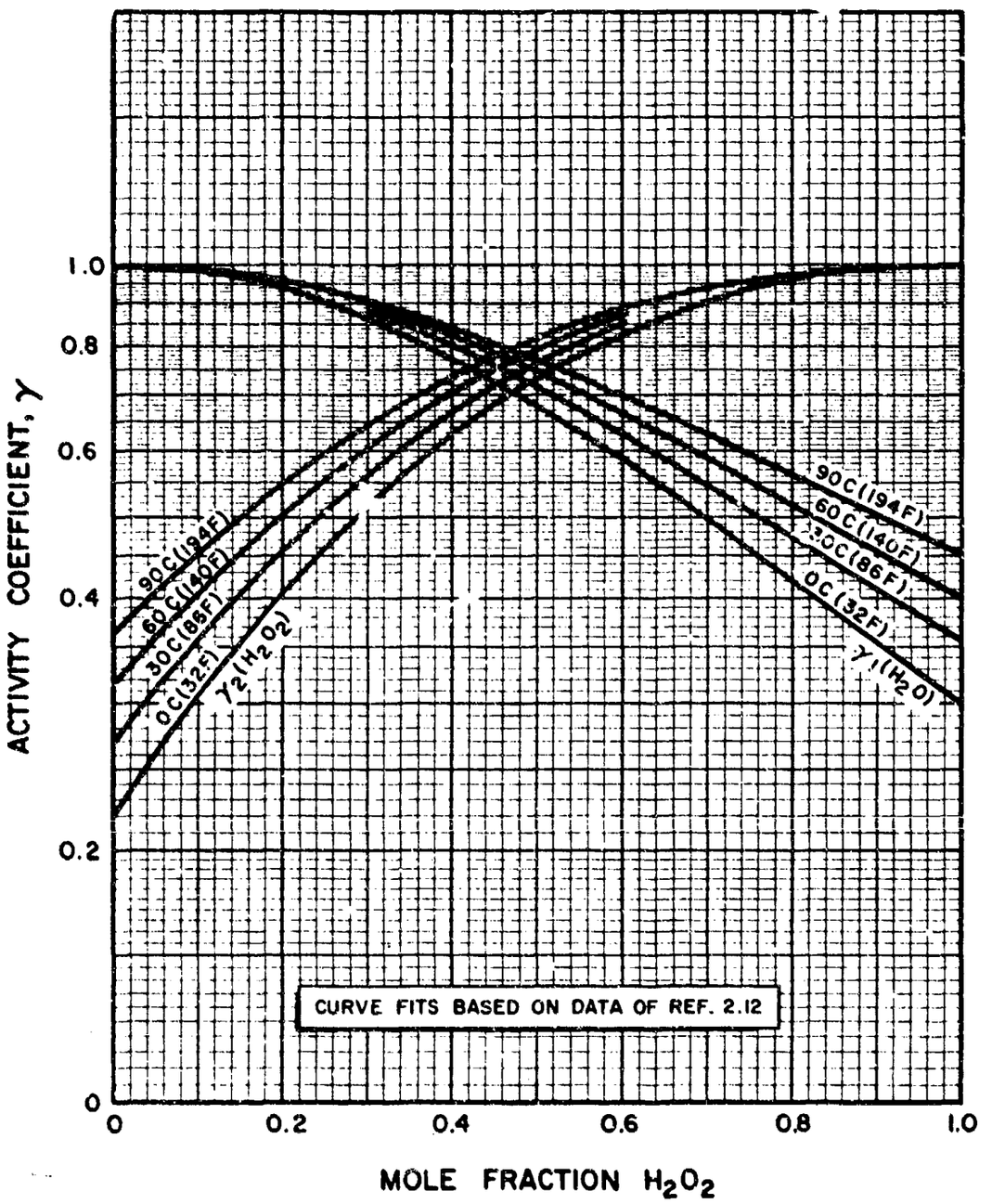


Figure 2.10. Activity Coefficients for Hydrogen Peroxide-Water Solutions (Ref. 2.22)

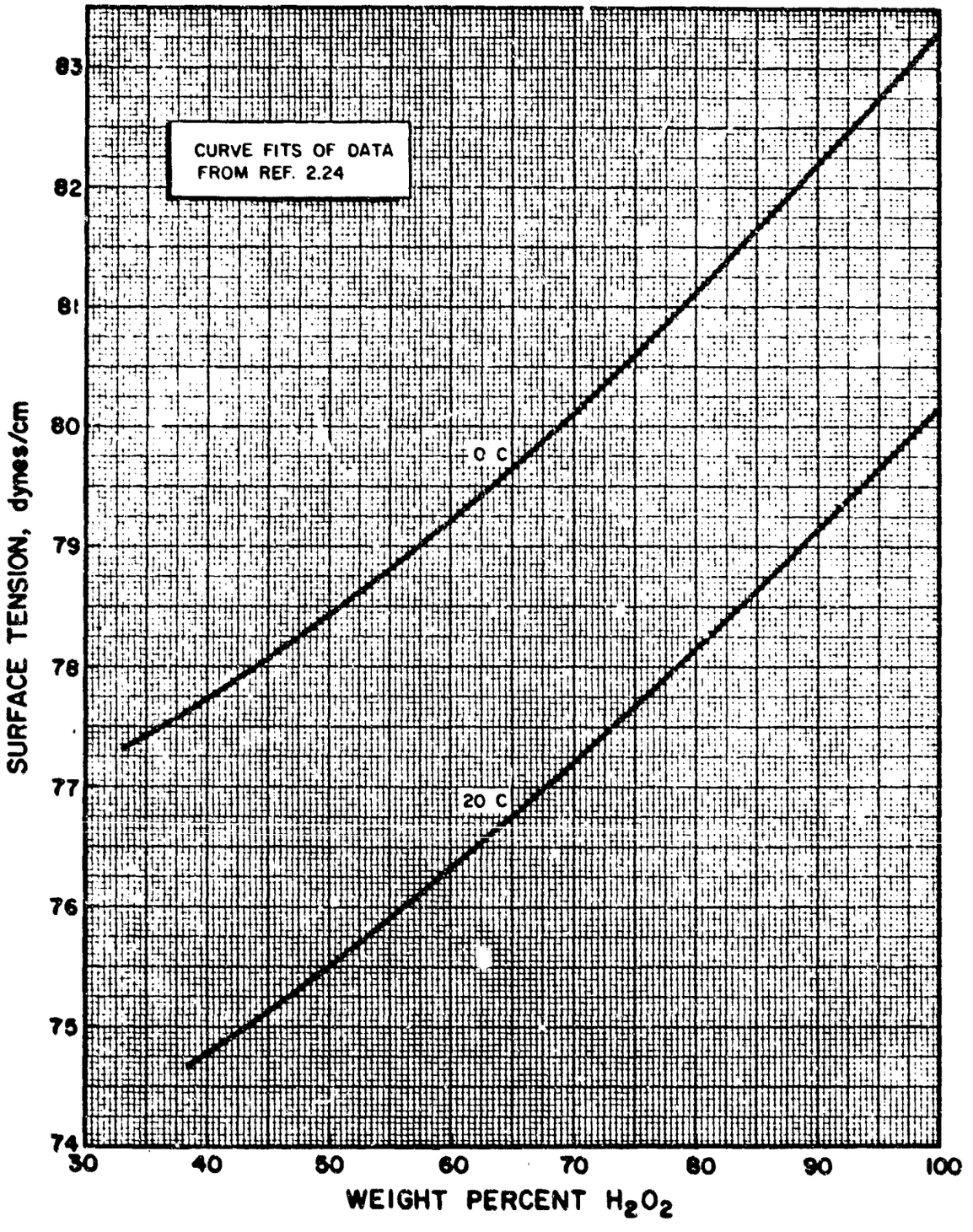


Figure 2.11. Surface Tension of Hydrogen Peroxide-Water Solutions

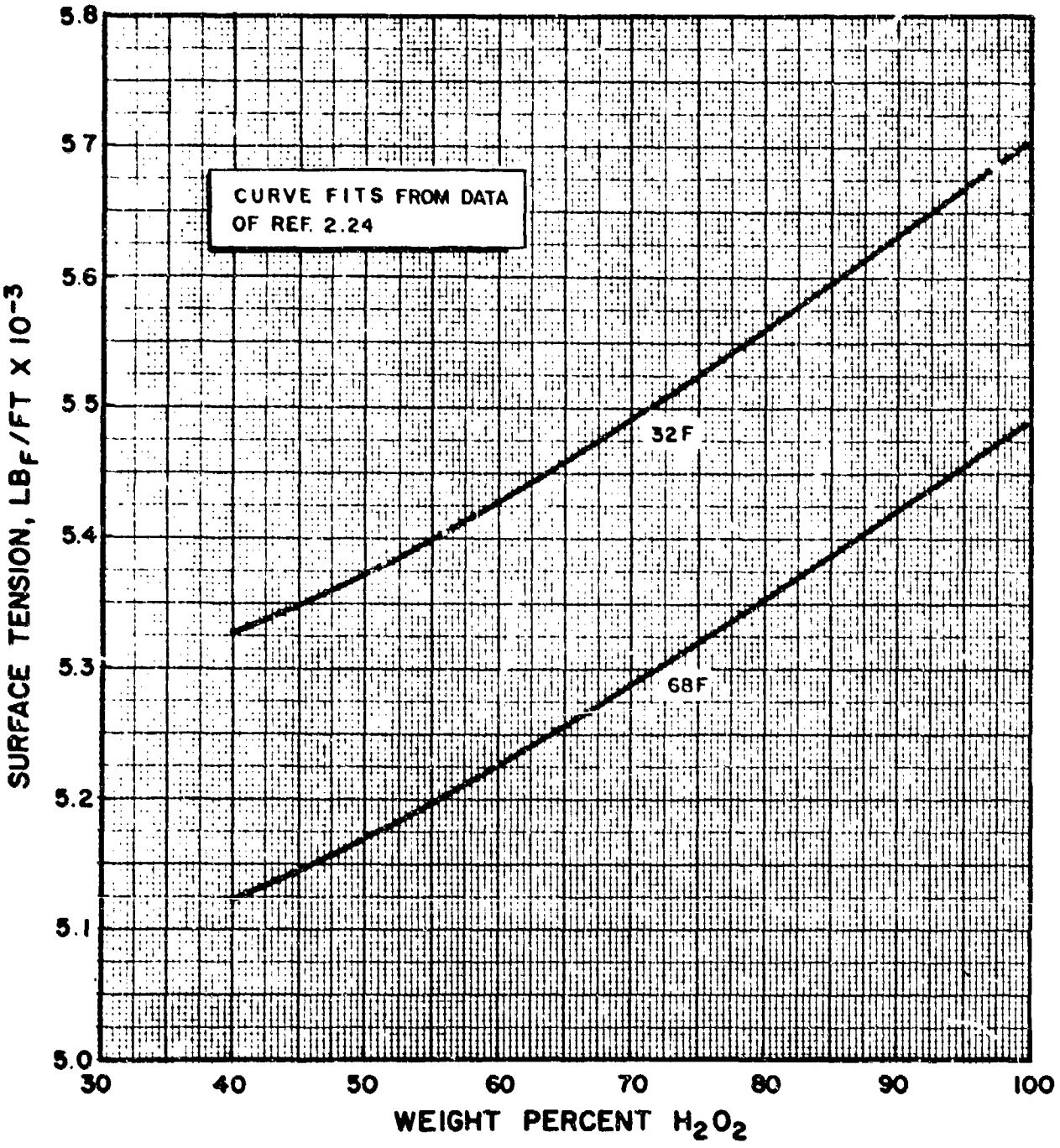


Figure 2.11a. Surface Tension of Hydrogen Peroxide-Water Solutions

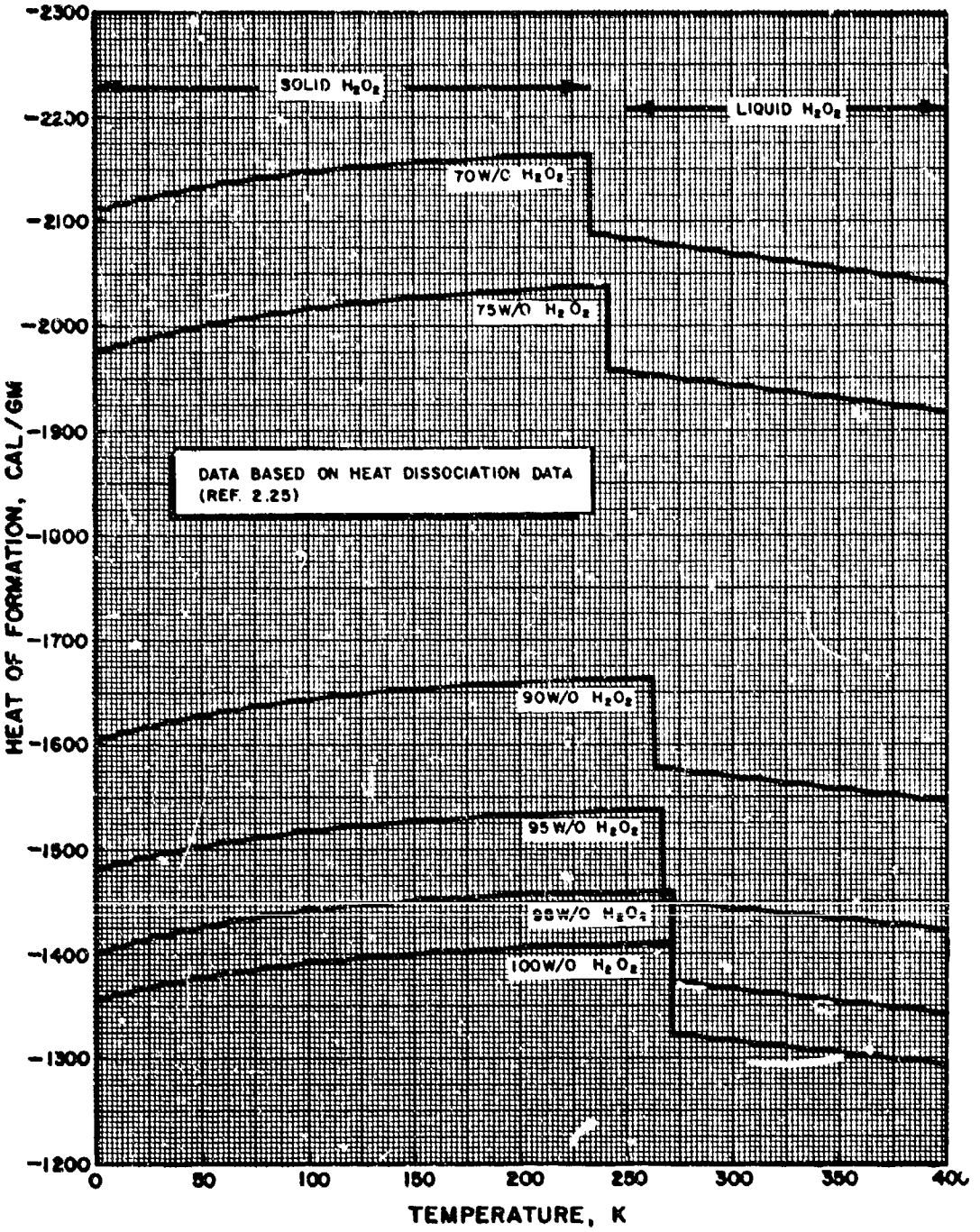


Figure 2.12. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions

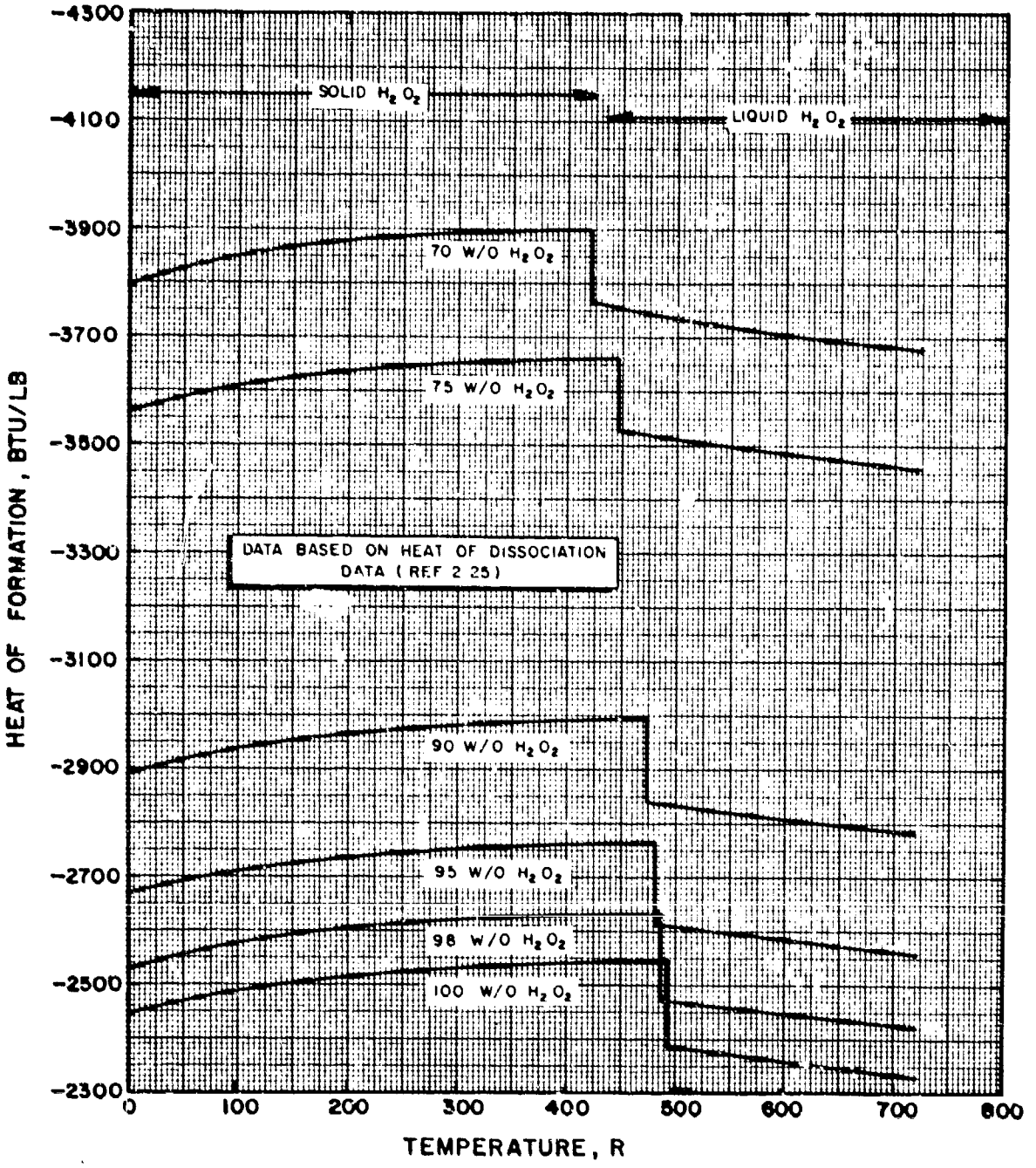


Figure 2.12a. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions

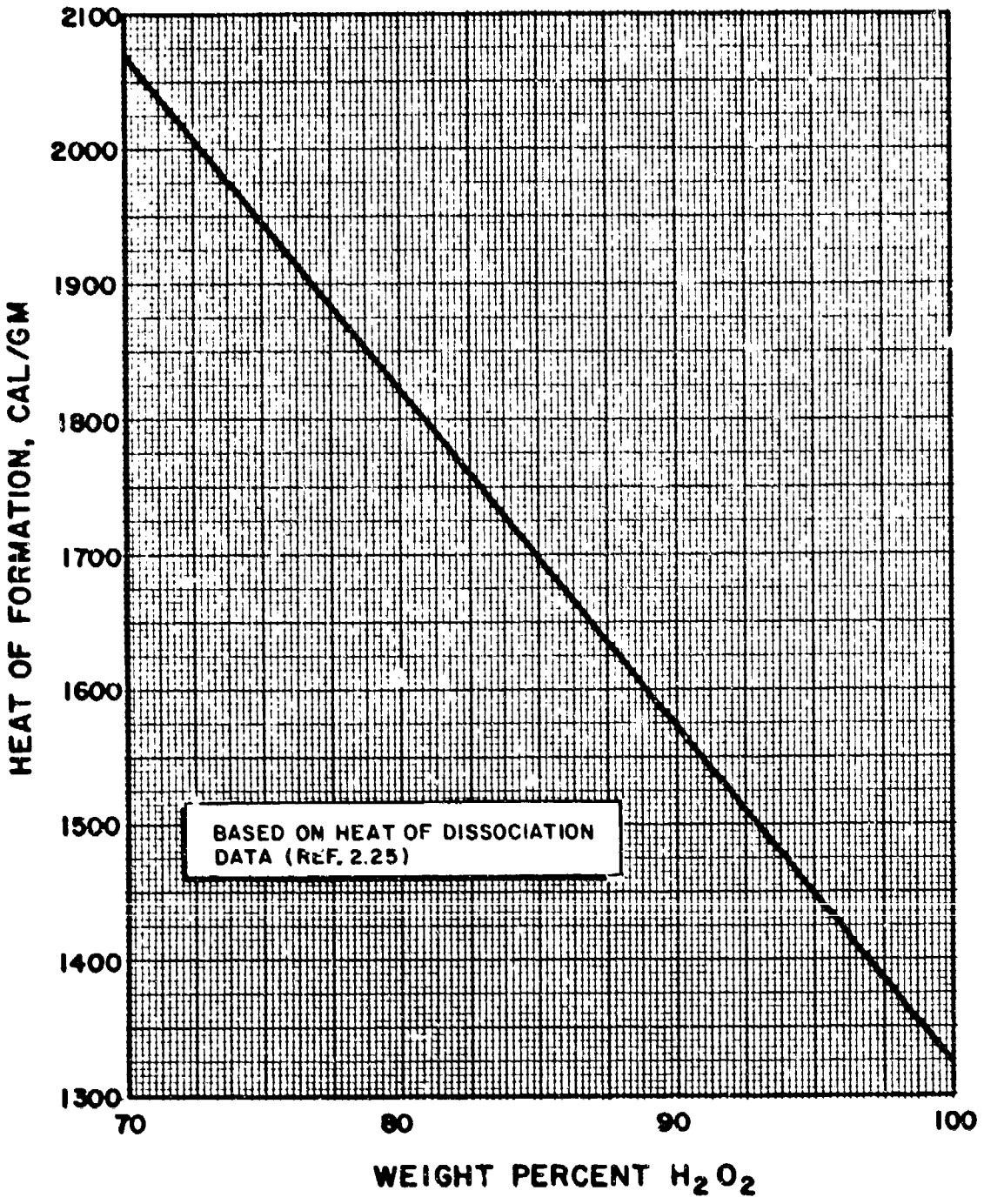


Figure 2.13. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions at 25 C

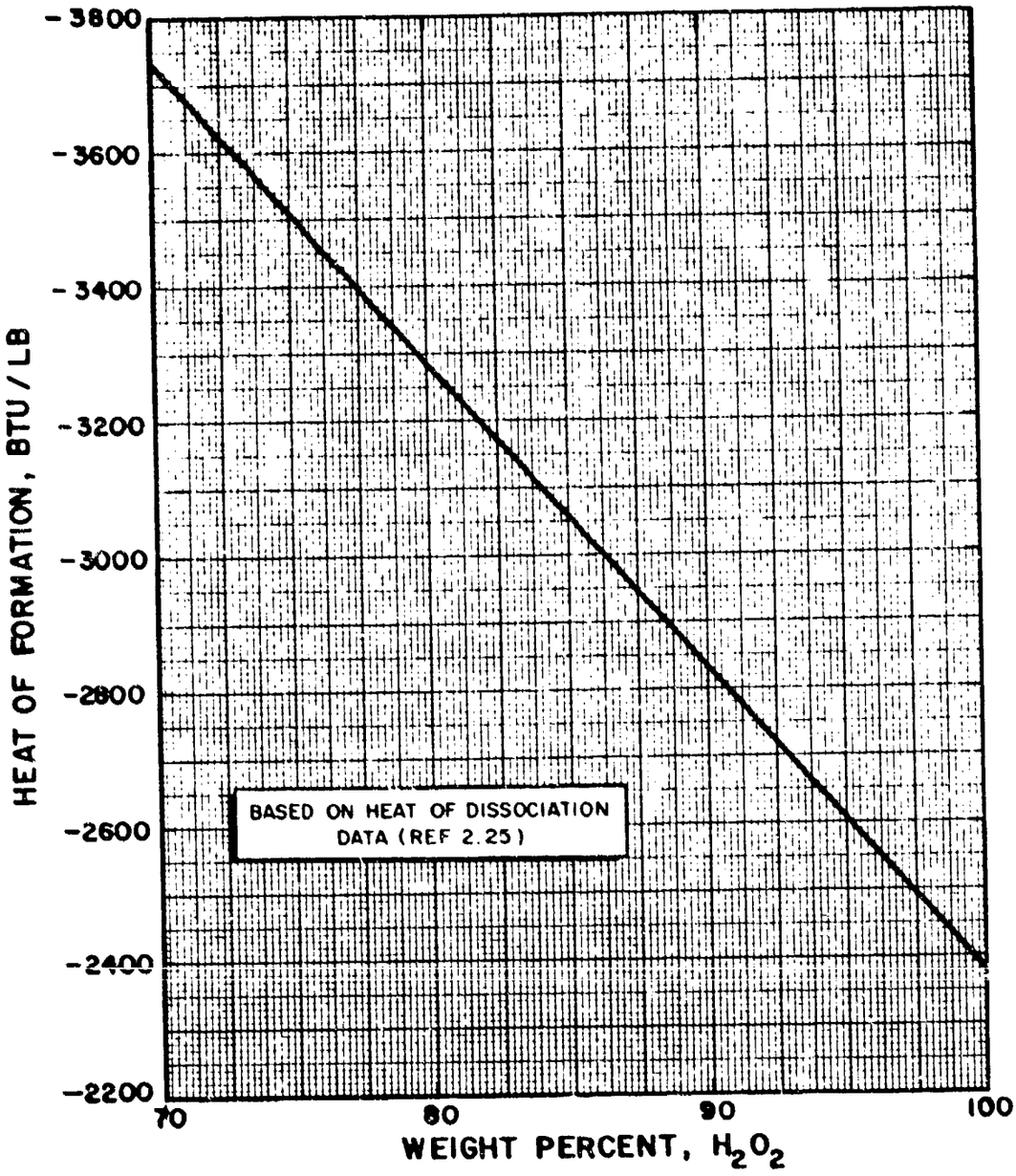


Figure 2.13a. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions at 77 F

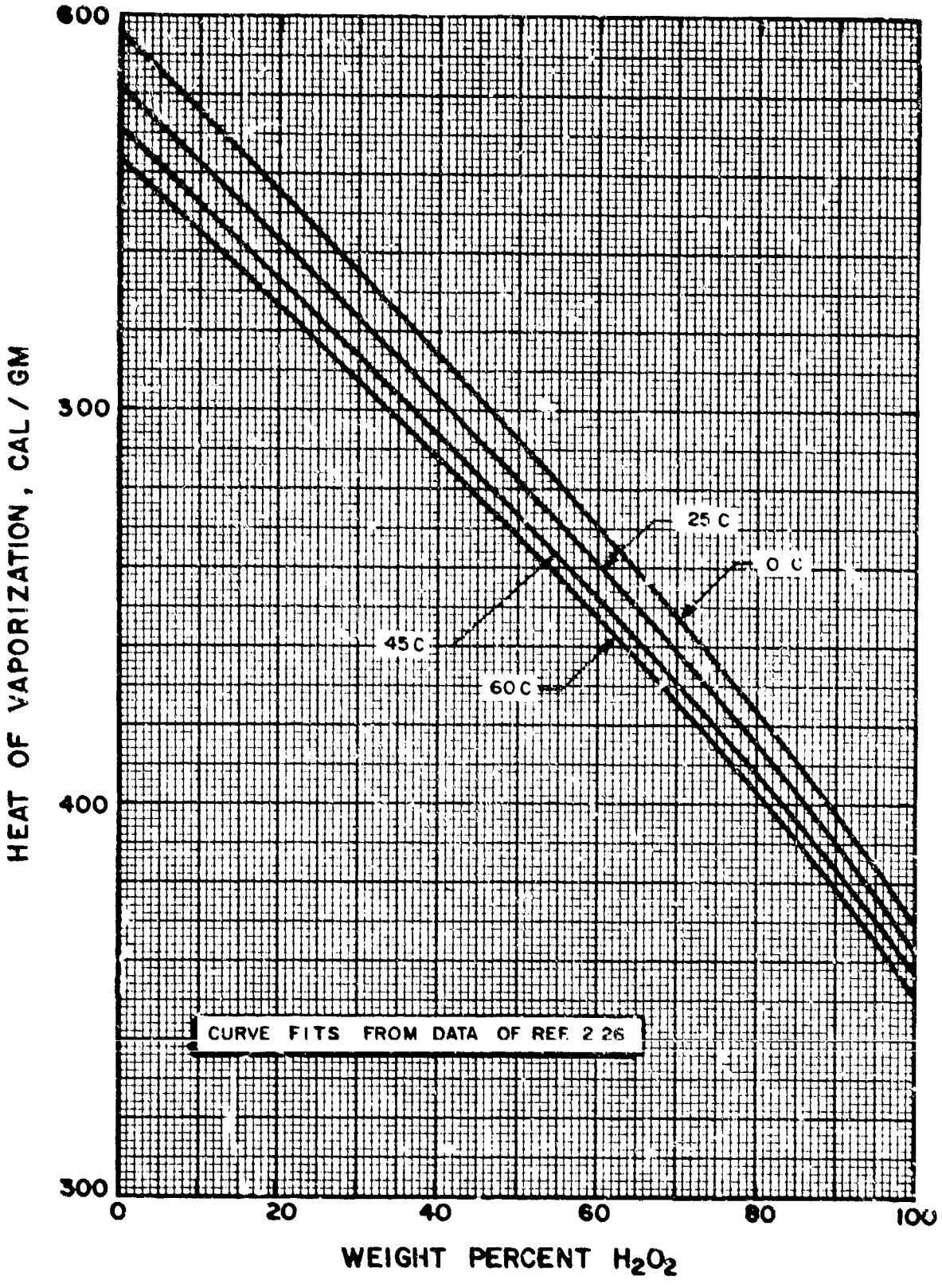


Figure 2.14. Heats of Vaporization of Hydrogen Peroxide-Water Solutions

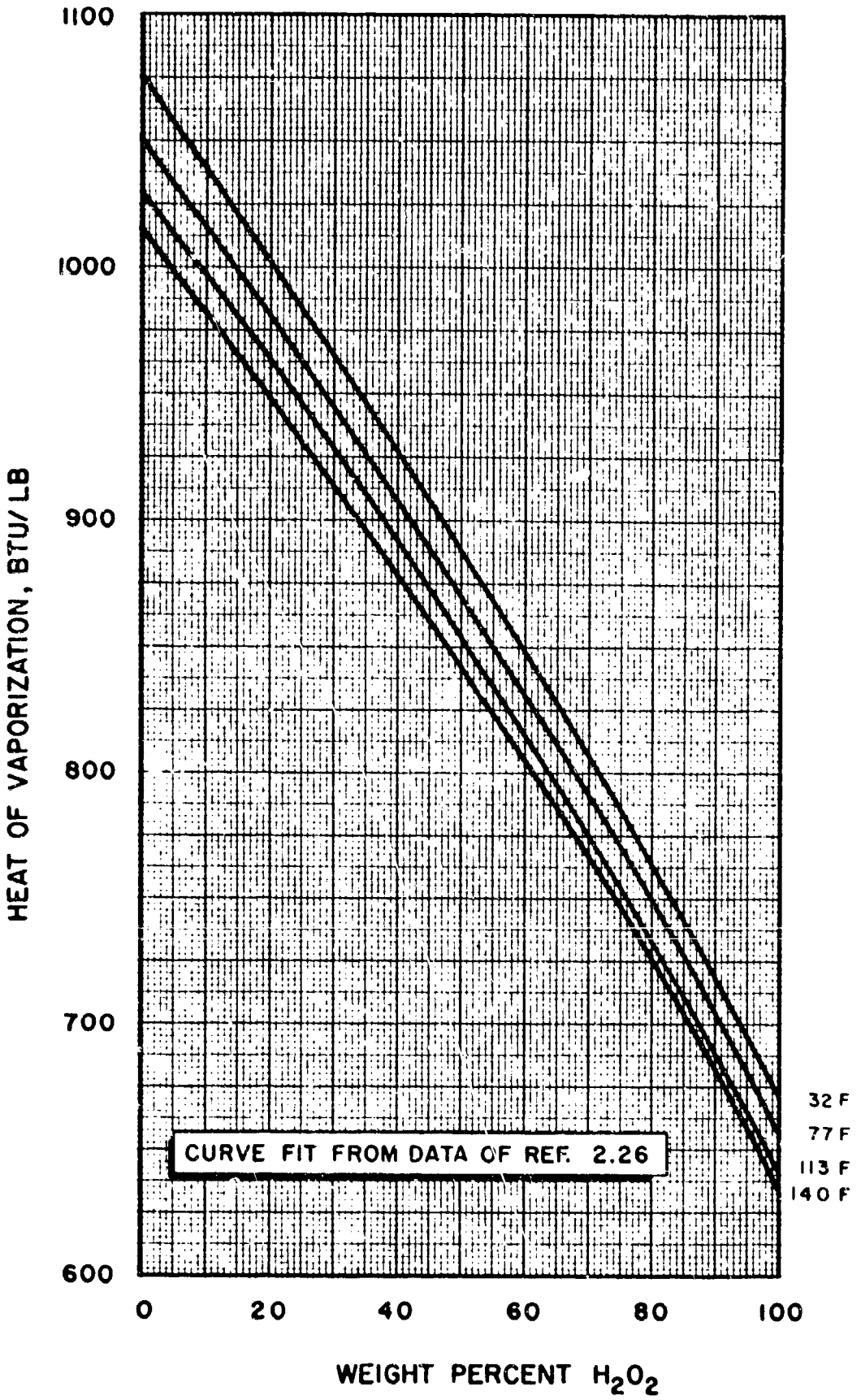


Figure 2.14a. Heats of Vaporization of Hydrogen Peroxide-Water Solutions

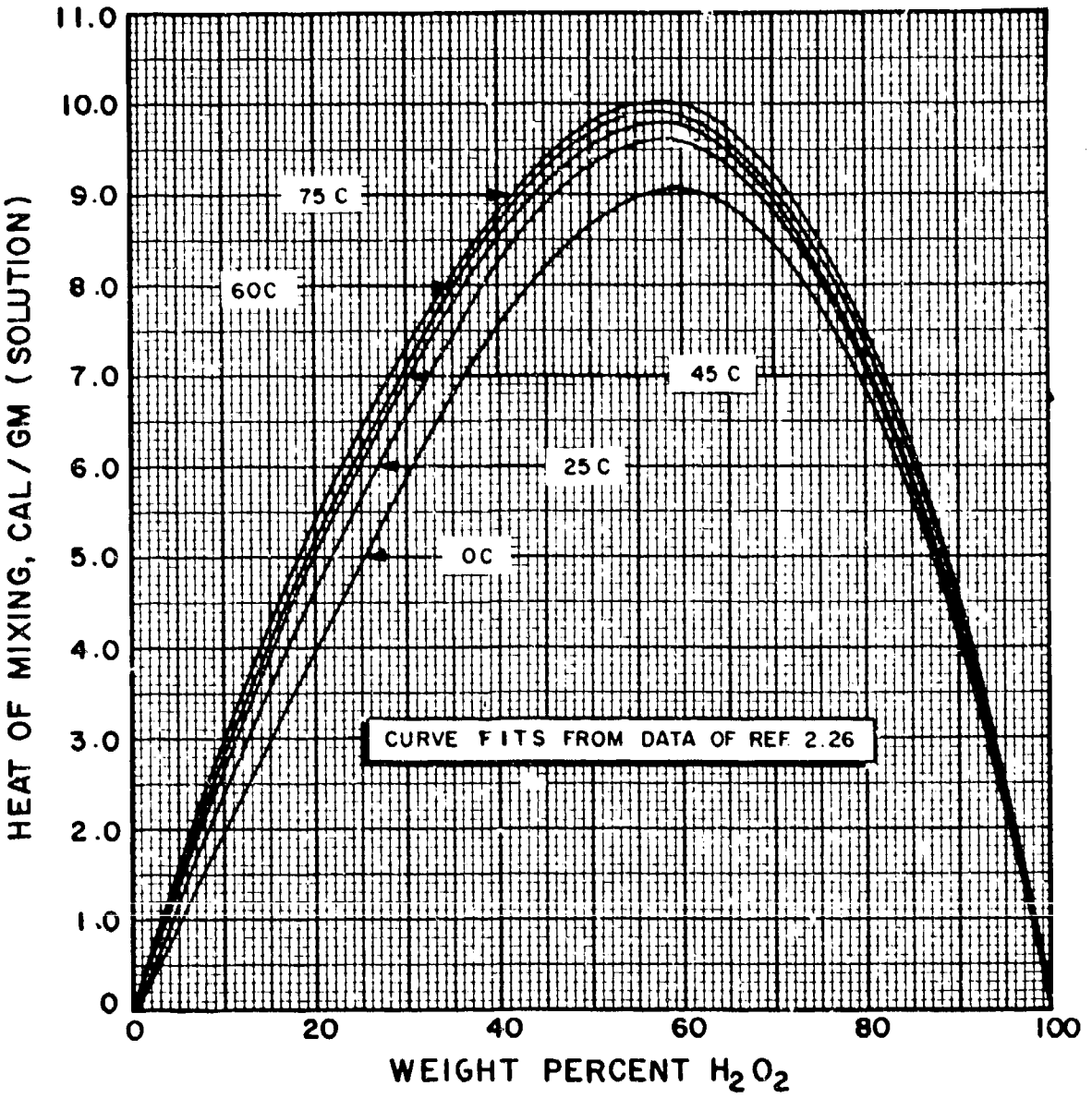


Figure 2.15. Heats of Mixing of Hydrogen Peroxide-Water Solutions

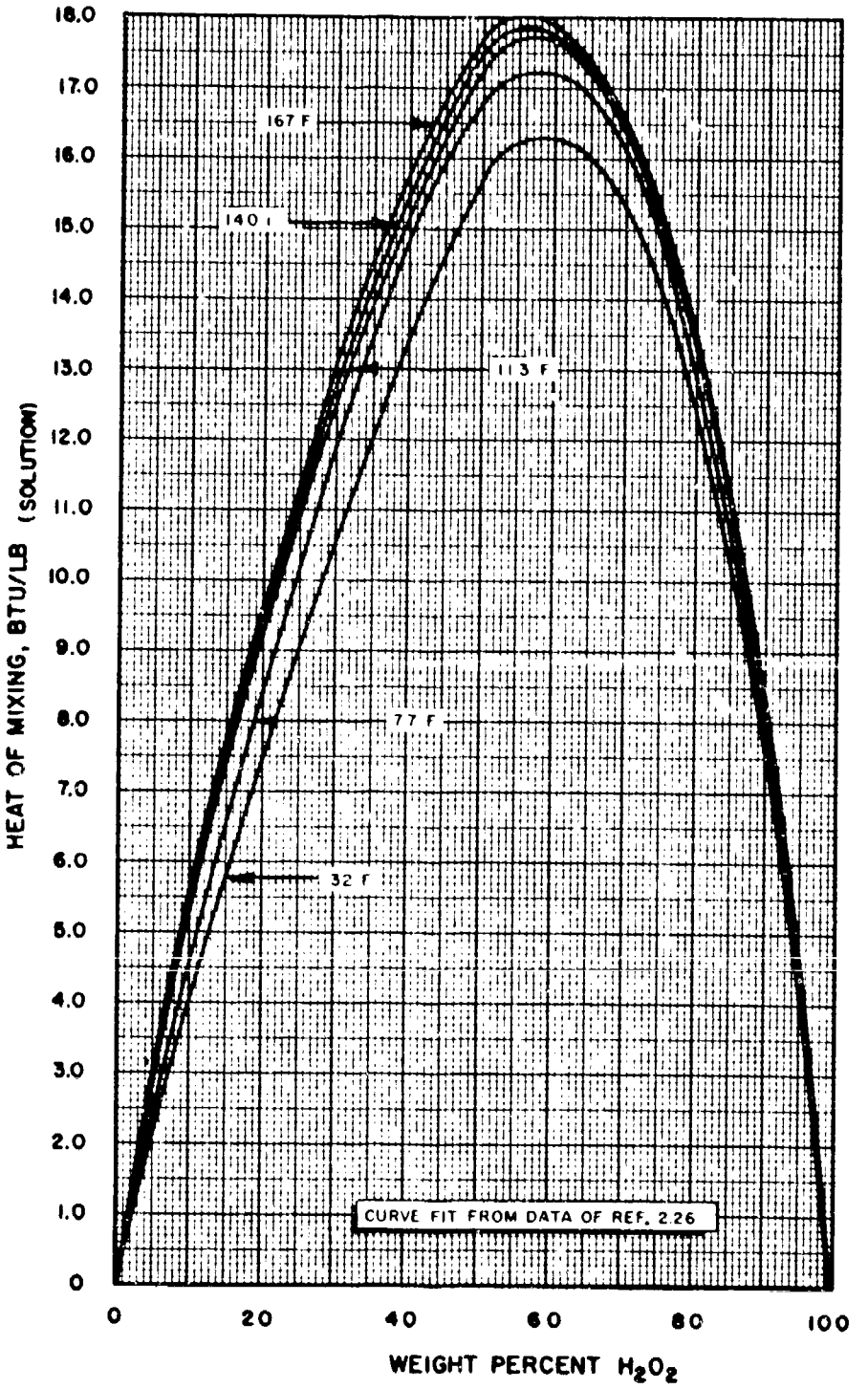


Figure 2.15a. Heats of Mixing of Hydrogen Peroxide-Water Solutions

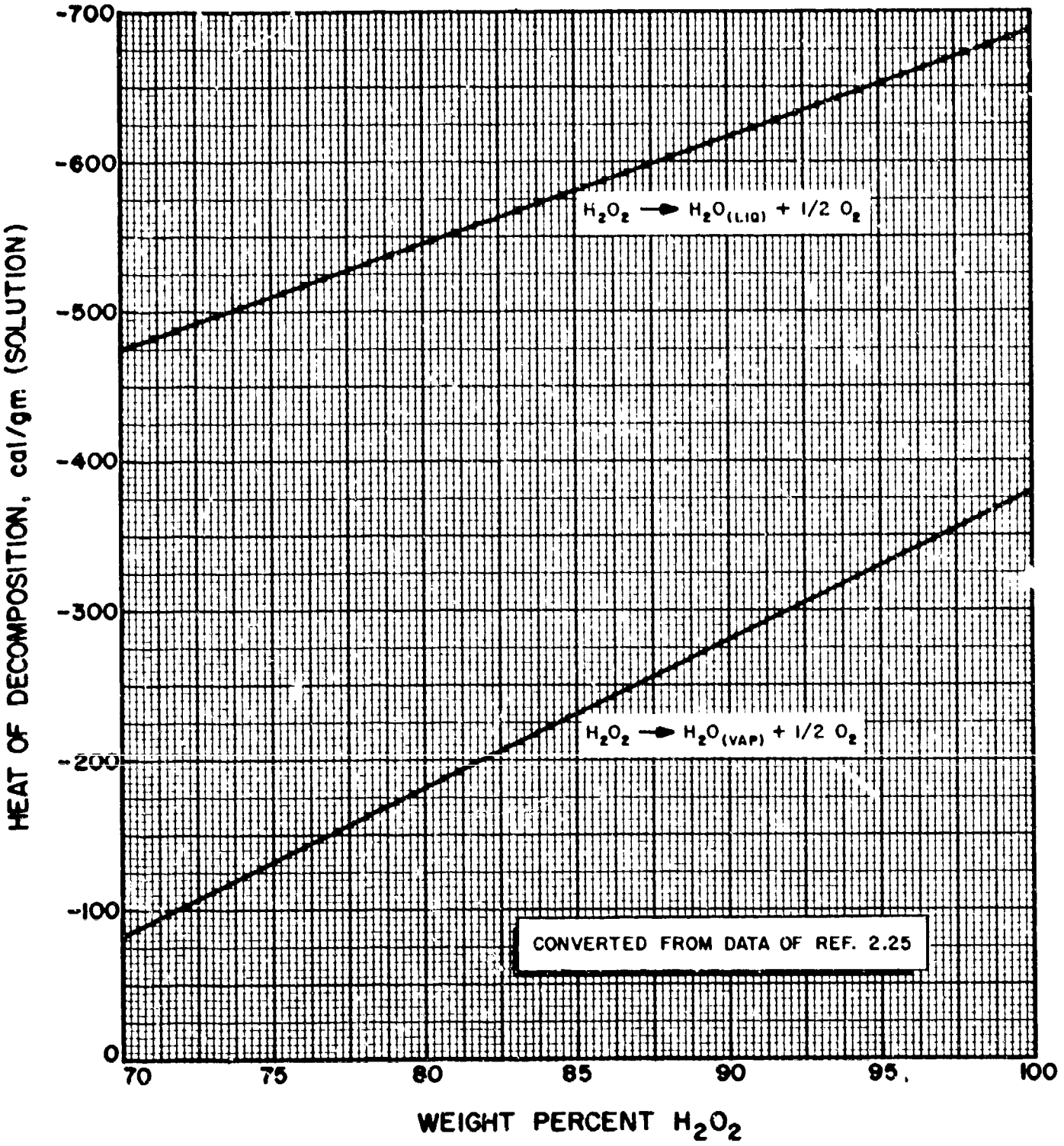


Figure 2.16. Heats of Decomposition of Propellant-Grade Hydrogen Peroxide-Water Solutions at 25 C

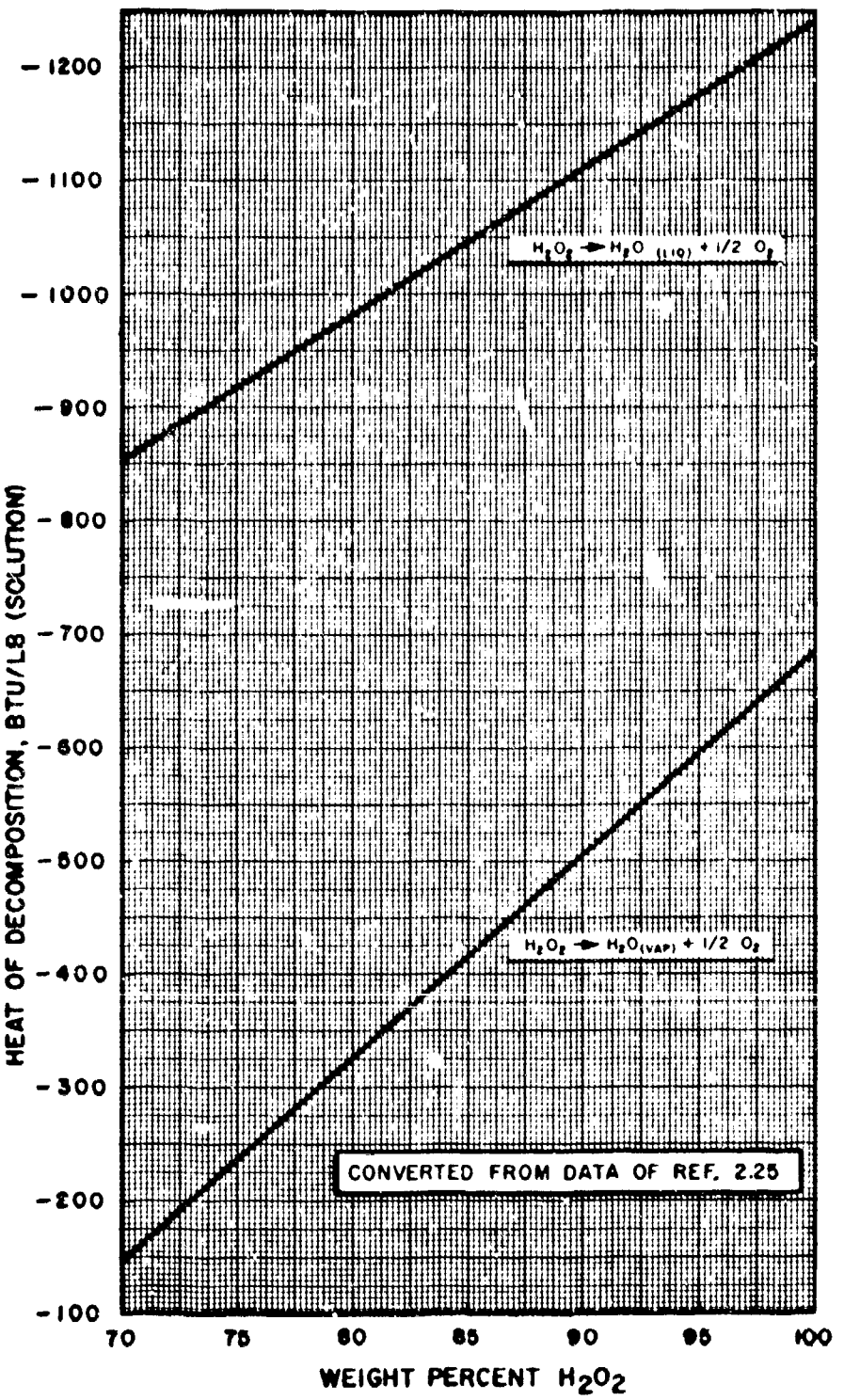


Figure 2.16a. Heats of Decomposition of Propellant-Grade Hydrogen Peroxide-Water Solutions at 77 F

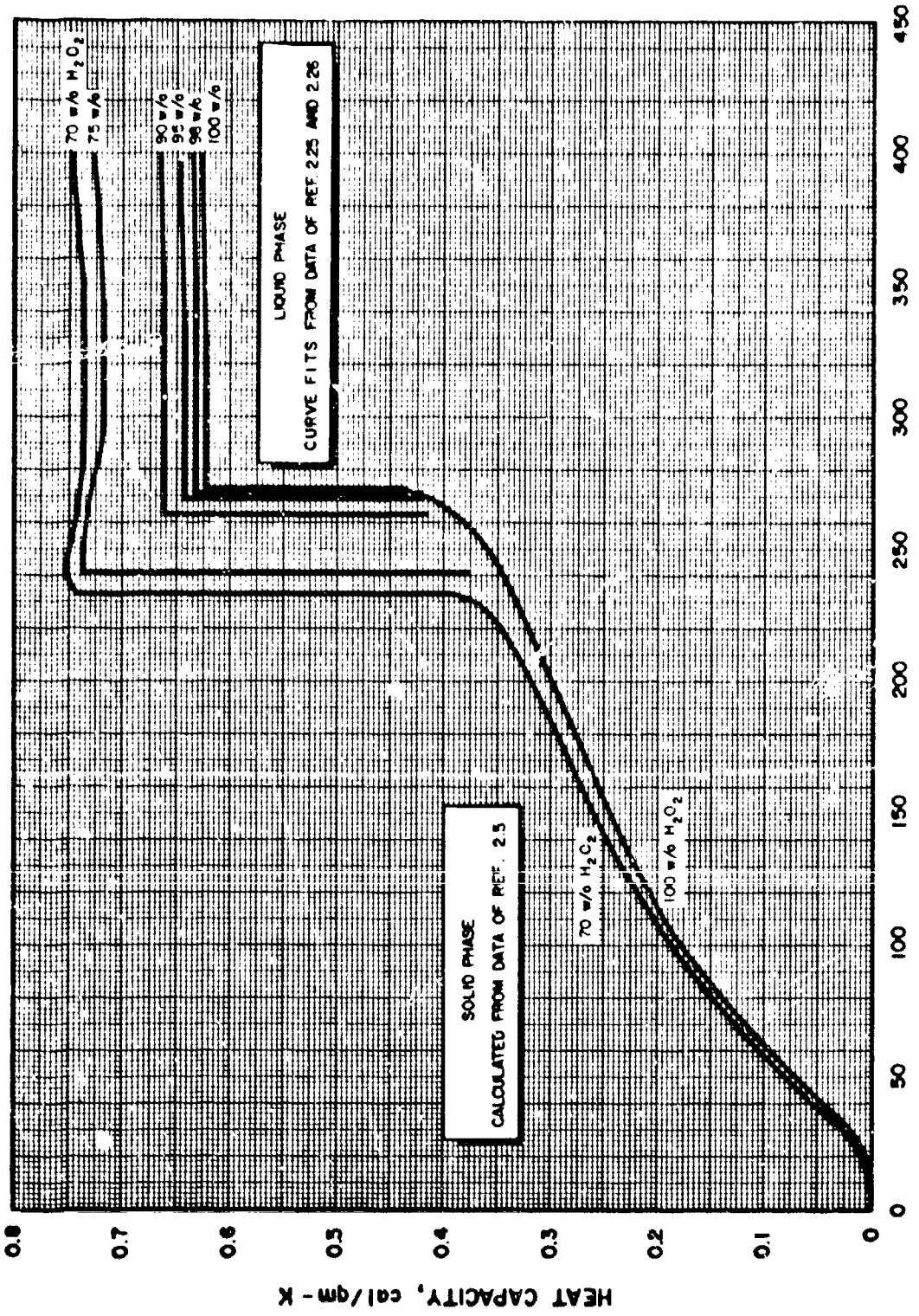


Figure 2.17. Heat Capacities of Propellant-Grade Hydrogen Peroxide-Water Solutions

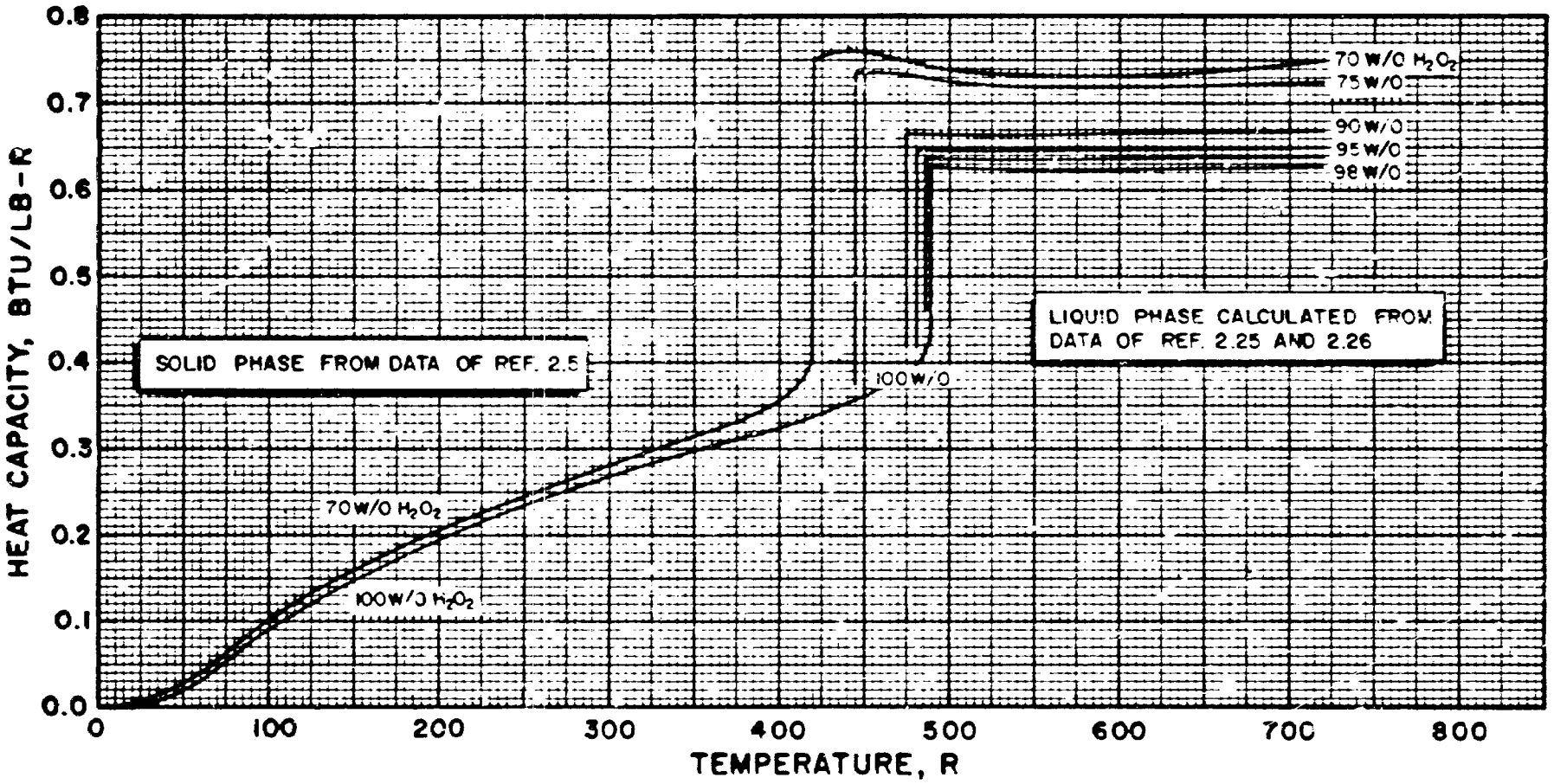


Figure 2.17a. Heat Capacities of Propellant-Grade Hydrogen Peroxide-Water Solutions

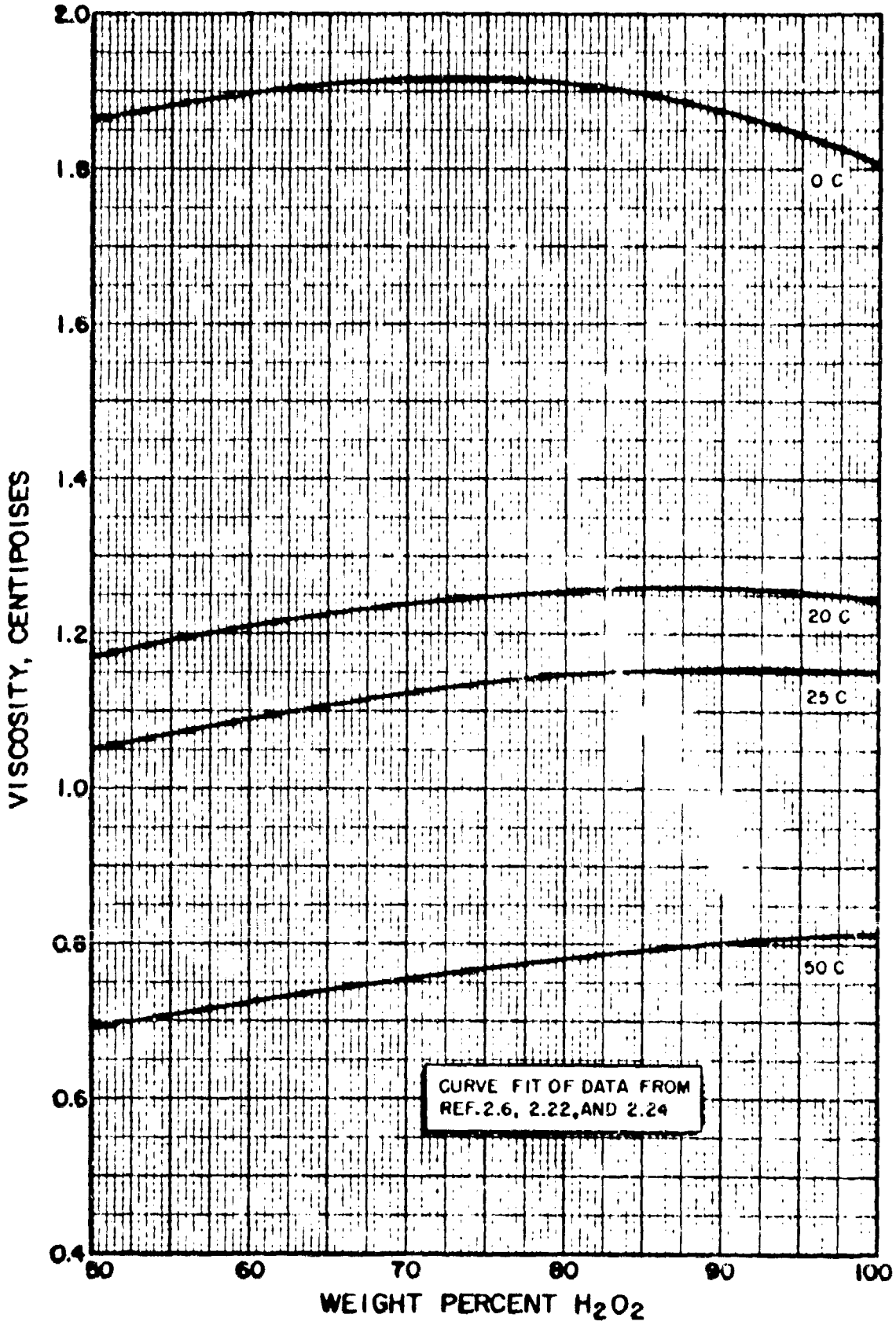


Figure 2.18. Viscosity of Liquid Hydrogen Peroxide-Water Solutions

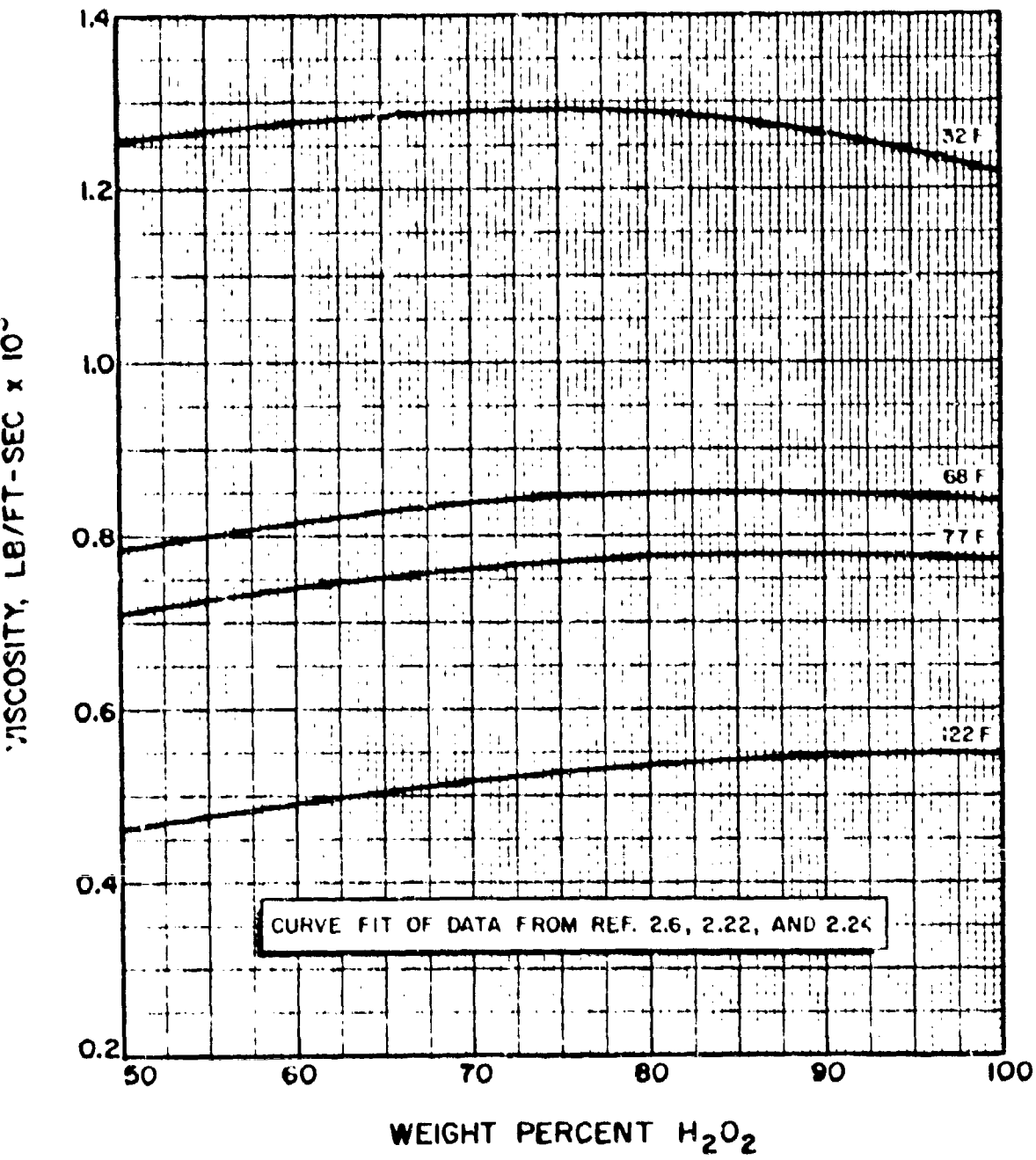


Figure 2.18a. Viscosity of Liquid Hydrogen Peroxide-Water Solutions

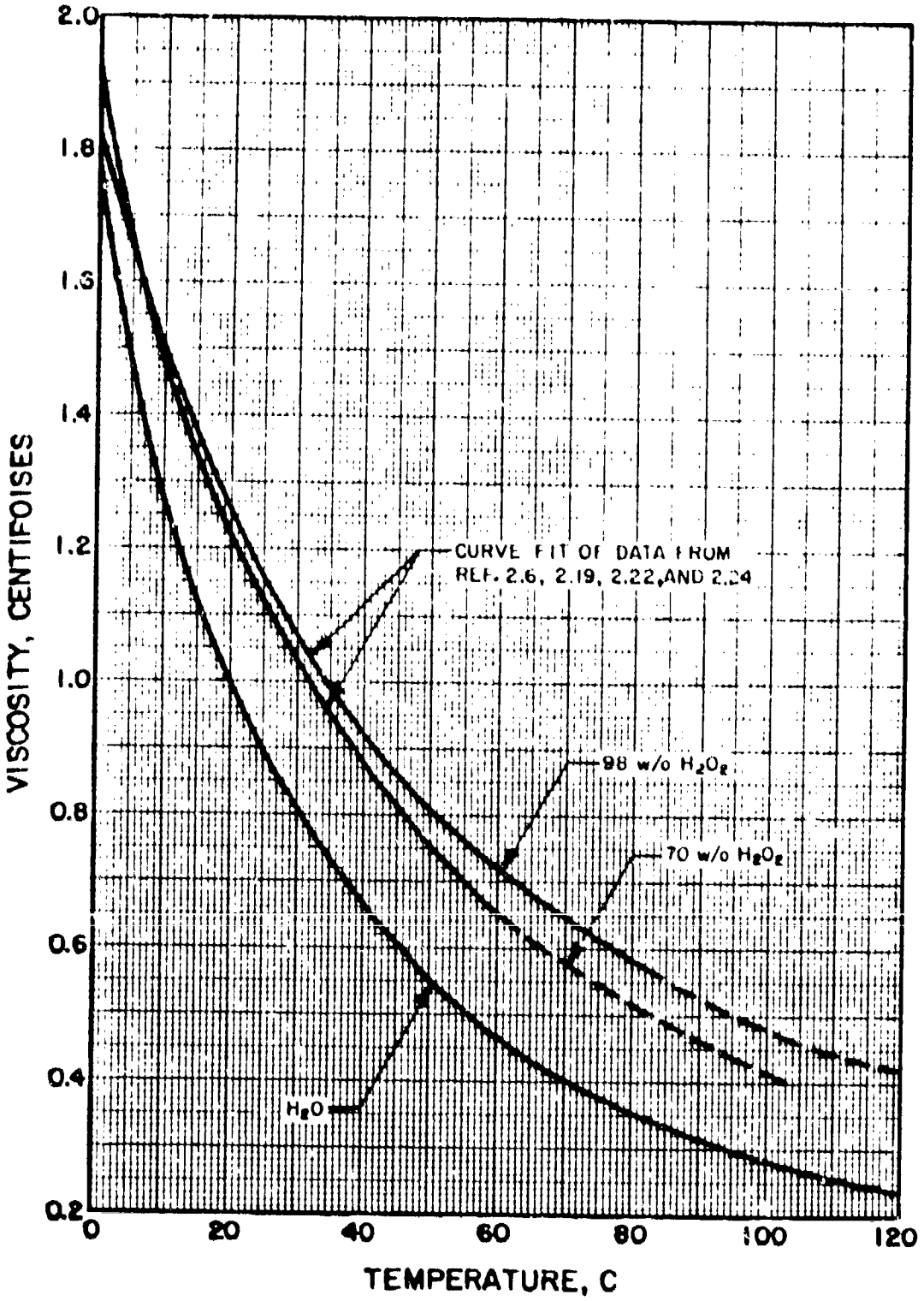


Figure 2.19. Viscosities of 98 w/o Hydrogen Peroxide, 70 w/o Hydrogen Peroxide, and Water

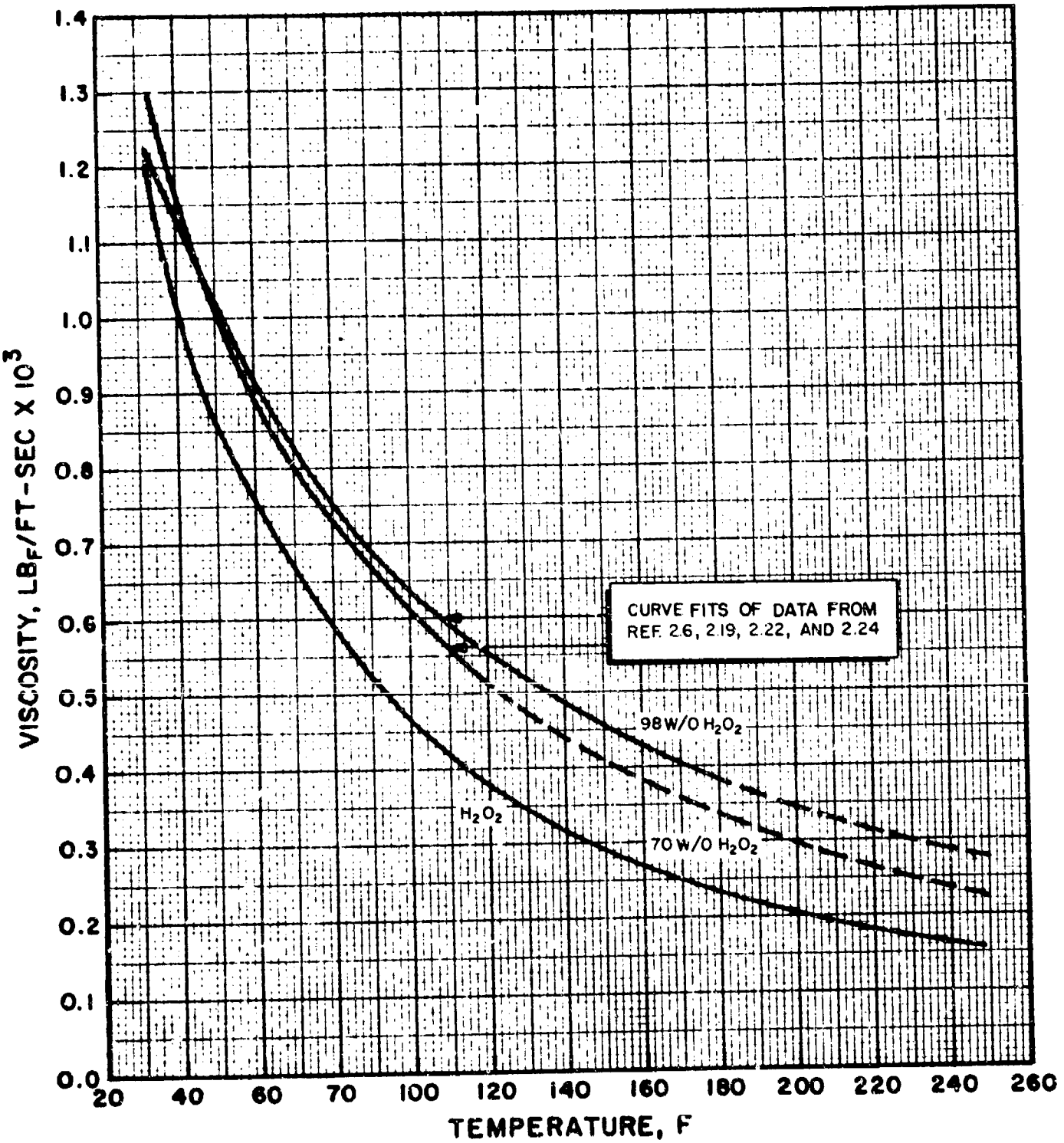


Figure 2.19a. Viscosities of 98 w/o Hydrogen Peroxide, 70 w/o Hydrogen Peroxide, and Water

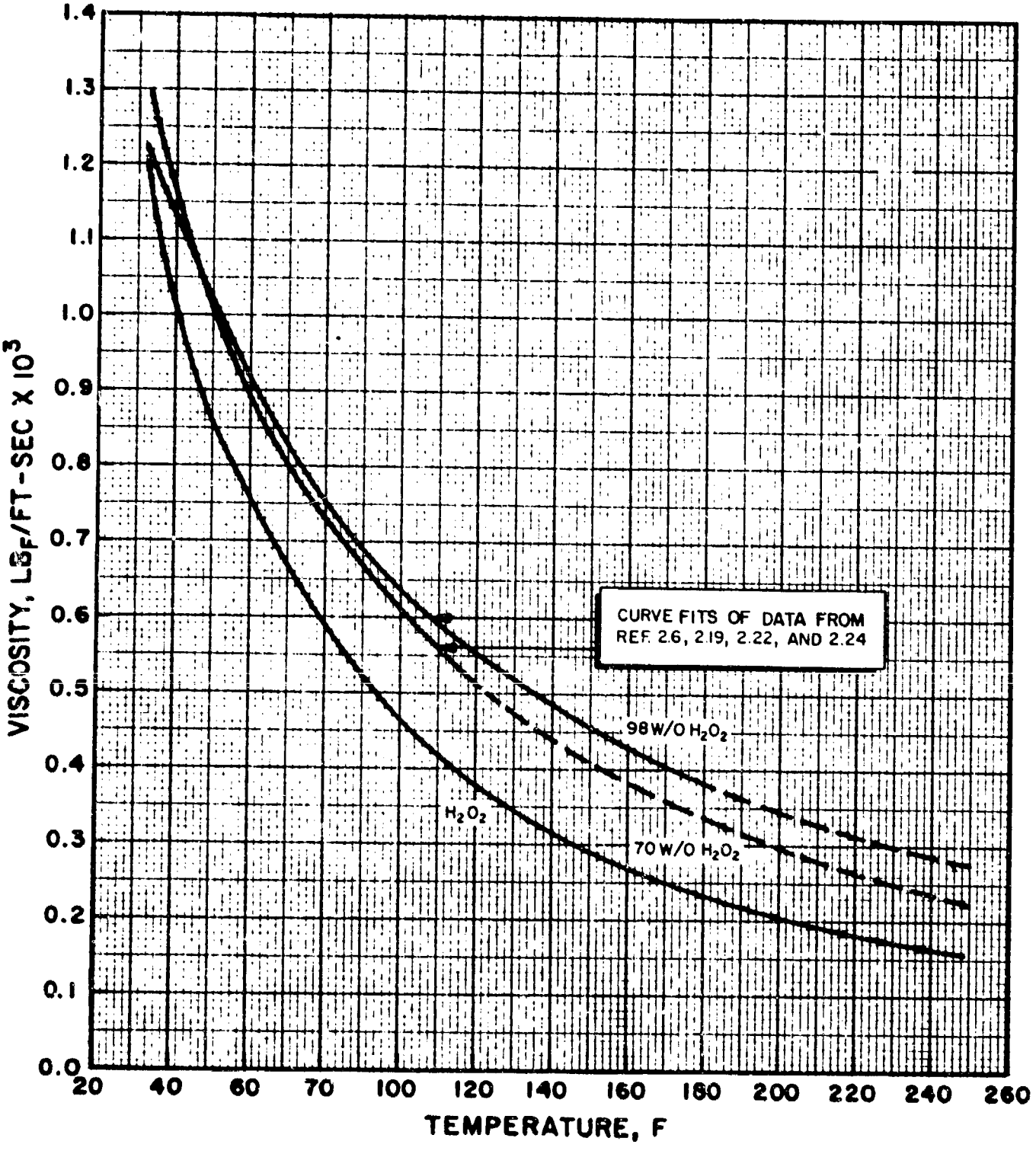


Figure 2.19a. Viscosities of 98 w/o Hydrogen Peroxide, 70 w/o Hydrogen Peroxide, and Water

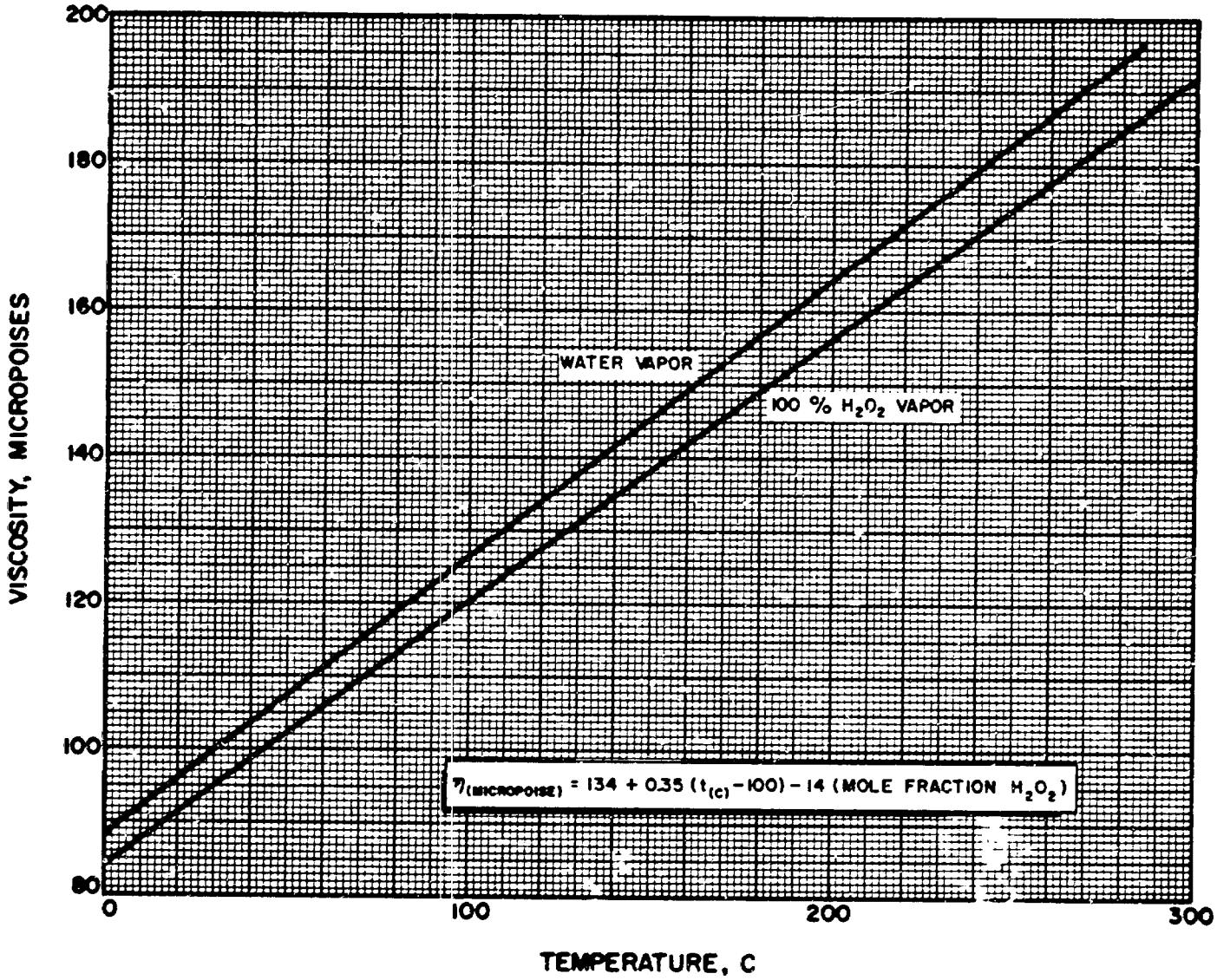


Figure 2.20. Viscosity of Hydrogen Peroxide and Water Vapor

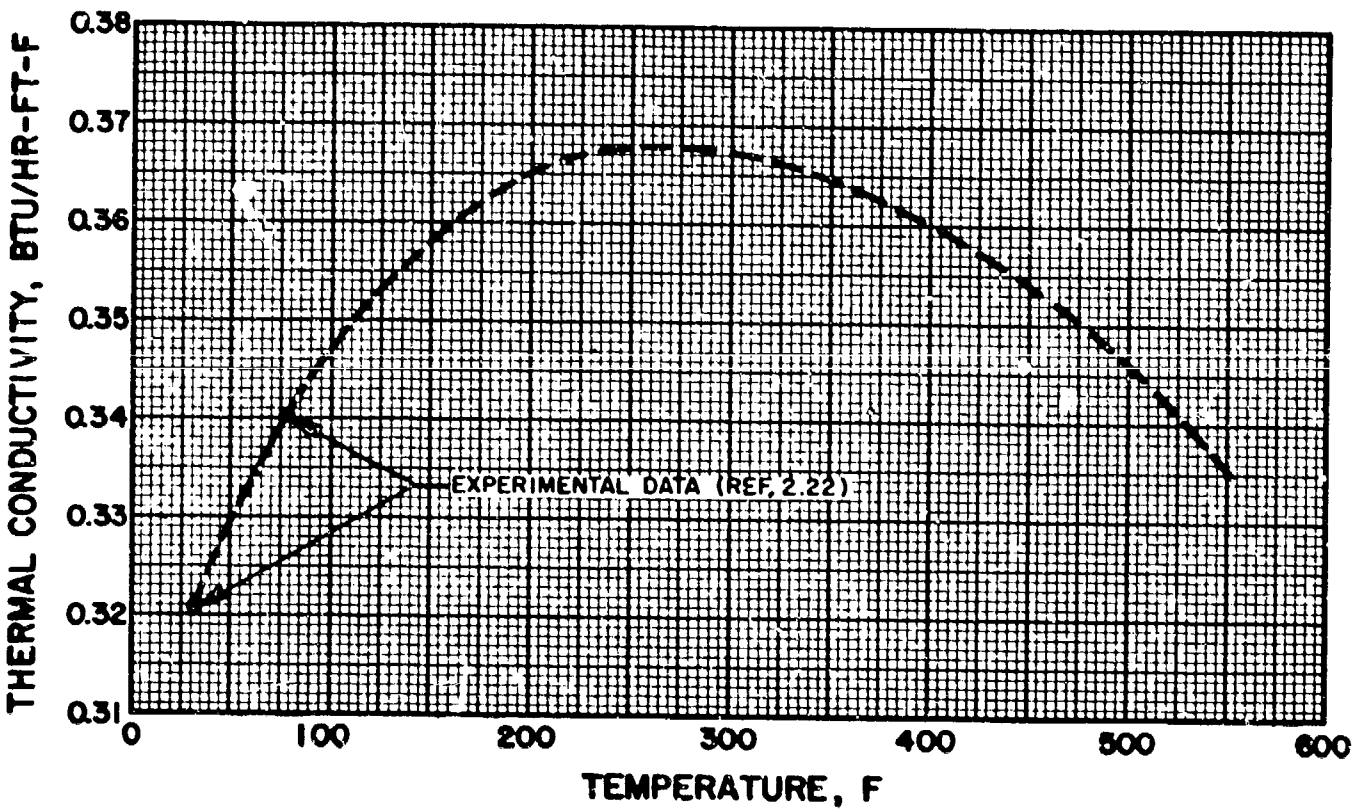


Figure 2.21. Thermal Conductivity of 98.2 w/o Hydrogen Peroxide (Ref. 2.31)

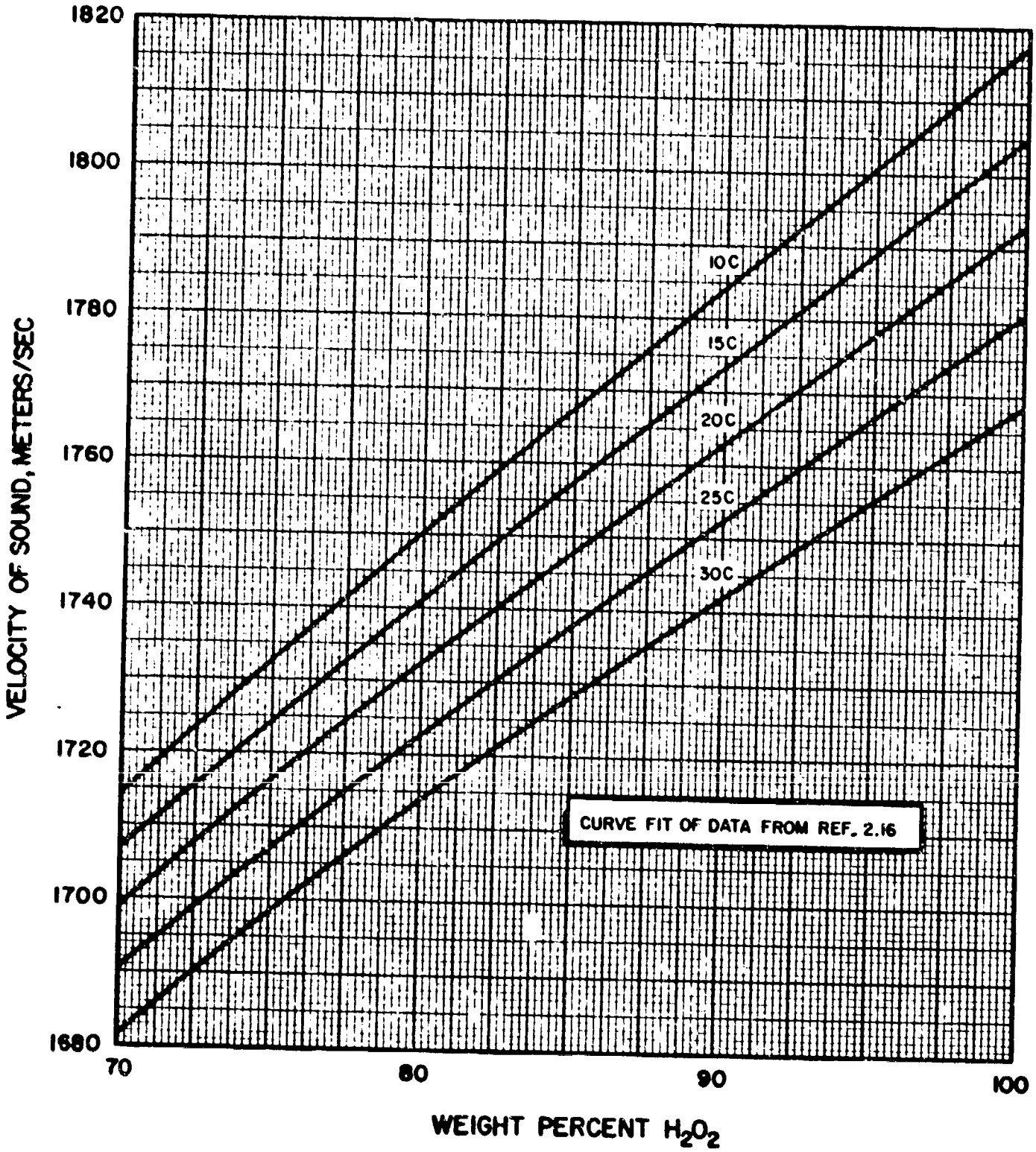


Figure 2.22. Velocity of Sound in Propellant-Grade Hydrogen Peroxide-Water Solutions

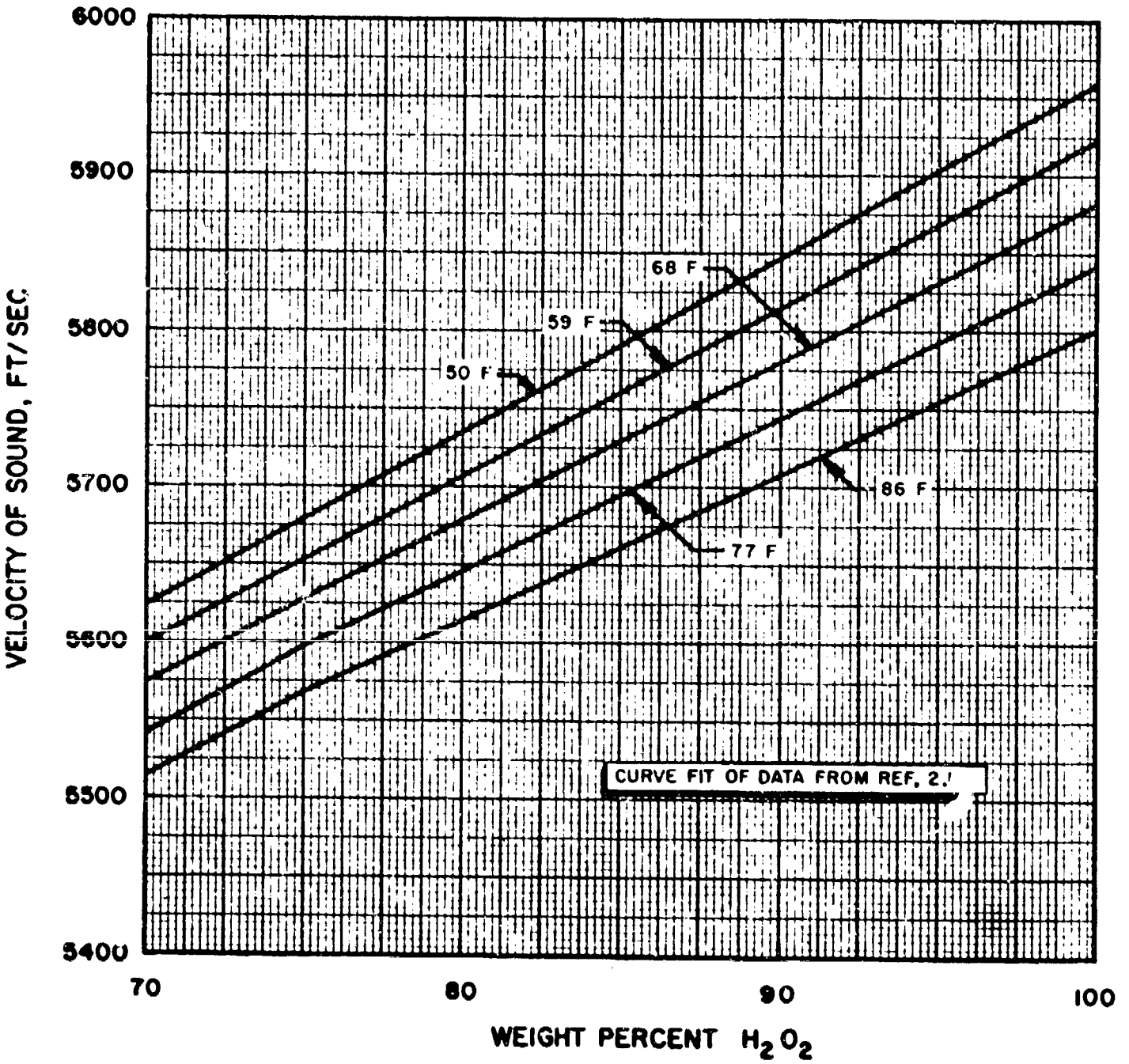


Figure 2.22a. Velocity of Sound in Propellant-Grade Hydrogen Peroxide-Water Solutions

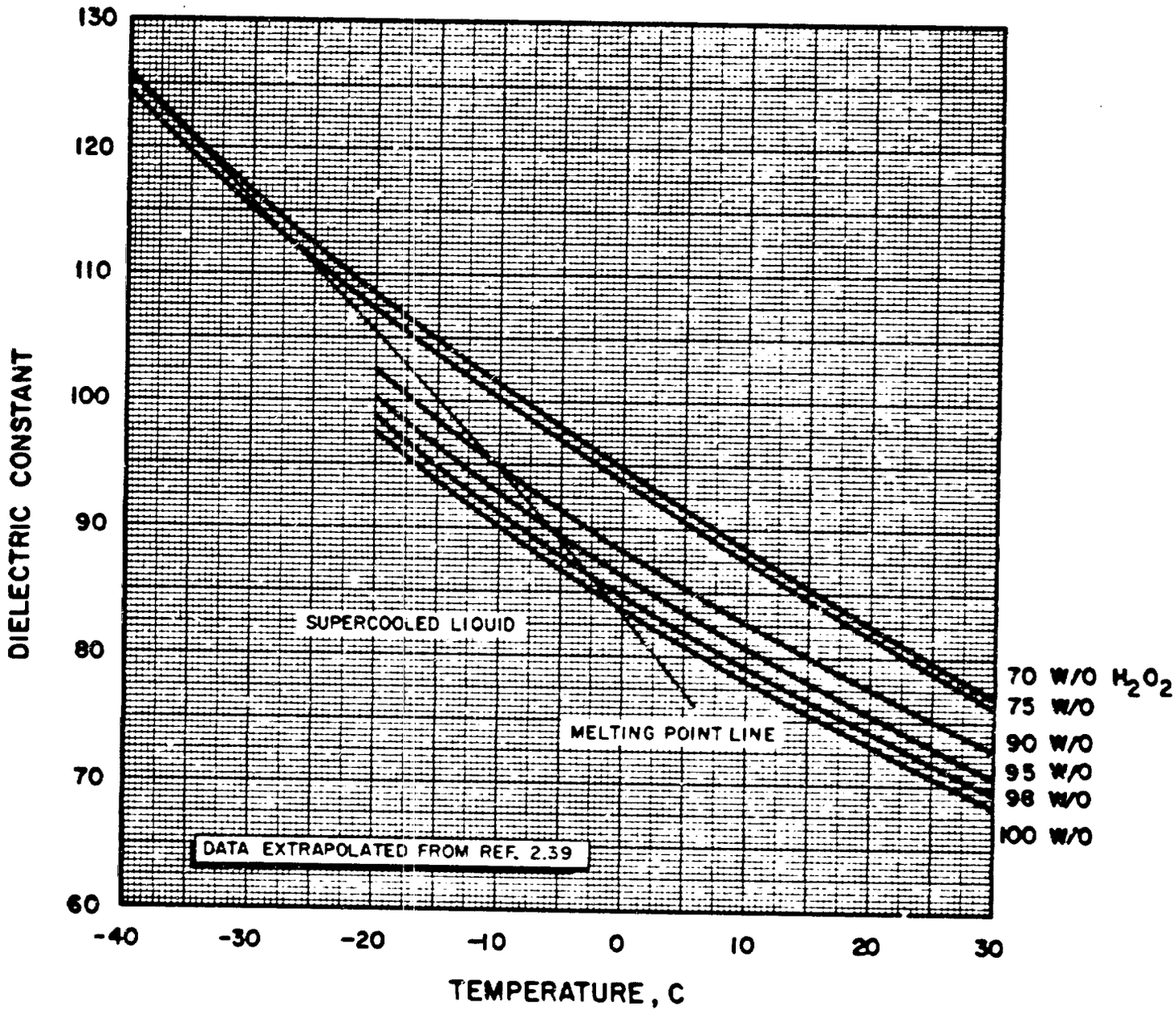


Figure 2.23. Dielectric Constant of Propellant-Grade Hydrogen Peroxide-Water Solutions

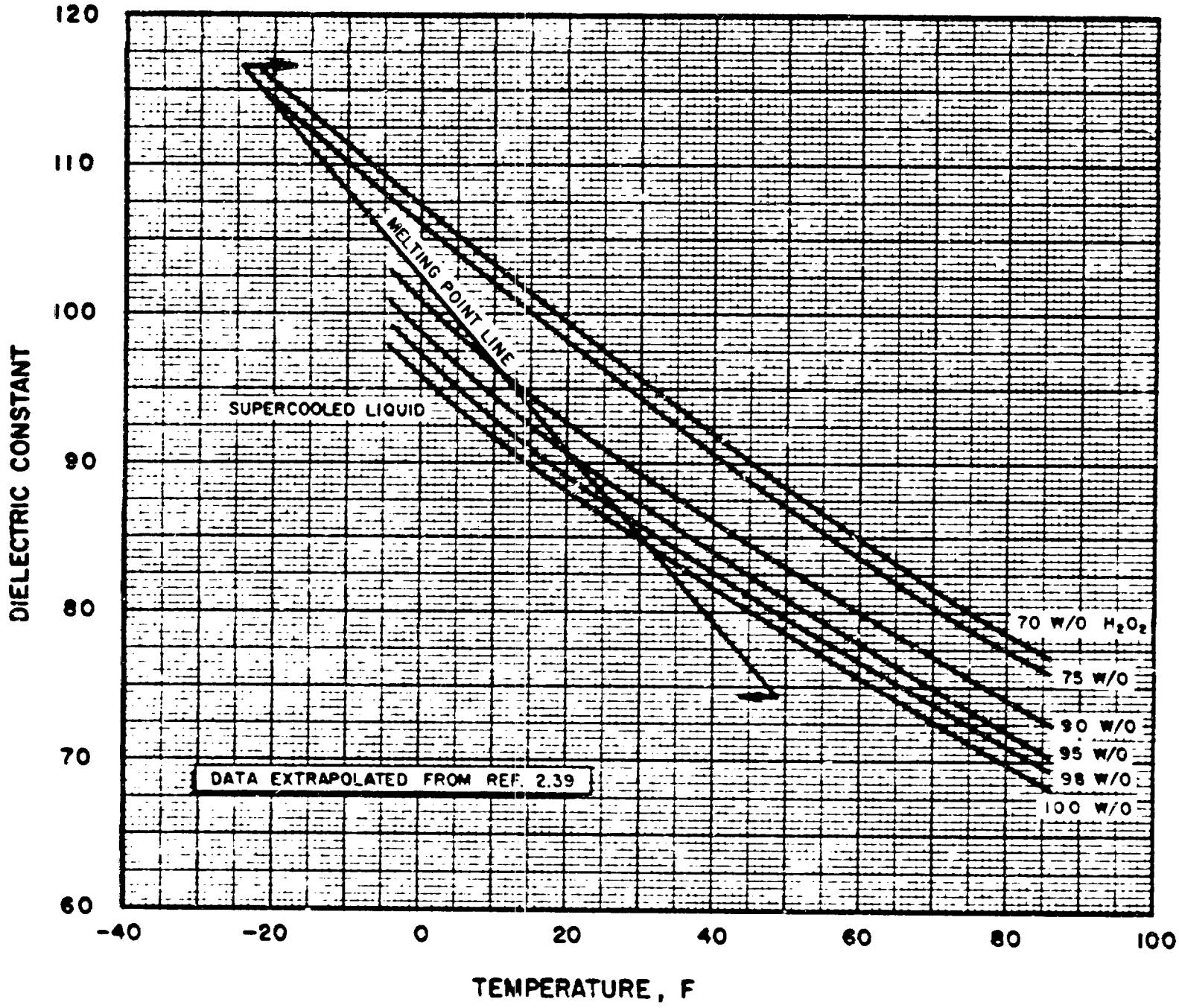


Figure 2.23a. Dielectric Constant of Propellant-Grade Hydrogen Peroxide-Water Solutions

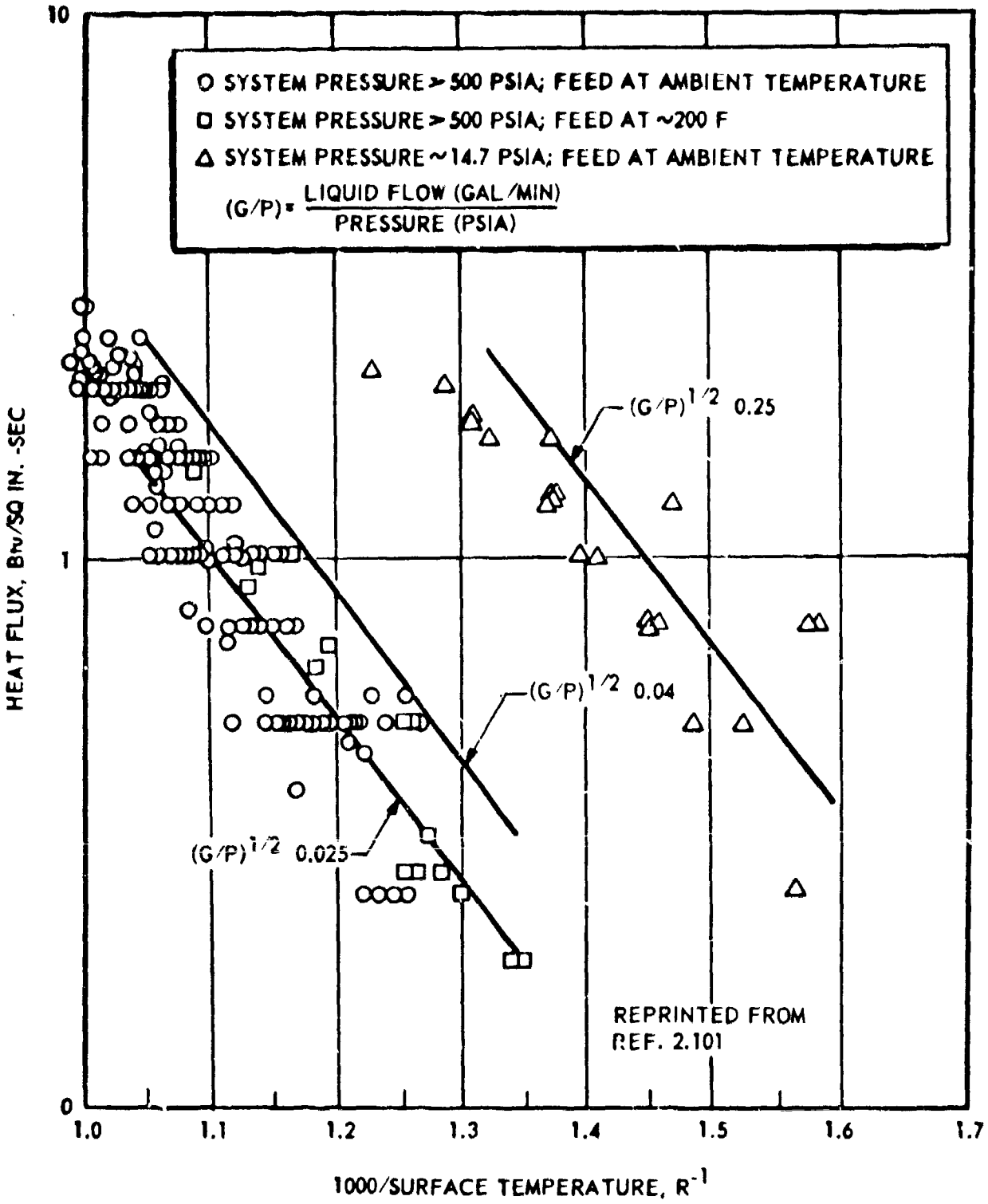


Figure 2.24. Heat Flux From a 347 Stainless-Steel Surface to 90 w/o Hydrogen Peroxide as a Function of Surface Temperature

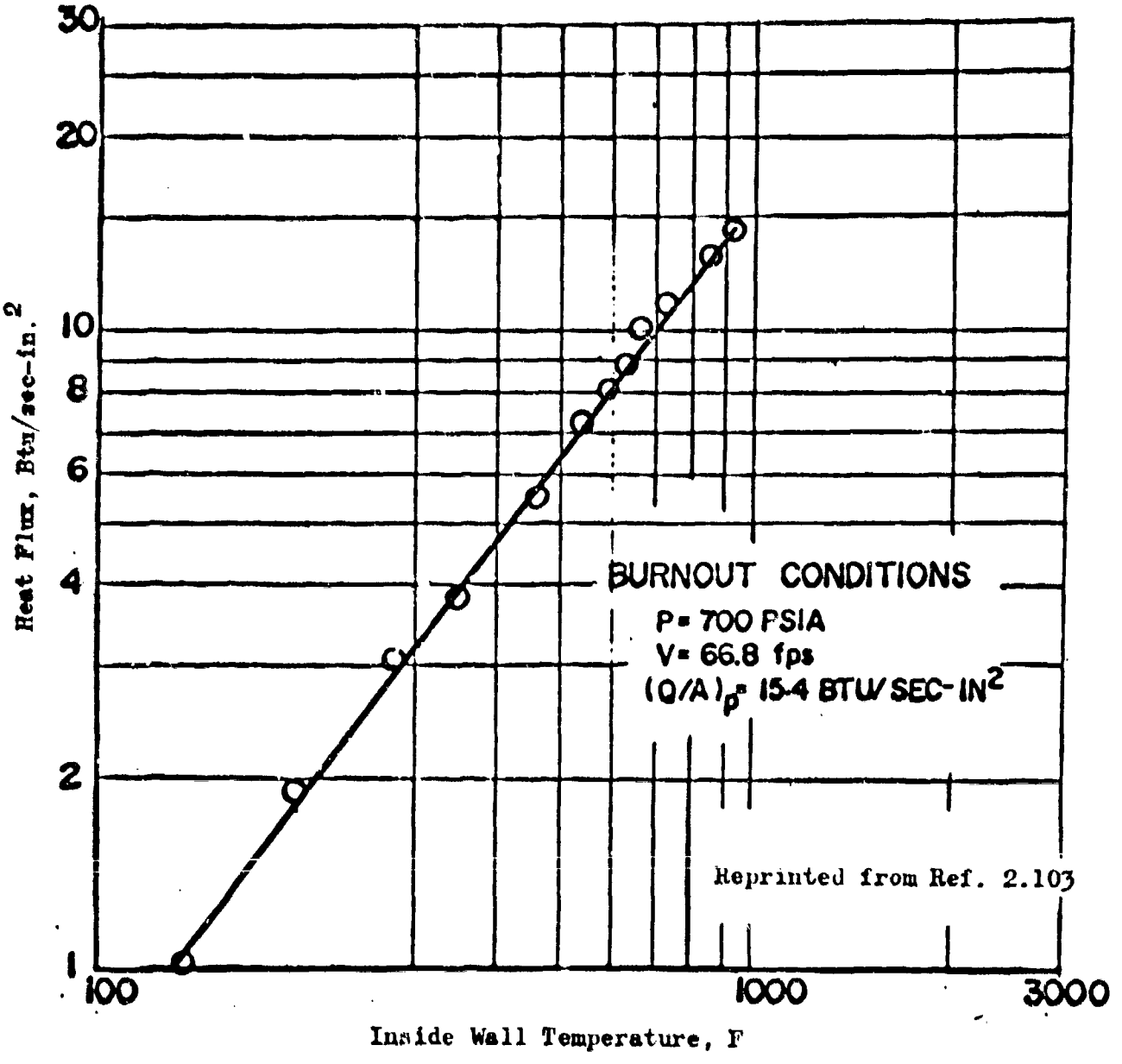


Figure 2.25. Typical Curve of Heat Flux vs Inside Wall Temperature (98 w/o Hydrogen Peroxide 1-1/2 Inches Upstream From Exit of Heated Section)

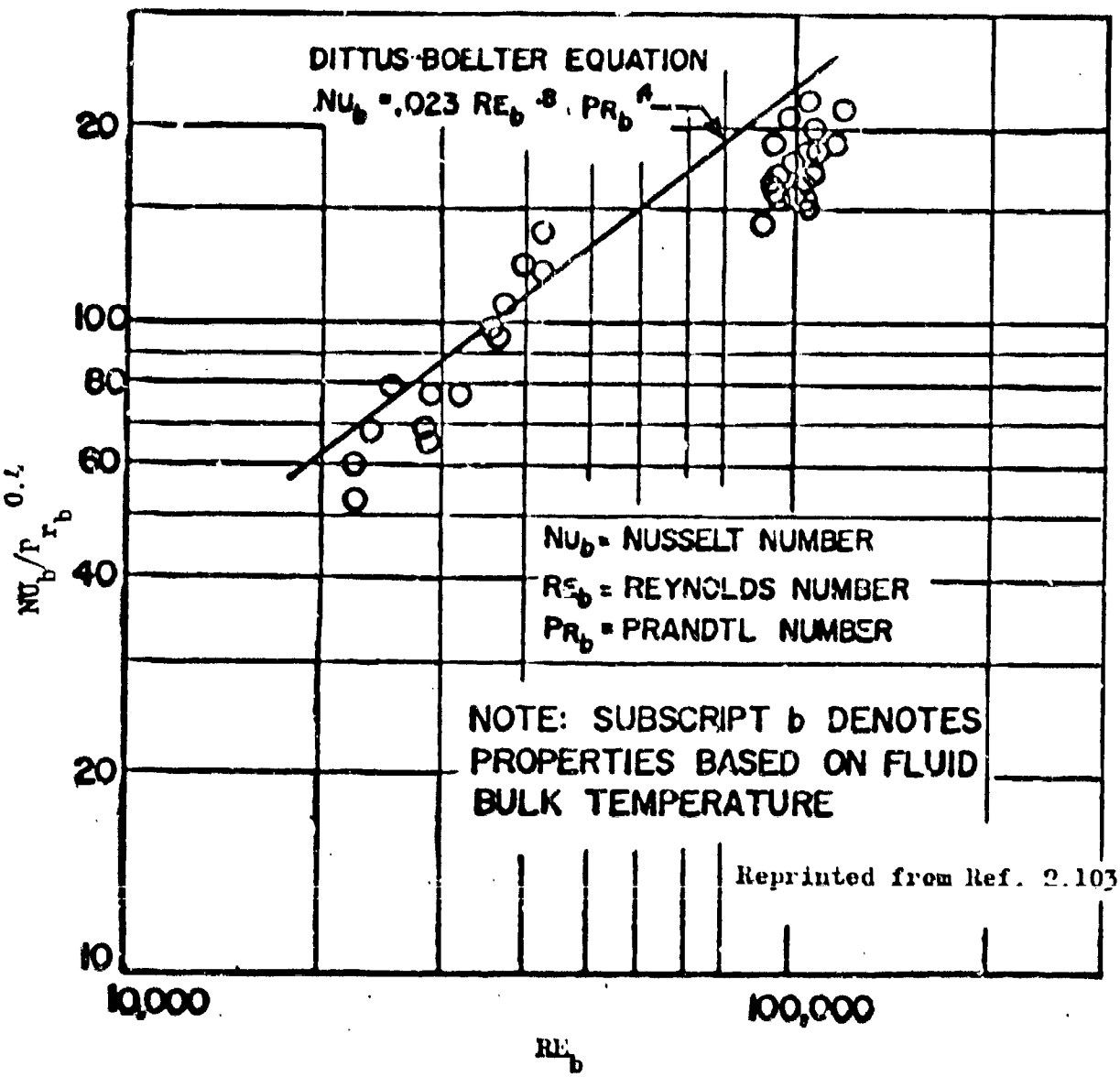


Figure 2.26. Correlation of Heat Transfer Coefficients of 98 w/o Hydrogen Peroxide With Dittus-Boelter Equation (Convective Region)

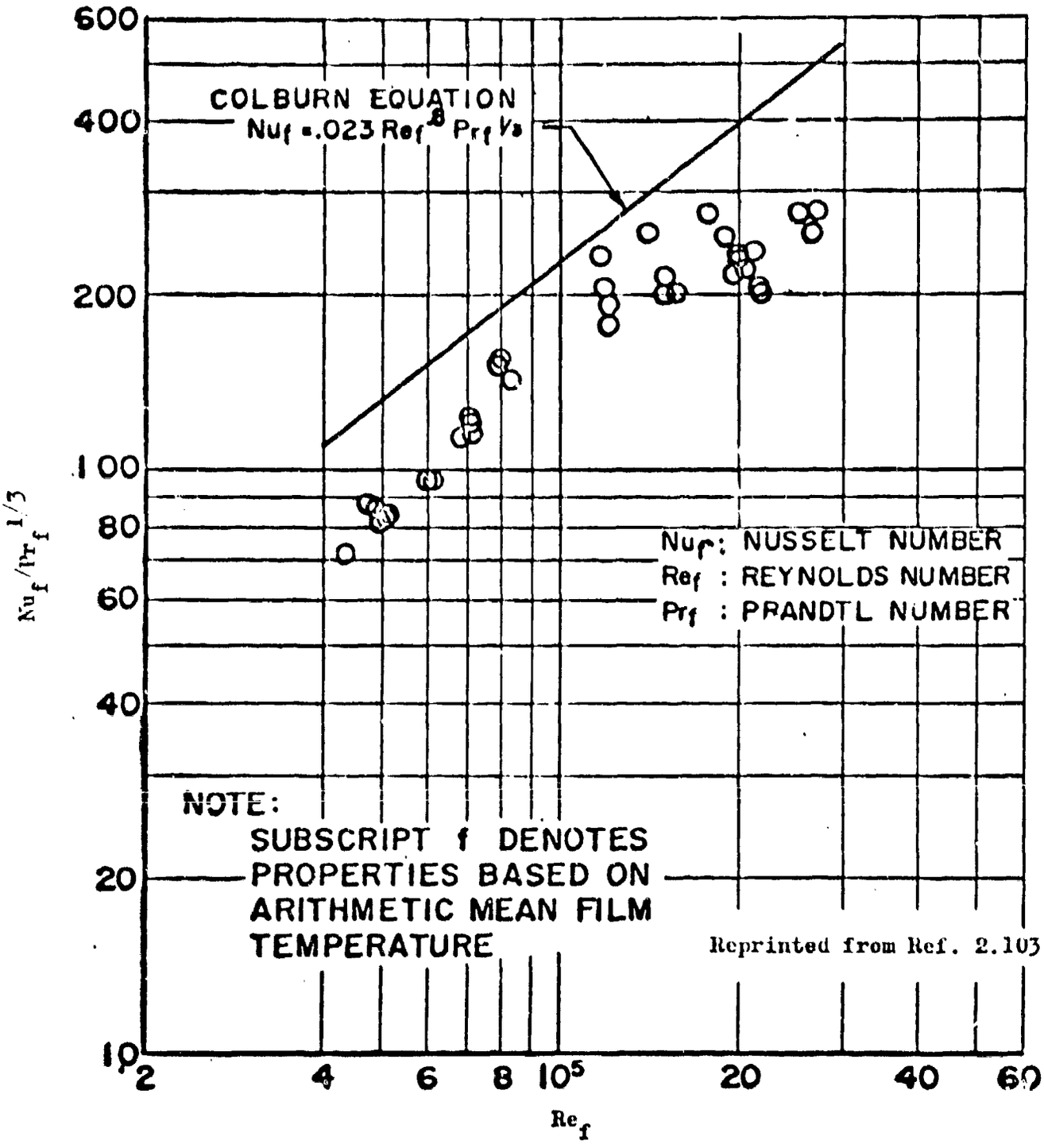


Figure 2.27. Correlation of Heat Transfer Coefficients of 98 w/o Hydrogen Peroxide With Colburn Equation (Convective Region)

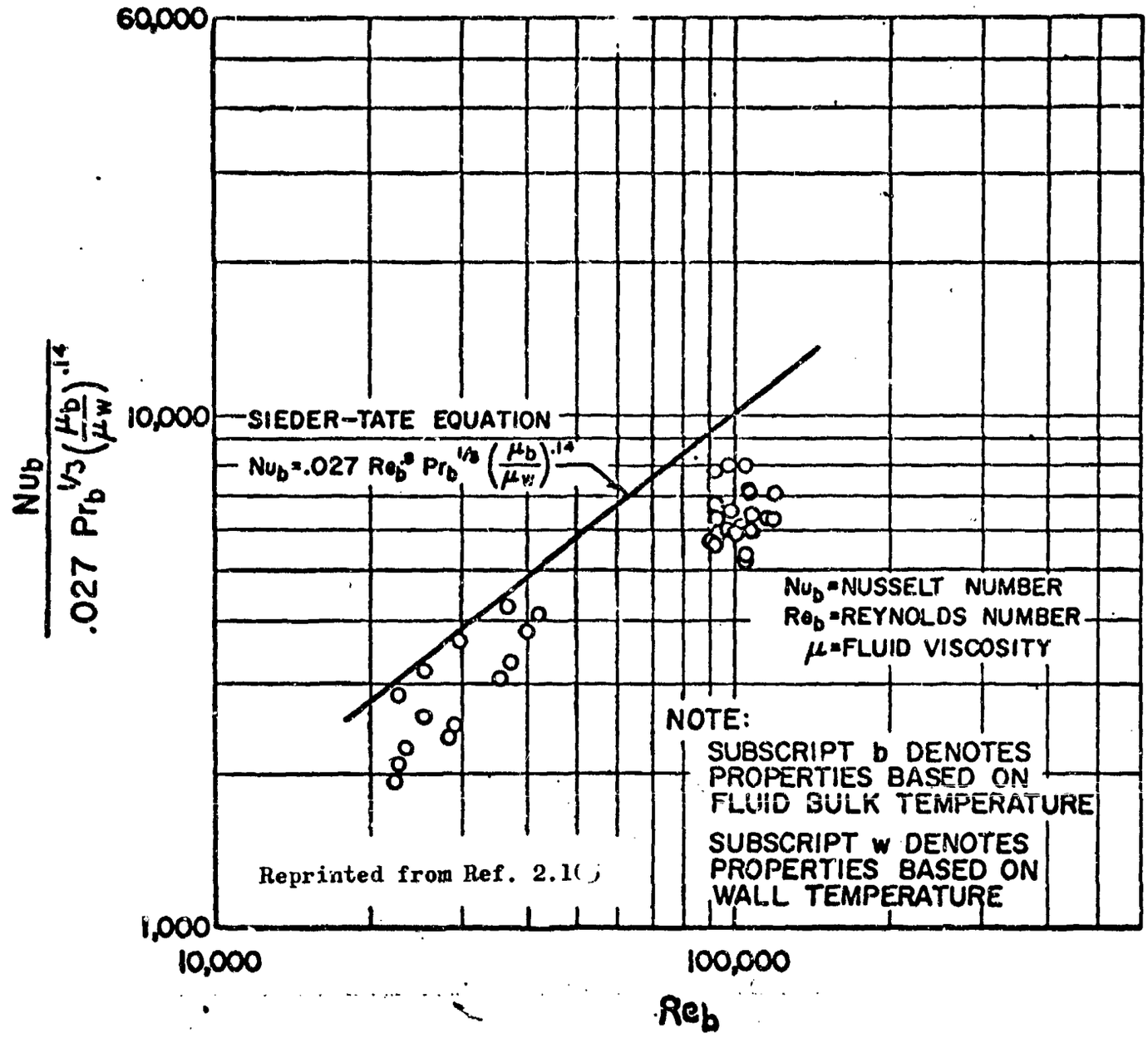


Figure 2.28. Correlation of Heat Transfer Coefficients of 98 w/o Hydrogen Peroxide With Sieder-Tate Equation (Convective Region)

3.1 MANUFACTURING TECHNIQUES

3.1.1 Preparation

The early laboratory preparation of hydrogen peroxide was based on the technique that Thenard used during the initial preparation of hydrogen peroxide. In this technique, barium nitrate, purified by recrystallization, was decomposed by heating in air in a porcelain retort. The resulting oxide was further oxidized by heating in a stream of oxygen to a dull red heat. The barium peroxide which formed was then dampened, ground, and dissolved in hydrochloric acid (nitric acid was used in Thenard's initial experiments). A slight excess of sulfuric acid was then added to precipitate barium sulfate and regenerate hydrochloric acid. The procedure of barium peroxide solution and sulfate precipitation was repeated several times in the same solution to increase the peroxide concentration (concentrations of up to 33 percent by weight hydrogen peroxide could be achieved in this manner).

The concentrated solution containing water, hydrogen peroxide, and hydrochloric acid, along with accumulated impurities, was cooled with ice and saturated with barium peroxide; iron and manganese impurities in the solution were then precipitated out as phosphates. The hydrochloric acid was removed by the addition of silver sulfate and the sulfate ion was removed by the subsequent addition of barium oxide. Further concentration was accomplished by vacuum distillation until "no further density increase occurs." Thenard reported that 100 w/o hydrogen peroxide (on the basis of density data and the measurement of the volume of oxygen released) could be obtained by this technique.

The first record of commercial production of hydrogen peroxide appeared in the 1865 to 1875 period. The first commercial production in the United States was by the Oakland Chemical Company, Brooklyn, New York, in 1881. Laporte Chemicals Ltd. established a factory in Yorkshire, England, in 1888. With the exception of substitution of fluorosilicic acid for the hydrochloric acid, Thenard's process was used essentially unchanged for the manufacture of hydrogen peroxide until nearly 1900. The formation of hydrogen peroxide in the electrolysis of sulfuric acid was first reported in 1853; later developments made the manufacture of hydrogen peroxide by an electrolytic process possible in 1908. By 1939, only 10 percent of the world's production was by the barium peroxide process.

Currently, hydrogen peroxide is commercially manufactured either by an electrolytic (inorganic) method or one of two organic processes. The electrolytic process (Ref. 3.1) involves the electrochemical formation of either peroxydisulfuric acid or peroxydisulfates (from an ammonium bisulfate solution), their subsequent hydrolysis, and separation of hydrogen peroxide by distillation. The basic equations for these reactions may be summarized as follows:

$$2NH_4HSO_4 \xrightarrow{\text{electrolysis}} (NH_4)_2S_2O_8 + H_2$$

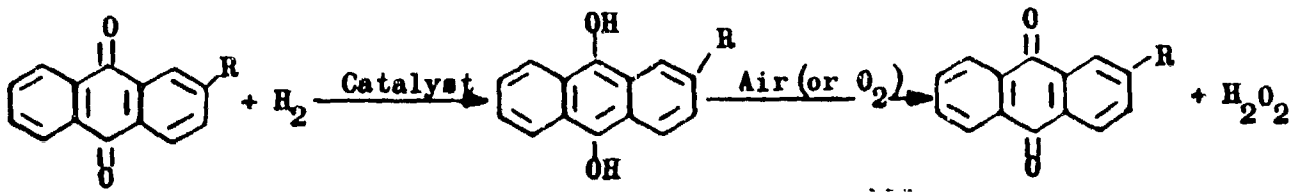
$$(NH_4)_2S_2O_8 \xrightarrow{\text{hydrolysis}} 2NH_4HSO_4 + H_2O_2$$

Although sulfuric acid may be used as the starting material, the ammonium bisulfate process is cheaper and has a higher cell efficiency.

The electrolysis is carried out in stoneware tanks with platinum electrodes; conversion of bisulfate to the persulfate takes place at the anode. After hydrolysis of the persulfate (with steam) in an evaporator, the resulting dilute aqueous solution of H_2O_2 is separated from the bisulfate and further distilled in a

stoneware distillation column. The resulting solution is approximately 30 w/o H_2O_2. Both the cathode liquor (after purification) and the bisulfate from the evaporator (and separator) are recycled back to the cells.

One of the organic processes used commercially for the manufacture of hydrogen peroxide involves the catalytic reduction of a substituted anthraquinone and subsequent oxidation back to the quinone structure with the production of H_2O_2 (Ref. 3.2). Although the process may vary slightly among the several commercial manufacturers who use it, the basic reactions can be summarized as follows:



where R may be ethyl, t-butyl, etc.

The reduction of the substituted anthraquinone with hydrogen is accomplished from room temperature to 40 C or more and at 1 to 3 atmospheres of pressure in the presence of a Raney nickel, nickel, palladium, or platinum catalyst. The catalyst is separated from the hydroquinone solution and recycled to the hydrogenator. After oxidation of the hydroquinone by either air or oxygen, the resulting quinone solution containing 0.5 to 1 w/o H_2O_2 is extracted with water at 25 to 40 C. The aqueous solution of hydrogen peroxide (~ 15 to 35 w/o H_2O_2) is cleaned of organic contamination and vacuum distilled to ~ 70 w/o H_2O_2. The organic phase from the extractor is evaporated from entrained water, partially dried, cleaned of H_2O_2 (by a decomposition catalyst), and recycled as the work solution to the hydrogenator.

The second organic process used in the present commercial manufacture of hydrogen peroxide is based on the oxidation of propane or a propane derivative (such as isopropyl alcohol). Although the actual details of hydrogen peroxide manufacture by these processes are not defined, the basic reactions of the propane oxidation are postulated as follows (Ref. 3.3):

$$C_3H_8 \xrightarrow{O_2} C_3H_7\cdot$$

$$C_3H_7\cdot + O_2 \longrightarrow C_3H_7OO\cdot \longrightarrow \text{oxygenated species}$$

$$C_3H_7\cdot + O_2 \longrightarrow C_3H_6 + HO_2\cdot$$

$$C_3H_7\cdot + \cdot H \longrightarrow C_2H_4 + CH_4$$

$$HO_2\cdot + C_3H_8 \longrightarrow C_3H_7\cdot + H_2O_2$$

As noted, the side products in this reaction series are a variety of oxygenated organic species, propylene, methane, and ethylene.

The oxidation of isopropyl alcohol may occur as follows (Ref. 3.3):

$$(CH_3)_2CHOH + O_2 \longrightarrow (CH_3)_2CO + H_2O_2$$

It is reported that the latter reaction can be conducted in either the liquid or vapor phases. Hydrogen peroxide concentrations of 15 to 17 w/o H_2O_2 and 25 to 30 w/o H_2O_2 are obtained from the propane and isopropyl alcohol oxidations, respectively.

3.1.2 Concentration

In most applications outside the propulsion field, only dilute solutions of hydrogen peroxide are required and the product grades normally obtained from the conventional commercial processes are adequate. To meet the demands of propellant-grade hydrogen peroxide, additional concentration is required. Although hydrogen

peroxide is normally concentrated commercially by fractional distillation to concentrations $\leq$ 90 w/o H_2O_2, other concentration procedures, such as fractional crystallization combined with vacuum distillation, have been frequently used for small-scale purification. The concentration of the 90 w/o H_2O_2 solutions to ~ 98 w/o H_2O_2 is presently being accomplished commercially (Ref. 3.4) by fractional crystallization. This crystallization process also removes most of the impurities.

The high volatility of water with respect to hydrogen peroxide makes it relatively easy to concentrate peroxide by simple distillation procedures; however, there are several disadvantages to this technique. Concentration of the nonvolatile impurities, which occurs in the hydrogen peroxide during distillation, decreases the stability of the product. In addition, the rate of decomposition increases with temperature rise (2.3 times for each 10 C rise in temperature). Finally, hydrogen peroxide vapors which are in excess of 26 m/o H_2O_2 are explosive.

3.1.3 Purification

For some purposes, a relatively high impurity and stabilizer content may be innocuous and a lower stability acceptable; however, for most propellant applications it is essential that the impurities be removed or kept to a minimum. This is particularly true when concentrations of 80 w/o or more are desired. High purities in the propellant-grade solutions are obtained by a multiple-stage distillation process in which the hydrogen peroxide is completely vaporized in the first stage, leaving only the nonvolatile impurities. A vacuum distillation is usually performed (Ref. 3.3) to keep the temperature (and subsequently, the decomposition) to a minimum. This technique also decreases the potential explosion hazard.

Theoretically, the removal of impurities by distillation or fractional crystallization should be complete except for impurity pickup from the apparatus itself in either the final process

condenser or receiver. However, because of the catalytic impurities acquired during the handling and storage operations, a stannate stabilizer is usually employed in small concentrations to buffer the effects of these impurities. However, the gradual dropout of this stabilizer during storage results in additional emphasis on the importance of impurity removal from hydrogen peroxide solutions.

Although ionic impurities may be removed by applying an electric potential, the use of ion-exchange resins may prove to be a more practical means of purification because this method could be applied easily at the point of final use to remove contamination acquired during transfer operations as well as residual manufacturing impurities. Extensive experimental studies in this area (Ref. 3.5) have indicated that stannic acid seems the most likely choice for an ion-exchange media.

3.2 CURRENT PRODUCTION

3.2.1 Availability

The principal European manufacturer of hydrogen peroxide is Laporte Chemicals, Ltd. of Luton, Bedfordshire, England. Principal U.S.A. manufacturers are Allied Chemical & Dye, Columbia Southern Chemical Corporation, E. I. duPont de Nemours and Company, Inc., Food Machinery and Chemical Corporation (FMC), and Shell Chemical Company. Of these U.S.A. manufacturers, duPont (anthraquinone process), FMC (electrolytic and anthraquinone processes), and Shell (oxidation of isopropyl alcohol) are the major producers of propellant-grade ($\geq$ 70 w/o H_2O_2) hydrogen peroxide. Allied Chemical, which presently produces H_2O_2 grades to 70 w/o, has indicated a potential interest in production of higher grades. Presently, FMC is the only commercial manufacturer of > 90 w/o H_2O_2 grades. Although hydrogen peroxide concentrations of 99.7 to 99.8 w/o H_2O_2 have been produced commercially (Ref. 3.4 and 3.6), the economic- and

application-feasibility tradeoff will probably limit commercial manufacture to maximum concentrations of 98 to 99 w/o H_2O_2.

The production of hydrogen peroxide was estimated (Ref. 3.7) to be 55,000 short tons (as 100 w/o H_2O_2) for the year 1966. This quantity, which includes all grades of hydrogen peroxide, represents an increase over the productions of 52,567, 45,519, and 39,085 short tons which were quoted for the previous 3 years. The present production capacities of the duPont (Memphis, Tenn.), FMC (Buffalo, N.Y., Charleston, W. Va., and Vancouver, B.C.), and Shell (Norco, La.) hydrogen peroxide plants have been quoted as 2.5×10^6, 3×10^6, and $> 5 \times 10^6$ pounds hydrogen peroxide (as 100 w/o H_2O_2) per year, respectively.

Hydrogen peroxide is available in various quantities up to tank car sizes (4000-, 6000-, or 8000-gallon capacity). The use of 500- and 1300-gallon capacity portable hydrogen peroxide tanks that can be filled at the plant and used as storage vessels at the user's site offers many advantages, particularly for remote, overseas, or temporary sites. Tank trucks with capacities up to 4000 gallons are presently in service or available. Small quantities are normally purchased in 50-gallon drums.

3.2.2 Cost

Because hydrogen peroxide sales are of a highly competitive nature, the cost of propellant-grade hydrogen peroxide is flexible. The grade (including concentration, purification, stabilization, etc.), quantity, and present competition are all prime factors in the determination of hydrogen peroxide cost. Thus, all individual manufacturers should be contacted at the time of procurement to determine the exact cost.

For the purpose of estimation, the current price list (Ref. 3.6) of FMC includes the following prices for three different grades of hydrogen peroxide in tank car quantities:

98 w/o H_2O_2--$0.60/lb

90 w/o H_2O_2--$0.50/lb

70 w/o H_2O_2--$0.34/lb

The quoted list prices of the other manufacturers are similar for the 90 and 70 w/o H_2O_2 grades. However, the last Air Force procurement (FY 1967) of 90 w/o H_2O_2 was based on a cost of $0.23+ (tank car lots) to $0.30/lb (drum lots).

In the procurement of low concentrations of hydrogen peroxide for initial system passivation, pond decontamination, or other applications requiring limited stability, it has been recommended by various manufacturers that higher concentrations be purchased and diluted on site; this technique effects some cost savings in transportation (cost per pound of solution shipped as H_2O_2). However, for the high-purity grades or grades requiring special degrees of stabilization, product treatment should be limited to that performed at the manufacturing site.

3.3 PROPELLANT SPECIFICATION

Currently, there are two government specifications for the procurement of hydrogen peroxide. These are:

1. MIL-P-16005D, "Propellant, Hydrogen Peroxide," (18 March 1965).
2. MIL-H-22868 (Wep)—"Hydrogen Peroxide - Stabilized, 70% and 90% (for Torpedo Use)," (21 March 1961).

In addition, during the development and utilization of the Redstone Missile System, there was a "purchase description" document, ABMA-PD-H-763, dated 14 August 1958, which was issued by the Army Ballistic Missile Agency for the purpose of procurement of H_2O_2 used in this system. Although no longer applicable, this document controlled the previous procurement of 76 w/o H_2O_2.

A comparison of the limits and analytical techniques used in these specifications, which have been used in the procurement of 90 w/o propellant-grade, 70 and 90 w/o torpedo-grade, and 76 w/o propellant-grade hydrogen peroxide, respectively, is presented in Table 3.1. It should be noted that many of the users of propellant-grade hydrogen peroxide have company-procurement and use specifications for hydrogen peroxide; however, because of the many variations, these specifications are not discussed in this handbook.

The impurity limits established for torpedo-grade hydrogen peroxide are based on stabilization requirements for maximum storability with respect to torpedo use; thus, the high concentrations of the phosphates, tin, and nitrate ions are required. In the establishment of limits for propellant-grade hydrogen peroxide, minimum stabilization requirements had to be met, but impurities that cause H_2O_2 catalyst poisoning were strictly controlled. These impurities were identified during an experimental study reported in Ref. 3.8. Phosphate, which acts as a stabilizer by complexing the heavy metal ions which promote H_2O_2 decomposition, is a severe catalyst poison; thus, its content in propellant-grade H_2O_2 is limited. Tin (as stannous chloride) is added to the peroxide as a stabilizer to offset the effects of residual phosphate; therefore, a minimum limit was established for tin. (The tin content in H_2O_2 will gradually decline during storage due to drop-out from the solution). The chloride and sulfate ions are limited because they cause container corrosion (through solution of aluminum). Nitrate has been found to inhibit the effects of chloride and sulfate, and a lower level has been established for this ion to inhibit container corrosion. Although certain carbonaceous materials are known to be catalyst poisons, the effect of carbon is not entirely defined. This effect is discussed further in Section 7.2.1.3.1.

All manufacturers of propellant-grade 90 w/o hydrogen peroxide can presently meet the limits established in MIL-P-16005D. This is illustrated in Table 3.2 with typical analyses of products from three different manufacturers, duPont, FMC, and Shell, compared to the procurement specification requirements.

> NOTE: Although there are some differences in impurity types and levels in the hydrogen peroxide produced by the various manufacturers, the limits criteria established by MIL-P-16005D are adequate to govern the procurement and operational quality of propulsion-grade 90 w/o hydrogen peroxide. Further discussion of this analysis is presented in Section 7.2.1.3.

Currently, there is no government procurement specification for 98 w/o hydrogen peroxide. However, the Air Force Rocket Propulsion Laboratory, which has been assigned primary responsibility for DOD and NASA propellant specification coordination, has indicated (Ref. 3.9) that a procurement specification for 98 w/o H_2O_2 will be released in 1967. Present plans are to revise MIL-P-16005D to include the limitations for higher concentrations of H_2O_2. The tentative limits on the H_2O_2 assay of the higher concentration are 98 w/o minimum and 99 w/o maximum. In addition, the revision will include some changes in the analytical techniques recommended in the present specification. An indication of these changes is given in the following discussion under Chemical Analysis.

3.4 CHEMICAL ANALYSIS

The currently recommended procedures and techniques for the complete analysis of propellant-grade hydrogen peroxide are presented in the appropriate procurement specifications. The chemical analysis of other propellant grades, not included in the present procurement specifications, can be conducted with similar techniques. Chemical analysis techniques for hydrogen peroxide also are available from the hydrogen peroxide manufacturers upon request.

Because of the space limitations of this handbook and the ready availability of the analytical procedures, they are not reproduced in this handbook. However, in summation of the analytical techniques recommended by MIL-P-16005D, H_2O_2 assay is determined by standard titration with ceric sulfate to a ferroin end point. The Al, Cl, NH_4, NO_3, PO_4, and SO_4 ions are all determined spectrophotometrically, and tin is determined polarographically. Carbon content is determined by combusting the sample in a furnace to change the carbon materials to CO_2; this is subsequently determined by titration (Ref. 3.9). There are some differences in the analytical techniques recommended by MIL-P-16005D and those recommended by the various manufacturers and used in the industry. The differences in these procedures, which are for the most part minor, are summarized in the following paragraphs. The Air Force Rocket Propulsion Laboratory has recognized these differences and has indicated probable changes in the presently recommended analytical techniques during the next revision of the procurement specification.

3.4.1 H_2O_2 Assay

Although MIL-P-16005D recommends determination of H_2O_2 assay by ceric sulfate titration, a survey of the industry has indicated that most laboratories prefer H_2O_2 assay determination by a permanganate titration because of the ease in identification of the end point. However, all laboratories can perform the ceric sulfate titration with equivalent accuracies.

3.4.2 Aluminum

In the spectrophotometric procedure specified in MIL-P-16005D for determination of the aluminum ion, an aluminon-gelatin buffer solution is used for color formation. The duPont (Ref. 3.10) and Shell (Ref. 3.11) procedures suggest the use of 8-hydroxyquinoline and extraction with chloroform for

color formation. The FMC (Ref. 3.6a) procedure suggests that the sample size be increased from 10 to 25 milliliters and that the buffer solution, prepared by the specification method, may be slightly less stable than the buffer solution preparation detailed in the FMC procedure.

3.4.3 Chloride

Shell (Ref. 3.12) suggests determination of the chloride ion by measurement of turbidity with a colorimeter instead of the spectrophotometer specified in MIL-P-16005D. The FMC procedure (Ref. 3.6b) is a colorimetric method using mercuric thiocyanate and ferric ammonium sulfate.

3.4.4 Ammonium

In determination of the ammonium ion by spectrophotometry, duPont (Ref. 3.10) separates the ammonia from the other contaminants by distillation before color formation. The FMC (Ref. 3.6) and Shell (Ref. 3.13) procedures essentially agree with MIL-P-16005D except FMC suggests that greater accuracy may be achieved by increasing the sample size from 10 to 50 milliliters.

3.4.5 Nitrate

FMC (Ref. 3.6) recommends that the heating step with the phenol-disulfonic acid reagent, employed in the determination of the nitrate ion, be increased to 15 minutes (from 5 minutes) to ensure complete contact and nitration of the sample residue. The Shell procedure (Ref. 3.14) utilizes a larger sample size and increases the heating time to 10 minutes.

3.4.6 Phosphate

The duPont procedure for the determination of the phosphate ion is essentially identical to MIL-P-16005D except that the ether extraction is omitted (Ref. 3.10). The Shell (Ref. 3.15) procedure also omits the ether extraction and uses hydrazine instead of stannous chloride to develop the molybdenum blue color. The FMC (Ref. 3.6c) procedure is somewhat different. FMC (Ref. 3.6) reports that attempts to use this procedure (MIL-P-16005D) failed to give valid or comparative results. Although only preliminary investigations have been conducted, studies indicate an error in pH adjustment of the sample solution before extraction with ether. It also appears that the stannous chloride reagent is too acid, as the blue molybdate color is removed by this reagent. Three reagents added to the sample solution (HBr, HCl, and HNO_3), are not added in the calibration curve procedure. Thus, the PO_4 content of the sample could be enhanced by any PO_4 contained in these reagents.

3.4.7 Sulfate

For the determination of sulfate, duPont (Ref. 3.10) recommends the use of a preliminary perchloric acid oxidation to measure total sulfur, instead of only sulfate sulfur. Shell (Ref. 3.16) recommends precipitation with barium chloride, stabilization of the suspension by the addition of alcohol and glycerine, and turbidity measurements with a photoelectric colorimeter. FMC (Ref. 3.6d) also suggests the use of a turbidimeter (rather than the spectrophotometer), and a method which converts SO_4 to H_2S instead of a caustic addition with $BaSO_4$ precipitation.

3.4.8 Tin

Both duPont (Ref. 3.10) and FMC (Ref. 3.6e) suggest the use of a polarographic method for determining tin in contrast to the spectrophotometric technique recommended in MIL-P-16005D. Shell (Ref. 3.17) uses a spectrophotometric technique which is different from that in the MIL-P-16005D; the stannic tin is extracted into an 8-hydroxyquinoline-chloroform solution at a pH of 0.85, and the tin is determined spectrophotometrically in the chloroform extract.

3.4.9 Carbon

DuPont (Ref. 3.10) suggests that measurement of change in conductivity of the barium hydroxide scrubbing solution is a more accurate technique for carbon determination than the titration recommended in MIL-P-16005D. FMC (Ref. 3.6) suggests that the MIL-P-16005D procedure is (1) "time consuming and hence expensive to run, and (2) it requires rather elaborate combustion equipment." Instead, FMC suggests the use of a procedure (Ref. 3.6f) where the sample is decomposed by addition of silver nitrate solution and the noncondensable vapors, from boiling of the resulting solution, are passed through a combustion tube packed with copper oxide at 750 C; the resulting gas is passed through a solution of barium hydroxide and potassium persulfate, which is then titrated with standard HCl solution to determine carbon. Shell (Ref. 3.18) uses a combustion technique to convert the carbon to CO_2, which is determined in a gas chromatographic column.

3.4.10 Residue

DuPont (Ref. 3.10) obtains residue by atmospheric pressure concentration rather than in a vacuum oven.

3.4.11 Particulate

The stringency of the particulate limit, 1 mg/liter, established by MIL-P-16005D has been noted (Ref. 3.6) in comparison to that established (10 mg/liter) for other propellants. In addition, duPont (Ref. 3.10) prefers the use of a Teflon polytetrafluoroethylene filter instead of a polyethylene filter for reasons of safety.

3.4.12 Stability

Most laboratories prefer gas collection techniques for determining stability in contrast to the weight loss technique recommended in MIL-P-16005D.

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3.6c Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-21.

3.6d Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-22B.

3.6e Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-12.

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TABLE 3.1

SUMMARY OF MILITARY SPECIFICATIONS CD IN THE PROCUREMENT OF HYDROGEN PEROXIDE

Property	MIL-P-16005D			MIL-H-22868			AMMA-PD-E-763	
	Limits		Analytical Technique	Limits		Analytical Technique	Limits	Analytical Technique
	Minimum	Maximum		Minimum	Maximum		Maximum	
Weight Percent H_2O_2	90.0	91.0	$CeSO_4$ Titration	69.5 to 71.0	89.5 to 91.0	$KMnO_4$ Titration	76 ±0.5	$KMnO_4$ Titration
Aluminum, mg/liter		0.5	Spectrophotometric				0.6	Spectrophotometric
Chloride, mg/liter		1.0	Spectrophotometric (turbidimetric)		1.0	Turbidimetric	0.5	Turbidimetric
Ammonium, mg/liter		3 0	Spectrophotometric				3.5	Colorimetric
Nitrate, mg/liter	3.0	5 0	Spectrophotometric	90	130	Colorimetric	5.0	Colorimetric
Phosphate, mg/liter		0.2	Spectrophotometric	25	33	Colorimetric	0.5	Colorimetric
Sulfate, mg/liter		3.0	Spectrophotometric (turbidimetric)		10.0	Turbidimetric	3.25	Turbidimetric
Tin, mg/liter	1.0	4.0	Spectrophotometric	28	36	Polarographic	3.0[*] 2.5[**]	Polarographic
Carbon, mg/liter		200.0	Combustion	—	—		—	
pH	—	—		1.2 to 1.6	0.0 to 0.4	pH Meter	—	
Surface Tension, $\frac{dynes}{cm}$	—	—		72	74 at 20 C	Capillary Rise	—	
Evaporative Residue, mg/liter		20.0			325		10	
Stability, percent		5	(Loss in weight after 24 hours at 100 C)		2	(Loss in weight after 24 hours at 100 C)	—	
Color	(Clear, colorless)			(Clear, colorless)			(Clear, colorless)	
Container Condition	(No defects, leaks or signs of decomposition)			(No defects, leaks or decomposition)				

TABLE 3.2

COMPARISON OF TYPICAL ANALYSES FOR PROPELLANT-GRADE 90 w/o HYDROGEN PEROXIDE FROM THREE DIFFERENT COMMERCIAL MANUFACTURERS

	Military Specification	DuPont	Shell	FMC
Percent H_2O_2	90.0 to 91.0	90.7	90.7	90.8
Percent AOL	5.0 maximum	0.9	0.3	1.1
Carbon, mg/liter	200 maximum	11	150	BDL*
Residue, mg/liter	20 maximum	15	15	15
Cl^{-1}, mg/liter	1.0 maximum	0.2	< 0.1	0.2
PO_4^{-3}, mg/liter	0.2 maximum	0.1	0.04	0.07
NO_3^{-1}, mg/liter	3.0 to 5.0	3	3.6	3.5
SO_4^{-2}, mg/liter	3.0 maximum	0.3	< 3.0	0.02
Sn, mg/liter	1.4 to 4.0	1.8	1.8	1.9
NH_3, mg/liter	3.0 maximum	0.3	< 3.0	0.03
Al, mg/liter	0.5 maximum	0.2	0.2	0.07
Insolubles, mg/liter	1.0 maximum	<1.0	<1.0	<1.0

*Below Detectable Limits

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SECTION 4: STORAGE AND HANDLING

4.1 STORABILITY

4.1.1 General

The storability (or storage stability) of hydrogen peroxide is usually described in terms of decomposition rate and/or concentration change of the H_2O_2 over a period of time. Because storability is directly related to decomposition, it becomes a function of the considerations involved in the decomposition mechanisms. In a simplification of these mechanisms, which are described in detail in Section 7, the basic factors controlling decomposition rate in a storage system are H_2O_2 concentration; temperature; impurity types and concentrations in the H_2O_2; and the composition, area, and condition of the surface in contact with the H_2O_2. Although many of these factors are discussed in other sections of this handbook as a result of studies of materials compatibility, passivation techniques, decomposition mechanisms, etc., they are interrelated and presented in this section in terms of storability.

Until the early 1960's, the generally accepted decomposition rate AOL* of commercial, unstabilized, propellant-grade hydrogen peroxide under normal storage conditions (e.g., in a 30-gallon storage drum at an S/V of 0.38 $in.^{-1}$) was ~1 percent/year at ambient temperatures of 77 to 86 F (Ref. 4.1). This rate is theoretically equivalent to a propellant-grade hydrogen peroxide concentration loss of ~ 0.5 w/o H_2O_2/year. Some examples of decomposition rates actually experienced during drum storage (under field handling conditions) of various types of hydrogen peroxide between 1945 and 1963 are shown in Table 4.1 in terms of concentration changes and actual oxygen loss. These results, which are essentially representative of propellant manufactured before 1960 and of storage at the S/V (0.38 $in.^{-1}$) typically found in 30-gallon storage drums, were reported in Ref. 4.2.

*AOL (active oxygen loss) is defined in Section 4.2.1.1.4.

There are some discrepancies noted in Table 4.1 between the reported oxygen losses and the H_2O_2 concentration changes. It would appear that if the magnitudes of the reported H_2O_2 concentration changes were entirely attributable to H_2O_2 decomposition, the oxygen losses would be much higher. Although it is possible that some of the H_2O_2 concentration change during the storage period was due to moisture absorption from the air (during drum "breathing"), the discrepancies do cause some doubt in the validity of the oxygen losses reported. Because the technique for determination of oxygen loss is not reported, and it is assumed that such a measurement would be difficult under the uncontrolled conditions of drum storage, the concentration change appears to be the most indicative factor of decomposition rate during these tests.

From the H_2O_2 concentration changes reported in Table 4.1, the decomposition rate of the unstabilized 90 w/o H_2O_2 can be estimated as approximately 1-percent AOL/year which corresponds to that rate generally accepted by the industry during this period. The data presented in the table also indicate smaller decomposition rates for both the 98 w/o H_2O_2 propulsion grade and the stabilized torpedo grades (90 and 70 w/o H_2O_2) under essentially the same storage conditions. These effects are discussed further in Sections 4.1.3.2 and 4.1.3.5.

Recently, improvements have been reported in the storage stability of hydrogen peroxide, particularly, in the 90 w/o grade. The gross result of this improvement is illustrated in Table 4.2 with data from studies conducted in 1947 (Ref. 4.3) and in 1965 (Ref. 4.1 and 4.4) on 90 w/o H_2O_2 and studies on 99+ w/o H_2O_2 in 1953 (Ref. 4.5). In this table the rate of decomposition of the hydrogen peroxide has been reported as a function of temperature and as a function of contamination for the three different time periods. Although the reasons for the improvement in hydrogen peroxide stability are not defined in Table 4.2, the data are indicative of the progress that has been made in the storability of hydrogen peroxide.

4.1.2 Storability Improvement Studies

This recent increase in the storage stability of hydrogen peroxide is a result of a combination of factors including (1) increased purity of the hydrogen perioxide, (2) better selection of the container materials, (3) improved surface treatment and passivation of the container, and (4) development of more effective stabilization techniques. A recent characterization of these factors resulted from three primary studies directed at the improvement of hydrogen peroxide storability. These studies, which were conducted by duPont (Ref. 4.6), FMC (Ref. 4.7), and Shell (Ref. 4.1, 4.8 and 4.9), are summarized in the following paragraphs.

DuPont (Ref. 4.6) conducted studies on (1) the stability of solid and low-temperature (32 F) liquid hydrogen peroxide (90 to 100 w/o H_2O_2) in Pyrex; (2) the effect of aluminum, Pyrex, polyethylene, and fluorocarbon polymers on the stability of H_2O_2 in the 122 to 158 temperature range; and (3) the reaction mechanisms of hydrogen peroxide decomposition. As a result of this study, the decomposition rate of high-purity or commercially stabilized hydrogen peroxide at -76 to 32 F was found to be less than 0.04 percent per year in Pyrex. In addition, the decomposition rate of 90 w/o H_2O_2 in contact with a Teflon FEP fluorocarbon film that had been mildly irradiated in air was less than one-third of the rate involved in contact of the 90 w/o H_2O_2 with a passivated aluminum surface and less than one-half the rate with Pyrex.

Sealed storage studies of the commercial and propulsion grades of 90 and 98 w/o H_2O_2 in TFE Teflon bladders (contained in mild steel tanks) were conducted at 70 to 72 F (5 months), 120 F (7 days), and 165 F (72 hours) by FMC (Ref. 4.7). Although bleaching and cracking of the bladders were experienced, the tests demonstrated a reduction in H_2O_2 decomposition rates through

improved surface pretreatment and passivation techniques and use of stabilizers. Extrapolations of the data indicated the oxygen losses of 98 w/o H_2O_2 were less than 0.4 percent/year at 70 F in the bladders. Compatibility screening studies indicated that other bladder materials such as NAA Vicone 185, duPont Viton B (805), and 3M Fluorel 2141 were superior to the TFE Teflon material.

In the study conducted by Shell (Ref. 4.1), experimental investigations were directed into three major areas: (1) improvement of H_2O_2 purity, (2) development of an improved liquid decomposition inhibition system, and (3) assessment of container materials of construction for long-term storage. Storage decomposition rates for 90 w/o H_2O_2 were reduced to 0.04 percent/year at ambient temperature as a result of H_2O_2 stabilization and careful selection and preparation of the storage container material (Pyrex). It was also indicated that the use of other materials such as ACLAR-33C and Kel-F plastics, 1260 aluminum, and electrolytic tin plate (special preparation) in large storage tanks [minimum surface-to-volume ratio (S/V)] could reduce overall decomposition rates under normal storage conditions to 0.1 percent/year. Various means of purification such as distillation, recrystallization, and ion exchange on insoluble inorganic exchangers have also been effective in reducing the decomposition rate; it was also indicated that decomposition rates of 99 w/o H_2O_2 were slightly lower than those of 90 w/o H_2O_2 under the same environmental conditions (including the degree of contamination).

Shell has continued the investigation of hydrogen peroxide purification and stabilization techniques and the passivation of container materials to determine the feasibility of sealed hydrogen peroxide storage for periods of 5 years (Ref. 4.8 and 4.9). In this study, which was scheduled to be concluded in January 1968, β-stannic acid was determined to be the most effective ion-exchange purification medium for increasing the stability of hydrogen peroxide in storage; decomposition rates of 90 w/o H_2O_2 treated with this technique were approximately one-third the

rates of untreated 90 w/o H_2O_2 after storage in aluminum for periods of 1 year. It was also determined that the minimum decomposition rate of hydrogen peroxide in contact with aluminum surfaces was achieved when the aluminum was subjected to a caustic-nitric acid-hot (212 F) 90 w/o H_2O_2 pretreatment sequence prior to testing; however, only minor changes in stability resulted from various types of chemical pretreatment of stainless-steel surfaces (Tables 4.31 and 4.31a and Section 4.2.2.12). The decomposition rate of 90 w/o H_2O_2 in contact with tin-plated (electroplated) aluminum was greater than that observed with either the best tin surface or the best passivated aluminum surface.

4.1.3 Factors Affecting Storability

As noted throughout the various studies of storability, decomposition, passivation, materials compatibility, propellant purification, etc., reported in various sections of this handbook, storage stability of hydrogen peroxide is dependent on a variety of factors. Because it is difficult, however, to separate the influence of each contributing factor under actual storage conditions, many of these studies have been conducted under ideal or isolated environments. Although, for this reason, the translation of the data from these tests into gross storability in terms of particular rates are difficult, the general degree of influence can be fairly accurately predicted and established. Thus, the general effect of factors such as concentration, purity, temperature, container material, container surface pretreatment, and passivation, S/V container ratio, and propellant stabilization system on storability are discussed briefly in the following paragraphs.

4.1.3.1 Concentration. Under equivalent storage conditions, it has been determined that the storage stability of hydrogen peroxide is increased with its concentration (Ref. 4.1 and 4.2). This is

generally attributed to the decrease in impurities and ionization with the loss in water content, and to the decrease in container contact area with decrease in surface tension. This effect is illustrated as a function of concentration from 90 to 98 w/o in Fig. 4.1; comparisons of other decomposition rates between 90 and 98 w/o H_2O_2 are shown at two other conditions in Fig. 4.2 and 4.3.

4.1.3.2 Purification. As the various inorganic and organic contaminants are removed from hydrogen peroxide-water solutions, storage stability will approach that of high concentration (98 w/o) hydrogen peroxide; however, because of the various effects (described in Section 4.1.3.1) resulting from water elimination, the storability of the more aqueous solutions will never equal the stability of 98 w/o H_2O_2 assuming the same degree of impurities (Ref. 4.1). Current studies (Ref. 4.8 and 4.9) have demonstrated that various types of purification techniques will produce hydrogen peroxide with homogeneous decomposition rates on the order of 0.03 to 0.07 percent AOL/year at 77 F.

4.1.3.3 Temperature. In general, the decomposition rate of hydrogen peroxide has been found to increase 2.3 times for each 10 C (18 F) rise in temperature; this effect is illustrated in Fig. 4.4 which was reprinted from Ref. 4.1. Other data on this effect have been reported in Ref. 4.5.

4.1.3.4 Container Surfaces. The effect of the storage container on the storability of hydrogen peroxide is essentially a function of the type of material, the surface treatment and passivation, and the S/V of the material in contact with the liquid volume.

4.1.3.4.1 Container Material. The effect of various materials in contact with the hydrogen peroxide is described and compared in the Materials Compatibility Section (Section 4.2.2). However, for comparison purposes, decomposition rates resulting from the effect of selected materials in combination with other effects are shown in Fig. 4.4 (Ref. 4.1) and 4.5 (Ref. 4.1 and 4.10) for 90 w/o H_2O_2.

4.1.3.4.2 Surface Treatment and Passivation. Several studies (i.e., Ref. 4.1, 4.7 to 4.9, and 4.11 to 4.18) have established the importance and effect of surface pretreatment and passivation on the decomposition rate and the stability of hydrogen peroxide. Detailed data in this area are presented in Section 4.2.2.12 and Tables 4.21 through 4.31a as part of the Materials Compatibility Section. An example of the effect of surface pretreatment in terms of storability of hydrogen peroxide is shown in Fig. 4.6.

4.1.3.4.3 Surface to Volume Ratio. The effect of the storage container surface on the decomposition rate of the hydrogen peroxide is usually illustrated in terms of S/V. This ratio is generally defined as the immersed surface area (that area in contact with the liquid hydrogen peroxide)/liquid volume of the hydrogen peroxide. The relationship between these two factors has been found to be an effective means of expressing the contribution of the heterogeneous decomposition rate of the liquid to the overall decomposition rate of the hydrogen peroxide.

In determination and comparison of the compatibility of various materials, the S/V is usually kept constant. For most of the studies illustrated in Section 4.2.2, a sample size of 1-1/2 by 1/2 by 1/16 inch has been immersed in 75 milliliters of hydrogen peroxide, thus establishing a S/V value of 0.38 $in.^2/in.^3$ (0.38 $in.^{-1}$). This number generally corresponds to the

conditions found in the storage of hydrogen peroxide in a standard 30-gallon storage drum.

It is obvious that as the surface in contact with the liquid is reduced ($S/V \rightarrow 0$), the heterogeneous decomposition rate is reduced. Thus hydrogen peroxide stored in large storage tanks should have a minimum decomposition rate, assuming the equivalency of the other factors. This is illustrated in Fig. 4.5a in which experimental studies (Ref. 4.1) were used to predict the decomposition rates shown in the figure; as S/V is reduced, the overall decomposition rate of the hydrogen peroxide approaches that of the homogeneous decomposition rate. Further, it was indicated in this study that "decomposition rates of the order 0.1 percent AOL/year at ambient temperature appear to be readily attainable by use of highest quality (90 w/o H_2O_2) stabilized with sodium stannate and stored in vessels of low surface activity and low S/V ratio.

Other experimental studies (Ref. 4.5 and 4.10) of the effect of S/V on hydrogen peroxide storability are illustrated in Fig. 4.5b, 4.5c, and 4.7. Figure 4.5a, 4.5b, and 4.5c also indicate the effect of S/V as a function of different materials. Figure 4.7 represents work (Ref. 4.5) that attempted to limit the homogeneous decomposition rate through the use of high purity (99+ w/o) hydrogen peroxide and limit the catalytic effect of the container surface by using carefully pretreated glass. It was concluded from the latter study that "the whole inside surface of the container plays a part in the decomposition, but per unit area the immersed surface is more effective than the nonimmersed surface."

4.1.3.5 Stabilization. The use of stabilizers to improve hydrogen peroxide storage stability is essentially based on the premise that they will inhibit decomposition by contamination incurred during storage and handling operations. If the hydrogen

peroxide could be protected against contact with soluble and insoluble contaminants, stabilization would not be required. In addition to the contamination of the hydrogen peroxide by the system fabrication materials, H_2O_2 contamination may result from improper storage and/or handling system, cleaning and passivation techniques. The incomplete removal of organic solvents, acids, detergents, chromic acid cleaning solutions, etc., by inadequate rinsing or the use of rinse waters which contain various impurities can readily cause contamination of hydrogen peroxide by the storage or handling system. For the preceding reasons, and because the normally manufactured hydrogen peroxide does contain traces of impurities that will cause H_2O_2 decomposition, some degree of stabilization has been effected in most of the commercially manufactured hydrogen peroxide. The degree and type of stabilization has depended on the planned use of the H_2O_2.

There is no single stabilizing agent which may be designated as the most effective or the most desirable. The selection of a stabilizer must be made with regard to the conditions under which the hydrogen peroxide ultimately is to be used, to the type of contamination likely to be encountered, and to such considerations as the required storage period and the probable prevailing temperature during that storage period. If the storage period is to be relatively brief, an organic stabilizer may be satisfactory; however, over a long period of time, slow oxidation may destroy the effectiveness of an organic component. However, limitations may be placed upon the choice of an inorganic stabilizer because of the quantity of undesirable residues which may remain after a large quantity of hydrogen peroxide has been decomposed. It is also apparent that a large proportion of stabilizer is unsatisfactory.

An extensive number of stabilizers, both inorganic and organic have been tested (i.e., Ref. 4.1, 4.5, 4.8, and 4.9) with both dilute and concentrated hydrogen peroxide solutions. Among

these substances, the most notable success was obtained, especially in the case of the highly concentrated hydrogen peroxide solutions (Ref. 4.5), with sodium stannate or 8-hydroxyquinoline ("oxine") in the presence of a soluble pyrophosphate, or a phosphate-pyrophosphate mixture. A detailed discussion of hydrogen peroxide stabilizers is presented in Ref. 4.19 and 4.20.

Recently, the effect of the contaminants most commonly encountered in propellant-grade hydrogen peroxide on the stability of hydrogen peroxide was characterized (Ref. 4.21). Separate 90 w/o hydrogen peroxide solutions were contaminated with various concentrations of selected ions (Cr^{+3}, Fe^{+3}, Cu^{+2}, Ni^{+2}, PO_4^{-3}, SO_4^{-2}, NO_3^{-1}, Cl^{-1}) to determine their influence upon the stability of the hydrogen peroxide. Copper was found to exhibit the greatest effect (toward decreasing the stability) followed by iron, nickel, and chromium (Table 4.2). The anions exhibited no detectable influence in the concentration ranges studied when stability was measured by standard weight loss technique.

4.1.3.5.1 Stabilization Effects. The total effectiveness of hydrogen peroxide stabilization depends largely on the type and quantity of stabilizer used, the initial H_2O_2 concentration and purity, and the container material type and surface pretreatment. Recent studies by Shell (Ref. 4.5) on storage in 5-gallon drums has demonstrated that commercially available 90 w/o hydrogen peroxide can be stabilized and stored in properly prepared vessels with a decomposition rate as low as 0.04 percent/year at ambient temperatures. The evolved gas at such rates can be contained in the vessel with relatively low ullage and at reasonable pressures for several years. The decomposition rate depends to an appreciable extent upon the container material and the surface finish. Pyrex effects the lowest decomposition rate. However, with the proper passivation and surface treatment, containers of ACLAR, Kel-F, 1260 aluminum

and electrolytic tin having low S/V demonstrated decomposition rates as low as 0.1 percent/year. The rates predicted for these materials as a function of S/V are shown in Fig. 4.5a.

Other examples of the end results of stabilization are illustrated in Fig. 4.1, 4.8, and 4.9. Figure 4.1 (Ref. 4.2) compares oxygen loss over a 24-hour period between commercially stabilized and unstabilized hydrogen peroxide as a function of concentration at 212 F. Figure 4.8 (Ref. 4.7) illustrates the reduction in AOL by commercial stabilization of 98 w/o hydrogen peroxide as a function of temperature. The effect of stabilizer quantity is illustrated in Fig. 4.9 (Ref. 4.8); the stabilizer used in this illustration was sodium stannate, which was added in varying amounts to hydrogen peroxide obtained from three different manufacturers.

4.1.3.5.2 Stabilization Requirements. The requirement for hydrogen peroxide stabilization is based on the end use to which the hydrogen peroxide will be applied. Generally, stabilizers are added to extend the storage life of the propellant, and as such, would appear to be desirable for all situations. However, when the end use of the propellant depends on its decomposition in a fixed catalyst bed chamber, the use of stabilization is severely limited by the poisoning effect of the stabilizer on the catalyst (Section 7). This is reflected in the two primary propellant specifications presently in use. The torpedo-grade propellant specification, MIL-H-22868, which requires long-term sealed storage propellant not subject to decomposition in a fixed-bed catalyst, specifies a large amount of stabilizers. MIL-P-16005D, which is the procurement specification for propulsion-grade hydrogen peroxide, limits the total stabilizer content to a few mg/liter because of the usual application of this hydrogen peroxide grade in fixed catalyst beds. Hydrogen peroxide used in the chemical pretreatment and passivation of hydrogen peroxide systems is sometimes

(Ref. 4.2) heavily stabilized to provide enough ions to complex all of the potential catalytic sites. Therefore, the quantity and type of hydrogen peroxide stabilization is dictated by the end use of the material.

Stabilization is usually effected by the hydrogen peroxide manufacturer as a condition of the procurement. The individual requirements should be discussed with the manufacturer and his assistance sought in determining the need for and type and amount of stabilization required. All hydrogen peroxide manufacturers indicate that conventional stabilization should be accomplished at the manufacturing site.

4.1.3.5.3 Emergency Stabilization. Stabilization of hydrogen peroxide at storage sites has been utilized under "emergency conditions." The conditions, which necessitate this corrective action, are usually associated with self-heating of hydrogen peroxide storage systems due to excessive decomposition caused by unanticipated contamination of the system. One source (Ref. 4.22) has recommended such corrective action when the temperature of the hydrogen peroxide (without external heating) rises to a level 20 F greater than that of the surroundings. The rate of temperature rise also determines the urgency of the corrective measures. Another source (Ref. 4.3) considers it desirable to maintain time-temperature records of all storage units and recommends taking corrective action when the bulk temperature achieves a 2 to 3 F increase in temperature over the maximum ambient temperature. Corrective action is also recommended if the rate of temperature increase is greater than 0.5 F/hour. The more conservative methods limitations of Ref. 4.3 should result in fewer "incidents" and provide additional time to consider appropriate action.

In estimating the necessity of corrective action based on AOL, Ref. 4.23 states that for a 30-gallon drum, a rate of more than 2 percent AOL/year (or 0.0054 percent AOL/day) is abnormal;

for a 500-gallon tank, a rate greater than 1 percent AOL/year or 0.0027 percent AOL/day is excessive and for flow systems a decomposition rate of 0.05 percent AOL/hour is the maximum permissible rate concurrent with a temperature rise of approximately 5 F above ambient conditions.

In the early stages of storage system self-heating, temperature rises may be counteracted by the use of water spray on the storage container. If adequate pure water is available, if container free space is available, and if moderate dilution is not critical to the end use, the most rapid cooling may be achieved by the addition of water directly to the hydrogen peroxide in the storage container. This cooling period allows greater flexibility and additional time for analysis, procurement, or preparation of stabilizer, but does not eliminate the need for further action.

When attempting to control a self-heating tank, a careful record of the temperature vs time should be maintained to help evaluate the effectiveness of the control technique. In projecting a time-temperature curve from previous experience, several assumptions must be made. Most of the approximations will overestimate the hazard and underestimate the time before eruption from the storage container. There are two major factors which may result in decomposition rate accelerations with time: (1) excessive temperature rise may result from the decomposition of the stabilizer, and (2) decomposition at the container walls may result in the formation of a gas blanket which prevents adequate heat transfer through the container wall causing additional temperature increase of the solution and increased decomposition. In the latter case, a temperature-indicating device on the outside wall of the tank will not indicate the temperature increase in the liquid but will indicate a lower temperature. Because heat transfer under these conditions may be somewhat erratic, this temperature is a poor indication of true liquid conditions.

The hydrogen peroxide bulk temperature will lag changes in air temperature depending on the container size. A large tank which has been warmed during the day will require some time to cool because of the volume of solution. For a tank to be warmer than air temperature at night is normal and no cause for alarm. For the tank temperature to be gradually increasing toward an increased air temperature is normal. For the temperature of a tank not exposed to direct rays of the sun to be increasing in temperature when the air temperature is decreasing is abnormal. For the tank temperature to be consistently higher than ambient air temperature is not normal.

In making a decision to stabilize a "hot system," the advice of the hydrogen peroxide manufacturer should be sought if at all possible. If the conditions are so critical that this contact cannot be accomplished, the guide of Paragraph 1.6.6 in "The Handling and Storage of Liquid Propellants - Hydrogen Peroxide" (Ref. 4.24) can be used:

> 1.6.6 Emergency Stabilization: The decomposition of hydrogen peroxide at an accelerating rate, as evidenced by increasing gas evolution and temperature may be brought under control by the following emergency stabilization procedure: add 1 pound of 85 percent phosphoric acid solution (in water) for each 100 gallons of hydrogen peroxide solution. Mixing is not necessary because the turbulence will disperse the stabilizer. After being thus stabilized and if the decomposition subsides, hydrogen peroxide may be stored in aluminum containers until consumed or otherwise disposed of. This solution must not be used in applications involving catalytic decomposition chambers, because the stabilizer will poison the catalyst.

4.1.3.5.4 Effective Life of Stabilizers. Storage in metal containers slowly destroys the stabilizing effect of stannate by precipatation out of the solution. This normally takes approximately 4 months for aluminum containers; in Pyrex containers the stabilizer is approximately 45 percent depleted in 4 months; however, in polyethylene, no loss of stabilizer was detectable (Ref. 4.20). The analysis of hydrogen peroxide solutions for

tin will also reveal varying concentrations depending upon the age of the solution when tested. Comparison of analytical reports from separate laboratories on the same solution must allow for this variation.

Hydrogen peroxide used by the Germans during World War II was usually 85 percent by weight H_2O_2 and was stabilized with 8-hydroxyquinoline in the form of the pyrophosphate or mixed with sodium pyrophosphate. This stabilizer slowly oxidized and in approximately 6 months had effectively disappeared. This organic stabilizer is normally considered superior to stannate in protection against iron.

4.2 MATERIALS OF CONSTRUCTION

Initial selection of materials for application in hydrogen peroxide storage and handling systems is based on a series of materials compatibility tests. These tests may range from an evaluation of a material sample under a set of general test conditions to the definition of the specific limitations of various pieces of hardware fabricated from a number of different materials. Although the compatibility of materials with a propellant is usually based primarily on the ability of the material to withstand chemical attack by the propellant (as expressed by corrosion rate), the emphasis in the evaluation of materials compatibility with hydrogen peroxide is placed on the effect of the material on hydrogen peroxide stability (as expressed by decomposition rate). Because hydrogen peroxide decomposition is a function of several variables, including material type, surface area, contamination, temperature, etc., it is essential that the selection of a material represent an evaluation of all of these potential effects.

The available technology on materials compatibility testing with hydrogen peroxide is summarized in this section. A description of the compatibility studies that have been conducted

and the criteria established by these results are used to provide a basis for the selection of materials of construction for hydrogen peroxide service. The final evaluation of a material and its suitability for an application involving contact with H_2O_2 is based on experience resulting from that application. In general, the recommendations of materials classification for H_2O_2 service contained herein are based on both the results of laboratory tests and on practical experience. In a few instances, practical experience has revealed results different from those of laboratory tests. Whenever this is the case, the greater consideration has been given to practical experience and conclusions are drawn accordingly. Criteria established for laboratory tests are based as far as possible on correlations with experience resulting from placing the materials in service.

> NOTE: The user of this handbook should be cautioned that the materials compatibility data presented herein should only serve as a basis for selection of materials for hydrogen peroxide service. Careful consideration should be given to the conditions of testing; the use of the material under a different set of conditions may have an entirely different effect. Materials which are not suitable for use at high temperatures may be acceptable for uses at lower temperatures. Different fabrication procedures and passivation techniques may result in variation in compatibility classification. Even different lots of the same parts fabricated from "compatible" materials by the same manufacturer using the same manufacturing techniques have revealed variations in compatibility. Thus, it must be emphasized that any material used in hydrogen peroxide service be thoroughly tested and qualified under the conditions of its intended use before it is placed in service.

4.2.1 Compatibility Studies

Compatibility studies that have been conducted with hydrogen peroxide are described in terms of standard test procedures,

standard compatibility classification definitions, and standard rating criteria. Although the illustrated procedures and classifications do not necessarily reflect the most desirable methods for all purposes, they do represent the most typical (as noted in Ref. 4.25) of the general tests, classifications, and rating criteria presently employed.

4.2.1.1 Compatibility Test Procedure. The compatibility test procedure normally consists of three basic tests. An initial screening test is performed to eliminate all materials that cause gross decomposition of the hydrogen peroxide. The compatibility of the preselected materials with hydrogen peroxide is then determined by measuring a rate of H_2O_2 decomposition (as percent AOL) during an immersion of the materials in hydrogen peroxide (of a selected composition) for a stated temperature and time interval. The final evaluation in the compatibility test procedure is the determination of the stability of the hydrogen peroxide after contact with the material.

4.2.1.1.1 Screening. Prior to quantitative testing, a new or untried material should be immersed (after chemical pretreatment) in 75 milliliters of hydrogen peroxide in a passivated container at room temperature for 24 hours. Special attention should be directed to possible violent decomposition, combustion, solution, dimensional distortion, etc. If no unusual action occurs, the sample should be subjected to a further screening at 150 F for 24 hours. If no gross reaction occurs under these preliminary conditions, the material is further tested using the following technique.

4.2.1.1.2 Sample Size. In determinations of the compatibility of solid materials, a sample strip, 3 by 1/2 by 1/16 inches, is normally used for evaluation of both the liquid and vapor phases. For those materials that will be used in a continuously

wetted condition, a sample strip, 1-1/2 by 1/2 by 1/16 inches, is usually immersed in 75 milliliters of the hydrogen peroxide solution. This test condition simulates an apparent sample surface area of 1 sq in. per 42.8 milliliters of hydrogen peroxide (which approximates the 0.33 $in.^2/in.^3$ S/V of the wetted surface of a standard drum containing 250 pounds of H_2O_2). If it is necessary to test a differently sized sample, retention of this apparent S/V will aid in comparison of the results with those of previous studies. In evaluating materials for specific applications, the S/V of the application should be duplicated if possible. In testing the compatibility of liquids with H_2O_2, a 5-milliliter sample size is normally used; evaluations of greases are usually conducted with samples of 5-milliliter size which have been smeared on the inside of the test flask. It is important to record and report surface area of the test sample and the liquid volume of the H_2O_2 used. Vapor space or ullage should be minimized or held constant in comparison of different materials.

4.2.1.1.3 Cleaning and Passivation of the Test Container and Specimens. Prior to use, all glassware (the test container) should be immersed in a 10-percent sodium hydroxide solution for 1 hour at room temperature, rinsed with water, immersed in a 10-percent HNO_3 solution (3-hour minimum), and finally rinsed with distilled water. The use of chromic acid cleaning solutions should be avoided, and passivation with hot concentrated (70+ percent) hydrogen peroxide is recommended.

Aluminum samples should be scrubbed with a warm detergent solution, immersed in 0.26 w/o (N/15) sodium hydroxide at room temperature for 15 to 20 minutes, washed, immersed in 45-percent nitric acid for 45 minutes to 1 hour at room temperature, and finally washed with distilled water. The samples should then be pretreated with 35 w/o H_2O_2 at 68 to 72 F for 8 to 24 hours.

Stainless-steel samples should be degreased by scrubbing with trichloroethylene, rinsed with water, allowed to drip dry, and immersed in 70-percent nitric acid for 4 to 5 hours at room temperature. Then, the samples should be washed with clean water, washed with distilled water, and finally pretreated with 35 w/o H_2O_2. In instances where the stainless-steel specimens do not respond well to the preceding passivation technique (as noted by decomposition activity in the 35 w/o H_2O_2), stainless-steel specimens may be passivated by the following alternate procedure which has been utilized successfully in the past:

1. Degrease by scrubbing with trichloroethylene and allow to drip dry.
2. Immerse the specimen in 2-percent $Na_2Cr_2O_7$ solution, wash twice with H_2O, and immerse in a 20-percent HNO_3 solution for 1/2 hour at 120 to 130 F. (This procedure has been questioned because contamination with chromate ions is possible.)
3. Flush with potable water.
4. Flush with distilled water and pretreat with 35 w/o H_2O_2.

In the case of rusted stainless-steel surfaces and stainless-steel welds, an acid pickling is required before satisfactory passivation can be achieved. The procedure for this treatment is as follows:

1. Immerse in a 3-percent hydrofluoric acid-10-percent nitric acid solution for 30 minutes at 100 F, or 2 to 3 hours at 65 to 70 F.
2. Flush with potable water and scrub with a stiff brush to remove welding scale and rust.

3. Passivate by immersion in 70-percent nitric acid for 4 to 5 hours at room temperature, rinse with clean potable water, and finally rinse with distilled water. Expose the specimen to 35 w/o H_2O_2 at 68 to 72 F for 8 to 24 hours.

Plastics and elastomer samples should be thoroughly scrubbed in an 0.5-percent solution of a synthetic detergent, rinsed with distilled water, and immersed in a 10-percent HNO_3-water solution at 68 to 72 F for 1 hour. The samples should then be pretreated with 35 w/o H_2O_2.

During the final rinsing of all passivated specimens, the samples should not be touched with bare fingers; at this point only gloves or tongs should be used in sample handling. It is usually convenient to wash sample strips on a Pyrex funnel (as a handling medium), taking care to wash all areas. The strip should be dried between two sheets of filter paper at room temperature or in a 122 F oven and then placed in a test flask which is immediately capped with aluminum foil to eliminate possible contamination by dust, dirt, etc.

4.2.1.1.4 AOL Determination by Weight Loss. The specimen, prepared as described in the preceding paragraph, is placed in a passivated 100-milliliter Kjeldahl flask that has been rinsed with a small volume of hydrogen peroxide of the required strength. The flask is weighed to 0.01 gram and the desired quantity (usually 75 milliliters) of hydrogen peroxide of the desired strength is added to the flask. The flask is reweighed and the initial weight of hydrogen peroxide solution is recorded as the difference between these weights. At conclusion of the desired test, the flask and its contents are removed from the constant-temperature bath, cooled to room temperature and weighed. As a minimum requirement, these tests should be conducted in duplicate.

The percent of active oxygen lost is calculated as follows:

$$\text{Percent Active Oxygen Loss} = \frac{W_1 - W_2}{CW_1 \times 0.470} \times 100$$

where

W_1 = initial net weight of hydrogen peroxide

W_2 = final net weight of hydrogen peroxide

C_1 = initial weight fraction of hydrogen peroxide, $\frac{(\text{percent concentration})}{100}$

The results of some compatibility tests (Ref. 4.10 through 4.16 and 4.18) have been based on H_2O_2 concentration determinations before and after the tests. During these tests the active oxygen loss is determined by the expression

$$\text{Percent AOL} = \frac{(W_1C_1 - W_2C_2)}{W_1C_1} \times 100$$

where

W_1, W_2, and C_1 are as defined previously and C_2 is the final concentration of hydrogen peroxide.

NOTE: The term 0.47 in the first equation represents the weight fraction of available oxygen in 100 w/o H_2O_2.

Qualitative observations are also recorded on such effects as discoloration of the hydrogen peroxide and apparent changes in the physical properties of the test material. The latter includes: (1) for metals--corrosion, staining, and any surface change during or after testing; (2) for plastics and elastomers--blistering, swelling, distortion, changes in flexibility,

color, transparency, tensile strength, and tear resistance; and (3) for fabrics—changes in color, tensile strength, burning, and tear resistance.

4.2.1.1.5 AOL Determination by Gas Evolution. During compatibility tests where the AOL is small, probably the most accurate method of measurement is by gas evolution. This technique, which is described in detail in Ref. 4.26, involves the collection of the gas evolved during the test period in a small gas measuring buret. The long neck on the special test flask acts as an air-cooled condenser to reduce loss of the hydrogen peroxide vapor. The neck is connected by means of small bore tubing to nozzles submerged under a few centimeters of water in a trough. Burets are inverted over the nozzles to collect the gas. A multiple arrangement of differently sized burets with appropriate valving is used to permit selection of the proper size and additional volume without loss of any gas. The volume of gas collected is converted to weight of oxygen evolved by use of the relationships expressed in the perfect gas laws. The percent AOL is then computed from the following expression:

$$\text{Percent AOL} = 100 \times \text{weight of oxygen evolved} / 0.47 \times C_1 \times W_1$$

where C_1 and W_1 refer to the original concentration of hydrogen peroxide in the test sample expressed as weight fraction and W_1 is the original weight of the test sample.

4.2.1.1.6 Stability Determination. The recommended procedure for stability determinations on the resultant hydrogen peroxide is the same as presented in the MIL-P-16005D procurement specification (Ref. 4.27). The stability of the H_2O_2, which is obtained from the compatibility test flasks, is measured by determining the active oxygen loss (by either weight loss or gas evolution techniques) over a 24-hour period at 212 F.

In MIL-P-16005D the stability is expressed in percent AOL, although most procedures essentially express stability as (100-AOL) percent.

4.2.1.1.7 Special Compatibility Test Methods. A suggested procedure (Ref. 4.25) for determining the compatibility of protective clothing is performed on 4 by 4 inch clean test samples of "as received" material. The H_2O_2 is permitted to drop on the cloth sample at a rate of 4 milliliters per minute for ~ 1 hour. Results are evaluated by visual observation of any changes in the material during this period. To simulate "soiled cloth," a swatch of the material is soaked in a 0.005 N $KMnO_4$ solution for 30 seconds and dried at 230 F for 1 hour. The test is then performed with the procedure used with the "as received" material.

Sealing compounds are tested (Ref. 4.25) initially for impact sensitivity while immersed in H_2O_2. Qualified (nonimpact sensitive) materials are then applied to the male threads of a plug and a nipple, which are assembled into a coupling and tightened with a torque wrench (using a 1200 in. lb torque on stainless-steel assemblies and a 600 in. lb torque on aluminum assemblies). After drying at room temperature for 24 hours to set the sealing compound, the assemblies are tested for leakage by charging them with nitrogen and immersing them in water. A maximum of 1200-psig nitrogen pressure is applied to a stainless-steel assembly and 500-psig pressure is applied to an aluminum assembly. The pressure at which leakage, if any, occurs is noted. The torque required for disassembly should be noted. The sealing compound may also be tested by coating 1-1/2 by 1/2 by 1/16 inch, clean, passivated metal strips of 1060 aluminum and 316 stainless steel on one side. After drying at room temperature for 24 hours, the strips are subjected to the normal strip compatibility test described in Section 4.2.1.1

Protective coating materials are usually evaluated in accordance with standard compatibility procedures. The coating is applied according to the manufacturers' specifications to standard test strips and is tested as generally described in Section 4.2.1.1. (It is important to differentiate between compatitiblity of the coating material and the effectiveness or covering ability of the coating on the base metal.) The percent AOL is determined, and visual observations of any physical changes in the coating are noted. Other variations of this coating test involve filling a coated steel cup with H_2O_2, inverting a second coated cup on top of the cup containing the liquid, and maintaining two such sets at 86 and 150 F for 1 year and 1 week, respectively. A final laboratory test involves the half-filling of a coated 5-gallon container with H_2O_2 and allowing the test container to stand at room temperature in the laboratory or in a controlled temperature room. Containers with a 12-inch ID and 12 inches high with a 2-inch vented opening in the top are recommended for a 12-month test duration. Hydrogen peroxide concentration is determined initially and bimonthly thereafter for both the cup tests and the container test. Prior inspection of the coating for blisters or pinholes should be made before the tests are initiated.

A method for determining the compatibility of bladder materials has been suggested in Ref. 4.28. In this procedure, the bladder is immersed in concentrated HNO_3 for 10 days at the maximum potential application temperature (110 F, Ref. 4.28). At the conclusion of the immersion test, the bladder is removed and the HNO_3 is evaporated to dryness. The "residue" is treated with the test H_2O_2 at 140 F; acceptance of the bladder material depends on the resultant nonreaction between the "residues" and the test H_2O_2.

4.2.1.2 Hydrogen Peroxide Materials Compatibility Classifications. The results of the various laboratory materials compatibility evaluations and of application experience have shown that materials can be classified into various categories based on their contemplated types of use in hydrogen peroxide service. All materials need not be suitable for indefinite storage because in applications requiring only short-time contact with H_2O_2, materials of a lesser degree of compatibility can be employed. To facilitate selection on this basis, materials have been generally classified according to the types of applications for which they are suited.

A system of four classes has generally been adopted (Ref. 4.25, 4.29, and 4.30) for materials for hydrogen peroxide service. These classes are arbitrary but they do provide a standard for rating materials compatibility with H_2O_2. These classes are:

Class 1: Materials Satisfactory for Unrestricted Use with H_2O_2. Such service includes long-time contact with the H_2O_2. Typical use is for storage containers.

Class 2: Materials Satisfactory for Repeated Short-Time Contact with H_2O_2. Such materials are used for transient contact with the H_2O_2 prior to storage of the H_2O_2, or limited contact with the H_2O_2 prior to use. Such contact is not to exceed 4 hours at 72 C (160 F) or 1 week at 22 C (70 F). Typical uses are for valves and pumps in H_2O_2 transfer lines and feed tanks.

Class 3: Materials Which Should be Used Only for Short-Time Contact with H_2O_2. These materials should be used only where neither a Class 1 nor Class 2 material would suffice. These materials can be used for repeated contact, but a single use period should not exceed 1 minute at

160 F or 1 hour at 70 F. An example of a Class 3 application is materials for use in a flow system. The hydrogen peroxide should be consumed in the application or disposed of after the test because contamination of hydrogen peroxide solutions with Class 3 material is usually sufficient to render it unsuitable for storage. Many Class 3 materials indicate satisfactory room temperature service; however, the material should be checked prior to use.

Class 4: Materials not Recommended for Use with H_2O_2. These materials (1) cause excessive decomposition of H_2O_2 even on short-time contact, (2) are attacked or deteriorate on contact, (3) yield corrosion or deterioriation products which cause excessive decomposition of H_2O_2 on subsequent contact, or (4) form impact-sensitive mixtures with concentrated H_2O_2.

Other Classifications: Clothing materials are classified as "suitable" or "unsuitable". Within the classification of "suitable," choices are made on the basis of resistance of the material to deterioration in contact with the H_2O_2.

4.2.1.3 Test Evaluation Criteria. An explanation of typical (Ref. 4.25) criteria used to evaluate the materials compatibility tests described in Section 4.2.1.1 (as well as results from application experience), and to rate the results in the appropriate classifications per Section 4.2.1.2 is illustrated in Table 4.3. Because the illustrated classification system is general for all types of materials of construction that may be used in hydrogen peroxide storage and handling systems, and the classification limits were selected arbitrarily, more precise limits should be established for specific applications. The application of the criteria of Table 4.3 to results from

compatibility tests are usually subjected to the following modifying considerations (Ref. 4.25):

1. If there is any doubt as to whether a material should be in a given category, e.g., Class 1 or 2, the material is placed in the lower category, e.g., No. 2.
2. If the results of practical experience are at variance with the results of laboratory tests, then the greater weight is given to the practical experience in selecting the classification.
3. The main distinction between Class 2 and 3 is the possible effect on the stability of the H_2O_2. If there is any doubt as to whether the stability might be affected, the material is placed in Class 3. Slight deterioration of the materials causing foreign matter to enter the H_2O_2 might cause decreased stability of the H_2O_2.
4. Numerical limits for the various classes are approximate. Class 1 materials would fall within rather narrow limits, while Class 2 materials have much broader limits. In general, the higher the active oxygen loss for a particular material, the less reproducible are the results.

The AOL reported during H_2O_2 materials compatibility tests has numerous meanings in the study of hydrogen peroxide solutions. This report uses the expression "Active Oxygen Loss" (AOL) or percent AOL as defined in the government procurement specifications for hydrogen peroxide; this definition may be simply explained by the following mathematical expression:

$$\text{Percent AOL} = 100\ (H_2O_2 \text{ weight loss during testing}) / \text{initial } H_2O_2 \text{ weight} \times 0.470$$

The weight loss is measured over a specific period of time at a controlled (and known) temperature. The generally accepted criteria for AOL vs compatibility rating are presented in Table 4.3.

Hydrogen peroxide stability, which is usually reported as percent stability, is the test used to determine the relative homogeneous decomposition reaction rate of hydrogen peroxide solutions. As applied in the materials compatibility tests, it is essentially a measure of the degree of contamination of the solution by the test material. This is determined by essentially measuring the AOL of the H_2O_2 during a 212 F exposure for 24 hours. The stability is then expressed as (100-AOL) percent.

Another rating criteria for H_2O_2 materials compatibility is that of impact sensitivity. Liquid and powdered materials, including solids which might yield finely divided particles in service such as a carbon bearing ring, must be evaluated for possible sensitivity to impact when in intimate contact with hydrogen peroxide solutions. This impact sensitivity is determined by subjecting varying proportions of the material and H_2O_2 to the impact of a weight dropped from a specified height. Illustrations of some impact sensitivity results are presented in Table 4.14; however, no weight-distance data were reported for many of the positive results. Because there are appreciable variations in impact results with various machines, operators, and facilities, these data are not quantitative, but simply indicate that under some conditions sensitive situations are possible with the noted materials. In some impact test procedures, a small amount of wetting agent is added to the H_2O_2 to simulate the intimate contact which might be created by mechanical load (such as might be found in pump packings or bearings). This practice, however, is not employed consistently. Any material which is impact sensitive when in contact with H_2O_2 in any proportion is

considered a Class 4 material. The criteria of impact sensitivity of a material in contact with the H_2O_2 is the incidence of any positive detonation on the basis of a minimum of 10 trials. A mixture which gives negative results during the initial 10 valid tests is tentatively considered to be non-impact sensitive unless later tests produce a positive result.

During tests of protective coating materials, special care is necessary (and perhaps additional criteria are necessary) if the test is to determine the compatibility of the coating material and not its efficiency or covering power. Ideally, coating materials should first be tested alone or as coatings on known Class 1 base metals; after these tests are completed, the materials should be tested as coatings on the particular base metal contemplated for end use in the composite assembly. Criteria (Ref. 4.25, 4.29 used in expressing the results of coating tests will depend on the type of service contemplated; the coating must yield the class of compatibility required for the application and must continue to tightly adhere to the metal during the standard compatibility tests. Exact criteria for these coating tests have not been established; but it is believed that the coating should show no blisters or deterioration in contact with either the liquid phase or vapor phase for a period of 1 year at 86 F or 1 week at 150 F (or at the desired service temperature). Splash resistance coatings to be used as protection for surfaces in H_2O_2 installations should not react violently with the H_2O_2 and should not blister during a period of 24 hours at room temperature.

Clothing materials are normally classified (Ref. 4.25) according to recommendations for their use. Criteria for such classification are as follows:

First Choice: The material does not burn on immersion or during drip tests in the "as received" or "soiled"

condition; the material fibers are not appreciably weakened after immersion for 1 month in H_2O_2.

Second Choice: The material does not burn on immersion or during drop tests in the "as received" stage; however, the material may show some tendency toward burning in the "soiled" state and its fibers may be significantly weakened.

Not Suitable: The material either causes excessive decomposition of the H_2O_2, burns, dissolves, and/or disintegrates in either the "as received" or "soiled" state.

Selection of materials for use as joint sealing compounds with H_2O_2 is based primarily on the impact sensitivity of the compound with the appropriate concentration of hydrogen peroxide. The impact tests should show no positive results with a 3 kg-meter impact at room temperature. Decomposition of the H_2O_2 in contact with the compound is of secondary importance; however, the compound must not act as a strong H_2O_2 decomposition catalyst and the compound should not be a Class 4 material. These compounds should also show zero leakage during the tests described in Section 4.2.1.1.7.

4.2.2 Materials Compatibility

A large number of laboratory hydrogen peroxide materials compatibility tests and the experience provided by a number of years of H_2O_2 usage have resulted in a comprehensive knowledge of the effects of certain materials on hydrogen peroxide. These materials compatibility data are summarized in Tables 4.4 through 4.31a. Although the most extensive compilation of materials compatibility data was taken from Ref. 4.25, the most recent data are those of Ref. 4.10 through 4.18.

In general, the compatibility data reported in these tables are tests for usage with 90 w/o H_2O_2; but it has been found that materials suitable for ≥90 w/o H_2O_2 service are usually suitable for use with lower concentrations. In a few instances, materials that are unsuitable for ≥ 90 w/o H_2O_2 service have been found suitable for service at lower concentrations. However, it is uncertain as to whether materials suitable for 90 w/o H_2O_2 service will be suitable for use in higher concentrations. Therefore, some compatibility data have been generated (Ref. 4.9, 4.25, 4.29) on a selected number of materials with 98 w/o H_2O_2 and are presented in Tables 4.4, 4.5, 4.8, 4.19, and 4.31.

The results presented in these tables indicate that, in general, the materials suitable for 90 w/o H_2O_2 service are suitable for 98 w/o H_2O_2 service. Some plastics are attacked more severely by the more concentrated H_2O_2 solutions. With metals, 98 w/o H_2O_2 generally showed less active oxygen loss than did 90 w/o H_2O_2. This apparent greater stability of 98 w/o hydrogen peroxide in the presence of metals was found to result in increased storage stability in the pure aluminum shipping drums which are used for all hydrogen peroxide shipments. The data in Tables 4.4 through 4.18 are presented and classified according to the criteria of Section 4.2.1.2. Materials compatibility presented in Tables 14a, and 4.19 through 4.31a are results of studies conducted under special and specific conditions. These results are presented only in terms of measured values and no attempt has been made to classify the results to meet a specific set of standards.

The results presented herein are based on the conditions noted. Different conditions (i.e., temperatures, passivations, fabrication techniques, etc.) can result in significantly different results. The data should be used as a basis for materials selection; however, all systems after construction or fabrication should be tested for compatibility prior to actual use.

The materials compatibility data presented in Tables 4.4 through 4.31a are summarized with respect to various types of materials in Sections 4.2.2.1 through 4.2.2.10, and various controlling effects in Sections 4.2.2.11 through 4.2.2.14.

4.2.2.1 Aluminum and Aluminum Alloys. The results of a large number of compatibility tests of aluminum alloys with 90 and 98 w/o are summarized in Tables 4.4, 4.20, 4.21, and 4.31. These results indicate that several aluminum alloys meet the stringent requirements of Class 1 materials. Of these, aluminum alloys with low copper content such as 1060, 1160, 1260, 5254, and 5652 have shown excellent service. Minimum corrosion has been experienced with 1060 alloy, and this alloy is the one most frequently used in storage containers. The higher strength 5254 and 5652 aluminum alloys have shown excellent service in shipping drums, tank trucks, and tank car fabrication materials. The 5254 alloy, in various grades of temper, has been used successfully in several missile applications.

Aluminum 1060 has been used extensively for standard piping despite its low tensile strength and ultimate yield. Where pressures may be involved which are too great for standard pipe, the use of schedule 90 pipe of 1060 aluminum is recommended. Alternate choices of piping material are 5254 and 5652 aluminum.

Other aluminum alloys with low copper content, such as 6061 and 6063, have shown Class 2 compatibility. The high strength structural alloys such as 2014, 2017, and 2024 are unsuitable for service with H_2O_2 because of corrosion and a high rate of decomposition of the H_2O_2 in contact with them.

Aluminum casting alloys 43 and 356 have been employed successfully for pump and valve bodies for many years although some corrosion generally does occur. The low copper casting alloy

B-356 has indicated Class 1 compatibility during laboratory tests with H_2O_2, and satisfactory service experience has resulted with various H_2O_2 concentrations.

Some testing has been conducted on hard-coat aluminum. The laboratory results from tests of 10-, 20-, and 30-minute penetration on aluminum alloy 6061 indicated Class 3 compatibility with H_2O_2. Use experience is very limited, but it may be desirable to apply hard-coat aluminum in place of 300 series stainless steel in equipment that is fabricated predominantly of aluminum. Experience is needed to determine the resistance of hard-coat aluminum to corrosion in service with intermittent wetting.

Most cases of aluminum corrosion in H_2O_2 systems result in localized pitting (cell effect) because of the presence of foreign materials, and hydrated aluminum oxide formed during wetting and drying cycles. The presence of chloride ion in hydrogen peroxide results in aluminum pitting; however, if a 7:1 ratio of nitrate ion to chloride ion is present, almost complete elimination of corrosive action is obtained (Ref. 4.25). Therefore, the nitrate ion is added to H_2O_2 to counteract the possibility of chloride damage to aluminum.

4.2.2.2 Stainless-Steel Alloys. The compatibility of stainless-steel alloys with 90 and 98 w/o H_2O_2 is presented in Tables 4.5, 4.19, 4.22, 4.23, 4.24, 4.25, 4.31 and 4.31a. Although there are no Class 1 stainless steels, several Class 2 stainless-steel alloys are known. In general, the wrought or forged AISI 300 series stainless-steel alloys with proper passivation are suitable for Class 2 service with hydrogen peroxide. Cast stainless steel is generally unsatisfactory for H_2O_2 service unless special casting techniques are followed.

It has been reported that some formulas of the type 303 free machining alloy are not suitable for use with H_2O_2. Therefore, prior to use of this alloy, it is suggested that a sample of the lot to be used be evaluated for compatibility with the pertinent H_2O_2 grade.

Cryogenically prestrained 301 stainless steel offers high yield (200,000 psi) strength and a 280,000 tensile strength. The test data in Table 4.5 reveal that this treatment results in a material that has a borderline Class 1/Class 2 compatibility with 90 or 98 w/o H_2O_2.

Experience with use of the wrought 300 series stainless steel for seamless tubing, seamless pipe, fabricated equipment for piping systems, and welded tanks has been satisfactory. The use of 300 series stainless steel is recommended for high-pressure flow systems and applications where the presence of aluminum oxide, which is difficult to avoid in H_2O_2 handled in aluminum, cannot be tolerated.

Usually hydrogen peroxide test tanks have been fabricated of 347 stainless steel which contains niobium (columbium) as a welding stabilizer. More than 15 years of satisfactory service have been achieved at FMC with these tanks in the handling of 90 and 98 w/o H_2O_2. Although 321 stainless steel has been used in some systems, the titanium welding stabilizers have a slight catalytic effect upon the H_2O_2. The extra-low carbon 304 stainless steel has been shown to be an excellent H_2O_2 tank material. This material demonstrates good compatibility with H_2O_2 at room and elevated temperatures.

An extensive amount of testing has been conducted on precipitation-hardening stainless-steel alloys such as AM-350 and 17-7 PH alloys. The AM-350 material has given excellent

service in flight vehicles; however, the material hardness must be less than 42 Rc (Rockwell Hardness Scale C), or there is an increase in H_2O_2 decomposition and development of metal rusting. The '' 7 PH material has proved very successful with 70 w/o H_2O_2 and moderately successful with 90 w/o H_2O_2; however, a special passivation treatment (Ref. 4.31) is required to achieve a Class 2 rating for this material. Surface finishing of the sample with 120-grit abrasive compound was found to be effective in improving the compatibility of this alloy.

The AISI 400 series stainless steels, whether annealed or in the heat-treated form, 40 to 58 Rc, will rust if the surface finish is greater than 10 rms. This type of corrosion phenomenon indicates that it is necessary to examine samples from compatibility tests after the actual test has been completed. It is suggested that this examination should be made at 24-hour and 1-week intervals of exposure to air after the sample is dried. It has been found that immersion of a sample in distilled water for 24 hours following the compatibility test will tend to induce this type of stainless-steel corrosion.

In general, stainless steels suitable for H_2O_2 service, i.e., AISI 300 series and precipitation-hardening alloys, are nonmagnetic or only weakly magnetic. Therefore, any metals that are magnetic should be suspected of incompatibility with H_2O_2. For example, iron, mild steel, and AISI 400 series stainless steels are magnetic and are not suitable for H_2O_2 service. Any unknown material that is magnetic is of questionable compatibility with H_2O_2 until completely tested.

It has been determined experimentally that, in general, the smoother the material finish of H_2O_2 system components, the better the compatibility. Finishes should not exceed 32 rms,

and should be smoother if possible. This is especially important in stainless-steel storage and handling systems; a rough spot in a tank, for example, will cause H_2O_2 decomposition. This condition can be avoided with proper design and system fabrication. In addition, it has been noted (Ref. 4.32) that stainless-steel alloys require cleaning and repassivation after extended service in H_2O_2 to limit the gradual buildup of decomposition activity.

4.2.2.3 Pure Metals and Other Metal Alloys. The compatibility of pure metals and various other metal alloys with 90 w/o hydrogen peroxide is presented in Tables 4.6 and 4.7, respectively. Many metals other than the aluminum and stainless-steel alloys have been evaluated, but few have been found suitable for H_2O_2 service. Silicon, tantalum, tin, and zirconium are exceptions. Of these, tin has been utilized to the greatest extent, i.e., for gaskets and as a solder for stainless steel.

Most other metallic elements exhibit catalytic action in contact with H_2O_2. This is especially true of silver, lead, cobalt, and platinum. Iron oxide causes rapid catalytic decomposition of H_2O_2. Titanium and zinc are severely attacked by the H_2O_2.

A few alloys have shown suitability for Class 3 service and might, with other passivation techniques, be made suitable for Class 2 service; however, additional research would be required in this area. Unfortunately, none of the extreme hardness metals tested have shown suitability for even Class 3 service, except the 10 rms finish 440C stainless steel (56 to 58 Rc) and hard-bearing chrome plating (58 to 70 Rc).

4.2.2.4 Plastics and Rubber Compounds. An excellent summary of the results of compatibility tests with various plastic and rubber compounds, presented in Tables 4.8 through 4.12 and 4.26 through 4.30, was presented in Ref. 4.25. Because plastics and rubber compounds are organic in nature, the compatibility with hydrogen peroxide varies considerably. Even those materials which have shown excellent compatibility with 90 w/o H_2O_2, both in the laboratory and in use, may be suspect when new conditions are met which have not been encountered or simulated previously. Conditions which may lead to reaction between a plastic material and H_2O_2 are extremely varied and difficult to predict or to evaluate in the laboratory. However, the following one generalization must always be considered: the combination of high-strength hydrogen peroxide, organic materials, and heat from either an external source or from H_2O_2 decomposition may lead to an explosive reaction.

The compatibility of plastics often is not determined by the chemical nature or composition of the polymer itself but is determined by the impurities present in it. Contamination of molding materials during handling and storage with dirt, dust, and other organic materials as well as inclusion of metal chips or granules can cause noticeable decomposition reactions. A surface speck of foreign material originating in the mold may initiate a reaction with hydrogen peroxide with sufficient heat release to initiate reactions with the polymer. Laminated plastics or compression molded materials which contain minute pores or air pockets may be incompatible because of the accumulation of organic material in these voids. This is usually the result of some cleaning or rinsing process involving organic materials.

For these reasons, there may be differences in the compatibility of plastics from different manufacturers and even lot-to-lot variations in a given polymer material from the same manufacturer. Lot-to-lot variations are usually much less noticeable than

differences caused by various processing and handling techniques. Compatibility of plastic and other polymeric or composite materials are therefore usually associated with a manufacturer's name.

Clean polyethylene has been safely utilized during laboratory work, and polyethylene has proved to be a satisfactory material for use with 27.5 through 50 w/o H_2O_2. However, polyethylene at its melting temperature has ignited on contact with concentrated hydrogen peroxide and is therefore not recommended for concentrations in excess of 70 w/o H_2O_2. Although no information has been obtained, this possibility should also be considered in the use of other combustible polymers for service at temperatures approaching their melting point or thermal decomposition temperature.

High-temperature service materials such as Kel-F and Teflon have not demonstrated any indication of reaction with hydrogen peroxide over the entire concentration range at ambient temperature conditions. These materials were also found to be compatible with 90 w/o H_2O_2 up to 270 F. There is no known reason to avoid using these materials in any H_2O_2 service where the H_2O_2 will remain below its normal atmospheric boiling point. However, mixtures of these materials with other materials must always be evaluated because reactions are varied and the compatibility of any added ingredient must always be considered. Glass-filled Teflon is acceptable, carbon-filled Teflon may be acceptable, and asbestos-filled-Teflon is not acceptable. Kel-F, Aclar, and "virgin" Teflon are the most compatible plastic materials at high operating temperatures and should be utilized wherever the physical properties are suitable. It is especially recommended that these materials, which have exceptionally low coefficients of friction, be applied in H_2O_2 service as dynamic bearings

and seals without lubricants wherever possible because of the limitations of the available lubricants. Special high-pressure, 2-hour compatibility tests at 132 C (270 F) and 1000 psig with 90 w/o H_2O_2 demonstrated that Teflon and Kel-F are not adversely affected. The AOL for these 2-hour periods is comparable to the percent AOL experienced at 66 C (151 F) in 7 days. Filled plastics such as Kel-F elastomers, 9711 Silicone, and Vitons show swelling at the high test temperatures.

Kel-F elastomeric compounds are generally inferior to Kel-F itself in compatibility with H_2O_2, and most of these materials tested have met the Class 2 criteria.

Aclar, Mylar, and Dacron plastics have demonstrated excellent compatibility with H_2O_2 in the laboratory. Dacron has been used fairly extensively as cloth for protective clothing and reinforcement of other plastics which contact H_2O_2. Mylar film has been used very little because it does not heat seal, and a compatible adhesive has not been found. Aclar is heat sealable and is being used in some applications. Use of these materials, particularly Aclar 33C film, as bag liners for storage containers is currently under study (Ref. 4.9).

There are many plastic materials that break down upon extended exposure (> 7 days) to 90 and 98 w/o H_2O_2 at elevated temperatures (151 to 165 F) but exhibit no effect upon 24-hour exposure. The majority of Viton A, Viton B, Fluorel 2141, and Fluorel 4121 compounds show this effect. However, most service applications are at ambient temperature conditions 10 to 50 C (50 to 120 F) and these same plastics and rubbers demonstrate excellent service at these temperatures.

Viton A and Fluorel materials demonstrate Class 1 ratings in 10 to 49 C (50 to 120 F) service. Viton A 271-7, produced by Parker Hannefin Corporation, has demonstrated excellent service as O-rings in 90 and 98 w/o H_2O_2 solenoid valves and for component seals. Seals Eastern Corporation's Fluorel 2141 and Fluorel 4121 O-rings, seals, and bladders have proved satisfactory in the moderate temperature range. David Clark Company's Omni (Viton A) has proved useful as O-rings and when used to impregnate glass or Teflon cloth, produces a material which is satisfactory for use as an H_2O_2 splash cloth or curtain (Table 4.8).

Polyvinylchloride-based materials vary in their reaction with H_2O_2 because of the plasticizer content and because other additives such as fillers and pigments are used. It is generally true that such additives reduce the compatibility of the compound with H_2O_2. Koroseal 700 (molded) has been extensively used as a gasketing material in low-pressure service. The formula for this material was developed specifically for H_2O_2 service. Koroseal 116 and 117 (molded) are both inferior to Koroseal 700 (molded) for H_2O_2 service. Calendered Koroseal is unsuitable because the H_2O_2 penetrates into the sheet and develops gas pockets which separate the layers of material. Calendered materials which do not exhibit this condition can only be fabricated of materials which are absolutely impermeable to H_2O_2.

Polyvinylchloride plastics are generally permeated by 90 w/o H_2O_2. This has been determined for both molded and plastisol types of polyvinylchloride. The absorption of H_2O_2 is indicated by the fact that the materials which are generally clear or translucent turn an opaque white after a period of contact with the H_2O_2. The polyvinylchloride material containing

absorbed H_2O_2 may be shock sensitive although no adverse experience of this nature has ever been encountered. Polyvinyl-chloride plastics will also leach chloride ion into the H_2O_2 which will cause corrosion of aluminum even when present in minute quantities.

Silicone rubber elastomers also vary considerably in compatibility with hydrogen peroxide because of the use of pigments and fillers in some compounds. However, there are a number of these compounds, mostly unpigmented, which indicated Class 2 compatibility with H_2O_2. Of these, Silastic 9711 has demonstrated the most satisfactory compatibility with 90 w/o H_2O_2. Silastic 9711 is used in various applications as an O-ring, gasket, hose, and bladder material. Although silicone rubbers are not subject to heat sealing, welding techniques have been developed and Silastic 9711 welded with Silastic 2200 indicated satisfactory compatibility with H_2O_2.

The compatibility of several possible bladder materials is reported in Tables 4.26 through 4.28. Compatibility tests of 90 w/o H_2O_2 at 110 F for 10 days with Silastic 9711 (surgical grade), Fluorel 2141, and Aclar 22C (Ref. 4.17) revealed Aclar to be the most compatible material. A similar study involved the use of Vicone 185, alone and as part of a composite structure with aluminum in addition to the preceding materials. Vicone 185 was not quite as satisfactory as Aclar in the pure state. In the composite structures, Vicone 185 with aluminum exhibited the highest decomposition rate while Fluorel with aluminum exhibited the most stable combination. Following compatibility tests conducted at 160 F, both Silastic and Fluorel were badly blistered (Ref. 4.12 and 4.15 through 4.17). These results are in slight conflict with Ref. 4.25 which reported the most compatible bladder material readily available for 90 w/o H_2O_2 is North

American Aviation's Vicone 185 (Table 4.26). Other satisfactory bladders are the B. F. Goodrich Company's 9711 high purity silicone material, and duPont's thin film FEP Teflon (heat sealed). There are other materials that show promise as bladder materials, such as Viton A and B.

Some adhesive agents for bonding silicone rubber Silastic 9711 to aluminum 6061 were evaluated in the form of finished washers. Chemloc 607 appeared to be most suitable and DCA 4094 is only slightly inferior to it. With the adhesive present, compatibility results were reported to be poorer than would be expected for the silicone rubber and aluminum alone; however, a control test was not run for comparison.

Silicone rubbers that indicate Class 2 results for H_2O_2 service are considered to be superior to polyvinylchloride materials because the possibility of chloride leaching is eliminated and, in general, the flexibility of silicone rubbers varies much less over a wide temperature range. Permeability studies of silicone rubber to H_2O_2 indicate slow seepage and layer separation because of oxygen evolution in the pores. Because of the permeability of silicone rubber to hydrogen peroxide, prolonged contact even at atmospheric pressure may make the silicone rubber susceptible to rapid oxidation should a flame be encountered.

Most of the plastic materials discussed can be utilized as gaskets in the proper type of flanges. However, there are two reinforced Teflon gasketing materials which have exhibited satisfactory compatibility, and should find application. Korda-flex, a Teflon-coated glass fabric, has indicated Class 1 results and Duroid 5600 yielded Class 2 results. Actual use experience has not yet been gained with either of these materials.

Several tests have been made of built-up diaphragms, usually a plastic and cloth sandwich type construction using Dacron or glass fabric. The compatibility of these diaphragms with 90 w/o H_2O_2 has been satisfactory when using Omni (Viton A) impregnated glass, Teflon, or Dacron cloth. Polyethylene and Kel-F sheet diaphragms have been utilized successfully in pressure transducers with water on the pressure gage side. Stainless-steel diaphragms have also been utilized satisfactorily. In designing equipment for H_2O_2 service, it is best to avoid diaphragms if possible. If a diaphragm must be used, there should be adequate testing of diaphragm materials with H_2O_2 before the materials for its construction are chosen.

4.2.2.5 Porous Materials. The results of compatibility tests of 90 w/o hydrogen peroxide with porous materials, presented in Table 4.13, are summarized in Ref. 4.25. In this summary, it was indicated that porous materials are generally of interest for use in the filtration of hydrogen peroxide to collect any solid foreign material which accidentally enters into the H_2O_2. Whereas a minor amount of catalytic dirt might be tolerated in a large tank of H_2O_2, collection of this dirt on a filter in a relatively small quantity of H_2O_2 could cause considerable decomposition. Therefore, care must be exercised to keep the use of filters to a minimum and to select filtering media that will not readily react with decomposing H_2O_2. Therefore, for concentrations of H_2O_2 above 50 w/o, low melting materials such as Dacron are not recommended for filter elements (Ref. 4.25).

Some porous porcelain bacteriological filters have exhibited good serive in H_2O_2 power system refueling operations. Tests indicate that porous Teflon and Kel-F may be suitable for use as filter media.

Stainless-steel filters fabricated of wire, either wrapped or woven, yield Class 2 or 3 results. When using these materials for filter elements, welding should be kept to a minimum. Filters made of 316 stainless steel have been used successfully in various H_2O_2 operations, such as fueling operations involving flight vehicles. Porous stainless-steel elements formed by sintering powdered metal have not proved satisfactory for H_2O_2 service.

Filtros C has been used extensively for filtering all concentrations of H_2O_2 and for filters on storage and shipping tank vents, but it is fragile and difficult to back-wash. Replacement of this material for both uses is being investigated. It is not recommended for power-system use.

When using filters for H_2O_2 service, it is important to keep them clean and to examine them frequently. When dirt on a filter is allowed to dry, oxidation may occur which may cause increased catalytic action. Therefore, it is a good policy to flush a filter before use, and to back-wash an H_2O_2 filter immediately after use with distilled or clean water.

4.2.2.6 Lubricants. The compatibility of various lubricants (Ref. 4.25 and 4.33) with 90 w/o H_2O_2 is presented in Tables 4.14 and 4.14a. The test results indicate that only the fluorinated hydrocarbons are sufficiently compatible with 90 w/o H_2O_2 to be considered. Even these materials can probably react with the 90 w/o H_2O_2 if there is sufficient force or heat applied to the mixture. However, the use of fluorinated hydrocarbons has been satisfactory in transfer pump packing glands in use with 300 series stainless-steel shafts.

The present fluorinated hydrocarbons do not possess good lubricating qualities, and their viscosities vary widely with temperature. Some lubricity additives were evaluated several years ago, but none was completely satisfactory because of the difficulty of attaining stable emulsions. In addition, use of fluorinated hydrocarbons as lubricants for aluminum threads or in conjunction with aluminum with a high surface area in applications where heat may be created (which is a natural condition in all applications requiring lubricants) may lead to detonating reactions without any H_2O_2 present. Two instances of such an occurrence, one during a thread cutting on aluminum pipe using Fluorolube as a cutting lubricant and the other when fluorinated hydrocarbon was used as a thread compound on the aluminum head bolts of a decomposition chamber, have been reported. This reaction was reproduced in the laboratory by dropping a fluorinated hydrocarbon on heated aluminum in powder form.

There also is some indication that presence of a fluorinated hydrocarbon in intimate contact with an organic material and 90 w/o H_2O_2 may cause increased sensitivity. Although this phenomenon has not been adequately evaluated, it appears that the use of fluorinated hydrocarbons in conjunction with organic materials in concentrated H_2O_2 service should be avoided unless the specific system to be used has been adequately tested. The best practice if possible, is to eliminate the need for lubricants.

In evaluating lubricants for H_2O_2 service, the results of the impact test are of greatest significance. However, there is no standard impact tester, and the reproducibility of most testers is marginal. The modified Bureau of Mines Impact Tester used for the results reported in Table 4.14 is simple to use and has been proved to be generally reliable; but it

is subject to variations in results with different operators, and the condition of the anvil plunger or weight is another variable. Despite the practice of regular calibration of the tester with a "known" mixture of ethyl alcohol and 90 w/o H_2O_2 in equal-volume proportions, poor reproducibility has been experienced. Because of this situation, it is thought that any positive detonation should be sufficient to place a lubricant in Class 4 for H_2O_2 service. Thus, even though a lubricant or grease may pass all tests with negative results and then give a positive result during a later check test, it will be classed as unsuitable for H_2O_2 service.

Pump packing lubrication is one problem which can be overcome by the use of mechanical seals which require no lubrication. Seals fabricated of 300 series stainless steel with ceramic and glass-filled Teflon mating surfaces and cooled with the liquid H_2O_2 being pumped have been successfully applied to centrifugal transfer pumps for several years.

4.2.2.7 Ceramic and Refractory Materials. A summation of the results of compatibility tests of 90 w/o hydrogen peroxide with ceramic and refractory materials, which are presented in Table 4.16, has been taken from Ref. 4.25. Testing of materials in this category has been limited because applications are often limited by fragileness where shock impact may be experienced. Most of these materials have been considered for applications where hardness is important or as filter elements contained in a stainless-steel housing. Coors Ceramic AB-2 has been utilized successfully in conjunction with glass-filled Teflon for mechanical seals on H_2O_2 transfer pumps, which use H_2O_2 as a coolant for the seal. Coors Ceramic AB-2 and AI-200 have been utilized for plunger pump parts, but no experience has been obtained with H_2O_2.

Selas porous porcelain microbiological filters have shown satisfactory service with 90 w/o and 98 w/o H_2O_2 and may be used to filter high-strength H_2O_2.

Aluminum oxide coating materials were evaluated and found to be unsatisfactory. The poor results may be due to the method of coating, added agents, or the roughness of the coating.

Laboratory glassware is used extensively for carrying out compatibility and stability tests as well as general laboratory handling. Pyrex glass is superior to soft glass and is used extensively as piping in the H_2O_2 manufacturing facilities. Glass linings have been evaluated to a limited extent; the more common glass used for lining contains cobalt, which demonstrates poor compatibility with H_2O_2. Some glass formulas do, however, show excellent compatibility with H_2O_2, but there is no use experience available with these linings.

Synthetic sapphire has not been applied extensively despite its excellent compatibility with H_2O_2. Rotameter floats are probably the only present application.

4.2.2.8 Protective Coating Materials. The compatibility of protective coatings (Ref. 2.25 and 4.29) with 90 w/o H_2O_2 is presented in Table 4.17. Protective coatings are not recommended for H_2O_2 storage tank service, but may be of value for special purpose tanks and to protect incompatible materials from H_2O_2 splash. Of the protective coatings evaluated for service with 90 w/o H_2O_2, only Teflon, Kel-F, and hot air-sprayed polyethylene have indicated suitability for more than splash contact at temperatures to 71 C (160 F) for Teflon and Kel-F, and temperatures of 49 C (120 F) for polyehtylene; however, there has been no experience with such coatings in actual service. The application of such coatings

or paints is recommended for surfaces of materials subject to corrosion. Prevention of rust in H_2O_2 handling and storage areas is a safety measure because the possibility of contaminating the H_2O_2 is reduced.

Kanegin-coated (electroless nickel) mild steel has shown good compatibility with 90 w/o H_2O_2. Tin-plating, followed by a heat treatment at 215 C (420 F) to seal the pores, has proved to be an effective coating for H_2O_2 service.

It is believed that protective liners may be used to advantage in H_2O_2 service for prevention of corrosion of aluminum surfaces and for special cases of high-pressure feed tanks to allow fabrication from metals which possess high strength-to-weight ratios but are not sufficiently compatible with the H_2O_2 to allow a practical holding time.

In general, platings, such as tinplate, strip off when exposed to 90 w/o H_2O_2 unless special precautions are taken to prevent this. Apparently, the H_2O_2 seeps through pinholes in the plate or under the edge and then decomposes when it contacts the undersurface, liberating oxygen gas. The gas then forms a blister which eventually breaks and allows more H_2O_2 to contact the undersurface.

4.2.2.9 Protective Clothing Materials. The results of compatibility tests of protective clothing materials with 90 w/o hydrogen peroxide, summarized in Tables 4.18 and 418a, are discussed in Ref. 4.25. The study of materials for protective clothing was directed primarily at finding materials which would not ignite if 90 w/o H_2O_2 was spilled on them when they were soiled with catalytic dirt. The chief hazard encountered when concentrated hydrogen peroxide is accidentally splashed

on a worker is the possibility that the worker's clothing will ignite. The materials were also evaluated for resistance to deterioration by the action of concentrated hydrogen peroxide.

As a result of this study, it was found that in both the clean and soiled condition, "virgin" Dacron in all forms, Saran-monofilament, and 55 percent Dacron-45 percent wool cloth resisted ignition. Dynel and Saran stable fiber resisted ignition in the clean condition and ignited only with difficulty when soiled. Dacron was unaffected by 90 w/o H_2O_2, and Dacron-wool and Dynel were only slight detiorated. It must be noted that some treated and dyed Dacrons in the "soiled" condition will ignite with 90 w/o H_2O_2, and all samples must be tested before use.

Based on this study, sources were developed for permeable and impermeable clothing; a recommended protective clothing and necessary accessories list for H_2O_2 handling is presented in Section 6.4. This list includes safety clothing and equipment such as goggles, gloves, aprons, and shoe coverings which are made from plastics or rubbers acceptable for the purpose. Dacron and Dynel work clothing have been utilized to a considerable extent with satisfactory service.

It must be pointed out that even protective clothing MUST BE KEPT CLEAN and particularly free of ordinary greases and catalysts such as potassium permanganate. Grease-soiled samples of Dacron, Dynel, and 55 percent Dacron-45 percent wool fabrics have been found to ignite and burn vigorously when wetted with 90 w/o H_2O_2. When laundering or cleaning Dynel fabrics, special techniques must be employed because of Dynel's low softening and embrittling points. Dacron may be laundered without special precautions. Thus, Dacron is preferred for this reason in addition to its better resistance to the H_2O_2.

4.2.2.10 Joint Sealing Compounds. The results of physical and chemical tests of joint sealing compounds with 90 w/o hydrogen peroxide are summarized in Ref. 4.25 and Table 4.15. Most commerical pipe joint sealing compounds were found to be unsuitable for high-strength hydrogen peroxide service. In systems for concentrations of less than 52 w/o H_2O_2, Aviation Grade Permatex No. 3 and equivalent have been used satisfactorily. There are two thread compounds that have shown good service in 52 through 98 w/o H_2O_2 systems. These are T Film, a Teflon water-dispersion paste for small pipe threads and Teflon tape for 1/4- through 4-inch-size pipe thread. Fluorinated hydrocarbon-based materials react violently with hot powdered aluminum. Therefore, these compounds must not be used on hot aluminum threads and must never be used as a thread cutting lubricant.

Applications of even the approved joint sealing compounds to threads for an H_2O_2 flow system must be made so that no compound will enter the system. The compound should be used sparingly, only on the male part and not on the first two threads. Thus, the surplus amount will press out of the threads, not into the system. Pipe threads should be avoided in H_2O_2 systems; flanges and 37-degree flare connections are recommended.

4.2.2.11 Temperature Effects. The effect of high temperatures, in the 212 to 270 F region, on materials compatibility with 98 w/o H_2O_2 is shown in Table 4.19. This effect is of particular interest in selection of materials for use in H_2O_2 regeneratively cooled thrust chambers (Ref. 4.29).

The effect of high-temperature storage conditions (151 F) on materials compatibilities with H_2O_2 is shown in Tables 4.21, 4.22, and 4.24 through 4.30. The appropriate references to this work are given in each of the corresponding tables.

4.2.2.12 Evaluation of Passivation or Surface Preparation Techniques. Laboratory tests (Ref. 4.13) have been conducted to: (1) determine the effectiveness of selected passivation methods upon 321 stainless steel, 6061-T6 aluminum (bare and anodized), and Silastic 9711, (2) determine the influence of cyclic exposure of passivated surfaces to hydrogen peroxide; and (3) investigate the effects of various storage conditions upon passivity of materials used in hydrogen peroxide service. The passivation methods employed in these studies are given in the following references:

CVA-10-62a (Ref. 4.34)
NAA LA 0110-003 (Ref. 4.35)
Walter Kidde 520007 (Ref. 4.36)
FMC Bulletin 104 (Ref. 4.25)
McDonnell A/C 13002 (Ref. 4.37)
LTV 308 - 20-3 (Ref. 4.38)
CVA 10-64a (Ref. 4.39)

The results of these tests are given in Tables 4.21, 4.24, and 4.27.

The preferred passivation method for 321 stainless steel was found to be CVA 10-62a with posttreatment with 35 w/o commercial hydrogen peroxide. For 6061-T6 aluminum (bare and anodized), the best passivation technique was according to North American Aviation Specification LA-0110-003. All passivation methods investigated were found to give about the same results with Silastic 9711. The ease in passivation of all materials was found to improve with each exposure to concentrated hydrogen peroxide. Environmental exposure tests revealed that 321 stainless steel can be stored best in clean air with relative humidities up to 100 percent; anodized 6061-T6 aluminum remains more passive in a dry nitrogen atmosphere. Silastic 9711 appears to retain its passivation best in a relative humidity of 100 percent.

The loss of oxygen in 90 w/o H_2O_2 solutions in contact with 316L and 321 annealed stainless-steel tubing for 3, 5, 7, and 10 days at a constant temperature of 110 F was determined as a function of two different passivation techniques. One-half of the tubing specimens was passivated by CVA Specification 10-62a with a posttreatment of 35 w/o hydrogen peroxide inhibited with a 0.03-percent H_3PO_4 solution; the other half was passivated by Walter Kidde Co. Specification No. 520007. The stability of the H_2O_2 solution was also determined after each test. In general, 321 stainless steel produced less hydrogen peroxide decomposition than the 316L material. The best passivation method, as indicated by the AOL results for both the 316L and the 321 stainless, was found to be CVA Specification 10-62a plus posttreatment (Ref. 4.18). These data are summarized in Tables 4.23 and 4.24.

In another study (Ref. 4.9), the effect of surface treatment on the compatibility of various materials was determined and expressed in heterogeneous reaction rates (k_2), as shown in Tables 4.31 and 4.31a.

4.2.2.13 Effect of Surface Finish. The effect of surface finish on materials compatibility with H_2O_2, summarized in Ref. 4.14, is shown in Tables 4.21 through 4.25. Five different surface finishes applied to 304 stainless steel and aluminum alloy 6061-T6 (both bare and anodized) were evaluated in contact with 90 w/o hydrogen peroxide to determine the influence of surface finish on the stability of the peroxide. The stainless-steel specimens were passivated according to CVA Specification 10-62a with posttreatment in 35 w/o inhibited (0.03 percent H_3PO_4) hydrogen peroxide. The aluminum specimens were passivated according to North American Specification LA 0110-003. Although inconsistent correlations were obtained between the surface finish and AOL with the 304 stainless steel and the bare 6061-T6 aluminum specimens,

the active oxygen loss resulting from the anodized aluminum in contact with the hydrogen peroxide indicated an increase in AOL values with surface roughness. (Surface roughness may simply be considered as a surface area factor; the rougher the surface the higher the actual surface area compared to the apparent surface obtained through measurements of the linear dimensions of the sample.)

This investigation has strongly indicated (Ref. 4.14) that the Industry Standard AOL test is not an adequate tool for highly selective screening of materials for hydrogen peroxide service. The AOL test is considered insufficiently sensitive to the detection (with any degree of accuracy) of the catalytic decomposition influence exhibited by small variations in surface roughness or materials in contact with concentrated hydrogen peroxide.

4.2.2.14 Effects of Dissimilar Metals. The results of an experimental investigation of dissimilar metal couples compatibility in H_2O_2 (Ref. 4.11) are shown in Table 4.30. In this study, the decomposition rate of 90 w/o hydrogen peroxide was measured with the following couples: 1060 Al + 6061-T6 Al; 6061-T6 Al + 321 stainless steel; 6061-T6 Al + 316L stainless steel; 321 stainless steel + 316L stainless steel. The AOL and H_2O_2 stability was determined during an exposure of 10 days at 110 F and 7 days at 151 F. The tests at 110 F revealed no significant influence of the dissimilar metal upon the hydrogen peroxide; however, the 151 F test revealed that the catalytic decomposition of the hydrogen peroxide was greater for the dissimilar metal couples than for either of the single-metal alloys.

4.3 MATERIALS TREATMENT AND PASSIVATION

4.3.1 General

All material surfaces that come in contact with propellant-grade hydrogen peroxide must be specially cleaned and treated prior to their use to minimize hydrogen peroxide decomposition and material corrosion. The general terminology applied to this process, which is designed to provide an inactive surface and eliminate potential contamination sites, is passivation. This section provides a detailed outline of the passivation procedures normally used for materials in hydrogen peroxide service.

The passivation procedure essentially consists of three primary steps prior to the material contact with propellant-grade hydrogen peroxide. The initial step is a chemical and physical cleaning procedure designed to remove oxides, scale, dirt, weld (and heat treat) slag, oil, grease, and other foreign material from the base material. The second step is usually the treatment ("basic passivation") of the material with an alkaline or acid solution to form a film (probably a complex oxide) on the surface to minimize chemical or catalytic activity between the surface and propellant. Finally, the material is subjected to propellant conditioning to check the completeness of the chemical treatment and to eliminate, through further oxidation and chemical complexing, all remaining active sites. Normally, propellant conditioning is conducted in 35 w/o H_2O_2, although many organizations prefer additional propellant conditioning of materials at the conditions (H_2O_2 concentration and temperature) that will be experienced in final application of the material.

The material surfaces should be subjected to passivation after part fabrication and before component or system assembly.

Basically, items such as valves, pumps, actuators, system piping, etc., cannot be cleaned properly in the assembled state, because the solvent, cleaning solution, residual contamination, etc., may be trapped in inaccessible areas. The cleaning should be conducted immediately before component or system assembly, unless provisions are made for packaging the passivated part to protect against re-contamination until ready for assembly. After assembly, components, such as valves, should be packaged until they are utilized in the final system assembly. It is also standard procedure to check all passivated items with propulsion-grade hydrogen peroxide prior to assembly in the system.

All cleaning, passivating, and rinse solutions should be applied by immersing, spraying, wiping, circulating, or other manner so that all surfaces to be cleaned will be completely wetted and flushed with the solutions. Any section of the item to be cleaned that can trap or retain any liquid should be drained or emptied between the applications of each different solution or chemical mixture. The item should be rinsed until it is chemically neutral between each operation. Surfaces should not be allowed to dry off between the cleaning and the "basic passivation" steps. The water grade used, depending upon the passivation stage, should be distilled, deionized, or potable tap water (which has been filtered through a 40-micron nominal filter). Unless otherwise specified, all chemicals should be C.P. (chemically pure) grade or better.

4.3.2 Passivation Facilities

The passivation of materials for hydrogen peroxide service should be conducted in an area designed only for that purpose. The area must be kept clean and free of combustible

material. Equipment to be used in the passivation procedures should be large enough to accommodate all items to be placed in the intended system and provide a method of complete wetting (with all solutions) of the surfaces requiring passivation.

Procedures for handling hydrogen peroxide and the various passivation solutions should be well established and observed. Some of the more important requirements are discussed in the following paragraphs.

4.3.2.1 Personnel Education. All personnel operating in the area should be well informed of all operating procedures, potential hazards, safety precautions, proceaures, etc. (see Section 6.0).

4.3.2.2 Area Cleanliness. The area must be protected from dust and dirt to prevent contamination of the cleaned parts. Although a clean room atmosphere is not essential, it is recommended, particularly, for passivation of flight hardware.

4.3.2.3 Drainage. An adequate water supply and drain must be available for flushing away spilled acid and hydrogen peroxide. All spillage or dump of chemicals must be heavily diluted before passage into a drainage system; protected open trough drainage is recommended.

4.3.2.4 Safety Showers. An adequate number of deluge safety showers must be provided for area personnel. The locations of these showers should be such that they can be reached within a few steps from any location.

4.3.2.5 Eye Wash Fountains. An adequate number of eye wash fountains should be provided in easily accessible locations.

4.3.2.6 Ventilation. Adequate ventilation must be provided to maintain a minimum concentration of solvent and acid fumes. Hoods with suction fans should be installed and used wherever possible.

4.3.2.7 Warning Signs. Safety and warning signs should be placed where they can be seen and should be appropriate to the hazards created by the cleaning, passivating, and hydrogen peroxide solutions.

4.3.2.8 Personnel Protection. Personnel, when handling the various passivating solutions, should be dressed in suitable protective clothing. The minimum garb should consist of a face shield or goggles, rubber (acid-resistant) gloves, rubbers, and an apron. (For additional information, see Section 6.0).

4.3.2.9 Minor Equipment. Various-sized polyethylene beakers should be provided for the treatment of small parts. These beakers are resistant to all reagents normally recommended and used in the passivation procedures. Although glass beakers can be substituted for the polyethylene beakers in the use of all but hydrofluoric-nitric acid solution, their easy breakage can result in a greater hazard. The polyethylene beakers should not be used for conditioning or surveillance tests with H_2O_2.

4.3.3 Cleaning and Passivation Solutions

Generally, the chemical solutions required in the passivation procedure may be prepared as described in the following paragraphs.

4.3.3.1 Detergent Solutions. A 1 w/o solution of a powdered commerical detergent such as Dreft, Naconal, Tide, All, Swerl, etc., in potable water is normally used for cleaning materials and glassware. Liquid detergent (of the same approximate concentration) or a mild solution (5 to 7 ounces/gal) of a commercial alkaline cleaner such as Turco No. 4090 (or its equivalent) may also be used; however, it should be noted that a strongly alkaline cleaning solution must be avoided. The container for the detergent solution should be rust-resistant and covered to minimize dirt pickup. Since most procedures recommend the use of hot detergent solution, provisions should be made for heating the detergent container to 140 to 160 F.

4.3.3.2 Degreasing Solvents. Commercial-grade trichloroethylene, perchloroethylene, or a commercial solvent such as Varsol or Sunoco cleaner are used for degreasing metals which are heavily soiled or very greasy. Alternate degreasing may be performed in a vapor degreaser using trichloroethylene (which meets the Mil-T-7003 specification) or an equivalent grade of one of the above solvents; however, it should be noted that the working temperature of the vapor degreaser must be higher than the boiling point of the selected solvent. The solvent should be stored in a covered galvanized iron, black iron, steel, or other suitable container. Care should be taken to prevent entry of water into the chlorinated solvents contained in the mild steel containers because the resulting conversion to acids will cause corrosion of the metal and subsequent contamination of the material during passivation.

4.3.3.3 Sodium Hydroxide (NaOH) Solution, Approximately 1/15 N. A mild (0.25 w/o) NaOH solution can be used as an alternate method for cleaning heavily soiled aluminum equipment. A supply of this solution, which should be available at all times, can be stored in a stainless-steel drum or polyethylene

container which has been previously washed with a detergent solution and rinsed with clean potable water.

4.3.3.4 Sodium Hydroxide (NaOH) Solution, 10 w/o. A 10 w/o solution of NaOH solution is used for cleaning glassware which is heavily soiled or has contained an unknown solution.

4.3.3.5 Sulfuric Acid (H_2SO_4) Solution, 35 w/o. A solution of H_2SO_4 is used primarily for passivating glassware. The solution can be stored in a polyethylene-lined container or the glass carboys in which it is received. A lid must be provided if stored outdoors. Heated storage may be necessary depending upon the concentration of the acid and the winter temperature of the locality where stored.

4.3.3.6 Nitric Acid (HNO_3), 42 degrees Baume'. A nitric acid of 42 degrees Baume' (~70 w/o HNO_3) is recommended by FMC (Ref. 4.25) for passivating stainless-steel equipment. It should always be readily available and stored in the containers in which it is received.

4.3.3.7 Nitric Acid (HNO_3), 45 w/o. A 45 w/o HNO_3 solution is preferred by most organizations for the "basic passivation" step for aluminum and stainless-steel parts. The acid is normally stored in a polyethylene-lined or AISI 300 series stainless-steel container. A lid must be provided to keep out dirt and confine the acid fumes.

4.3.3.8 Nitric Acid (HNO_3) 35 w/o. A dilute HNO_3 solution of 35 w/o is recommended by FMC (Ref. 4.25) for passivating aluminum equipment. This acid is stored as above (Section 4.3.3.7).

4.3.3.9 Hydrofluoric Acid (HF)-Nitric Acid (HNO_3) Mixture, 3 w/o-10 w/o. A 3 w/o HF-10 w/o HNO_3 solution is used for pickling and cleaning stainless steel when rust or other surface contamination exists which cannot be removed by the nitric acid solution. A polyethylene-lined container, with a lid to keep out dirt and confine the acid fumes, should be used for storage.

4.3.3.10 Hydrofluoric Acid (HF)-Nitric Acid (HNO_3) Mixture, 1 w/o-10 w/o. Unanodized aluminum and aluminum alloy components that are excessively dirty or contain oxide film from welding, heat treating, etc., may be treated with a 1 w/o HF-10 w/o HNO_3 solution. This solution should be stored in the same manner as the solution discussed in Section 4.3.3.9.

4.3.3.11 Clean Potable Water. Drinking water, after filtration through a 40-micron nominal filter, is used for rinsing parts during the initial stages of passivation.

4.3.3.12 Fresh Distilled or Deionized Water. Distilled or deionized water, which is used for rinsing parts after passivation, should have a maximum specific conductivity of 10^{-6} mhos/cm. This water should not be stored in aluminum H_2O_2 storage tank for any length of time results in slime formation which may render the tank unsuitable for H_2O_2. In the storage and handling of potable water, distilled water, or deionized water, the potential contamination by tanks, valves, lines, etc., should be considered (i.e., the use of copper in the system should be avoided). Storage time of deionized or distilled water should be minimized, preferably less than 1 week. Distilled water should be used for the preparation of deionized water.

4.3.3.13 Hydrogen Peroxide Solution, 35 w/o. Although a stabilized 35 w/o hydrogen peroxide solution is available (from various commercial manufacturers) for the initial propellant-conditioning step, many users utilize 35 w/o H_2O_2 solutions obtained by dilution of higher concentrations. However, various hydrogen peroxide manufacturers recommend that if the 35 w/o H_2O_2 is obtained by dilution of propellant-grade H_2O_2 (with no or minimum stabilization), a stabilizer should be added to the dilute H_2O_2 and the pH of the solution adjusted so that residual active metal sites can be deactivated by complexing with the stabilizer (recommendations of the hydrogen peroxide manufacturers are encouraged in this area). Regardless of the user's preference in the use of stabilizers, any dilution of H_2O_2 must be conducted with distilled or deionized water of suitable quality. The 35 w/o solution should be stored in an aluminum 1060, 5052, or 5254 container. The storage container must be vented at all times, and the vent line should be provided with a suitable filter to keep out dust or dirt. A hydrogen peroxide shipping drum is a convenient container; however, once removed, the hydrogen peroxide must not be returned to the original drum or container. Hydrogen peroxide from a satisfactory activity test may be reused, if economics dictate.

4.3.4 Typical Passivation Technique

Specific passivation procedures that are being or have been previously used by various organizations involved in hydrogen peroxide usage are contained in the following documents:

Chance-Vought Aircraft*	Specification CVA 10-62a
Chance-Vought Aircraft*	Specification CVA 10-64a
FMC	Bulletin 104 (Ref. 4.25)
LTV Astronautics	Specification LTV 308-20-3
McDonnell Aircraft	Specification 13002

*NOTE: CVA specifications were obtained from LTV Astronautics (Ref. 4.34 and 4.39).

North American Aviation, Inc.	Specification NAA LA 0110-003
Reaction Motors Division	Specification RMI 7000
Walter Kidde Company	Specification 520007

There are numerous differences in the exact techniques and procedures used by various organizations for the passivation of materials, parts, systems, etc., for hydrogen peroxide service. However, for the most part, these differences are insignificant and the general techniques used are very similar. Although various storability and compatibility studies (see Section 4.1 and 4.2) have indicated the greater effectiveness of some techniques over others, it is believed that no one technique has consistently demonstrated a repeated superiority.

Thus, in developing a procedure to be used by any facility, the general or typical technique described below can be used as a starting point. More specific (in detail) procedures or modifications of these typical procedures may be developed and preferred with the acquisition of "passivation experience"; however, the typical procedures described will passivate most compatible materials. The solutions called out in the procedure are those designated in Section 4.3.3.

4.3.4.1 Degreasing and Cleaning. Excessively greasy metal parts should be initially degreased either by cold flushing with a solvent for 30 minutes (repeat with clean solvent if necessary), or through the use of a solvent vapor degreaser for at least 10 minutes. All metal parts should then be cleaned with a hot (140 to 160 F) commercial detergent solution or a mild alkaline commercial cleaner. (A 1/15 N NaOH solution has been used for nonanodized aluminum.) Cleaning can be accomplished by agitation of the part in the cleaning solution, scrubbing with a stiff nylon brush, and/or pumping the solution through the part (as in the case of tubing and

piping). The metal parts should then be rinsed thoroughly in warm potable water to remove all traces of the cleaning compound.

Nonmetallic and bonded nonmetallic parts such as gaskets, O-rings, chevron rings, hoses, etc., should be degreased by immersion or scrubbing at 140 to 160 F, with a commercial detergent or a mild alkaline cleaner, followed by a thorough rinsing with warm distilled or deionized water. Teflon, polyethylene, Kel-F, or Viton, except when bonded to metal, may be cleaned with a solvent, but immersion time should be limited to a short period (~5 seconds). Items which have solvent or water remaining on their surface and are not to be chemically cleaned further, will be dried immediately with clean dry nitrogen gas or air.

NOTE: Following the degreasing and cleaning step, the cleaned surfaces of the parts should be handled with clean gloves or tongs only. Any possible means of recontamination of the part should be avoided from this point.

4.3.4.2 Descaling. Newly fabricated or reworked metal parts, which have scale from welding, or heat treatment, or impurities from casting or forging, should be descaled ("pickled"). Descaling solutions should not be used after finish-machining of precision surfaces without protection, or on parts that do not have heavy oxide or foreign material buildups in the form of rust or scale. The contact time of the descaling solution with the item to be cleaned should be the minimum time necessary to clean the part or the maximum allowable time per this section, whichever is shorter. Only plastic-coated or nonmetallic gaskets should be used with nitric-hydrofluoric descaling baths to prevent excessive metal loss caused by electrolytic corrosion.

4.3.4.2.1 Stainless Steel. Stainless-steel parts should be etched for a minimum period, and not longer than 60 minutes, at room temperature (60 to 80 F) with a mixture of 3 w/o technical-grade hydrofluoric acid, 10 w/o technical-grade nitric acid, and the remainder water.

> CAUTION: A close visual check should be maintained during descaling operations with the $HF-HNO_3$ mixture to prevent material pitting or excessive etching. After descaling, the part should be thoroughly rinsed with potable water to remove all traces of descaling solutions. Loosely adhering smut or flux may be removed by spraying with water or scrubbing with a stainless steel or hemp brush. If the parts are to be passivated immediately after acid cleaning, they need not be dried. The parts may be dried completely by purging with dry, hydrocarbon-free nitrogen or air, or in an oven at 140 to 150 F. The AISI 400 series, 303S, 303SE, and AM 355 stainless steels will be descaled by mechanical methods such as machining, abrasive tumbling, or grit blasting.

4.3.4.2.2 Aluminum and Aluminum Alloys. Nonanodized aluminum and aluminum alloy parts may be descaled by immersion in a 1 w/o HF-10 w/o HNO_3 solution for 30 seconds to 5 minutes at 115 F maximum.

> CAUTION: A close visual check should be maintained during descaling operations with the $HF-HNO_3$ mixture to prevent material pitting or excessive etching. After descaling, the part should be thoroughly rinsed with potable water to remove all traces of the acid solution. It should be noted that a 35 w/o H_2SO_4 solution at ~115 F can also be used as an alternate "pickling" solution for aluminum and aluminum alloys.

4.3.4.3 "Basic Passivation." Immediately following the cleaning (or descaling) operation, the metal parts should be subjected to the "basic passivation" step. Although this step is always accomplished with HNO_3 solutions, the concentrations used by different organizations vary. The following procedures are those preferred by the majority. It should be noted that plastic and synthetic rubbers should not be subjected to this step in the passivation procedure.

4.3.4.3.1 Stainless Steel. Stainless-steel parts should be immersed in a solution of 45 w/o HNO_3 at 60 to 80 F, for a minimum period of 30 minutes. FMC (Ref. 4.25) recommends the use of 70 w/o HNO_3 for a period of 4 to 5 hours as the stainless-steel passivation step. The parts should then be rinsed and flushed thoroughly with deionized or distilled water to remove all traces of the passivating solution. Unless the part is immediately placed in the propellant-conditioning solution, it should be drained and dried by purging with dry, filtered, hydrocarbon-free nitrogen or air, or dried in a dust-free oven at 140 to 150 F; the part should then be protected from recontamination by sealing in a sealed clean plastic bag.

The nitric acid passivation solution should be used for the AISI 300 and 400 series stainless steel. The protective film resulting from this passivation process will not normally be visible, but surfaces will be uniform in appearance, free from scale, corrosion, pitting, and contaminants. Normal discoloration from welding will be permitted, provided no scale or rust is associated with the discoloration.

Some organizations recommend electropolishing of stainless-steel parts (except for AM 355) by the best available commercial practice as an alternate method for stainless-steel

passivation. Following electropolishing, the material should be cleaned with detergent (Section 4.3.4.1) rinsed thoroughly with deionized or distilled water, and dried in an oven.

4.3.4.3.2 Aluminum and Aluminum Alloys. Aluminum and aluminum alloy materials are usually passivated with a solution of 45 w/o HNO_3 at room temperature for a period of 1 hour; however, FMC (Ref. 4.25) recommends the use of 35 w/o HNO_3 as the passivation acid. The materials should be rinsed and flushed with water to remove all traces of nitric acid, and unless immediately conditioned with the propellant, the materials should be drained and dried by purging with dry, filtered, hydrocarbon-free nitrogen or air, or dried in a clean oven at 140 to 150 F. Machined aluminum barstock parts do not normally require descaling or passivating processes and can be prepared for service by degreasing and thoroughly rinsing. Welded, cast, or corroded parts will require descaling, cleaning, and passivating. Anodized aluminum parts will not be descaled or passivated and should be prepared for service by degreasing and thorough rinsing.

4.3.4.4 Propellant Conditioning. Following cleaning and acid treatment steps, metallic materials should be propellant conditioned to check passivation ("activity testing") and passivate further potentially active sites in the materials. The nonmetallic materials are propellant conditioned following the cleaning step. Normally, most procedures recommend initial propellant conditioning with 30 to 35 w/o H_2O_2 (see Section 4.3.3.13). Following this conditioning, most procedures call for conditioning with hydrogen peroxide of the grade with which the material will eventually be applied. Propellant conditioning, which should be conducted for a minimum period of 3 to 6 hours, is conducted on both the unassembled parts and components and the assembled systems.

4.3.4.4.1 Materials, Parts, and Components. Before the initial activity tests are conducted, components such as valves, pumps, etc., should be assembled (care must be taken to avoid contamination during assembly). The passivated surfaces should be exposed to the selected H_2O_2 solutions by either immersion of the part or by filling the composite assemblies (components) with the H_2O_2. Low openings in the composite assembly may be closed with passivated plugs of the same material or polyethylene-covered rubber stoppers; however, there must be a vent to allow escape of gases from the assemblies. During the tests of the composite assemblies, all sliding surfaces must be completely wetted (through valve actuation, etc.) by the H_2O_2.

Acceptance of passivation is contingent upon no reaction of the material with the hydrogen perioxide (as evidenced by the lack of gas bubbles evolving from the H_2O_2). If, at the end of the exposure period, the gas bubble rate is very minimal, the unexposed surfaces of the materials are cool to the touch, and the gas bubbles are not confined to a particular location, the material or part is considered acceptable. If rapid bubbling, clouding of solution, or a local hot spot is observed during the test, the solution should be discarded and the active part repassivated in accordance with Sections 4.3.4.1 and 4.3.4.3. If it is practical, the active area should be marked for future observation. A component or part should be rejected if it fails three consecutive passivation tests. If a part shows only marginal unacceptable reaction, it should be removed from the H_2O_2 solution, rinsed several times with distilled or deionized water, and reconditioned with fresh H_2O_2 solution; the part should then be repassivated if it continues to demonstrate marginal unacceptability. Parts which cause discoloration of the H_2O_2 solution will be reimmersed in fresh H_2O_2 solutions; if discoloration continues, the part should be rejected and the discolored H_2O_2 solution disposed of immediately.

Any part which shows blackening, rust streaks, or signs of excessive corrosion should be rejected.

After the materials, parts, and/or assemblies have passed all activity checks in the selected H_2O_2 solutions, they should be rinsed thoroughly in distilled or deionized water and dried with clean dry air or nitrogen. Heat may be used to dry if the plastic materials are maintained below 120 F and the metals below 150 F. All parts must be handled with clean tongs and/or clean neoprene-gloved hands to prevent recontamination. After drying, the materials should be assembled in the final system or packaged according to Section 4.3.7.

4.3.4.4.2 System Assembly. After complete assembly of a handling installation, storage facility, or any other hydrogen peroxide system from compatible and passivated materials (that have undergone preliminary activity checks), the system should be conditioned as a whole. The entire system assembly should be filled with 30 to 35 w/o H_2O_2 (see Section 4.3.3.13) and activity checks conducted. Again, it is noted that the system should be vented and all valves and sliding surfaces should be operated to wet all surfaces with H_2O_2. The test should be conducted for a period of 4 hours unless a local heated area or excessive gas evolution indicates the test should be terminated. The observations and conclusions in the assembled system tests are identical to those of the materials, parts, and components conditioning (Section 4.3.4.4.1) with one exception; most organizations advocate an activity check of the system using a laboratory-type "wet test meter" to measure the actual gas rate.

After successful preliminary testing of the system with 30 to 35 w/o H_2O_2 solution, the system should be conditioned with H_2O_2 solutions of the grade it will eventually

utilize. Following this passivation, the system is considered ready for hydrogen perioxide service. All such passivated systems should be protected against further contamination with dust caps. In addition, the system should be continuously surveyed during use for evidence of excessive H_2O_2 decomposition.

4.3.5 Glassware Passivation

Because glassware passivation is slightly different from that associated with the materials commonly used in hydrogen perioxide system fabrication and more often involves a laboratory-type operation, the technique used has been seperated from the typical passivation section. The procedure for the passivation of glassware, which includes thermometers and hydrometers, is contained in the following paragraphs.

Glassware that is heavily soiled should be immersed in a 10 w/o NaOH solution for 1 hour at room temperature. If the glassware is relatively clean, a commercial detergent should be used instead. Following this cleaning, the glassware should be rinsed thoroughly in clean potable water.

Chemical passivation is accomplished by immersion in 35 w/o H_2SO_4 for at least 1 hour at room temperature. After the glass is thoroughly rinsed in distilled or deionized water, it should be dried with clean air or nitrogen, or in an oven at 230 F.

The passivated glassware can be stored in a "ready-for-use" condition by packaging in accordance with Section 4.3.7. Bottles, flasks, or other containers can be stored by covering the opening tightly with aluminum foil.

4.3.6 Passivation Aids

So that materials passivation be accomplished with minimum difficulty, several general rules should always be observed. The primary rule is, of course, strict adherence to cleanliness thoughout the procedure. Other considerations, primarily associated with the materials treatment prior to initiation of passivation procedures, are noted below.

4.3.6.1 Metal Machining. In addition to the selection of compatible metals, the effectiveness of future passivation of these metals for hydrogen peroxide service depends upon eliminating contamination of the materials with incompatible materials during machining. Thus, the use of zinc, copper, copper alloys (i.e., bronze or brass), tin, iron (low carbon, non-stainless types), silver, lead, cadmium, carbide, sand, etc., should be avoided in tooling and machining operations.

4.3.6.2 Surface Finish. All surfaces which contact hydrogen peroxide should be as smooth as possible, with manufacturing marks, identification symbols, and irregularities reduced to a minimum. All surfaces contacting hydrogen peroxide should be free of cracks, pits, inclusions, and foreign material. Whenever practical, sharp corners should be broken and a surface finish of 40 rms (root mean square) or finer achieved.

4.3.6.3 Abrasives. Abrasive cleaning methods should not be used if a suitable chemical method is available. When abrasives are necessary, only glass beads, aluminum oxide abrasives, or stainless-steel wire brushes should be used. AM 355 should be cleaned only by mechanical methods. Acid descaling should be avoided if possible.

4.3.6.4 Anodized Aluminum. Aluminum surfaces which contact hydrogen peroxide should be anodized. Exceptions are surfaces whose shape makes anodizing impracticable (i.e., the interior of long tubes). Sulfuric acid anodizing is preferred and should be used where that process is available. Sealing of sulfuric acid-anodized surfaces should be done in hot water (195 ± 10 F for 30 minutes). Deionized water is preferred for sealing although tap water may be used.

4.3.6.5 Rework. All fabrication and fitting of detail parts and components should be completed prior to passivation treatment. Any rework on passivated areas makes repassivation mandatory.

4.3.6.6 Welded Assemblies. For welded assemblies, each part should be cleaned prior to welding. Completed weld assemblies must be passivated prior to further assembly.

4.3.6.7 Pressure Testing. Pressure testing of a system using various test fluids or replacement of a component in any assembly will automatically make it mandatory to repeat the activity testing procedure for that assembly.

4.3.7 Handling of Passivated Materials

Items that have been cleaned and passivated should be handled, stored, or packaged in a manner to prevent recontamination. Immediately following cleaning and passivation, large valves, piping sections, vessels, flex joints, subassemblies, and other prefabricated items should be dried and have ends and openings capped, plugged, or flanged and sealed with clean compatible sealing material. Small valves and components

should be purged with clean, dry gaseous nitrogen and wrapped and sealed in clean plastic or metal foil bags. These components should be kept sealed until installation.

4.3.7.1 Acceptable Materials. Small items should be sealed in clean preformed envelopes, rolls, or sheets of: (1) polyethylene film, polyethylene-backed paper, polyethylene-backed cloth, or polyethylene-backed aluminum foil, (2) vinyl (Vinylite), (3) Koroseal, (4) Saran, or (5) Mylar. Materials for short-term storage of passivated items can also include aluminum foil (or aluminum-backed cloth or paper) and cellophane.

4.3.7.2 Indefinite Storage. In the packaging of small passivated items for long-term storage, the items should be dried and packaged as soon as practicable after passivation and activity testing. Any openings of the items should be sealed with clean new polyethylene or aluminum caps (used closures will be discarded to prevent reuse). The materials should be enclosed in a clean envelope and sealed to stop free passage of air. This envelope should then be wrapped in heavy paper or placed in a protective container.

4.3.7.3 Identification. The passivated parts should be identified with standard markings such as date, part number, part name, etc., but in addition, a tag should be attached which notes the equivalent of the following:

PASSIVATED PART

This part passivated for use with w/o hydrogen peroxide. Activity Test OK

_____ _____
(Date) (Inspector)

NOTE: If a part is contaminated before packaging or if a package containing a passivated part is torn, the part should be returned to proper area for passivation or activity test as needed.

4.4 FACILITIES AND EQUIPMENT

4.4.1 Storage and Handling Facilities

A facility for the storage and handling of hydrogen peroxide may exist in the form of: (1) a singular storage facility for hydrogen peroxide only, (2) a special handling area for hydrogen perioxide, such as an equipment passivation area, (3) a storage complex for oxidizers including hydrogen peroxide, (4) an area storage complex for fuels and oxidizers, or (5) a handling complex for various propellants. Although it is desirable that any such facility be located in an isolated area, out of necessity, it may be located in the proximity of a test or launch facility.

The specific design criteria for each type of hydrogen peroxide-containing facility must be considered independently although most considerations apply to all facilities. This is necessary because any other propellants stored or handled at the facility also require special considerations. In addition, a facility located in the proximity of a launch or test installation, for example, is exposed to vibrational, thermal, and possibly shrapnel effects, all of which require special considerations.

The design principles presented in this handbook apply to those criteria associated with storage and handling facilities for only hydrogen peroxide. Thus, in the use of these criteria in areas where other propellants are stored and/or handled, the facility designer must consider the integration of various other requirements in his design of the hydrogen peroxide facility.

4.4.1.1 Facility Layout and Orientation. Hydrogen peroxide storage and handling areas should be situated in such a manner as to provide the least hazard to surrounding facilities and

personnel under any given condition. Since the layout of test areas is dependent upon particular requirements and considerations, in which many attendant hazards must be accepted, the layout considered here is related primarily to storage or handling areas which can be situated as desired. All such facilities should have adequate drainage and be situated so that they are exposed to the minimal climate changes for the particular area. Some air flow should normally be available.

4.4.1.1.1 Meteorological Considerations. Hydrogen peroxide does not present a serious toxicology threat to personnel through vapor inhalation because of its low vapor pressure and comparatively high threshold limit value. Thus, very little consideration is usually given to the potential release of hydrogen peroxide vapor into the atmosphere, either through venting or gross spillage. Normally, such situations do not pose a threat to personnel outside of the immediate area, particularly if spillage is immediately diluted with large quantities of water. However, site orientation should be such that a vent or spill of any conceivable magnitude will be reduced to relatively harmless concentrations by the time it reaches downwind population.

4.4.1.1.2 Quantity-Distance Considerations. All hydrogen peroxide solutions above 52 w/o H_2O_2 are classified as Hazard Group II propellants by the criteria established for the Department of Defense (Ref. 4.52). As such, these solutions are grouped with other strong oxidizers as a fire hazard. The DOD criteria (Ref. 4.52) also indicate that solutions above 96 w/o H_2O_2 can detonate and appropriate precautions should be taken (Ref. 4.53). Based on the Hazard Group II designation, the following criteria have been recommended in Ref. 4.52 for the location of hydrogen peroxide sites in relation to surround habitations and public transportation.

Propellant Quantity, pounds		Distance in Feet to	
Over	Not Over	Inhabited Buildings, Railroads, Highways, and Incompatible Group II Storage	Intragroup and Compatible Group II Storage
	100*	60	30
100	500*	100	50
500	1,000	120	60
1,000	10,000	180	90
10,000	50,000	240	120
50,000	100,000	270	135
100,000	300,000	330	165
300,000	500,000	360	180
500,000	1,000,000	410	205

*NOTE: These criteria do not apply to a single standard minimum size shipping container (such as one 55-gallon drum); these should be stored and handled as prescribed by the controlling authority.

4.4.1.2 Storage Containers. The storage capacity of each facility is dependent upon the particular requirements of that facility. A user may require one large bulk storage facility with several ready storage facilities, each to supply a particular test site. Large storage facilities for propellant-grade hydrogen peroxide may contain one or more bulk storage tanks with capacities ranging from 5000 to 25,000 gallons. In addition, the various facilities may require areas for drum storage.

The propellant-grade hydrogen peroxide tanks and containers should be stored in an area by themselves and not integrated with other oxidizer storage (Ref. 4.24). The area layout should allow for easy access and egress for loading and unloading vehicles and adequate separation of the bulk storage tanks from each other, and from the drum storage area. All storage tanks and associated valves and piping should be

located aboveground to facilitate the detection of leaks. All main tank connections should be made through the top portion of the tanks to reduce the possibilities of propellant spill.

4.4.1.3 Buildings. Hydrogen peroxide bulk storage tanks do not require surrounding buildings; however, they should, if possible, be shielded from direct sun radiation. Drums are usually stored on a raised pad under an open-wall roof. The structural framework for either protective covering should consist of either steel or masonry. Wooden supports should not be used. Any siding should be brick, tile, or other masonry units; corrugated sheet asbestos; aluminum; or steel with an approved protective coating. Slate shingles, corrugated sheet asbestos, aluminum, or coated steel can be used for roofing; but the use of petroleum-based roofing materials is prohibited. A vinyl-base, high-temperature aluminum paint can be used as weather protection for the applicable structural materials. Floors should be smooth, finished concrete with a built-in slope for drainage.

4.4.1.4 Diking and Retainment. Each hydrogen peroxide bulk storage tank should be installed within a separate dike, revetment, or walled area to retain spilled propellant. This containment should have a smooth, impervious, and acid-resistant cement lining. The dike or retainment should be capable of retaining 1.5 to 2 times the tank capacity. The diking system should be designed so that it will gravity drain into a collection basin via open-trough, concrete-lined drainage canals.

4.4.1.5 Safety and Fire Protection. Good system design, development and observation of good operating procedures, and

good housekeeping are the best safety precautions in hydrogen peroxide storage and handling areas. These areas must be kept neat, clean, and absolutely free of any type of combustible material. All leaks and spills should be flushed immediately with large amounts of water. Frequent inspection of the areas to ensure compliance with these regulations should be maintained.

4.4.1.5.1 Personnel Education. Standard operating procedures should be established for all operations and potential situations that might occur in hydrogen peroxide storage and handling areas. Thorough education of all operating personnel with respect to these procedures is mandatory. In addition, these areas should be restricted to a minimum number of previously authorized personnel required for operation and safety.

4.4.1.5.2 Personnel Protection. Proper protective clothing, an adequate number of deluge safety showers and eye baths, and easy egress from the area should be provided for the protection of operating personnel. This equipment should be clearly located and marked.

4.4.1.5.3 Facility Protection. An adequate water supply must be available for fire fighting, flushing and decontamination, tank cooling, tank dilution, and personnel safety equipment. In storage areas where the tank temperature may be over 100 F for extended durations, a tank sprinkling system should be provided to cool the tanks. The locations for floor flushing, drainage flooding, and fire protection valves (either for hoses or fixed nozzles) should be clearly marked by signs and red lights. In the absence of a fixed tank dilution installation, an adequate hose length should be available to reach the dome of any storage tank for dilution in an emergency situation.

4.4.1.6 Electrical Concepts. All electrical installations throughout the hydrogen peroxide storage and handling areas should conform to the national, state, and local codes for the type of area and service involved. The areas should be floodlighted in accordance with good industrial and safety practices for the type of operation involved. Electrical power distribution within the areas should be through rigid aluminum or steel conduits, which are preferably located underground. Spark-proof or explosion-proof fixtures are not required, but vapor-proof fixtures are recommended. Adequate electrical receptacles should be strategically located for maintenance purposes.

All vent stacks, storage tanks, and steel structures should have integrally mounted lightning protection systems in accordance with Section 8 of Ref. 4.54. All storage tanks, pumps, loading points, electrical equipment, and propellant transfer lines should be grounded and bonded electrically, in accordance with national, state, and local codes.

4.4.1.7 Access Roads. At least two access roads to transfer and storage sites should be provided with adequate space at each site for turning. The use of asphalt-paved access roads in close proximity to storage and handling facilities should be prohibited.

4.4.1.8 Fencing. Storage and handling areas, drainage ditches, and catch ponds should be fenced and equipped with warning signs, safety placards, and other equipment and techniques typical of good industrial practice.

4.4.2 Equipment Design Criteria

In the design of an item of equipment for hydrogen peroxide service, the same basic principles of design apply as for any other fluid-handling system. For hydrogen peroxide service, simplicity in design is essential. Since the decomposition rate of hydrogen peroxide is a direct function of the surface area contacted, the material surface area relative to the hydrogen peroxide volume should always be minimized. The number of parts in a system or component assembly should be kept to a minimum that is consistent with the mechanical and structural requirements of the equipment, and the equipment must be designed so that all units can be easily disassembled into component parts for ease in passivation and inspection.

Throughout the design and layout of a hydrogen peroxide system, the potential integrity of the system with respect to cleanliness and compatibility with the hydrogen peroxide must be constantly reviewed. The use of each material and its potential contact with the propellant must be consistent with the material compatibility data, as illustrated in Section 4.2.2. Because of the possibility of unforeseen hydrogen peroxide contamination (with resulting decomposition and gas release), all systems must be designed so that they can be completely vented and pressure relieved. Whenever possible, the system should be designed to "fail open."

Typical equipment design and selection considerations are given in the following paragraphs. Although these considerations will aid the hydrogen peroxide user in the design of hydrogen peroxide storage and handling systems, they are not intended as a substitute for good engineering practices nor do they exclude other competent and knowledgeable considerations. It is also noted that the following criteria are primarily for semipermanent or permanent facilities

and do not apply to flight hardware although many of the considerations may be applicable.

4.4.2.1 Storage Vessels. All pressure vessels for hydrogen peroxide storage and feed should be constructed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, latest edition (Ref. 4.55). Also, all pressure vessel design and construction should satisfy applicable local and state codes for such vessels. All other storage vessels for hydrogen peroxide service should be designed and fabricated in accordance with good engineering practice for the pressure and service in which they are to be used. A minimum safety factor of 4 for vessel and vessel support material strength should be maintained in all designs with adequate allowances for local seismic and atmospheric disturbances, temperature conditions, and external and/or internal corrosion.

Hydrogen peroxide storage tanks are normally fabricated of Class 1 materials. The majority of the tanks used for bulk storage are fabricated from aluminum 1060, which is 99.6 w/o aluminum. When greater strength is required, aluminum alloys 5254 and 5652 are normally used for bulk storage. In consideration of requirements for high-pressure lightweight tankage, AM 350 stainless steel has been used successfully. The 17-7 precipitation hardening stainless steel has been used successfully in 76 and 90 w/o H_2O_2 systems; however, this material is generally more difficult to passivate than the AM 350 material, particularly when used in 90 and 98 w/o H_2O_2 systems. Both steels offer yield streagths of 160,000 psi.

The hydrogen peroxide tankage used in rocket test facilities and various other feed and ready storage applications (which required only short periods of hydrogen peroxide storage)

are usually fabricated from 347 stainless steel. Other materials successfully utilized in tankage for these types of applications are the low-carbon 304, 316, and 321 stainless steels.

The cryogenic prestrained 301 stainless steel has demonstrated excellent compatibility with 90 and 98 w/o H_2O_2, and the high strength of this material (260,000 psi yield) favors its use for hydrogen peroxide tankage in flight vehicles and for high-pressure applications.

4.4.2.1.1 General Considerations. The particular requirements of the storage and handling facility will determine the size and number of storage and feed tanks. If hydrogen peroxide shipments are received in tank trucks or tank cars, storage tanks with capacities greater than 8000 gallons should be available, and more than one bulk storage tank is recommended at each particular installation. Bulk shipments should preferably be maintained in containers of similar size instead of being transferred to a number of smaller containers. In addition, the number of hydrogen peroxide transfers from the initial storage to final use should be minimized. Observation of these rules will limit the chance of contamination and the number of hazards involved.

Although atmospheric-pressure, horizontal tanks have usually been preferred to vertical tanks for the bulk storage of hydrogen peroxide, any well-engineered tank is suitable. High-pressure feed or ready storage tanks are usually vertical so they can be fully drained. It should be noted that the optimum stress-to-weight ratio is contained in a spherical tank, and this type of tank provides a minimum surface-to-volume ratio. A 2-to-1 length-to-diameter ratio tank is also advantageous with reference to strength-to-weight and surface-to-volume ratios. Regardless of the shape, the tank should be designed with sufficient volume

capacity to limit the liquid level from rising above the head attachment weld.

Normally, all hydrogen peroxide tankage should be provided with openings for filling, draining, venting, special instrumentation (temperature, pressure, and liquid level indication), and pressure relief (usually a large burst disk). Large storage tanks should be provided with a top opening manway of at least 18 inches diameter for cleaning and inspection. All bulk storage tanks should have at least a 6-inch-diameter opening for use during cleaning and passivation. Many organizations fit the large openings on atmospheric-pressure bulk storage tanks with a floating cover, which is designed to exclude dirt but free to relieve pressure buildup in the tank. A cover of this type is especially effective in providing a large emergency vent to prevent pressure rupture of the tank in case of massive contamination of the contained hydrogen peroxide.

Top inlet and outlet connections are usually recommended for large bulk storage tanks; however, a bottom outlet is generally required for propellant feed and ready-storage tanks to provide complete drainage. Flanged connections should be used for all openings whenever possible. Storage tanks must have a filtered (to protect against inflow of dirt) vent of at least 2 inches, which cannot be inadvertently closed. Pressure vessels should be designed with fail-open vents. In addition, many storage tank designs incorporate a temperature alarm, in which a thermocouple is installed in a protective aluminum tube inside the tank or fastened to the outside wall of the tank below the liquid level (with external glass wool insulation). Mercury thermometers and liquid-type manometer gages should not be used in direct contact with the liquid.

4.4.2.1.2 Pressure or Volume Changes. Throughout the design, fabrication, and application of hydrogen peroxide storage vessels, the pressure and volume changes resulting from hydrogen peroxide decomposition must always be considered. A liberation of oxygen from decomposition results in a subsequent change in gas volume and/or pressure of a sealed container. To illustrate this point, Fig. 4.10 shows the volume of oxygen liberated per unit volume of hydrogen peroxide as a function of hydrogen peroxide concentration and temperature, assuming a decomposition rate of 0.1 percent AOL per year and a constant pressure of 14.7 psia. Figure 4.11 demonstrates the pressure increase resulting from this decomposition in an unvented system with an initial ullage volume of 10 percent. Pressure increases observed under actual storage conditions are illustrated in Fig. 4.3 and 4.6.

For these reasons, venting of systems for normal long-term hydrogen peroxide storage is necessary. This venting may be either continuous or of the intermittent variety. The latter is used when the rate of pressure increase is used as a measure of stability. Commercial shipping containers are normally of the continuous-venting type. A somewhat labyrinthine path is made with holes drilled through the cover material. The geometry is such that the possibility of contaminants entering through the holes is neglible, and the possibility of trapping and subsequent blowing overboard of liquid hydrogen peroxide is insignificant. For most aerospace applications, nonvented systems are employed and allowances for pressure increase during the storage period must be made in the design.

4.4.2.1.3 Self-Heating. Another important consideration in the design of storage tanks is related to self-heating of the hydrogen peroxide. This behavior, thoroughly discussed in Ref. 4.56, can be briefly summarized by the following comments from that discussion:

"All hydrogen peroxide solutions decompose at a finite rate, and this decomposition releases a relatively large amount of heat (1200 Btu/lb of hydrogen peroxide consumed). Consequently, every hydrogen peroxide storage vessel must continually transfer heat to its surroundings, a corollary being that such storage vessels are always warmer than the surroundings. The magnitude of this temperature difference is established by the balance between heat released by decomposition and heat transferred to the atmosphere. The actual mechanism, of course, involves a gradual temperature rise in the contents of the vessel until the rate of heat transfer to the surroundings becomes equal to the rate of heat liberation by decomposition. However, the rate of heat transfer to the atmosphere increases only linearly with temperature, while the rate of decomposition increases exponentially. As a consequence, for any particular storage vessel there exists a critical decomposition rate beyond which the rate of heat liberation will always exceed the rate at which heat can be transferred to the surroundings. Once a storage vessel passes the critical condition, a self-accelerating decomposition will set in which, unless checked, may reach a very high rate. As hydrogen peroxide solutions are nearly impossible to detonate and vapor explosions are possible only over very strong solutions, the primary hazard is due only to pressure rise and possible rupture of the container."

Because of this potential effect in storage, the design of any hydrogen peroxide storage container should incorporate features which control self-heating. Assuming various hydrogen peroxide decomposition rates, a maximum safe-tank size can be calculated for a given hydrogen peroxide concentration stored at a given temperature in a given tank material (Ref. 4.56). Hydrogen peroxide tankage should be located so as to permit free movement of the surrounding air, and since heat dissipation from the tank is necessary to prevent self-heating, the insulation of hydrogen peroxide storage vessels under normal earth ambient storage conditions should be prohibited. Because knowledge of impending

self-heating is desirable, adequate instrumentation should be provided for all bulk storage tanks; this instrumentation is discussed more thoroughly in Section 4.4.2.11.

4.4.2.1.4 Surface Area Effects. One of the important considerations in the design of hydrogen peroxide storage tanks is the effect of surface area. This is discussed in many other sections of the handbook, and the system designer should be well aware of its contribution to the decomposition of hydrogen peroxide. With proper knowledge of this effect, it can be minimized by proper design. Since the current high-purity of propellant-grade hydrogen peroxide minimizes the homogeneous decomposition reaction, the primary cause of decomposition results from the heterogeneous reaction. This is the controlling reaction under the normal ambient storage conditions assuming inadvertent contamination of the hydrogen peroxide does not occur in sufficient quantities to initiate the homogeneous reaction mechanism.

Surface area effects, which are the basis of the heterogeneous reaction, can be minimized by optimizing container design for minimum surface area per unit volume (the ultimate design being a sphere). Further optimization requires a minimum number of storage containers. Previous production plant storage data show that the active oxygen loss in the storage of hydrogen peroxide can be reduced 50 percent by going from an 8000-gallon storage tank to a 25,000-gallon storage tank (Ref. 4.25). Since such volumes are not practical for many applications, compromises have to be made with respect to convenience of handling and minimum quantity required at the storage site for assurance of continuing operation.

4.4.2.2 Piping Systems. Information of a general and specific nature relating to pipe, pipe material, and piping installation is extensively covered in Ref. 4.57 through 4.60.

4.4.2.2.1 System Design. All piping used in the storage, venting, and transfer of hydrogen peroxide should be designed in accordance with Sections 3 and 6 of Ref. 4.57. Allowable tensile stresses for pipe materials are listed in Table 12 of Ref. 4.57. Material specifications for pipe, fittings, valves, flanges, tubing, and boltings are listed in Table 8 of Ref. 4.57.

In design of hydrogen peroxide piping systems, all piping and items of equipment, especially valves and pumps, should be designed for complete drainage on shutdown. This can be accomplished by providing easily accessible draincocks at the low points and by placing equipment containing dams, such as some types of valves, in vertical rather than horizontal positions. A piping system which holds hydrogen peroxide in stagnant pools, even if properly vented, may be subject to excessive corrosion even when fabricated from the recommended materials of construction.

There should be no places in the flow system where hydrogen peroxide can be trapped for any period of time without a vent path or a relief arrangement. Since hydrogen peroxide solutions will constantly decompose at a slow but steady rate, the resulting gas, if completely confined, could eventually build up sufficient pressure to cause rupture. "Dead ends," of which a Bourdon tube gage is an example, should be avoided since foreign material can accumulate in these spots. Ball, plug, and gate valves are examples of valve designs where the hydrogen peroxide can be trapped when the valve is closed; if one of these types of valves

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is to be used, the cavities must be vented to relieve any gas formation. It is recommended also that the number of valves in a system be kept to a minimum to prevent trapping of the hydrogen peroxide between valves.

In the use of pumps in the system where the point of pump discharge is lower than the storage tank liquid level, the pump suction line from the top outlet should have a valved vacuum breaker to prevent siphoning after the pump is stopped. The pump installation should also be designed to prevent hydrogen peroxide from flowing back to the storage tank upon pump shutdown.

4.4.2.2.2 Pipes and Fittings. Pipe and welding fittings are normally manufactured according to standard thickness and weight, as proposed by the American Standards Association. Adherence to these standards in the design of hydrogen peroxide piping systems will eliminate unnecessary cost in the purchase of pipe and will facilitate purchases in small lots. Pipe wall thicknesses should be determined in accordance with Ref. 4.57, Section 2, Chapter 4, Paragraph 214 (-3).

The most compatible piping for hydrogen peroxide service is 1060 aluminum, and this material is generally recommended, particularly if the liquid hydrogen peroxide is to remain in long-time static contact with it. However, where greater strength or hardness is required over that of aluminum 1060, or where other aluminum alloys (3003 and 6063) may be more readily obtainable in piping, other Class 1 or Class 2 aluminums may be used. Piping of 300-series stainless steel may also be used in certain Class 2 (Section 4.2.1.2) applications.

Welded and flanged construction is recommended in hydrogen peroxide piping with a minimum of fittings and joints. Bends are preferred to elbows, and joints should be stud-ends with lap joint flanges or flanges welded to the piping. The use of stainless steel and galvanized or aluminum-clad bolting with galvanized steel back flanges is recommended, because rusting of carbon steel would afford a source of possible contamination of the piping when the flanges are opened. If possible, threaded fittings and connections should be avoided; however, where they must be used, it is recommended that the tapered pipe threads be sealed with Teflon thread tape. Normal pipe thread compounds must never be used.

4.4.2.2.3 Pipe Hangers and Supports. Pipe supports, hangers, anchors, guides, and braces should be designed to prevent excessive stress, deflection, and motion in operation of the system, or too large a variation in loading with changes in temperature, and to guard against shock or resonance with imposed vibration and/or critical conditions. Design and selection of the pipe supports should be in full accordance with Section 6, Chapter I of Ref. 4.57. Additional information is included in Ref. 4.58 through 4.63.

4.4.2.2.4 Flexible Connections. A corrugated, seamless hose of 304 or 316 stainless steel, with open pitch construction and welded flanged ends is recommended as a flexible connection for hydrogen peroxide service. Flexible hose lines with Teflon or Silicone S-5711, fitted with flanged connections, also have been successfully used. Another type of flexible connection that has been applied successfully in hydrogen peroxide service is aluminum piping with swing joints of stainless steel and Teflon.

4.4.2.2.5 Identification. Hydrogen peroxide piping should be identified in accordance with MIL-STD-101A(10). The primary warning color (band) is green. The secondary warning color (arrow) is blue.

4.4.2.3 Stainless Steel Tubing and Fittings. Tubing and fittings of 300 series stainless steel are used almost exclusively for pressurized hydrogen peroxide systems. (It should also be noted that the X-15 experimental aircraft uses an all stainless-steel hydrogen peroxide system.) All systems designed with stainless-steel tubing should conform to MIL-T-8808A (for type 321) MIL-T-8606A (for type 347), or MIL-T-8504 (for type 304). Fittings should conform to AN or MS standards for flared tube fittings.

4.4.2.4 Valves. Selection of valves for hydrogen peroxide service imposes certain design requirements that are more stringent or critical than with most other propellants. The design should be such that trapping of hydrogen peroxide in any part of the valve is impossible during any operation cycle of the valve. As a result, globe or Y-type valves are usually recommended for hydrogen peroxide service. Modification of some types of gate, plug, and ball valves to provide self-venting has also permitted their use in certain applications.

Materials used in approved hydrogen peroxide valves are normally Class 1 or 2 (see Section 4.2.1.2). Stainless steels 321 and 347 have been employed successfully as valve materials; however, some aluminum alloy valves have been subjected to severe galvanic corrosion when used in conjunction with stainless-steel poppets or fittings. A metal-to-Teflon (or Kel-F) seal between the plug and valve seat is normally

preferred over metal-to-metal contact. Materials approved for gaskets are normally used as valve packing.

4.4.2.5 Relief Devices. The preferred relief device for hydrogen peroxide systems is a rupture disk. The relief device should be rated at not more than 100 percent of the vessel or system rating when used as a primary relief device or 105 percent when used as a secondary relief device. Sizing of the device should be large enough to prevent the pressure from rising 10 percent above the maximum allowable working pressure of the system under any projected condition. Burst relief devices on hydrogen peroxide tank cars are designed to relieve at 45 psig pressure.

4.4.2.6 Regulators. Regulators are used primarily to supply regulated nitrogen gas for transfer, purge, and control systems. The selection of a regulator for service in hydrogen peroxide systems depends upon its particular intended service. If the regulator is in an attendant system which cannot be contaminated with hydrogen peroxide, no special requirements are necessary. However, when contamination is a possibility, the regulator materials must conform to compatible material specifications.

4.4.2.7 Pumps. Pumps manufactured from wrought or forged 300-series stainless steel (304, 316, 321 and 347) and pumps made with aluminum alloys B356, 356, or 43 which also have a 300-series stainless-steel shaft, are recommended for pumping hydrogen peroxide. Cast stainless steel should be avoided because it is subject to chromium leaching, which seriously contaminates the propellant and hastens decomposition. Self-priming pumps should be used for transferring hydrogen peroxide from tank cars or storage tanks with top outlets;

the pump normally used in this service is a 2-inch, self-priming centrifugal. Where higher pressure or low capacities are desired, a special rotary pump is recommended.

Pump shafts should be stainless steel, and any packing must be made of compatible materials. Where used, packing should be rings of either Teflon or Vitrium, lubricated with a fluorinated hydrocarbon; excessive gland tightening of the packing should be avoided, because overheating could result in the rupture of the gland. Stainless-steel mechanical seals with glass-filled Teflon and ceramic faces are recommended. All pumps should be equipped with drain valves and, where desired, temperature alarms to warn against overheating.

4.4.2.8 Filters. Liquid filters have been used in hydrogen peroxide storage and transfer systems to maintain propellant cleanliness from insoluble contaminants. Because of the massive surface area available (for promoting heterogeneous decomposition), the filter should be selected from Class 1 or 2 materials, and should be located where it is not constantly immersed in the liquid (such as the inlet or outlet of a transfer line). Also, it should be located for easy and repeated opening and cleaning. A 25-micron, type 316 stainless-steel filter with a 1000-sq in. minimum element area (100 gpm H_2O_2 at 15 psi ΔP) has been used successfully in large handling systems.

4.4.2.9 Gaskets. The selection of gaskets for hydrogen peroxide service is related to the type of service to be provided. Materials normally used as gaskets are Teflon, Kel-F, certain silicone rubbers, some polyvinyl plastics, Koroseal 700, pure tin, and either a combination of spirally wound stainless steel and Teflon (Flexitallic) or a Teflon

envelope over asbestos. The metal-containing gaskets are usually recommended for high-pressure and vacuum systems; however, contact between dissimilar metals should be avoided to prevent galvanic corrosion. The use of certain elastomeric meterials as gaskets must be avoided because the plasticizer or filler material may be incompatible or impact sensitive (see Section 4.2.2).

4.4.2.10 Lubricants. The use of lubricants in propellant-grade hydrogen peroxide service should be minimized or avoided wherever possible. Results of compatibility tests (Section 4.2.2.6) indicate that only the fluorinated hydrocarbons are sufficiently compatible with hydrogen peroxide to be considered, and even these materials may react under certain conditions.

4.4.2.11 Instrumentation. In the design of instrumentation internal probes or sampling tubes for hydrogen peroxide storage and handling systems, the proper selection of compatible materials is the primary consideration. Dissimilar metals in contact with hydrogen peroxide demonstrate a tendency for electrolytic corrosion, with the more concentrated solutions showing less galvanic action. However, even with 90 w/o hydrogen peroxide, the use of dissimilar metals should be avoided. Attempts at insulating one metal from the other by a plastic have not been very effective in past applications where intermittent wetting occurs. If two dissimilar metals must be in contact, the anodic metal should have a larger surface area than the cathodic metal. In addition, the use of soldered joints (particularly silver solder), which is common in various types of probes and sensors should be avoided (because of catalytic decomposition of the hydrogen peroxide).

As noted previously, "dead ends," which are those places that could be filled with hydrogen peroxide without permitting adequate recirculation of the fluid, should be avoided wherever possible. (A common example of this in instrumentation design is the typical Bourdon tube pressure gage.) The disadvantage of having a dead end in a piece of apparatus is that there is a possibility that small impurities will accumulate in the dead end until extensive hydrogen peroxide decomposition results. If dead ends cannot be avoided, they should be placed above the low point in the system so that liquid hydrogen peroxide solutions will not collect in them.

4.4.2.11.1 Pressure Gages. If gages are required or used in hydrogen peroxide service, they should be constructed of compatible materials and meet the other considerations noted above. Where Bourdon tube-type pressure gages are used, their design and assembly should allow for proper passivation and inspection of the gage inlet, and there should be no welds in contact with the hydrogen peroxide. For example, a stainless-steel diaphragm held between two bolted stainless-steel flanges should be used in conjunction with a Bourdon tube pressure gage, with the assembly placed in a vertical position. Gas legs and diaphragm protectors have also been used with success in preventing direct exposure of the gages to liquid hydrogen peroxide.

4.4.2.11.2 Storage Tank Temperature-Measuring Devices. A study of temperature-measuring devices for high-strength hydrogen peroxide storage systems has been reported in Ref. 4.64. A summary of this study, shown in Table 4.32 , illustrates the presently available techniques. Selection of any one of these techniques is dependent upon the requirements of the particular facility. However,

regardless of which technique is used, its limitations, operating characteristics, and relationship to potential "red line" conditions must be fully understood by facility personnel to ensure the usefulness of the system.

In consideration of the various techniques described in Table 4.32 , the surface measuring system with its sensing point at the bottom of the tank (Method 3) would be less affected by high vapor space temperature than any of the other measuring devices. The Manufacturing Chemists' Association (Ref. 4.65) has, in effect, recognized this technique as a suitable method by stating."The temperature of a tank may be monitored by temperature indicators attached to the exterior of the tank below liquid level which records the temperature automatically or an operator may record the temperature on schedule." While not directly measuring liquid temperature, such a system would show tank temperature changes (although it would probably be unsuitable for inventory purposes). Using a dial thermometer, this type of system would be the most economical direct temperature indicating system.

The use of a dial thermometer inserted in a thermal well below the liquid level (Method 4) would more closely indicate the true liquid temperature and be less affected by ambient temperatures than surface mounted systems. High vapor space temperature would not affect such a system unless the liquid level fell below the well.

Another type of surface measuring system (Method 7) encompasses the vapor space using a capillary sensing element which is sensitive to the warmest spot along its length. However, any time the vapor space is warmer than the liquid, this instrument will indicate the vapor space tank surface temperature rather than the liquid. One organization reported that it was necessary to set the

alarm point of such a system at 145 F to eliminate false alarms resulting from sun heating effects transferred into the vapor space. One manufacturer of this type of instrument does not recommend it for this use.

Another organization reported the use of an averaging surface measuring system covering the lower quadrant of the tank (Method 6). This system was affected in a manner similar to that of Method 7 at lower liquid levels, but to a lesser extent, since it averages the temperature rather than selects the warmest spot.

The Weston System (described as Method 10), using a resistance temperature element installed from top to bottom of the tank in a well, will average the liquid temperature from the liquid level to the bottom of the tank. A manual switch is provided to change the temperature-sensitive segment of the element to that position below the liquid level in up to six steps. This system gives good average liquid temperatures at any one vertical plane in the tank. Several elements installed in one tank or in several tanks could be used with one indicator. Such a system is expensive but might prove extremely valuable in the checkout of a new storage area, particularly by a group inexperienced in hydrogen peroxide handling and storage.

The use of automatic temperature alarms connected to the sensing device would be of little value in determining self-heating of the tank in the early stages. For example, in cold weather, self-heating could be progressing very rapidly by the time the alarm point set for 120 F would be reached. Conversely, in hot weather, the effects of the sun coupled with low liquid levels could result in frequent false alarms at this temperature. As a result of these false alarms, the alarm would soon be ignored (or if the alarm were set high enough to eliminate the false

alarms, it might provide a false sense of security). An alarm system could be set up to operate on a given temperature differential between ambient and storage temperatures; however, this involves additional expense.

It is generally recommended that the use of continuous plots of tank (with any of the indicated devices) and ambient temperatures be used as the method of evaluating storage conditions, at least until personnel have sufficient experience to evaluate the facilities properly.

4.4.3 System Fabrication and Assembly

Hydrogen peroxide storage and transfer systems are similar to those employed for handling ordinary fluids, except for materials of construction. Pump motors, solenoid valves, electrical switch-gear, and other electrical equipment in the hydrogen peroxide transfer and storage systems should be selected and installed in accordance with the requirements of the National Electric Code, Article 500, Class 1, Division 2. All seals and joints in the propellant system should be periodically and frequently inspected for leaks and damage.

In the layout, placement, and arrangement of operating systems and units, ample spacing should be provided for proper maintenance clearances and adequate ventilation. In many cases, the removal, replacement, and servicing of valves, pumps, piping sections, instrumentation, and other equipment must be done by personnel in protective clothing. Ample room and access must be provided for use of tools and for easy movement of equipment. Where possible, equipment, valves, and lines should be located so that

maintenance and service work can be accomplished from a position above the piping level to prevent propellant drips and leaks from falling on personnel.

Prior to fabrication and assembly of the system, the materials and equipment to be used should be carefully selected from the recommended lists as given in Section 4.2.2 and 4.4.2. Any questionable or unknown (with respect to compatibility) material or piece of equipment, which is to be used in the system, should be thoroughly checked in accordance with the procedures given in Section 4.2.1. In addition, the identity of each material used in the fabrication and assembly of hydrogen peroxide systems must be ensured; test kits are available for the identification of metals in the field (Ref. 4.66).

These selections should be judiciously reviewed by knowledgeable personnel who have had prior experience in the operation of hydrogen peroxide facilities. The selected materials and equipment should then be cleaned, passivated, and "activity" checked and the system fabricated and assembled according to the considerations given in the following paragraphs.

4.4.3.1 General. In the fabrication and assembly of hydrogen peroxide systems, the user is again reminded of general "rules of thumb" that should be observed in the design, preparation, and assembly of the system. These are noted as follows (Ref 4.25).

1. All hydrogen peroxide tanks should be designed with a minimum surface-to-volume ratio for maximum storage stability (i.e., a sphere is the optimum shape).

2. All storage tanks, vessels and drums should be designed so that sampling of their contents may be accomplished without the use of a sample thief or insertion of any device into the storage container.

3. Various seamless stainless-steel tubing can be used for high-pressure systems, but the 304L, 316L, 321, or 347 alloys should be used if welding is required.

4. Stainless-steel and aluminum components should not be coupled in the same system because electrolytic corrosion may result.

5. Free-machining, stainless-steel alloys should not be used.

6. Cast stainless-steel components should not be used unless the particular casting is thoroughly proved to be suitably compatible with hydrogen peroxide.

7. All markings should be removed from stainless-steel plates before they are formed into a tank.

8. Lap joints should not be used in fabrication of materials. Lap joints provide cracks, crevices, etc. (which cannot be readily cleaned), and may furnish a source of contamination; they also provide dead spaces for retention of hydrogen peroxide.

9. Clean rolling equipment must be used in material fabrication.

10. Head forming dies should be free of rust and smooth.

11. It is often advisable to degrease and passivate the tank head and bottom closures prior to fabrication. This eliminates difficulties in future tank and system passivations.

12. Flux and carbon formed in fabrication should be cleaned from welded areas in stainless steels by a 300 series stainless-steel wire brush. Any inclusions remaining should be ground out. For the grinding of cast surfaces, welds, and weld spatter on surfaces that will contact propellant-grade hydrogen peroxide, a clean white aloxide (aluminum oxide) abrasive is recommended.

13. Carborundum is <u>not</u> recommended for grinding because the iron in the carborundum is catalytic with hydrogen peroxide.

14. Metallizing or sprayed metal coatings are not suitable techniques for preparing surfaces for hydrogen peroxide service. It is possible for the hydrogen peroxide to seep behind the coating or an exposed edge, and cause the coating to blister.

15. Sandblasting is not recommended because it reduces the compatibility of metals with hydrogen peroxide due to the formation of a porous or pitted surface. The rougher surface decreases its compatibility with hydrogen peroxide.

16. Mechanical polishing of aluminum alloys is not advisable because of the possibility of introducing materials which are not compatible and could cause decomposition of the hydrogen peroxide. Electrochemical polishing (anodization) of aluminum is the recommended method.

17. If an aluminum system is employed, it should be anodized per Specification Mil-A-8625 (with no dyes), followed by a 1-hour rinse in boiling distilled water.

18. Aluminum materials and components should be handled carefully to prevent the possibility of embedding metal particles in the surface.

19. Hydrogen peroxide system components should not be brazed or silver soldered.

20. All plastic materials must be checked for metal particles, inclusions, etc., prior to use. The entrapment of organic solvents in porous materials should be avoided during cleaning operations.

21. Chromic acid solutions should not be used for cleaning because chromium is one of the better decomposition catalysts for hydrogen peroxide.

4.4.3.2 Welding. In general, the standards for welding pipe will conform to Chapter 4 of Ref. 4.57. Pipe fittings should be procured from reputable sources who permanently mark their fittings as to: (1) manufacturer, (2) size and schedule of pipe, and (3) material and heat code. The fittings should be of the butt-welded type to facilitate system cleaning and purging operations. A typical set of standards for the acceptance of pipe welds is as follows:

1. Cracks of any nature, whether crater, underbead, transverse, longitudinal, or parent metal will be cause for rejection.

2. Crater cracks which are determined to be only surface defects may be removed by machining or grinding. They need not be rewelded provided buildup is not less than 10 percent nor more than 30 percent of the metal thickness, nor if drop-through is not less than flush nor more than 30 percent of the metal thickness.

3. Normally acceptable defects occurring in conjunction with or adjacent to cracks will be cause for rejection if they occur within a distance of 2 inches each way from the crack.

4. Butt joints will have 100-percent penetration throughout 100 percent of the linear length of the weld.

5. Any lack of fusion will not be accepted.

6. Undercut, excessive drop-through, and excessive roughness will be cause for rejection. Folds in drop-through will be accepted if they are not greater in depth than 10 percent of the thickness of the parent metal.

7. Porosity or inclusions occurring in the weld metal, exclusive of the weld reinforcements, in which any radiographic image is darker than the parent metal or larger in its greatest dimension than 15 percent of the parent metal thickness will be rejected.

8. Porosity and inclusions in the weld reinforcement will be acceptable provided they do not extend through the surface of the reinforcements and provided they do not result in an objectionable stress riser.

9. Porosity and inclusions whose greatest dimensions are equal to or less than 15 percent of the parent metal thickness will be acceptable to the extent of one pore per inch of weld length.

10. Tungsten inclusions located in the penetration zone will be accepted provided the greatest dimension of any particle is not over 25 percent of the parent metal thickness.

In the welding of hydrogen peroxide systems, specific considerations must be observed to ensure the passivation and compatibility of the fabricated and assembled system with hydrogen peroxide. These considerations, noted in Ref. 4.25, are essentially dependent upon the design of tanks and equipment, which should be such that good welding techniques and machining practices can be readily utilized. Since weld splatter on surfaces which will contact the hydrogen peroxide will cause excessive decomposition, the design should allow for removal of weld splatter if it should occur.

Stainless-steel welds exposed to hydrogen peroxide should also be machined smooth if possible; however, aluminum welds should not be wire brushed or machined because this may introduce impurities and thus do more harm than good. Allowance for good machining will result in smooth surfaces which will cause less decomposition of the hydrogen peroxide than rough or poorly machined surfaces.

4.4.3.2.1 Aluminum Alloys. Weldability of aluminum and aluminum alloys varies over a wide range. The same procedures and techniques are employed in welding aluminum and its alloys as are used in welding other weldable alloys. In general, the less constitutents in the alloy, the more weldable the alloy.

The welding rod to be selected should be of the same composition as the parent metal. Unlike other alloys, the aluminum alloys do not lose any appreciable amount of the alloying elements during welding. In most cases, dissimilar aluminum alloys, which can be welded individually, can also be readily welded in combinations; the welding rod to be used should be of the harder material in the combination (i.e., in welding aluminum alloys 1060 and 5652, a 5652 rod would be used). The use of 5-percent silicon rods such as 43S, which are commonly used in aluminum welding, is not recommended for propellant-grade hydrogen peroxide service. During passivation and contact with hydrogen peroxide, such welds turn black and may cause decomposition of the solution. If use of the 43S rod is required, subsequent sulfuric acid anodization is necessary to stop the weld from turning black during passivation. During anodization, there may still be some blackening of 43S welds, but this discoloration does not seem to be a prior indication of an active site. Normally, a 5254 welding rod is recommended for welding of the 6061 alloy to other alloys.

Aluminum welds should not be wire brushed or machined if at all possible, because impurities may be introduced into the metal. In instances where wire brushing is a necessity, a 300 series stainless-steel brush will be used, and care must be taken to confine the brushing to the immediate weld area.

Automatic inert-gas welding processes, such as the Aircomatic or Sigma processes, give excellent results when used with the proper welding rod. The welds, in general, are nonporous, soft, and uniform. Electrode tip cups should be of stainless steel rather than copper (or other such materials) because the latter might melt into and contaminate the weld.

Heliarc inert-gas welding is, in general, a satisfactory process. Although it has many of the advantages of the automatic processes, it does have the disadvantage of "spitting" of tungsten from the tungsten electrode into the weld when the arc is initiated and when the arc is discontinued; these exposed tungsten deposits will cause decomposition of the hydrogen peroxide. The tungsten "spitting" may be decreased and, in many cases, eliminated by using a pure tungsten electrode, striking the arc on a separate piece of material and carrying the weld into the work, and then discontinuing the arc on a separate piece. For inert-gas welding, where the welding rod is not coated, it is recommended that strips be cut off the work scrap and used as the welding rod. Stainless-steel electrode tip cups should be used.

The weld resulting from the metal-arc process has two disadvantages: (1) porosity, and (2) brittleness. These characteristics are highly undesirable in hydrogen peroxide systems, and for this reason, the inert-gas processes are usually preferred and recommended. The metal-arc process

can be used, however, for structural aluminum welding (such as tank supports or ramps,) and is quite suitable for this purpose.

Oxyacetylene gas welding also has two undesirable features (for hydrogen peroxide system welds) when compared to the inert-arc processes. These are: (1) the excessive heat required causes warpage, and (2) the flux tends to be trapped in the weld. However, the welds are satisfactory from a strength point of view and, if the noted disadvantages can be tolerated, this process is acceptable. Oxyacetylene gas welding has been utilized for pipe and small parts made of aluminum when highly skilled and experienced welders are available. Thin sections can be welded more satisfactorily with this type of welding. Napolitan welding flux or its equivalent is recommended for use in gas welding.

4.4.3.2.2 Stainless Steel. Inert-gas and metal arc-welding processes are satisfactory in the welding of stainless steel for hydrogen peroxide systems. The inert-gas process is preferred because the inert-gas blanket results in a weld with less foreign material. In general, thoriated tungsten electrodes are used. Standard welding procedures should be used for both of these processes, and it is necessary that all welds be of high quality, smooth, homogeneous, and free of inclusions and blowholes. Carbide precipitation during welding must be avoided by the use of stabilized alloys such as 347 or 321 or the extra low-carbon alloys, 304 or 316.

After a weld is completed, all weld scale should be removed with a 300 series stainless-steel brush, and the inner weld surface should be ground with a white aloxide wheel to a maximum 32 rms finish.

Any installation of a flange or discharge pipe at the low point of a hydrogen peroxide tank should be welded from the tank interior and ground smooth prior to welding the bottom closure in place.

> NOTE: A carborundum wheel should not be used for grinding, or else iron will be deposited in the metal surface.

A narrow and thin stainless-steel backing ring should be installed at the weld placement in vertical tanks.

Polishing of stainless steels following welding is generally unnecessary but, for certain borderline cases, it may improve the compatibility of the metal with the hydrogen peroxide by smoothing the surface. In general, the smoother surface will provide a lower rate of hydrogen peroxide decomposition. For mechanical polishing, a wet or dry paper (aluminum oxide abrasive) with a kerosene lubricant can be used.

Electropolishing of stainless steel has also been effective in improving the compatibility of steel for hydrogen peroxide service. For routine hydrogen peroxide applications, electropolishing is not required because stainless steel is usually only applied in limited contact time service. For special applications, electropolishing of stainless steel might be justified, and in such cases, standard electropolishing techniques should be used.

4.4.3.3 Brazing and Soldering. Brazing and soldering techniques are not recommended for application in hydrogen peroxide systems. The joints produced by these methods are usually incompatible with the propellant.

4.4.3.4 Mechanical Joints. The advantages of relatively leak-free all-welded transfer systems are obvious. From a practical standpoint, however, some type of joint, whether flanged or otherwise, is required to provide adequate system flexibility. Small valves and components should be selected with AN flared-type connections. Large valves and components should be selected with flanged connections. Instrumentation connections should be of the AN type, and can be provided by welding boss fittings on large pipelines or by installing tee fittings on small lines.

4.4.3.5 Inspection. In the construction, installation, and modification of hydrogen peroxide systems, inspection is important to ensure quality of materials; adherence to design specifications; and proper fabrication techniques. Before installation, each piece of equipment, such as pumps, flex joints, valves, filters, etc., will be inspected and tested for:

1. Cleanliness
2. Proper lubricants (if allowable)
3. Leakage, internal and external
4. Pressure-proof test
5. Sealant and gasket materials
6. Proper operation
7. Freedom from defects
8. Adherence to applicable specifications--type, size, rating, dimensions, etc.

Piping and tubing sections will be inspected and tested for:

1. Conformance to design specifications and building codes
2. Identity and quality of materials of construction
3. Adequacy of supports; freedom from "cold spring"
4. Cleanliness

5. Proper fabrication workmanship

6. Proof-pressure and leak tests

7 Proper installation of flex joints

Electrical installations and equipment will be inspected and tested for:

1. Conformance to design specifications and applicable codes

2. Adequate grounding

3. Insulation resistance

4. Circuitry continuity and proper termination

5. Workmanship and fabrication technique

6. Proper support of conduits and wiring

Instruments (flowmeters, gages, transducers, etc.) will be shop tested, and calibrated and certified with due regard to using conditions, fluid density, operating range, material identity, repeatability, and sealing capability. These instruments must be inspected for cleanliness prior to installation.

Roads, buildings, structures, etc., should be inspected for conformance to design specifications and building codes.

4.4.3.6 Hydrostatic and/or Pneumatic Tests. All components and tanks to be placed in hydrogen peroxide service should undergo applicable hydrostatic and/or pneumatic proof testing before they are cleaned and passivated.

NOTE: Hydrostatic testing should be conducted with water.

After passivation, all proof and leak testing should be conducted only with deionized or distilled water, or with clean, filtered, hydrocarbon-free nitrogen gas or air.

4.5 DECONTAMINATION AND DISPOSAL

The initial step in the decontamination of equipment or facilities and subsequent disposal of hydrogen peroxide is its dilution with large quantities of water. All facilities which store and handle hydrogen peroxide should be equipped with an adequate water supply to ensure a maximum dilution of the hydrogen peroxide prior to its flush into the facility drainage system. Normally, dilution to 3 w/o H_2O_2 or less should be completed before the hydrogen peroxide solution is dumped or pumped into the drainage system (which should terminate in a large body of water). Further dilution is required before dumping into a public water table. Under no circumstances should hydrogen peroxide be dumped into sewers or drains that lead to public water tables, unless this maximum dilution has been performed at the originating site.

4.5.1 Equipment Decontamination

Equipment being removed from service, temporarily flushed of residual propellant, and/or being decontaminated of possible impurities, is normally flushed with distilled or deionized water. Emergency decontaminations may use water supplied by the normal facility water or "firex" (fire-fighting equipment) systems. Once flushed from the equipment, the hydrogen peroxide should be diluted further with facility or "firex" water.

4.5.2 Facility Decontamination

The decontamination of gross spillage or leakage at a facility is best accomplished through the use of a facility floor flush or a flooding water spray system. Large-volume fire hoses may be used as a substitute technique, but the method of attack should preclude washing concentrated hydrogen peroxide solutions into the drainage system ahead of the dilution water. Ordinary garden-type hoses can be used for small spills or for rinsing hydrogen peroxide from the outside of equipment.

> CAUTION: Unless an emergency exists (and massive water spray of equipment is required), care should be taken in flushing the outside of the equipment to prevent water damage to the attendant electrical and control systems.

All facility flushing should be thorough and can be conducted with normal facility water.

4.5.3 Drainage

All hydrogen peroxide facility drainage ditches (or other spillage catch basins) should be open and lined with impervious acid-resistant concrete. These ditches and catch basins should be kept clean of debris and combustible material. The use of the hydrogen peroxide drainage system for other chemical dumps should be prohibited unless an adequate water flow is maintained to ensure maximum dilution and drainage system flushing of all chemicals. The main drainage ditch should be supplied with a large water flush outlet at the highest point of hydrogen peroxide drainage and should be fenced from the facility to the catch basin. The design of the facility should be such that all areas are adequately drained by gravity into the main drainage system.

4.5.4 Catch Basins

Because hydrogen peroxide dumping into public water tables can be potentially hazardous if it has not been sufficiently diluted, most facilities utilize a catch basin which either stores the water for facility recirculation or acts as a settling or dilution pond prior to drainage into a public water table. In either situation, the hydrogen peroxide is diluted or reacted further with other chemicals (contained in the catch basin) to form water solutions that are nontoxic.

4.5.5 Final Dilution Requirements

Although local, state, and federal codes are not sufficiently clear with respect to regulation of hydrogen peroxide dumping into public streams, lakes, etc., it has been generally accepted that dilution to less than 3 w/o H_2O_2 concentration is required to ensure human safety.

In a bioassay study conducted by the Academy of Natural Sciences of Philadelphia for E. I. duPont de Nemours and Co. (Ref. 4.67), a concentration of 165 ppm H_2O_2 in water at ~70 F (with a dissolved oxygen content of 5 to 9 ppm) resulted in a 100-percent mortality rate of fish (4 to 10 centimeters long) of the Lepomis macrochirus Raf. (bluegill) species, which had been exposed to the contaminated water for a period of 24 hours. The resulting 24-hour TL_m (maximum threshold limit) for these species was 65 ppm at a solution pH of 7 and 90 ppm at a solution pH of 8.5.

Internal regulations used by the Rocketdyne Division of North American Aviation, Inc., have established a maximum concentration of 100 ppm H_2O_2 for water dumped into public water tables; these regulations have been accepted by local, state, and federal authorities.

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4.64 Shell Chemical Company, New York, New York, Technical Bulletin, Study of Temperature Measuring Systems for High Strength Hydrogen Peroxide Storage, Report No. IC:63-7, May 1963.

4.65 Manufacturing Chemists Association, Washington, D.C., Supplement B, Chemical Safety Data Sheet SD 53.

4.66 International Nickel Company, Rapid Identification (Spot Testing) of Stone Metals and Alloys.

4 67 Academy of Natural Sciences of Philadelphia, Department of Limnology, Philadelphia, Pennsylvania, Bioassay Tests for the Engineering Department, E. I. duPont de Nemours and Company, December 1962.

TABLE 4.1

STORAGE STABILITY OF HYDROGEN PEROXIDE[1]

Concentration, weight percent H_2O_2		Container Material	Storage Time, months	O_2 loss/year,[2] weight percent
Initial	Final			
Unstabilized 90 w/o H_2O_2 (Stored[3] 1945-1948)				
90.5	88.6	-[4]	36	0.254
90.5	89.1	-	36	0.210
90.5	87.8	-	36	0.381
90.5	89.3	-	36	0.169
90.5	89.3	-	36	0.169
90.5	88.7	-	36	0.254
Unstabilized 90 w o H_2O_2 (Stored[3] 11, 1954 to 12/1955)				
91.25	89.27	1060 Al	13	0.60
90.72	90.56	1060 Al	13	0.063
90.91	90.45	5052 Al	13	0.425
88.13	87.54	5052 Al	13	0.54
90.91	90.81	5254 Al	13	0.039
90.61	90.17	5254 Al	13	0.20
Unstabilized 98 w/o H_2O_2 (Stored[3] 8 1960 to 5/1963)				
98.59	98.47	-[4]	33	0.021
98.14	97.64	-	33	0.088
98.8	98.31	-	33	0.086
98.59	98.28	-	33	0.054
98.8	98.36	-	33	0.077
98.14	97.79	-	33	0.061
98.8	98.34	-	33	0.098
98.14	97.43	-	33	0.125
Stabilized Torpedo-Grade H_2O_2 (Storage[3] Completed 8/1962)				
90	88.51	1060 Al	62	0.12
90	86.75	1060 Al	63	0.26
70	68.32	1060 Al	76	0.088

(1) Data taken from Ref. 4.2

(2) O_2 less year does not correspond with concentration change

(3) Ambient storage in 30-gallon drum ($S/V \approx 0.38$ in.$^{-1}$)

(4) Drum material unknown; assumed to be aluminum alloy

TABLE 4.2

A COMPARISON OF THE RATE OF DECOMPOSITION OF 90 w/o HYDROGEN PEROXIDE MANUFACTURED IN 1947, 1953, AND 1965[1]

Effect of Temperature			
	Rate of Decomposition (AOL)		
Temperature, F	1947[2]	1953[3]	1965[4]
86	1% per year	0.5 to 1.0% per year	0.02 to 0.01% per year
151	1% per week	10% per year	0.1% per year
212	2% per day	4% per week	1% per year

Effect of Contamination		
	Decomposition Rate at 212 F	
Additive to 90 w/o H_2O_2	1947[2]	1965[5]
None	2% per day	1% per day
Al 10 mg/liter	2% per day	-
Cr 0.1 mg/liter	90% per day	2% per day
Cu 0.01 mg/liter	24% per day	10% per day
Cu 0.1 mg/liter	85% per day	66% per day
Fe 1.0 mg/liter	15% per day	25% per day
Zn 10 mg/liter	10% per day	-
Sn 10 mg/liter	2% per day	-

(1) Data reported as generalized criteria from tests using assorted test parameters and techniques; data generally represent tests under minimum S/V conditions.

(2) Data reported in Ref. 4.3

(3) Data reported for 99+ w/o H_2O_2 in borosilicate glass containers (Ref. 4.5)

(4) Data reported in Ref. 4.1

(5) Data reported in Ref. 4.4

TABLE 4.3

CRITERIA FOR CLASSIFICATION OF MATERIALS FOR HYDROGEN PEROXIDE SERVICE ON THE BASIS OF LABORATORY TESTS (REF. 4.25)

Class	Material	Maximum Amount of AOL Week		Minimum Stabilization of H_2O_2 After Test, percent	Other Observations
		86 F	150 F		
1	Metals	0.2	5.0	95	No other effect on H_2O_2 or material and non-impact sensitive to 3 kg-meter impact at 212 F
1	Bladder Material (plastics for diaphragms, drums and liners)	0.2	5.0	95	
	Plastics for Gaskets, Tubing, O-rings, etc.	0.4	6.0	95	
1	Oil and Greases	1.0	10.0	95	
2	Metals (stainless steel)	6.0	80.0	90	No other effect on H_2O_2; slight bronzing of the metal allowable, but no corrosion
2	Plastics for O-rings and Expulsion Devices	6.0	80.0	90	No other effect on H_2O_2; slight bleaching, swelling, embrittlement, or occasional blistering accepted; non-impact sensitive to 3 kg-meter impact at 212 F
2	Elastomers (bladder material)	6.5	95.0	90	No other effect on H_2O_2; slight beaching, or loss of small amount of elasticity of the material accepted; non-impact sensitive to 3 kg-meter impact at 212 F
2	Oils and Greases	6.0	80.0	90	No other effect on H_2O_2; non-impact sensitive to 3 kg-meter impact at 212 F

TABLE 4.3

(Concluded)

Class	Material	Maximum Amount of AOL/Week		Minimum Stabilization of H_2O_2 After Test, percent	Other Observations
		86 F	150 F		
3	Metals	11.0	100/24 hours	15(1)	Bronzing and staining, but not rusting or other corrosion products; slight attack may be allowed
3	Plastics	11.0	100/24 hours	15(1)	May become partially bleached, distorted, disintegrated, after 1 week of test; non-impact sensitive to 3 kg-meter impact at 212 F
3	Elastomers	11.0	100/24 hours	15(1)	Surface may be embrittled, bleached, blistered or lose elasticity; non-impact sensitive to 3 kg-meter impact at 212 F
3	Oils and Greases	11.0	100/24 hours	15(1)	Non-impact sensitive to 3 kg-meter impact at 212 F; excessive H_2O_2 decomposition approaching catalytic rate
4	Metals				Metals pitted and corroded during or after test
	Plastics				Plastics disintegrated, burned, blistered
	Elastomers				Elastomers burned, swollen, dissolved, disintegrated, blistered, gummy; loss of elasticity
	Oils and Greases				Oils and Greases melted, disintegrated, burned; any material which is impact sensitive to 3 kg-meter impact at 212 F

(1) The stability of the H_2O_2 after exposure to the material.

TABLE 4.4

COMPATIBILITY OF HYDROGEN PEROXIDE WITH ALUMINUM ALLOYS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Cast								
13[11]		90	4	—	—	—		
40E	O.P.W. Corp. (Kam Lok)	90	2	—	2	95.4	None[3]	Used successfully as pump impeller and quick disconnect
40E	Frontier Bronze	90	4	—	100	0	None	
43	Alcoa	90	2	—	17.8	—	None	
42B[12]	—	90	4	—	—	—		
53B[11]	—	90	4	—	—	—		
150	Kaiser	90	2	—	28.7	—	None	Limited use
150S[11]	—	90	2	—	—	—	None	
214[11]	—	90	4	—	—	—		
214B	Alcoa	90	2	—	50.0	—	Stained	Not recommended
214F	Alcoa	90	2	—	39.5	—	None	Not recommended
B214F	Alcoa	90	3	—	96.4	—		Not recommended
218	—	90	4	—	100.0	0	Corroded	Not recommended
355[11]	—	90	2	—	—	—		
355	—	98	3	—	100.0	—	None	
355F	Alcoa	90	4	—	100.0	0	None	Not recommended
356F	Alcoa	90	2	—	50.0	—	None	Not recommended
B356	Alcoa	90	1	—	2.8	98.0	None	Pumps, valves, housings
B356	—	98	1	—	3.9	98.0	None	For coating use
A360	Alcoa	90	3	—	96.8	—	None	Not recommended
750	Alcoa	90	4	—	100.0	—	None	Not recommended
A750	Alcoa	90	4	—	100/3 days	—	None	Not recommended
B750	Alcoa	90	4	—	100/3 days	—	None	Not recommended
Wrought								
1060	Alcoa	90	1	0.3	1.5	98.8	None	Storage tanks, piping
1060 (99.6)	Alcoa	98	1	—	1.5	98.0	None	Storage tanks
1100 (2S)	Alcoa	90	1[4]	0.4	3.0	—	None	Storage tanks, piping
1160	Alcoa	90	1	0.4	1.5	98.9	None	Storage tanks. piping
1160	Alcoa	98	1	—	1.5	98.0	None	Storage tanks

TABLE 4.4
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Wrought								
1260	Alcoa	90	1	—	1.5	98.8	None	Storage tanks, piping
1260	Alcoa	98	1	—	2.1[5]	98.0	None	Storage tanks
1260	Alcoa	98	1	—	1.2[6]	98.0	None	Storage tanks
1260, Pretreated[7, 13]	Alcoa	90	1	—	0.7 to 0.8[7]	—	None	Storage vessels, piping
1260, Pretreated[8, 13]	Alcoa	90	1	—	2.5[7]	—	None	Storage vessels, piping
1360[10]			1	—				
2014 (14S)	—	90	4	—	100.0	—	None	Not recommended
2017 (17S)	Alcoa	90	4	—	100.0	—	None	Not recommended
2017, H_2SO_4 Anodized	Alcoa	90	3	—	23.3	—	None	Limited service life (1 to 2 years)
2024 (24S)	Colonial Alloys	90	3	—	16.4	—	None	Not recommended
2024 (24S)		98	4	—	100.0	—	None	Not recommended
2024, Hardas Coated	Anachrome	90	3	—	20.6	50.3	Coating dissolved in spots	Not recommended
2024, Chromic Acid, Anodized	Colonial Alloys	90	4	—	100.0	—	None	H_2SO_4 anodized is better
2024, H_2SO_4 Anodized	Alcoa	90	3	—	15.0	—	None	Limited service life
3003 (3S)	Alcoa	90	2	—	13.8	94.4	None	Various uses, piping
4043 (43S)	Alcoa	90	2	—	52.0	98.8	None	Not recommended
5052 (52S)	Alcoa	90	2	—	8.3	—	None	Tubing, pipe
5052 (52S)		98	1		2.6	—	None	Storage vessels
5052, Chromic Acid Anodized	Colonial Alloys	90	2	—	11.0	—	None	H_2SO_4 anodized is better
5052, H_2SO_4 Anodized	Alcoa	90	2	—	5.0	—	None	Limited service life (1 to 2 years)
5054 (54S)	Alcoa	90	2	—	—	—	None	Tubing, pipe
5056 (56S)	Alcoa	90	2	1.5	13.1	—	None	Tubing, pipe
5058	—	90	2	—	—	—	None	—
5086[9]	—	90	2	—	—	—	None	—
5254 (XF54S)	Alcoa	90	1[3]	—	0.3	98.0	None	Storage tanks, piping
5254	Alcoa	98	1	—	1.7	99.0	None	Storage tanks, missile tankage
5254-O	Alcoa	90	1	—	0.3	96.0	None	Storage tanks, piping components

TABLE 4.4
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Wrought								
5254-H34	Alcoa	90	1	—	0.3	98.0	None	Storage tanks, piping
5652 (XF525)[9]		90	1	—	—	—	None	—
5652-0[13]	Alcoa	90	1[3]	—	5.0	98.4	None	Storage tanks, components
5652-0	Alcoa	98	1[3]	—	5.2	98.4	None	Storage vessels
6061 (61S)	Alcoa	90	2	—	4.8	98.7	None[3]	Subject to corrosion
6061	—	98	2	—	5.2	—	Pitted	
6061, Chromic Acid Anodized	Colonial Alloys	90	3	—	15.5	—	None	H_2SO_4 anodized is better
6061, H_2SO_4 Anodized	Alcoa	90	2	1.3	4.1	—	None	Limited service life (1 to 2 years)
4% HNO_3 Passivated	Alcoa (Keystone Chromium)	90	2	—	2.4	89.4	None	Limited service life (1 to 2 years)
Detergent Washed	(Keystone Chromium)	90	2	—	4.5	90.8	None	Limited service life (1 to 2 years)
WFNA Passivated	(Keystone Chromium)	90	2	—	3.6	87.2	None	Limited service life (1 to 2 years)
Hard Coat	Woodward-Governor	90	3	—	42.0	—	None	Coatings
0.001 Inch Thick	Stolle Corp.	90	3	—	23.2	64.2	None	Must be checked before using
0.002 Inch Thick	Stolle Corp.	90	3	—	24.7	69.8	None	Must be checked before using
0.003 Inch Thick	Stolle Corp.	90	3	—	26.5	52.3	None	Must be checked before using
6063 (63S)[9]	Reynolds	90	2					
Sheet	Reynolds	90	1	—	1.7	98.0	Dulls finish	Pipe and other items
Tubing	Reynolds	90	1	—	3.3	97.4	Slight dulling	Pipe and tubing
Hard Coat (Sanford)	Reynolds	90	2	—	3.1	98.0	Bleaching, spotting	Needs farther checking
6063[14]	—	90	-	1.6	2.9	97.8	—	—

TABLE 4.4
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week At 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Wrought								
6363	Alcoa	90	2	—	7.6	96.2	None	Various uses
7072 (728)	Alcoa	90	1[4]	—	2.1	—	None	Cladding material
7072 (728)	Alcoa	98	1	—	4.1	—	None	Storage vessels
7075 (758)	Kaiser	90	4	—	100.0	0	None	Not recommended

(1) Data taken from Ref. 4.25 unless otherwise noted

(2) Stability essentially defined as (100 - AOL) percent from test of 24 hours at 212 F

(3) Field experience shows this alloy to be subject to corrosion if not protected by anodizing

(4) Previously considered Class 2 (Ref. 4.40)

(5) Test temperature 74 C (165 F)/week, pretreated 90 w/o H_2O_2 24 hours at 66 C (151 F)

(6) Test temperature 74 C (165 F)/week, pretreated with Alcoa treating solution No. 1 48 hours at room temperature

(7) Sample preheated with 90 w/o H_2O_2 for 24 hours at 66 C (151 F)

(8) Test temperature 74 C (165 F)

(9) Reference 4.40

(10) Reference 4.41

(11) Reference 4.42

(12) Reference 4.43

(13) Reference 4.29

(14) Reference 4.44

TABLE 4.5

COMPATIBILITY OF HYDROGEN PEROXIDE WITH STAINLESS STEEL ALLOYS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent Stability[2] After Test	Effect on Material	Comments
202	Bruce Mueller	90	2	—	19.0	—	Bronzed	Machined parts
301	Portland Copper and Tank Works	90	3	—	20.0	57	Slight stain	Machined parts, end-use components
301	Arde Portland Corp.	98	2	—	8.7	95	Bronzed	High-pressure tankage
301 (cryogenically prestrained)	Arde Portland Corp.	90	2	—	4.2	94	Slight stain	High-pressure tankage, 260,000 psi yield
302	Whitehead	90	2	—	21.0	89.0	Bronzed	Machined parts, tubing
302	Various suppliers	98	2	Excellent service record		—	—	Machined parts, tubing
302 (porous)		90	3	—	—	—	Bronzed	
303 C	Allegheny-Ludlum	90	3	—	98.9	—	Heavily bronzed	Not recommended
304	Allegheny-Ludlum	90	2	—	40.0	77[3]	Bronzed	Machine parts, tubing
304	Allegheny-Ludlum	98	2	—	12.0	—	Slight bronzing at higher temperatures	Tubing, machined parts
304 (extra low carbon)	Allegheny-Ludlum	90	2	—	58.6	—	Bronzed	Test tanks, machined tanks
309	Carnegie	90	2	—	54.2	—	Bronzed	Machined parts
310	Carnegie	90	2	—	37.1	—	Bronzed	High-acid tank, H_2O_2 component baths
316	Republic	90	2	—	19.8	—	Bronzed	Machined parts
316	Republic	98	2	—	53.0	—	Bronzed	Machined components
316 (porous[7])		90	4	—				
316 (extra low carbon)	Armco Steel	90	2	—	10.5	—	—	Test vessels, machined parts
317	Allegheny-Ludlum	90	2	—	36.0	—	Bronzed	Machined parts; 302, 304, 316 preferred
318	Allegheny-Ludlum	90	2	—	69.4	—	Bronzed	Machined parts; 302, 304, 316 preferred

TABLE 4.5
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent Stability[2] After Test	Effect on Material	Comments
319	Union Steel Co.	90	3	19.1	62.3	—	Bronzed	Machined parts; 302, 304, 316 preferred
319L	Union Steel Co.	90	3	15.1	75.3	—	Bronzed	Machined parts; 302, 304, 316 preferred
321	Carnegie	90	2	—	37.0	—	Bronzed	Test tanks, 347 preferred
322	Carnegie	90	2	—	30.0	—	Bronzed	Heat treatable; do not exceed 40 Rc[11]
329	Hydromatic, Inc.	90	2	—	5.5	—	Dull finish	10 to 15 rms[12] finish, machined parts
329	Crane Valve Co.	90	4	—	100	—	Bronzed	Not recommended, rough finish
329	Crane Valve Co.	98	3	—	30.0	—	Bronzed	Machined components
329	Universal Cyclops	90	2-3	—	100	—	Bronzed	Rough finish
347	Carnegie	90	2	—	57	—	Bronzed	Gas generators; thrust motors
347	Various suppliers	98	2	Excellent service record		—	—	Pressure vessels
347	Whitehead Metals	98	2	—	13.2[4]	—	Slightly bronzed	Machined components
347	Whitehead Metals	98	2	—	—	30.0	Slight bronzing at high temperature for all samples	—
AM 350 (heat treat I)	Allegheny-Ludlum	90	3	—	7.8	90	Heavy bronzing	High-pressure vessels, 160,000 psi yield
AM 350 (heat treat II)	Allegheny-Ludlum	90	4	—	14.6	31	Very heavy bronzing	High-pressure vessels, Rc[11] above 42
AM 355	Allegheny-Ludlum	90	3	—	74.9	—	Bronzed	High-pressure vessels
410	Diesel Engineering	90	4	—	91.4	16.6	Rusted	To be avoided
416	Bendix	90	4	—	100	0	Rusted	To be avoided
420	Lee Co.	90	4	—	100/18 hours	0	Rusted	To be avoided
430	Allegheny-Ludlum	90	4	—	74.4	37.5	Rusted	To be avoided
431		90	4	—	100	0	Rusted	To be avoided
440	Bendix	90	4	—	100/24 hours	0	Rusted	To be avoided
440 C (56 to 58 Rc[11] 10 to 20 rms[12])	Bendix	90	3[5]	2.5	100/13 hours	—	Slight bronzed	Refer to note [6]

TABLE 4.5
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent ASL per Month at 86 F	Percent ASL per Week at 151 F	Percent Stability[2] after Test	Effect on Material	Comments
440 C, Malcomized HC[11], 50	Bendix	90	3[5]	5.2	100/48 hours	—	Slight stain	Refer to note [6]
443		90	4	—	100	0	Rusted	To be avoided
446	Allegheny-Ludlum	90	4	—	100	0	Rusted	To be avoided
613 (extra low carbon[8])		90	2	—	—	—	—	
10-9 DL[10]		90	3	—	—	—	—	
17-4 PH[9]	Armco Steel	90	3	—	90 to 100	—	Heavily browned	Not recommended
17-7 PH (unhardened)	Armco Steel	90	2	—	43.0	—	Browned	This alloy more suitable for use with lower than 90 percent H_2O_2 concentrations; high-pressure-system components.
17-7 PH (37-45 HC 120-grit surface finish; special passivation)	Armco Steel	90	2	—	20		Bronze in vapor phase and interface; very slight browning in liquid	
17-7 PH (37-45 HC[11], 120-grit surface finish, buffed, special passivation)	Armco Steel	90	2	—	22.0	—		
17-7 PH (37-45 HC[11] welded, 120-grit surface finish; special passivation)	Armco Steel	90	2	—	28.0	—		
17-7 PH (45 HC[11], 120-grit surface finish, electro-polished)	Armco Steel	90	3	—	57.5	—		
17-7 PH (45 HC[11], pickled to prevent intergranular attack; special passivation)	Armco Steel	90	3	—	100.0	—		
304[8]		90	2	--	—	—		

TABLE 4.5
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent Stability(2) After Test	Effect on Material	Comments
Carpenter 20	Carpenter Steel	90	3	—	100	—	Bronzed	Satisfactory room temperature use
Durimet 20	Durirem Co.	90	3	—	100	—	Bronzed	Satisfactory room temperature use
Durimet 7[8]		90	4	—	—	—		
Haseo-O-Seven	Haseo Valve and Machinery	90	2	—	27	—	None	Machine parts
Malin-Wilstabrite	Malin & Co.	90	2	—	25	—	None	Springs
15-7 Mo (Cond. A.Y.S.)	Air Research Mfg. Co.	90	3	—	34	28.0	Heavily bronzed	Machine parts, gas generator
15-7 Mo	Air Research Mfg. Co.	98	3	—	21.0	—	Heavily bronzed, liquid phase	Machine parts
Proley Type 302 Porous Wire[10]		90	3	—	21	—	Heavily bronzed	Machine parts
Rigimesh J Stainless Steel Porous Wire[10]		90	4	—	—	—		
300 Series Stainless Steel Powder Compact[10]		90	4					
Type 302 Powder Compact[10]		90	4	—	—	—		
Type 302B Powder Compact[10]		90	4	—	—	—		
Type 316 Powder Compact[10]		90	4	—	—	—		

TABLE 4.5
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Percent Stability[2] After Test	Effect on Material	Comments
Type 316+Cb Powder Compact[10]		90	4	—	—	—		
Inconel X-718	Aerojet-General	90	2		5[13]	94	None, 24 hours at 66 C (151 F)	High temperature service
Inconel X-718	Aerojet-General	90	4	—	100	C	Severe browning after 7 days	Not recommended
Inconel X-718	Aerojet-General	98	2	—	5[13]	94	None, 24 hours at 66 C (151 F)	High-temperature short period use
Inconel X-718	Aerojet-General	98	4	—	100	0	Heavy browning after 7 days at 66 C (151 F)	Not recommended for extended high-temperature service

(1) Data taken from Ref. 4.25 unless otherwise noted
(2) See footnote 2, Table 4.4
(3) Percent H_2O_2 remaining after 7 days at room temperature
(4) Stabilized 98 percent H_2O_2 used
(5) Surface finish must be better than 10 rms; avoid elevated-temperature H_2O_2 service
(6) Additional test data available from FMC Corp. for samples with special surface treatments in contact with stabilized H_2O_2.
(7) Reference 4.40
(8) Reference 4.42
(9) See also Ref. 4.45
(10) Reference 4.30
(11) Rockwell hardness C scale
(12) Surface finish-root mean square
(13) Based on 1-day test

TABLE 4.6

COMPATIBILITY OF HYDROGEN PEROXIDE WITH PURE METALS[1]

Material	Source	H_2O_2, weight percent	Class	Percent ADL Per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Aluminum (See Table 4.2)		90	---	---	---	---
Beryllium			4	190	0	Pitted
Cadmium						Pitted
Chromium						Very slightly soluble
Cobalt						Slightly soluble
Columbium	Heraus-Germany					Pitted
Copper						Very slightly soluble
Gold						None
Iron						Rusted
Lead						Dissolved
Magnesium						Slightly soluble
Manganese						None
Mercury						Violent decomposition of H_2O_2
Molybdenum						Dissolved
Nickel						None
Platinum						None
Silicon	General Electric Co.		2	3.5	97	Slight surface dulling

TABLE 4.6

(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability(2) After Test	Effect on Material
Silver		90	4	100	0	Attacked
Sodium			4	100	—	Violent decomposition and flame
Tantalum	Fansteel Met. Corp.		1(3)	—	—	None
Tin-C.P.	Baker Chem. Co.		2	28.7	—	None
Titanium	Rem-Cru Titanium, Inc.		4	100	0	Pitted
Tungsten			4	100	0	Dissolves
Zinc			4	100	0	Pitted
Zirconium			1	3.2	—	None

(1) Data taken from Ref. 4.25

(2) See footnote 2, Table 4.4

(3) Based on Service Experience

TABLE 4.7

COMPATIBILITY OF HYDROGEN PEROXIDE WITH METAL ALLOYS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Aluminum Oxide, Flame-Plated on Armco 17-7 PH	Linde Co.	90	4	100	—	One rust spot
Beryllium-Bronze	—				0	None
Beryllium-Nickel						None
Chemalloy H-3	Electro-Alloys Div.					Pitted
Chlorimet	Durimet			↓	↓	None
Chromaloy Coated Steel[4]	—			—	—	—
Croloy 16-13-3[5]	—			100	0	—
Dow Metal J1A	Dow Chem. Co.					None
Dow Metal MA	Dow Chem. Co.					None
Duriron (cast)	Duriron					None
Elgiloy	Elgin Watch Co.					Bronzed
Fanweld "O"	Fansteel Met. Corp.		↓	↓	↓	None
H-975	Carbide & Carbon		3	90	—	None
Hastelloy "A"[5]	Haynes-Stellite Corp.		4	100	0	Some rust in solution
Hastelloy "B"	Haynes-Stellite Corp.	↓	4	100/ 16 hours	0	None

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability (2) After Test	Effect on Material
Hastelloy "C"	Haynes-Stellite Corp.	90	4	100/ 16 hours	0	None
Hastelloy "D"			4	100/ 3 hours		Bronzed
Haynes-Stellite			3	65 to 72.7		Bronzed
Haynes 3			4	100/48 hours		None
Haynes 6			4	100/3 hours		None
Haynes 12			4	100/3 hours		None
Haynes 25			4	100/1 hour		Bronzed
Haynes C1712-3			H_2O_2 evaporated completely			—
Haynes C3087-3			4	100	0	Bronzed
Haynes F 17-3			4	97.8		Bronzed
Haynes L #3			4	100		Bronzed
Haynes L6			4	100		Bronzed
Haynes L1316			4	100		Bronzed
Haynes M1516-3			4	26.1		Bronzed
Illium "G"	Illium Corp.		4	100		Rusted
Inconel	International Nickel Corp.		4	100		None
Inconel "X" (Full Hard)	International Nickel Corp.		3	100/72 hours	—	Discolored

TABLE 4.7

(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Inconel X-718	Aerojet-General	90	2	5[7]	94	None, 24 hours at 66 C (151 F)
Inconel X-718	Aerojet-General	90	4	100	0	Severe bronzing after 7 days
Inconel X-718	Aerojet-General	98	2	5[7]	94	None, 24 hours at 66 C (151 F)
Inconel X-718	Aerojet-General	98	4	100	0	Heavy bronzing after 7 days at 66 C (151 F)
Kanegin Plated Mild steel	Keystone Chromium	90	2	0.6[3]	96.3	Slightly stained
Sample 3	Keystone Chromium	↓	3	82.1	88.8	Slightly stained
Sample 7	Keystone Chromium		3	51.2	95.1	Slightly stained
Sample 13	Keystone Chromium		3	60.3	92.5	Slightly stained
Kennametal K-3H	Kennametal, Inc.		4	100	0	None
Kennametal K-138	Kennametal, Inc.		4	100	0	None
Kennametal K-501	Kennametal, Inc.		4	100	0	None
Kennametal K-M	Kennametal, Inc.		4	100	0	None
Monel	International Nickel Corp.		4	100	0	None
Multimet N-155	Haynes-Stellite Corp.		4	100/ 16 hours	0	None
Ni-Resist Alloy	International Nickel Corp.		4	100	0	Rusted
Refractalloy 26	Westinghouse		3	45.3	—	None

TABLE 4.7

(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Refractalloy 27[6]	—	90	3	—	—	—
Refractalloy 70	Westinghouse		3	100	0	None
Rene' (Nickel Base)	Muskegon		4	100	0	Bronzed
Steel, Mild	Commercial		4	100	0	Rusted
Steel, Mild	Keystone-Chromium		2	0.9[3]	94.2	Slightly stained
Super Alloy, S-588	Allegheny-Ludlum		4	100	0	None
Super Alloy, S-590	Allegheny-Ludlum		4	100	0	None
Tantung	Allegheny-Ludlum		4	100	0	None
Timkin 16-25-6	Timkin Roller Brg. Co.		3	50	—	Slight bronzing
Tin-Plated Mild Steel	Keystone Chromium		2	0.6[3]	96.7	Slight staining
Titanium B120 VCA	Crucible Steel Co.		4	100	0	Severely discolored
Titanium, C120 AV	Crucible Steel Co.		4	100	0	Severely discolored
UCC-Star "J" Metal	Union Carbide			100/ 4 hours	—	Bronzed
Utiloy 3	Utility Steel Foundry		4	100/ 2 hours	—	None
Utiloy 20	Utility Steel Foundry		4	100/ 2 hours	—	None
Utiloy H	Utility Steel Foundry		4	100/ 3 hours	—	None
Utiloy NH	Utility Steel Foundry		4	100/ 2 hours	—	None

TABLE 4.7
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Worthite	Worthington Corp.	90	3	100	—	Bronzed
19-9DL	Universal Cyclops Steel	90	3	100	—	Bronzed

(1) Data taken from Ref. 4.25 unless otherwise noted

(2) See Footnote 2, Table 4.4

(3) Test conducted at room temperature rather than 66 C (151 F)

(4) Reference 4.40

(5) Reference 4.46

(6) Reference 4.42

(7) Based on 1-day test

TABLE 4.8

COMPATIBILITY OF HYDROGEN PEROXIDE WITH POLYETHYLENE AND HALOGENATED POLYETHYLENES

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Month at 86 F	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Aclar	Allied Chemical	90	1	0.6	1.2[3]	99.0	None	Bladder materials, drum liners
Aclar	Allied Chemical	98	1	0.5	0.5	99.0	None	Tank liners, bladders
70 Dere No. 5809	Belmont Packing	90	4		10.2	78.5	Severly blistered	Not recommended for 12 F use
Enjay Rubber	Humble Oil	90	4	—	—	—	Severly blistered	—
Ethylene Propylene (MD 460)	Enjay Chemical	90	4		42.0	0.0	Blistered	Not recommended
Fairprene PS 57-167[10] (Viton A, 116 glass)	DuPont	90	3		—	—	Surface attack and moderate blistering (1 week at 150 F)	—
Fairprene PS 57-168[10] (Viton A, Dacron)	DuPont	90	2		—	—	Moderate surface attack (1 week at 151 F)	—
Fluorel[10]	Minn. Min. & Mfg.	90	3	—	12.1	8.9	Blistered	—
Fluorel 2140	Seals Eastern, Inc.	90	4	—	2.6	96.0	Blistered	Not recommended for extended 150 F service
Fluorel 2140	Minn. Min. & Mfg.	90	1	1.0	—	98.0	None	O-rings, seals bladders
Fluorel 2140	Minn. Min. & Mfg.	90	2	—	1.1	98.5	Very slight blistering	—
Fluorel 2140	Seals Eastern, Inc.	90	1	—	0.3	99.0	None after 24 hours at 66 C (151 F)	Not recommended at this temperature
Fluorel 2140[4]	Minn. Min. & Mfg.	98	1	0.9	—	98.0	None	O-rings, seals, bladders
Fluorel 2140	Minn. Min. & Mfg.	98	4	—	—	98.0	Blisters after 24 hours at 66 C (151 F)	—
Fluorel 2141, Elastomer	Minn. Min. & Mfg.	90	3	—	2.9	98.1	Swollen and blistered	—
Fluorel 4121	Seals Eastern, Inc.	90	1	—	2.4	98.6	None	O-rings, seals, bladders
Fluorel 4121	Seals Eastern, Inc.	98	1	—	0.9[5]	99.3	None	O-rings, seals, bladders
Fluoreflex T-FP1001	Resisteflex Corp.	90	1	—	3.6	—	None	High-pressure hose
Fluoreflex T-FP1001 (Black)	Resisteflex Corp.	90	2	—	6.7	—	None	High-pressure hose
Fluran B-4100	U. S. Stoneware	90	3	—	48.3	0.0	Partially bleached	Not recommended
Fluorocomt	Polymer Corp.	90	3	—	38.8	33.1	None	Further testing required
Furane CF/9070 (black)	Whitro Assoc.	90	4	—	—	—	Disintegrated, H_2O_2 decomposed	Not recommended
Halgene	Pale Lab Supplies	90	2	—	4.6	—	None	Seals
Hypalon S-2	DuPont	90	4	—	100.0	—	Sample destroyed (1 hour)	Unsatisfactory
Hypalon Gasket	Metal Hose & Tubing	90	4	—	74.2	2.0	Severe attack	Unsatisfactory
Hypalon V-54-B (grey)	Raybestos-Manhattan	90	4	—	100.0	—	Blistered and swollen	Unsatisfactory

TABLE 4.8
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Month at 86 F	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Hypalon V-96-A (Grey)	Haybestos-Manhattan	90	4	—	100.0	—	Badly swollen	Unsatisfactory
Hypalon V-163-A (Black)	Haybestos-Manhattan	90	4	—	100.0	—	Blistered and swollen after 1 hour	Unsatisfactory
Hylam O-Ring (GCR 98-5)	Goshen Rubber Co.	90	3	—	19.0	74.4	Moderate surface attack	Not recommended
Irrathane 101 (irradiated polyethylene)	General Electric	90	2	—	3.0	96.6	None at room temperature; can ignite with 90 to 98 percent H_2O_2 if heated above 160 F	Seals, gaskets
Kel-F	—	98	2	—	8.3	—	None	—
Kel-F	Minn. Min. & Mfg.	98	1	—	1.3	—	None	Seals
Kel-F (unplasticized)	Minn. Min. & Mfg.	90	1	—	3.5	—	None	Gaskets, seals, seats
Kel-F 800[3]	Minn. Min. & Mfg.	90	1	—	2.9[3]	98.0	None	High-temperature service, seals, seats
Kel-F 800 (Lot 9649)	Minn. Min. & Mfg.	90	1	—	4.5	97.8	Very slight hardening	Gaskets, seals, seats
Kel-F 800	Minn. Min. & Mfg.	98	1	—	0.33	98.0	None	Seals
Kel-F 820 (64028)	Minn. Min. & Mfg.	90	2	—	9.0	96.4	Slight hardening	Gaskets, seals, seats
Kel-F 3700 (gum)	Minn. Min. & Mfg.	90	3	—	8.8	93.2	Blistering and bleaching	Gaskets, seals, seats
Kel-F 3700, Kel-F 800 (50-50)	Minn. Min. & Mfg.	90	2	—	3.6	97.0	Slight blistering	Gaskets, seals, seats
Kel-F 5500 (unpigmented)	Minn. Min. & Mfg.	90	2	—	26.3	95.7	Slightly tacky	Gaskets, seals, seats
Kel-F 5500 (gum)	Minn. Min. & Mfg.	90	3	—	18.5	—	Blistered and distorted	Not recommended
Kel-F 5500-121	Minn. Min. & Mfg.	90	2	—	19.0	—	Bleached	Use other compounds
Kel-F 5500-61	Minn. Min. & Mfg.	90	2	—	9.0	—	Bleached	—
Kel-F 5500, Kel-F 800 (50-50)	Minn. Min. & Mfg.	90	1	—	3.6	97.7	None	Gaskets, seals, seats
Kel-F 5500, Kel-F 800 (75-50)	Minn. Min. & Mfg.	90	2	—	3.2	94.2	Slight blistering	Gaskets, seals, seats
Kel-F O-Ring (Cpd. 7761-75)	Linear, Inc.	90	2	—	6.4	95.5	Moderate surface attack; slightly sticky	O-rings, gaskets
Kel-F D316	Firestone Tire & Rubber	90	2	—	5.1	97.0	Very slight bleaching	Expulsion bladders
Kel-F D316	Firestone Tire & Rubber	98	2	—	5.1	97.0	Very slight bleaching	Bladder material
Kel-F D385	Firestone Tire & Rubber	90	2	—	9.8	94.0	Very slight bleaching	Expulsion bladders
Kel-F D385	Firestone Tire & Rubber	98	2	—	6.3	94.0	Very slight bleaching	Bladder material

TABLE 4.8
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent ACL Per Month at 86 F	Percent ACL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Kel-F Elastomer 5160	Minn. Min. & Mfg.	90	2	—				
Kynar	Whitro Assoc.	90	2	—	1.1	96.0	Slight bleaching	Seals
Kynar-Vinylidene	Tube Turns, Inc.	90	2	—	3.8	91.0	Bleached and slightly distorted	—
Lexan Plastic Tube	General Electric	90	2	—	2.1	97.1	Bleached	Plastic lines, components
Halon-P-73-223	Voplex	90	2	—	1.9	99.0	Bleached	Plastic components
Omni (Viton ..)	David Clark Co.	90	1	0.7	—	96.0	None	O-rings, seals, coatings
Omni (Viton A)	David Clark Co.	90	2	—	1.3	96.0	Very slight bleaching	Seals, coatings
Penton 9215[5]	Hercules Powder	90	2	—	1.4	96.0	Bleached from olive to grey	Possibly plastic pipe and tube use
Penton 9215	Hercules Powder	90	2	—	7.9	95.0	Bleached from olive to grey	
Polyester M-85	Whitro Assoc.	90	4	—	4.0	97.0	Discolored, swollen	Not recommended
Polyethylene (porous)	Kem-E-Quip Corp.	90	4	—	6.6	90.0	Samples became brittle	Not recommended
Polyethylene (black)	Cabot Corp.	90	3	—	7.4	84.0	Bleached slightly	Not recommended except for room temperature use
Polyethylene	DuPont	90	2	—	1.0	95.0	None at room temperature; can detonate with H_2O_2 if heated	Laboratory use
Polyethylene[6]	DuPont	90	2	—	2.3	95.0	None; see (6)	Laboratory use
Polyethylene (pure unpigmented)	Several	90	2	—	2.3	—	Will detonate at melting point of plastic	For service below 100 F
Polyethylene H.D.[3]	General Electric	90	1	—	2.9[3]	98.0	None	Not recommended for high temperature
Polyethylene PE-2[10]	Plax Corp.	90	4	—	—	—	—	—
Polyethylene Foam[11]	Dow Chem.	90		—	—	—	No apparent swelling, but some bleaching (1 day at room temperature)	—
Polypenco K-51[3]	Pall Filt.	90	2	—	4.1[3]	98.0	None	Filter media
Polypenco K-51	Polymer Corp.	90	2	—	6.3	98.0	Slight bleaching	Plastic parts
Polypropylene (black)	Tube Turns, Inc.	90	2	—	1.7	98.3	Slight bleaching	Tube and pipe fittings
Rulon (Teflon base)	Dixon Corp.	90	2	—	5.9	—	Bleached slightly	—
Rulon (Teflon base)	DuPont	90	2	—	5.9	95.5	None	—
Rulon "A"	Dixon Corp.	90	4	—	54.7	0.0	Bleached	—
Rulon "B"	Dixon Corp.	90	3	—	15.6	78.2	None	—

TABLE 4.8
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Month at 86 F	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Viceme 185	North American Aviation	90	2	3.8	2.8	99.0	Slight bleaching	Bladder material
Viceme 185	North American Aviation	90	2	0.1	3.4	99.0	Very slight bleaching	Excellent elastomer
Viceme 185[9]	North American Aviation	90	2	0.6	1.1	99.0	Very slight bleaching	Bladder material
Viceme 185	North American Aviation	98	2	1.3	2.4	99.0	Very slight bleaching	Bladders
Viceme 51-2	North American Aviation	90	2	—	12.0	98.0	Slight bleaching	Expulsion bladders
Viceme 51-2	North American Aviation	98	3	13.0	12.0	98.0	Slight bleaching	Bladders
Vinylidon-Fluoride	Pall Filtration Corp.	90	1	0.5	—	98.6	None	Filter media
Vinylidon-Fluoride	Pall Filtration Corp.	90	2	—	1.3	97.0	Two out of three samples showed low stability	Filter media
Vinylite VU 1930	Prince Rubber Co.	98	2	—	2.7	—	Became opaque	Not recommended
Viton A (247; black)	DuPont	90	2	—	16.8	—	Slightly tacky	—
Viton A (271-7; 77545)	Parker Hannefin	90	2	0.75	—	98.6	Excellent service record	O-rings, diaphragms, bladders
Viton A (271-7)	Parker Hannefin	90	4	—	—	—	Blisters after 3 days at 151 F	—
Viton A (271-7; 77-545)	Parker Hannefin	98	2	0.58	—	99.5	Excellent service experience	O-rings, seals, bladders
Viton A (03-100 BR 31)	Seals, Inc.	90	2	—	15.6	95.0	None	O-rings
Viton A (03-100 BR 31)	B. F. Goodrich	90	2	—	15.4	98.6	None	O-rings, seals
Viton A (41144; black)	Hewitt Robbins	90	3	—	80.6	82.1	Blistered and swelled; bleached to blue color	Not recommended for service above 120 F
Viton A-6070	Michels Engineering	90	2	—	4.3	97.0	None	O-rings, bladders
Viton A-17004[13]	Precision Rubber	90	-	—	—	—	No noticeable attack in 1 day at room temperature, severe attack in 1 day at 200 F	—
Viton A-HS-251-70[13]	Stillman Rubber Co.	90	-	—	—	—	No noticeable attack in 1 day at 150 F; minor attack in 1 day at 200 F	—
Viton A-HS-270-70[13]	Stillman Rubber Co.	90	-	—	—	—	No noticeable attack in 1 day at 150 F; minor attack in 3 days at 200 F	—
Viton B (805)	DuPont	90	1	—	0.6	98.5	No effect after 72 hours at 151 F	O-rings, seals, bladders
Viton B (805)	DuPont	90	1	1.0	0.6	99.0	No effect after 72 hours at 151 F	O-rings, seals, bladders

TABLE 4.8
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent ASL Per Month at 86 F	Percent ASL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Scotch Pak 2045[8]	Minn. Min. & Mfg.	90	1	—	1.1	98.0	None	Film material
Scotch Pak 45410[8]	Minn. Min. & Mfg.	90	1	—	1.1	98.0	None	Film material
Teflon (white)	DuPont	90	1	—	2.8	95.0	None	Various uses
Teflon, 100X FEP Fluorocarbon	DuPont	90	1	—	2.6	98.5	None	Not effectively heat sealable
Teflon, 5-milliliter (molded 100X)	DuPont	90	1	0.55 (2 hours at 270 F, 545 psig)		98.0	None	—
Teflon Tape	DuPont	90	1	0.3	2.8	—	None	Thread compound
Teflon Tape, JRP 7321[10] and JRP 7952	DuPont	90	1	—	—	—	—	—
Teflon Tape, 547[10]	Minn. Min. & Mfg.	90	1	—	—	—	—	—
Teflon-Impregnated[10] Glass Cloth	DuPont	90	1	—	—	—	—	—
Teflon Welded	DuPont	90	1	2.0	2.7	—	None	Seals, bladders
Teflon (virgin)	DuPont	98			2.6	95.0	—	Seals, gaskets
Teflon (fuel cell)[5]	Dielectrix Corp.	98			2.2[5]	97.0	—	Bladder material
Teflon and Fluorsint	Potter Aeronautical	90	2	—	11.1	95.0	None	Bearing for turbine flow meter
Dispersion Teflon[8, 14] (fuel cell)	Dielectrix Corp.	98	2	—	7.4	94.0	Very slightly bleached	Bladder material
Dispersion Teflon TFE[8,14]	DuPont	98	1	—	0.33	98.0	None	Tank liner, bladders
Teflon Fuel Cell	Chemmgineers, Inc.	90	1	—	3.3	96.0	None	Expulsion bladders
Teflon Fuel Cell	Dielectrix Corp.	90	1	—	2.9[5]	97.0	Very slightly bleached	Expulsion bladders
Teflon Fuel Cell	Dielectrix Corp.	90	2	—	4.0[8]	94.0	Very slight bleaching	Expulsion bladders
Teflon TFE Cell	Chemmgineers, Inc.	90	2	—	3.6	97.5	Bleached	Expulsion bladders
Teflon TFE	DuPont	90	1	—	1.5[3]	98.0	None	Bladder material
Teflon, Carbon-Filled[12]				Decomposition rates were excessive in 24 hours				—
Teflon, Molybdenum[12] Disulfide-Filled				Decomposition rates were excessive in 24 hours				—

TABLE 4.8
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent ADL Per Month at 86 F	Percent ADL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material	Comments
Viton B (805)	DuPont	90	4	—	3.6	98.0	7 days at 151 F, slight blistering	Not recommended
Viton B (805)	DuPont	98	1	—	0.6	98.5	No effect to 72 hours	O-rings, seals, bladders
Viton B (5187)[15]	DuPont	90	2-3	—	15 percent fluid loss in 26 weeks	—	—	O-rings, seals
Viton B-4411-4-805	DuPont	90	1	0.7	—	98.0	None	Gaskets, seals
Viton B-Cure No. 23	Seals Eastern, Inc.	90	3	—	5.0	91.0	Very slight blistering	—
Viton B-Cure No. 805	DuPont	90	3	—	2.6	98.4	Swollen and moderate blisters	Not recommended for temperatures above 120 F

(1) Data taken from Ref. 4.25 unless otherwise noted
(2) Footnote 2, Table 4.4
(3) 7 days at 74 C (165 F)
(4) 5 months storage at 20 to 22 C (68 to 72 F)
(5) 1 week at 49 C (120 F)
(6) Not suitable for use above 200 F
(7) Subject to ignition if heated above 71 C (160 F) when contacting 90 or 98-percent H_2O_2
(8) 3 days at 74 C (165 F)
(9) Stabilized H_2O_2 used
(10) Reference 4.40
(11) Reference 4.45
(12) Reference 4.47
(13) Reference 4.48
(14) Reference 4.29
(15) Reference 4.49

TABLE 4.9

COMPATIBILITY OF HYDROGEN PEROXIDE WITH POLYVINYLCHLORIDE AND CO-POLYMERS[1]

Material	Source	H_2O_2, weight percent	Class	Percent ADL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Alanel Tubing	Malge	90	3	10.3	—	Embrittled
Beltaron 6200 (grey)	Belta	90	2	3.0	—	None
Enselite[6]	—	90	-	—	—	Retained resiliency, but decreased in tensile strength; swelling; bleached
Geon 118	B. F. Goodrich	90	4	8.5 (4 days)	85.6 (4 days)	Milky white, blistered, distorted
Geon 404 (yellow)	B. F. Goodrich	90	3	8.0	—	Bleached and became brittle
Geon 2042[5]	B. F. Goodrich	90	4	—	—	—
Geon 8372[5]	B. F. Goodrich	90	4	—	—	—
Geon PVC	B. F. Goodrich	90	2	—	85.0	Slight bleaching
Geon PVD Pipe[7]	B. F. Goodrich	90	2	1.3[3]	85.0	Slight bleaching
Grey[7]	B. F. Goodrich	90	3	10.6	97.0	Slight bleaching
I.P.S. Uscalite	Stritt and Priebe	90	4	7.2	89.8	Severely attacked and blistered
Koroseal 116	B. F. Goodrich	90	3	23.0	—	Bleached and hardened
Koroseal 116 (molded)[5]	B. F. Goodrich	90	3	—	—	—
Koroseal 117 (molded)	B. F. Goodrich	90	3	16.0	—	Bleached and hardened
Koroseal 117 (calendered)[5]	B. F. Goodrich	90	4	—	—	—
Koroseal 700	B. F. Goodrich	90	2	2.9	—	Slightly swollen, bleached, and stiffened
Koroseal 700 (molded)[5]	B. F. Goodrich	90	2	—	—	Bleached
Koroseal 700 With Hysar 1041 Plasticizer	Prince Rubber	90	4	14.9	0.0	Blistered and bleached
Koroseal Pipe (grey)	B. F. Goodrich	90	3	10.6	97.0	Slight bleaching
Lacoflex (translucent)	Lacoflex Plastic Fab.	90	3	10.1	—	Blistered and bleached
Lacoflex (white)	Lacoflex Plastic Fab.	90	3	11.2	—	Darkened, slight blistering
Marvinol 218-200	U. S. Rubber	90	4	100/2 hours	—	Sample became tacky after 1 hour
Marvinol 218-201	U. S. Rubber	90	4	100/1 hour	—	Deformed, charred
Marvinol MF-3005	U. S. Rubber	90	4	100/1 hour	—	Sample became tacky
Marvinol MR-6010	U. S. Rubber	90	4	100/1 hour	—	Became tacky and deformed
Pliovic[5]	Goodyear Tire	90	2	—	—	—
PVC	Walworth Pipe	90	2	1.2	98.4	Moderate bleaching
PVC	Walworth Pipe	90	2	10.5	86.0	Moderate bleaching
PVC	Prince Rubber	90	3	13.1	87.7	No change
PVC, Rigid	Vanco	90	2	5.3	90.4	Bleached and slight blistering

TABLE 4.9
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent ADL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
PVC, Rigid	Whitehead	90	2	7.5	96.0	Bleached
PVC, Sheet (dark grey)	Prince Rubber	90	3	13.0	87.0	Slight bleaching
Rubatex, R-510V[6]	—	90	-	—	—	Retained resiliency but decrease in tensile strength; swelling; bleached
Saran	Dow Chemical	90	2	12.5	—	Bleached
Saran Rubber Q-187	Dow Chemical	90	4	—	—	Burned
Transflex Tubing	Irvington Varnish & Insulation	90	4	1.1	—	Blistered badly
Tygon B-20	U. S. Stoneware	90	3	2.3	—	Bleached, blistered, and slightly distorted
Tygon B-32	U. S. Stoneware	90	3	2.2	—	Bleached, blistered, and slightly distorted
Tygon B-63	U. S. Stoneware	90	3	1.7	—	Bleached, blistered, and slightly distorted
Tygon B-71	U. S. Stoneware	90	3	3.5	—	Bleached, blistered, and slightly distorted
Tygon B-72	U. S. Stoneware	90	3	1.0	—	Bleached, blistered, and slightly distorted
Tygon B-136	U. S. Stoneware	90	3	2.0	—	Bleached, blistered, and slightly distorted
Tygon S-22-1	U. S. Stoneware	90	4	—	—	Blistered and swollen
Tygon TL-103	U. S. Stoneware	90	4	—	—	Blistered and swollen
Tygon 2807	U. S. Stoneware	90	4	—	—	Disintegrated
Tygon 3400	U. S. Stoneware	90	4	—	—	Embrittled and swollen
Tygon 3603	U. S. Stoneware	90	4	—	—	Swollen
Tygon 3604 A	U. S. Stoneware	90	2[4]	—	—	Becomes opaque
Tygon 3604 B	U. S. Stoneware	90	2[4]	—	—	Becomes opaque
Vinyl 79139	U. S. Rubber	90	2	1.7	—	Slight opaque; small blisters
Vinylite VS 1310	Bakelite Div.	90	3	2.3	—	Turned opaque; slight blistering
Vinylite VMD-9947[5]	Union Carbide	90	2	—	—	Turned opaque; slight blistering
Vinylite VU 1900	Bakelite Div.	90	3	2.5	—	Turned opaque; slight blistering
Vinylite VE 1907	Bakelite Div.	90	3	3.0	—	Turned opaque; slight blistering
Vinylite VG 1914	U. S. Rubber	90	2	1.5	—	Blistered slightly, bleached
Vinylite VU 1920	Bakelite Div.	90	3	2.0	—	Turned opaque; slight blistering
Vinylite VU 1930	Bakelite Div.	90	3	2.4	—	Turned opaque; slight blistering
Vinylite VU 1940	Bakelite Div.	90	3	2.0	—	Turned opaque; slight blistering
Vinylite VU 1940	U. S. Rubber	90	2	1.6	—	Bleached

(1) Data taken from Reference 4.25 unless otherwise noted
(2) Footnote 2, Table 4.4
(3) Tested at 86 F
(4) Based on service experience
(5) Reference 4.40
(6) Reference 4.45
(7) Reference 4.29

TABLE 4.10

COMPATIBILITY OF HYDROGEN PEROXIDE WITH SILICONE RUBBER COMPOUNDS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Fluorosilicone LS-53	Dow-Corning	90	2	16.7	91.3	None
GE 407B-217-1	General Electric	90	4	34.3	—	—
GE 1240	General Electric	90	2	72.4	—	None
GE 12601	General Electric	90	4	99.5	—	Hardened
GE 12062	General Electric	90	3	95.0	—	None
GE 12650 (unpigmented)	General Electric	90	2	48.5	—	Slight swelling
GE 12650 (pigmented red)	General Electric	90	3	89.0	—	Slight bleaching, swelled, distorted
GE 12670	General Electric	90	4	47.5	—	Hardened
GE 12670 (pigmented brown)	General Electric	90	4	45.0	—	Cracked; bleached
GE 15060 (pigmented)	General Electric	90	3	31.9	—	Blistered and warped slightly
GE 15080	General Electric	90	3	32.2	—	Blistered
GE 81223	General Electric	90	4	27.7	—	None
GE X7181	General Electric	90	3	18.3	—	Slightly hardened
Hadbar No. 8000-71[3]	Hadbar	90	-	—	—	Soft; pitted
Parkone White 467-1 O-Ring	Parker Appliance	90	4	29.6	—	Hardened and broke
SE 450 (unpigmented)	General Electric	90	2	13.3	—	Slight bleaching and swelling
Silastic 152	Dow-Corning	90	3	17.8	68.1	Slightly bleached
Silastic 160	Dow-Corning	90	3	37.8	—	Lost elasticity
Silastic 160 O-ring	Linear Inc.	90	4	71.0	—	Embrittled
Silastic 161	Dow-Corning	90	3	43.4	—	Lost elasticity
Silastic 181	Linear Inc.	90	3	39.3	—	Slightly blistered
Silastic 240	Dow-Corning	90	2	24.9	—	None
Silastic 250	Dow-Corning	90	4	92.6	—	Curled
Silastic 261	Dow-Corning	90	3	16.7	—	Lost elasticity
Silastic 675	Dow-Corning	90	3	5.0	—	Blistered and embrittled
Silastic 6-128	Dow-Corning	90	2	6.7	99.7	Slightly blistered; bleached
Silastic 7-180	Dow-Corning	90	3	17.7	—	Embrittled
Silastic 9711	Dow-Corning	90	2	7.4	99.1	Slightly bleached
Silastic 9711	Dow-Corning	90	2	5.7	98.0	Slightly bleached
Silastic HR-9711	Hewitt-Robins, Inc.	90	2	7.8	96.5	Slightly bleached
Silicone S-9711[4]	Fargo Rubber	90	-	—	—	No noticeable attack; material bleached (168 hours at 200 F)

TABLE 4.10
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Silicone PR-11555[5]	Precision Rubber	90	2-3	16-percent fluid loss in 24 weeks	—	—
Silastic 9711 Welded With S-2200	Dow-Corning	90	2	13.6	96.0	Weld unaffected; slight bleaching, mottling
Silastic MB-39631[6]	Hewitt-Robbins, Inc.	90	2	—	—	—
Silastic S-2000-4-480	Dow-Corning	90	2	16.1	95.5	Bleached and slightly mottled
Silicone 407-B-217-1	F. S. Bacon Lab.	90	3	34.5	—	Embrittled
Silicone 407-B-437-1	F. S. Bacon Lab.	90	2	20.3	—	None
Silicone HT 696	Connecticut Hard Rubber	90	3	17.4	95.7	Blistered
Silicone X-1054	Union Carbide	90	3	—	—	None
Silicone O-ring[5] No. 8419-80	Linear	90	-	13.4	86.7	No pitting, swelling, or bleaching
Silicone O-ring[5] Compound V399-7	Parker	90	-	—	—	Bleached completely
Silicone O-ring[5] No. S-455-7	Parker	90	-	32.2	0.0	Slight distortion
Silicone X-1038[6]	Union Carbide	90	4	—	—	Lost flexibility; cracked
Silicone Rubber SR5550	Connecticut Hard Rubber	90	2	32.4	—	None
Silicone Rubber SR5550	DuPont	90	2	45.0	—	None
Silicone Rubber SR5570	Connecticut Hard Rubber	90	2	30.9	—	None
Silicone Rubber SR5570	DuPont	90	2	46.5	—	None
Silicone X-7181	Stalwart Rubber	90	3	18.3	—	Lost some elasticity
Silicone Y-1419[6]	Union Carbide	90	3	—	—	None
Silicone Y-1749	Union Carbide	90	2	12.3	—	Small white blisters
Silicone TH-1047	Stillman Rubber	90	2	10.3	97.0	No effect
Silicone TH-1057[4]	Stillman Rubber	90	-	—	—	No apparent attack (1 day at 200 F); slightly attacked after 168 hours at 200 F
Silicone TH-1131	Stillman Rubber	90	2	15.0	94.0	Bleached slightly
Silicone Rubber[4] Comp. 78-038	Parker Seal	90	-	—	—	No noticeable attack (1 day at 200 F); slight brittleness after 3 days at 200 F
O-Ring No. 945-70[3]	Plastic Rubber	90	-	—	—	Swelled
O-Ring No. 005-18057[3]	P.R.P.	90	-	Failed	—	Completely disintegrated at 72 hours
O-Ring No. S8277-70[3]	Stillman Rubber	90	-	10.1; Failed	—	Swelled, pitted, very soft
O-Ring No. TH 1057[3]	Stillman Rubber	90	-	13.0	65.8	No swelling, pitting, or bleaching

(1) Data taken from Reference 4.25 unless otherwise noted
(2) Footnote 2, Table 4.4
(3) Reference 4.50
(4) Reference 4.48
(5) Reference 4.49
(6) Reference 4.40

TABLE 4.11

COMPATIBILITY OF HYDROGEN PEROXIDE WITH GENERAL RUBBERS AND PLASTICS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Acrylon Rubber BA-12	American Monomer	90	4	—	—	H_2O_2 turned black; sample partially dissolved in 2 days
Acrylon EA-5	American Monomer	90	4	—	—	H_2O_2 turned black; sample partially dissolved in 2 days
Adiprene C	Hewitt Robbins	90	4	100.0	—	Decomposed in 1 hour
Biselin No. 50	Bishop Mfg.	90	2	9.7	—	Slightly blistered
Buna N	—	90	4	—	—	—
Buna S[3]	—	90	4	—	—	—
Butyl Rubber A3405	Esso Lab	90	4	100.0	—	Softened to sticky mass in 24 hours
Butyl Rubber SR-384		90	4	5.0	—	Became tacky
Cycloloc (natural color)	Marbon Chem. Div.	90	4	7.6		Embrittled, swollen, solution turned yellow
Delrin	DuPont	90	4	100.0		Dissolved
Epon Resin[3]	Shell Chem.	90	4	—		—
Estane Plastic	B. F. Goodrich	90	4	6.0	55.0	Disintegrated
Garlock No. 5681 (Teflon-impregnated asbestos)	Garlock Packing	90	4	100/1 hour	—	Sample fell apart
Hycar PA 478-1-1 (black)	B. S. Bacon Labs	90	4	100/24 Hours	—	Dissolved completely
Haveg 41 (asbestos-filled phenolic)	Haveg Corp.	90	4	100.0	—	Partially dissolved
Haveg 60 (phenolic)	Haveg Corp.	90	4	100.0	—	Dissolved
Hysol 4-77 C (clear)	Houghton Labs	90	4	100.0	—	Bleached; distorted
Hysol 4-77D (amber)	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-77E	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-77F	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-78A (white)	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-78B (brown)	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-78C (amber)	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 4-78D (amber)	Houghton Labs	90	4	100.0	—	Blistered; distorted
Hysol 6000B (amber)	Houghton Labs	90	4	100.0	—	Partially dissolved
Kralite (Kraylite)	U. S. Rubber	90	3	26.7	—	Swollen and distorted

TABLE 4.11

(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Lexan	General Electric	90	2	2.1	97.0	Slight bleaching
Melmax No. 1077	Mechanical Products	90	4	100.0	—	Partially dissolved
Methyl Methacrylate[3]	Whitehead Metal Products	90	4	—	—	Softened
Mylar "A"	DuPont	90	1	5.0	—	None
Mylar "B"	DuPont	90	1	1.7	—	None
Neoprene Pure Gum	Spray Dip	90	4	—	—	Ignited and burned
Neoprene SR 365-B	Eclipse Pioneer Div., Bendix Aviation	90	4	100.0	—	Ignited and burned
Nylon	DuPont	90	4	100.0	—	Ignited and burned
Orlon[3]	—	90	4	—	—	—
Penton[3]	Hercules Chemical	90	2	—	—	—
Phenol-Formaldehyde	Durez Plastics Div., Hooker Electrochem	90	4	100.0	—	Ignited
Plexiglass	Rohm and Haas	90	4	100.0	—	Softened and partial solution
Polystyrene (Polyflex)	Plax Corp.	90	2	9.1	—	None
Polyurethane (green)	Dunlap	90	3	8.5	50.2	Partially dissolved
Polyurethane (tan)	B. F. Goodrich	90	3	56.0	59.9	Completely dissolved
Polyurethane (black)	B. F. Goodrich	90	4	98.5	0.0	Completely dissolved
Thiokol EC-801-LP2	Thiokol Chem. Corp.	90	4	100.0	—	Burst into flame
Thiokol 3000 FA	Thiokol Chem. Corp.	90	4	100.0	—	Dissolved
Thiokol 3000 ST	Thiokol Chem. Corp.	90	4	—	—	—
Thiokol 1620 AH	Thiokol Chem. Corp.	90	4	—	—	—

(1) Data taken from Reference 4.25 unless otherwise note

(2) Footnote 2, Table 4.4

(3) Reference 4.40

TABLE 4.12

COMPATIBILITY OF HYDROGEN PEROXIDE WITH LAMINATES, DIAPHRAGMS, AND ADHESIVES[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Chemolic MI-411 (Teflon fiberglass)	U. S. Gasket	90	2[3]	11.5	—	Bleached during screening
Duroid 5600 (fiber-reinforced Teflon)	Rogers Corp.	90	3	44.7	70.1	None
Fairprene FS 57-167 (Viton A, 116 glass)	DuPont	90	3	29.0	91.6	Moderate blistering and surface attack
Fairprene FS 57-168 (Viton A, Dacron)	DuPont	90	2	23.0	94.5	Moderate surface attack
Fairprene (Viton A)						
5806	DuPont	90	2	48.4	—	None
5807	DuPont	90	2	53.9	—	None
5809	DuPont	90	2	7.5	—	None
80-080 (1/32 inch)	DuPont	90	2	4.0	—	None
Glass Resins	Owen-Illinois Tech. Center	90	1	1.3	97.5	None
Kel-F Dacron, Diaphragm-VL-1101m4	Vernay Laloe, Inc.	90	4	95.0	—	Coatings and Dacron separated in 2 days
Kel-F 5160 Diaphragm	Nichols Engineering	90	2	30.6	—	Slightly blistered and tacky
Kel-F 5300 (grey) Diaphragm	Nichols Engineering	90	2	13.7	—	Slightly blistered and tacky
Kel-F 5300 (grey) on Dacron Diaphragm	Nichols Engineering	90	2	43.8	—	None
Korda Flex (Teflon-coated glass fabric)	Chicago Gasket	90	2	2.5	97.0	None
Polyester Fiberglass						
Duracor 1000	Will Corp.	90	3	25.9	15.7	Bleached
2000-5	Will Corp.	90	3	18.6	81.7	Bleached
6000-4	Will Corp.	90	3	21.4	70.0	Bleached
6000-8	Will Corp.	90	3	49.5	39.8	Bleached
E	Will Corp.	90	3	15.0	10.7	Dissolved
Rad	Buffalo Forge	90	3	12.0	79.7	Discolored and bleached
Straw	Buffalo Forge	90	3	22.0	28.0	Discolored and bleached
Ridgidon	Heil Process & Equipment	90	3	27.4	67.0	Slightly dissolved and bleached
9711 Silicone Seal Washer DC, Chemloc 607 Adhesive on Aluminum	Kirkhill Rubber	90	3	11.6	83.4	None
Silastic DC-9711 on Dacron Diaphragm	Kirkhill Rubber	90	3	9.7	96.4	Bleached and distorted
Vinyl-Coated Fiberglass	Birma Mfg.	90	3	49.8	—	None
9711 Silicone Seal Washer DC A4094 Adhesive (Dow Corning Silicate base) on Aluminum	Kirkhill Rubber	90	3	15.5	69.1	None

[1] Data taken from Reference 4.25

[2] Footnote 2, Table 4.4

[3] After 24-hour screening at 151 F

TABLE 4.13

COMPATIBILITY OF HYDROGEN PEROXIDE WITH POROUS MATERIALS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Percent[2] Stability After Test	Effect On Material
Al-Si Mag, Porous Ceramic No. 393	Lava Corp. of America	90	3	100/3 days	—	None
Aluminum Oxide, Porous-RA-98	Norton Abrasives	90	2	19.0	—	None
Armalon-Teflon Felt (impregnated)	DuPont	90	3	70.0	—	Bleached
Armalon	DuPont	90	3	28.0	—	Bleached
Daeron Cloth						
Dac-2100	Nat. Filter Media Corp.	90	2	5.0	—	Resiliency decreased
Dac-2101	Nat. Filter Media Corp.	90	2	3.0	—	Resiliency decreased
Dac-2102	Nat. Filter Media Corp.	90	2	6.0	—	Resiliency decreased
Filtres C Stone (55 microns)	Filtres Corp.	90	2	Classification based on experience		None
Glass Cloth G-206-C	Nat. Filter Media Corp.	90	2	18.0	—	None
Poreley-32288 Wire	Bendix Filter Div.	90	3	100.0	—	None
Porous Kel-F (15-micron pore)	Pall Filtration Corp.	90	2	9.8	98.0	Less brittle
Porous Porcelain (1.4 micron)	Selas Corp. of America	90	2	16.0	—	None
Porous Teflon (9-micron pore)	Pall Filtration Corp.	90	2	14.0	96.5	None
Rigimesh J Stainless-Steel Wire	Pall Filtration Corp.	90	3	100.0	—	Deep bronzing
Sintered 300-Series Stainless-Steel Powder Compact	Calif. Inst. of Tech.	90	4	100/2 hours	—	Bronzed and rusted
Sintered 302 Stainless-Steel Powder Compact	Amplex Div.	90	4	100/2 1/2 hours	—	Bronzed
Sintered 316 Stainless-Steel Powder Compact	Titeflex, Inc.	90	4	100/24 hours	—	Bronzed heavily
Sintered 316 Stainless-Steel Powder Compact	Pall Filtration Corp.	90	4	100/24 hours	—	Bronzed
Sintered 3025 Stainless-Steel Powder Compact	S-K-C Research Assoc.	90	4	100/2 hours	—	—
Sintered 316 and Cb Stainless-Steel Powder Compact	Rensselaer Poly. Inst.	90	4	100/5 hours	—	—
Teflon Cloth (25 grade)	Pall Filtration Corp.	90	3	20.0	79.0	Completely bleached
Teflon Cloth—Repeat (25 grade)	Pall Filtration Corp.	90	2	17.0	98.0	None
Teflon Cloth (40 grade) Teflon Felt (impregnated)	Pall Filtration Corp.	90	3	15.3	83.1	Completely bleached
Teflon Cloth T-2300	Nat. Filter Media Corp.	90	3	100.0	none remaining	Bleached white
Teflon Cloth T-2305	Nat. Filter Media Corp.	90	2	28.2	—	None
Zirconium Silicate (10 micron)	Selas Corp.	90	2	17.0	97.0	None

[1] Data taken from Reference 4.25 [2] See Footnote 2, Table 4.4

TABLE 4.14

COMPATIBILITY OF HYDROGEN PEROXIDE WITH LUBRICANTS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Impact[2] Sensitive
Alkaterge C	Commercial Solvents	90	4	—	Yes
Amino Silane Oil and Grease	—	90	4	—	Yes
Apiezon Hard Wax "W"	J. G. Biddle	90	4	Excessive	—
Arochlor 1221	Monsanto Chem.	90	4	—	Yes
Arochlor 1232	Monsanto Chem.	90	4	—	Yes
Arochlor 1242	Monsanto Chem.	90	4	—	Yes
Arochlor 1248	Monsanto Chem.	90	4	—	Yes
Arochlor 1254	Monsanto Chem.	90	4	—	Yes
Bardahl	Bardahl Corp.	90	4	—	Yes
Carum 200	Esso Labs	90	4	5.2	Yes
Ceresin Wax	—	90	4	—	Yes
CFE-1	Carbide and Carbon	90	4	—	Yes
Dichloro-bis-tri-fluoromethyl Benzene	Hooker Electro-Chem.	90	3	3.3	No[3]
Dichlorohexafluorobutene	Hooker Electro-Chem.	90	3	9.2	No[3]
Fluorolube FS	Hooker-Electro-Chem.	90	2	4.2	No[2]
Fluorolube FS + 5-Percent Fluorolube Light Grease	Hooker-Electro-Chem.	90	2	—	No[3]
Fluorolube Heavy Grease 10214	Hooker-Electro-Chem.	90	2	1.7	No[3]
Fluorolube Oil 10213	Hooker-Electro-Chem.	90	2	1.0	No[3]
Fluorolube S	Hooker-Electro-Chem.	90	2	2.5	No[3]

TABLE 4.14
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Impact[2] Sensitive
Fluorolube T	Hooker-Electro-Chem.	90	2	8.5	No[3]
Fluorolube Oil, S-30	Hooker-Electro-Chem.	90	2		No[4]
Fluorolube Grease, Hg-1200	Hooker-Electro-Chem.	90	2		No[4]
Fluorolube Grease, GR-560	Hooker-Electro-Chem.	90	2	—	No[4]
Formulation:					
F-9	Monsanto Chem.	90	4	—	Yes
OS-16	Monsanto Chem.	90	4	—	Yes
OS-22	Monsanto Chem.	90	4	—	Yes
OS-23	Monsanto Chem.	90	4	—	Yes
OS-27	Monsanto Chem.	90	4	—	Yes
OS-28	Monsanto Chem.	90	4	—	Yes
OS-30	Monsanto Chem.	90	4	—	Yes
OS-32	Monsanto Chem.	90	4	—	Yes
OS-33	Monsanto Chem.	90	4	—	Yes
OS-34	Monsanto Chem.	90	4	—	Yes
OS-35	Monsanto Chem.	90	4	—	Yes
OS-37	Monsanto Chem.	90	4	—	Yes
CP-3898-2	Monsanto Chem.	90	4	—	Yes
Skydrol (uncolored)	Monsanto Chem.	90	4	1.0	Yes
Halocarbon Oil 8-25-AV	Halocarbon Products Corp.	90	2	1.8	No[3]

TABLE 4.14

(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Impact[2] Sensitive
Halocarbon Oil 10-21	Halocarbon Products Corp.	90	2	2.9	No[3]
Halocarbon Heavy Oil 10-25[6]	Halocarbon Products Corp.	90	2	—	—
Halocarbon Light Oil 11-14	Halocarbon Products Corp.	90	2	2.1	No[3]
Halocarbon Medium Oil 11-21[6]	Halocarbon Products Corp.	90	2	—	—
Halocarbon Stopcock Grease	Halocarbon Products Corp.	90	2	1.8	No[4]
Halocarbon High Temperature[7] Stopcock Grease	Halocarbon Products Corp.	90	2	—	No[4]
Halocarbon Grease, 25-10[7]	Halocarbon Products Corp.	90	2	—	No[4]
Hexachlorobutadiene	Hooker Electro-Chem.	90	3	3.7	No[3]
Hexachloropropylene	Hooker Electro-Chem.	90	4	100.0	—
H-2 Hydraulic Fluid[6]	R. M. Hollingshead Corp.	90	2	—	—
Hydraulic Fluid RPM	Standard Oil of Calif.	90	4	1.4	Yes
Hydraulic Oil-Houghton Safe 620	Houghton	90	3	7.1[5]	—
Kel-F Alkane	Minn. Min. & Mfg.	90	2	1.0	No[4]
Kel-F Light Oil No. 1	Minn. Min. & Mfg.	90	2	1.7	No[3]
Kel-F Heavy Oil No. 10	Minn. Min. & Mfg.	90	2	3.2	No[3]
Kel-F No. 90 Grease	Minn. Min. & Mfg.	90	2	33.2	No[4]
Lindo HF (tricresyl phosphate)	Celanese Corp.	90	4	—	Yes
Lindol HFX	Celanese Corp.	90	4	—	Yes
Liqui-Moly Concentrate	Climax Molybdenum	90	4	—	Yes
Lubriseal	Arthur H. Thomas	90	4	—	Yes

TABLE 4.14
(Continued)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Impact[2] Sensitive
Mil-G-3278	—	90	4	—	Yes
Mil-G-4343	—	90	4	—	—
Mineral Oil	Various	90	4	--	Yes
Paraffin	Various	90	4	—	Yes
Perfluorolube Grease FCD-759	DuPont	90	2	10.5	No[3]
Perfluorolube Oil FC-331	DuPont	90	2	1.4	No[3]
Perfluorolube Oil FC-332	DuPont	90	2	1.7	No[3]
Perfluorolube Oil FC-333	DuPont	90	2	1.4	No[3]
Perfluorolube Oil FC-334	DuPont	90	2	0.8	No[3]
Perfluorolube Oil FC-335	DuPont	90	2	1.0	No[3]
Petrolatum	Various	90	4	—	Yes
Polychloropentane (stabilized)	Hooker Electro-Chem.	90	4	—	Yes
FR-240AC Grease[9]	DuPont	90	-	1.6	—
FR-240AC Grease (9)	DuPont	98	-	1.6	—
Renex	Atlas Powder	90	4	—	Yes
Silicone XF 224	Dow-Corning	90	4	—	Yes
Silicone Grease DC-11[8]	Dow-Corning	90	3-4	—	Yes
Silicone Oil DC-7	Dow-Corning	90	4	—	Yes
Silicone Oil DC-44	Dow-Corning	90	4	—	Yes
Silicone Oil DC-200	Dow-Corning	90	3-4	—	Yes
Silicone Oil DC-550	Dow-Corning	90	4	—	Yes

TABLE 4.14
(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL Per Week at 151 F	Impact[2] Sensitive
Silicone Oil DC-701	Dow-Corning	90	4	--	Yes
Silicone Oil DC-702	Dow-Corning	90	4	--	Yes
Silicone Oil DC-710	Dow-Corning	90	4	--	Yes
Silicone Oil GE 2V3733	General Electric	90	4	--	Yes
Silicone Oil GE 51346	General Electric	90	4	--	Yes
Tectyl	--	90	4	--	Yes
1, 1, 2, 2, Tetrafluoroethyl Dodecylether	DuPont	90	4	--	Yes
Texaco Uni-Temperature	Texaco	90	4	--	--
Tributyl Phosphate	Commercial Solvents	90	4	--	Yes
Ucon Hydrolube U-4	Carbide & Carbon Chem.	90	4	8.4 (ppt. formed)	--

(1) Data from Reference 4.25 unless otherwise noted
(2) No weight-distance data were given with the positive results
(3) Non-impact sensitive to 1 kg-m at room temperature
(4) Non-impact sensitive to 100 ft-lb at room temperature
(5) Non-impact sensitive at 1 kg-m at room temperature, but clouded during 150 F, 7 day test
(6) Reference 4.40
(7) Reference 4.29, 4.40
(8) Reference 4.43
(9) These tests were conducted by smearing the grease on the walls of the container. Contamination from an external source caused the loss of one of the 90-percent H_2O_2 and one of the 98-percent H_2O_2 samples. The results are therefore from a single analysis (Ref. 4.44)

NOTE: Ref. 4.51 tested a number of fluorolubes with 90-percent H_2O_2 at 10 kg-m impact sensitivity and found none which were 100-percent negative under these conditions.

TABLE 4.14a

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH POTENTIAL LUBRICANTS(1)(2)

NO VISIBLE REACTION

Halogenated Aliphatic Hydrocarbons

Polytetrafluoroethylene (solid)
Tetrafluoroethylene-hexafluoropyropylene copolymer (solid)
Polychlorotrifluoroethylene (molecular weight < 800)
Polychlorotrifluoroethylene (molecular weight > 800)
Perfluorokerosene
Dispersion of Polytetrafluoroethylene in Trichlorotrifluoroethane (solid)
Perchloropentacyclodecane (solid)
Perfluorodiethylcyclohexane (mixed isomers)
Dichlorodecafluoroheptane
Chlorofluoro Hydrocarbon (approximate molecular weight 725)
Chlorofluoro Hydrocarbon (approximate molecular weight 1000)
Fluorinated Hydrocarbon (77.4 percent F; approximate molecular weight 640)
Polychlorotrifluoroethylene (approximate molecular weight, 775; 80 percent halogens)

Silicon Compounds

Silicon Fluorides
Tri(p-trifluoromethyl phenyl) Silicon Fluoride
Trilaurysilicon Fluoride
Tris (3,5,5-trimethylhexyl) Silicon Fluoride
Dimethylpolysiloxanes
Dimethylpolysiloxane (2 to 500 Cs)
Fluoropolysiloxanes
$HCF_2(CF_3)_5CH_2O[Si(CH_3)_2O]_nCH_2(CF_2)_5CF_2H$, Fluoropolysiloxane, n = 1-26

TABLE 4.14a

(Continued)

NO VISIBLE REACTION (Continued)

Cyclic Fluorosiloxanes

Cyclic Fluorosiloxane (solid)

$CH_3(R)\underbrace{SiOSi(CH_3)(R)OSi(CH_3)(R)O}$

R = $CF_3CF_2CF_2CH_2-$

Cyclic Fluorosiloxane (solid)

$CH_3(R)\underbrace{SiOSi(CH_3)(R)OSi(CH_3)(R)O}$

R = $CF_3CH_2CH_2-$

Fluorosiloxane Elastomer (solid) Made From

$CF_3(CH_2)_2Si(CH_3)C_2$

Cyclic Fluorosiloxane (solid)

$CH_3(R)\underbrace{SiOSi(CH_3)(R)OSi(CH_3)(R)O}$

R = $CF_3CF_2CF_2CH_2-$

Mixed Cyclic Fluorosiloxane (solid)

$CH_3(R)\underbrace{SiO[Si(CH_3)(R)O]_n\ Si(CH_3)(R)O}$

R = $CF_3CF_2CF_2CH_2-$ n = 3 and higher

Dimethylpolysiloxane-Cyclic

Fluoropolysiloxane Blends

Fluorosiloxane Grease (No. 33 + inorganic gelling agent)

Fluorosiloxane Grease (No. 34 + inorganic gelling agent)

Mixed Dimethylpolysiloxane and Cyclic Fluoropolysiloxane

Mixed Dimethylpolysiloxane (average molecular weight < previous compound)

Halogenated and Nonhalogenated Aromatic Hydrocarbons

3-Heptyl-m-terphenyl

Isopropyl-m-terphenyl

Dinonylnaphthalene (mixed isomers)

1,3-Bis (trifluoromethyl) Benzene

TABLE 4.14a

(Continued)

NO VISIBLE REACTION (Continued)

2,3,5,6-Tetrachlorofluorobenzene (solid)

1,3,5-Trimethyl-2,4,6-Trifluorobenzene (solid)

1,3,5-Trimethyl-2,4-Difluorobenzene

Hexafluorobenzene

2,5-Dichlorobenzotrifluoride

2-Fluorobiphenyl (solid)

3,3'-Difluorobiphenyl (solid)

4,4'-Difluorobiphenyl (solid)

3,6,4'-Trifluorobiphenyl (solid)

Esters

Mixed Fluoroalkyl Camphorates Fluoroalkyl-$HCF_2(CF_2)_n\ CH_2$- n = 3,5,7

Bis-1H,1H,5H-perfluoropentyl Camphorate

Bis-1H,1H,11H-perfluoroundecyl Camphorate (solid)

Tetrabutyl Pyromellitate

Mixed Fluoroalkyl Pyromellitates

Bis (2,2,3,3,4,4,5,5,-octafluoropentyl)3-methylglutarate

Bis (2,2,3,3,4,4,5,5,6,6,7,7,-dodecafluoroheptyl)3-methylglutarate

2,2,3,3,4,4,-Hexafluoropentyl 1,5-bis (trimethyl acetate)

Bis(1-methylcyclohexylmethyl) Sebacate

Poly (1,1,5,5-tetrahydrohexafluoropentamethylene adipate)(solid)

Bis (2-ethylhexyl) Chlorendate

Dibutyl Chlorendate

Nitrogen Compounds

Hexadecytriphenylurea

2,2'-Dinitrophenyl Ether (solid)

4,4'-Dinitrophenyl Ether (solid)

TABLE 4.14a

(Continued)

NC VISIBLE REACTION (Continued)

2,6-Difluoro-3,5-dinitrochlorobenzene (solid)

2,4-Dinitro-5-fluorobromobenzene (solid)

Perfluorotributylamine

Perfluoro Compounds

Polytetrafluoroethylene (solid)

Tetrafluoroethylene-hexafluoropropylene Copolymer (solid)

Perfluorokerosene

Perfluorodiethylcyclohexane (mixed isomers)

Mixed Perfluorocyclic Ether, $C_8F_{16}O$ (five- or six-membered ring with side chain, oxygen in the ring)

Perfluorotributylamine

Perfluorodihexyl Sulfide

4-Chloro-3,5-difluoronitrobenzene (solid)

3,3'-Difluoro-4,4'-dimethoxybiphenyl (solid)

Ethers

Bis(m-phenoxyphenyl) Ether

1,4-bis(cresoxy) Benzene (mixed isomers)

$CF_3CF_2O(CF_2)_2SF_5$

2,2'-Dinitrodiphenyl Ether (solid)

4,4'-Dinitrodiphenyl Ether (solid)

4-Fluoro-6-methoxyacetanilide (solid)

3,3'-Difluoro-4,4'-dimethoxydiphenyl Sulfoxide (solid)

3,5-Difluoro-6-methoxyacetanilide (solid)

Mixed Perfluorocyclic Ether, $C_8F_{16}O$ (five- or six-membered ring with side chain, oxygen in the ring)

TABLE 4.14a
(Concluded)

SOLUBLE IN 90-PERCENT H_2O_2 WITH NO VISIBLE SIGN OF REACTION

2,2,3,3,4,4,5,5-Octafluorohexyl 1,6-bis (trimethylacetate)
2,2,3,3,4,4,5,5-Octafluorohexyl 1,6-bis (3,3-dimethylbutyrate)
Diethylene Glycol Succinate Polyester
Chlorotetrafluorobenzotrifluoride
p-bis(m-trifluoromethylphenoxy) Benzene

PARTLY MISCIBLE

2,4,6,3',5' Pentafluorobiphenyl (10-percent decrease in volume)
3,3' Difluoro-6,6' dimethoxybiphenyl (solid; 20-percent decrease in volume)
p-chlorobenzotrifluoride (20-percent decrease in volume)

SOME COLOR CHANGE

Bis(p-phenoxyphyenyl) Ether (solid)
3,5-Difluoronitrobenzene

GELLED ON MIXING

Tetrachlorodiphenyl Ethe (solid)

(1) Data taken from Ref. 4.33
(2) During testing, 1 milliliter (liquid) or 1 gram (solid) was mixed with 1 milliliter of 90 weight percent H_2O_2.

TABLE 4.15

RECOMMENDED JOINT SEALING COMPOUNDS FOR USE WITH[1]
90- AND 98-PERCENT HYDROGEN PEROXIDE

Name	Supplier	Formulation	Class	Remarks
Dixseel	Dixon Corp.	Teflon	1	Suitable for small-pipe service
T-Film	Eco Engineering	Dispersion Teflon-Water	1	Suitable for small-pipe service
Teflon Tape	Various	Teflon	1	Suitable for most applications

NOTE: Use sparingly to prevent carry-off into the H_2O_2 stream. Avoid threaded connections; use AN flares and flanges.

Compounds Not Recommended

Compound	Supplier
Calbar CB Pipe Seal	Calbar Paint & Varnish
Crane Thread Lubricant	Crane
Fel-Pro, C-5	Felt Products Mfg.
Graphite Paste	Key Graphite
Goop (blue)	Carl A. Pearson
Goop (silver)	Carl A. Pearson
Cyl-Seal	West Chester Chemical
Molybdenite Pipe Dope	
Permatex, Aviation Form A Gasket No. 3	
OS-18 Lubricant	Monsanto Chemical
Pecora Compound	Pecora Paint
Plastic Metal No. 22	National Engineering Products
Rutland Pipe Dope	Rutland Fire Clay
Skydrol	Monsanto Chemical
Weco No-Gall	Well Equipment Mfg
X-Pando	X-Pando Corp.

TABLE 4.15
(Concluded)

Compound	Supplier
Kel-F Grease No. 90	Minnesota Mining & Mfg.
Tin Plating on Aluminum 6061	
Alcoa Thread Lubricant	Alcoa
Rectorseal No. 15	Rector Well Equipment

(1) Recommendations taken from Ref. 4.25

TABLE 4.16

COMPATIBILITY OF HYDROGEN PEROXIDE WITH CERAMICS, REFRACTORIES, AND MISCELLANEOUS MATERIALS[1]

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Agate (natural)		90	3-4	100	-	None
Agate (polished)	Buffalo Meter		3	100	-	None
Al-Si-Mag Porcelain	American Lava		2	17.5	-	None
Alumina (bonded)	General Electric		4	—	-	Destroyed
Alundum LA 116	Norton		2	19.1	-	None
Bonded Alumina Filter[3]			4	—	-	
Bonded Alundum MR[3]			4	—	-	
Boron Nitride			4	—	-	
Carboloy 44-A	General Electric		4	100	0	None
Carboloy 55-A	General Electric		4	100	C	Etched
Carboloy 78	General Electric		4	100	0	None
Carboloy 999	General Electric		4	100	0	None
Ceramic AB-2	Coors Porcelain		2	8.5	-	None
Ceramic Al-200	Coors Porcelain		2	12.6	-	None
Charcoal			4	—	-	Ignited
Crystalon (SiC)	Norton		4	100	-	None
Glass, Pyrex[3]			1	—	-	
Glass, Soft[3]			2	—	-	
Graphitar No. 30	Lee		4	—	-	Dissolved at room temperature
Graphite P-5A6[3]	Vickers, Inc.		4	—	-	None
Graphite P-5A6, Silver Impregnated	Pure Bond		4	100	-	None
Graphite P-55, Copper Impregnated	Pure Bond		4	100	-	None

TABLE 4.16

(Concluded)

Material	Source	H_2O_2, weight percent	Class	Percent AOL per Week at 151 F	Percent Stability[2] After Test	Effect on Material
Graphite P-59L, Copper Impregnated	Pure Bond	90	4	100	-	None
Graphite P-692	Pure Bond		4	Excessive	-	None
Karbate	National Carbon Div.		4	100	0	None
KT Silicon Carbide	Carborundum		2	1.2	95.5	None
Norbide	Norton		2	15.6	-	None
Porcelain (white, chemical)[3]			2	—	-	
Pyroceram[3]	Corning Glass		1	—	-	None
Synthetic Sapphire (polished)	Linde		1	0.8	-	None
Zirconium Silicate	Selas Corp.		2	7.6	97	None

[1] Data taken from Ref. 4.25 unless otherwise noted

[2] Footnote 2, Table 4.4

[3] Reference 4.40

TABLE 4.17

RESULTS OF EVALUATION OF PROTECTIVE COATINGS FOR 90 W/O HYDROGEN PEROXIDE SERVICE[1, 2]

Material	Source	Class	Percent AOL per Week at 151 F	Applications	Remarks
Recommended Coatings for Long Time Contact and Splash Resistance to 90 w/o H_2O_2					
Teflon		1		Dispersion-coated thermaplastic	In Al 1060, 5-gallon container tests, H_2O_2 concentration loss was 35.5 to 54.9 percent from 90.4 percent in 52 weeks
Teflon (TFE)	Dielectrix	1	-	Dispersion coating	Difficult to obtain nonpermeable coating
Teflon (TFE)	Dielectrix	1	-	Bladder	Tends to be brittle; multithin layers are rewarding
Kel-F	M. W. Kellogg	1	-	Dispersion coating (Uniform coatings possible)	In Al 1060, 5-gallon container tests, H_2O_2 concentration loss was 0.7 percent in 39 weeks, and 22.9 percent in 79 weeks from 90.0 percent
Kel-F on 1060 Al	Metal Cladding, Inc.	1	0.0	Spray coating only (uniform coatings possible)	No effect on sample; 95 percent stability[2] after test
Kel-F on 5254 Al	Metal Cladding, Inc.	1	4.6	Spray coating only (uniform coatings possible)	No effect on sample; 96 percent stability[2] after test
Kel-F on 5652	Metal Cladding, Inc.	1	3.4	Spray coating only (uniform coatings possible)	No effect on sample; 92.2 percent stability[2] after test
Omni (Viton A)	David Clark	2	2.9 0.5[3]	Glass or Teflon cloth impregnated with Viton A	No effect upon exposure to 90-percent H_2O_2 for 7 days at 66 C (151 F)
Glass Lining (clear, light grey)	Pfaudler Corp.	1	2.4	Formed glass lining	No effect upon material
Glass Lining (cobalt-colored glass)	Pfaudler Corp.	1	3.0	Formed glass lining	No effect upon material
Kanegin (electroless nickel upon mild steel)	Keystone Chromium	2	-	Plating	Very slight bronzing after elevated H_2O_2 service
Kanegin Coated and Tin-Plated Metals	Keystone Chromium	2	9	Plating	No effect upon material

TABLE 4.17
(Continued)

Material	Source	Class	Percent AOL per Week at 151 F	Applications	Remarks
Recommended Coatings for Splash-Resistance Service to 90 w/o H_2O_2					
Omni (Viton A)	David Clark	2	-	Glass, Dacron, or Teflon cloth impregnated with Viton	Curtains, equipment covers
Teflon (TFE sheet)	DuPont	1	-	Films	Drop cloths, curtains, covers for equipment
Viton A	DuPont	2	-	Sheet form	Curtains, cover cloths, etc.
Metallic Aluminum (nonvolatile carrier)	Various suppliers	-	-	Paint	Excellent field experience for painting metal surfaces
Aluminum Foil	Various suppliers	1-2	-	Foil and film	Coverings for various items
Plastic Metal No. 22 (plastic paint)	National Engineering Products	2	-	Applied as ordinary paint	One small blister in 48 hours; three small blisters in 9 days (most favorable for splash resistance)
Mylar (plastic)	DuPont	1	-	Film	Coverings, splash shields
Scotch Pak (plastic)	Various suppliers	1	-	Film	Coverings, splash shields
Kanegin (electroless nickel)	Keystone Chromium	2	-	Plating	Excellent coating for mild steel and other metals)
Tin-Plated Kanegin	Keystone Chromium	2	-	Plating	Very low H_2O_2 loss upon H_2O_2 contact
Tygon Paint 7286 TP-81-Clear		-	-	Applied as ordinary paint	Blistered in 24 hours; no other effects noted
Tygon Paint 71253 TY-107B	U.S. Stoneware	-	-	Applied as ordinary paint	Blistered in 24 hours
Corrosite No. 521	Corrosite Corp.	-	-	Applied as ordinary paint	Blistered in 24 hours
Corrosite No. 551	Corrosite Corp.	-	-	Applied as ordinary paint	Blistered in 24 hours
Corrosite No. 581	Corrosite Corp.	-	-	Applied as ordinary paint	Blistered in 24 hours

TABLE 4.17
(Continued)

Material	Source	Class	Percent AGL per Week at 151 F	Applications	Remarks
Saran Rubber Q-1875	Dow Chemical	-	-		Softened and blistered in 1 week; specially applied by manufacturer
MV—Type No. 150	Gregg	-	-		Blistered in 48 hours
Amercoat No. 1262	American Pipe & Construction	-	-		Blistered in 48 hours
Heilex	Heil Process	-	-		One small blister in 24 hours; applied by fabricator
P-5, Co-Polymer	Watson Standard	-	-	Applied as ordinary paint	Blistered in 24 hours
Neolac Gray No. 8588	Chamberlain Engineering	-	-	Applied as ordinary paint	Blistered in 24 hours
Steelcote Stainless	Steelcote Mfg.	-	-	Applied as ordinary paint	Small blisters overnight

TABLE 4.17
(Concluded)

Material	Source	Results	Remarks
Coatings Not Recommended for 90 Percent H_2O_2 Service			
Geon Latex 31X	B. F. Goodrich	Blistered in 24 hours	Difficulty encountered in application
Flexcoat No. 1 Black	Bison Chemicals	Blistered in 16 hours	Blisters encountered in vapor phase
Lithgow LC-600 (grey)	Lithgow	Blistered in 24 hours	Applied by manufacturer
Amercoat Red	American Pipe & Construction	Blistered in 7 hours	
Prufcoat Medium Grey	Prufcoat Labs	Blistered in 24 hours	Applied by manufacturer
Lithgow LC-600 (brown)	Lithgow	Small blisters in 7 hours	Applied by manufacturer
Veloform F-10 CPP304	Firestone Rubber	Blistered heavily in 16 hours	Applied by fabricator
Cordo S-255 A	Cordo Chemical	Coating blistered in 12 hours	Applied by dipping
Cordo Plastic Coating (E-1 Resin + H-26 Activator)	Cordo Chemical	Excessive H_2O_2 decomposition and blister formation	Applied by laboratory per instructions
Chromalloy	—	High rate of H_2O_2 decomposition and chrome leaching	Applied by manufacturer to low-carbon steel samples
Unichrome Drum Lining B-124-17	United Chromium	Heavy blisters in 20 hours at 30 C; heavy blisters in 3 hours at 66 C	Applied by manufacturer
Ucilon System E Coating	United Chromium		
EX 63B Paint	American Paint		
Sealer EC 801 with Accelerator	Minnesota Mining & Mfg		
Penton Lining on 1060 Aluminum	Buffalo Lining & Fabricating		

(1) Data taken from Ref. 4.25
(2) Data taken from Ref. 4.29
(3) Percent AOL/month at 86 F

NOTE: The aluminum alloys all show good splash resistance. Any nonflammable plastics or metals listed in the previous tables having Class 1 through 3 are suitable for use as splash resistant materials.

TABLE 4.18

EVALUATION OF CLOTHING MATERIALS FOR CONTACT WITH 90 W/O HYDROGEN PEROXIDE[1]

Sample	Source	Percent AOL per Month at 86 F	Percent AOL per Week at 151 F	Inflammability Drip Tests		Remarks
				Clean	Soiled	
Permeable						
Dacron						
Monofilament	U.S. Rubber Co.	1.0	12.1	No effect	No effect[2]	Apparently no damage
Heavy Pile	G. W. Borg Co.	0.5	13.0	No effect	No effect[2]	Apparently no damage
Staple Fabric	Travis Fabrics, Inc.	0.8	13.4	No effect	No effect[2]	Apparently no damage
Saran						
Monofilament	Saran Yarns Co.	0.5	6.0	No effect	No effect[2]	Apparently no damage
Dacron-Wool						
55 to 45 percent	Deering Milliken	0.7	7.1	No effect	No effect	Weakened
Dynel	Burlington Mills	-	-	No effect	Burned	Partially dissolved at 66 C (151 F)
Saran (staple)	Saran Yarns Co.	1.3	4.0	No effect	Burned	Partially dissolved at 66 C (151 F)
Vinyon "N"	Milburn Co.	1.9	4.0	No effect	Burned	Partially dissolved at 66 C (151 F)
Impermeable						
Polyvinylchloride	Milburn Co.	0.2	3.6	Not tested		Hardens on prolonged contact at 66 C (151 F); bleaches
Flexigrip Zipper (vinyl)	Flexigrip, Inc.	1.0	4.8	No effect	Distorts	Hardens on prolonged contact at 66 C (151 F)

(1) Data taken from Ref. 4.25

(2) Some Dacron samples may burn upon contact with 90 percent H_2O_2 when soiled with catalyst.

TABLE 4.18a

CLOTHING MATERIALS NOT SUITABLE FOR USE WHEN HANDLING 90 W/O HYDROGEN PEROXIDE[1]

Sample	Effect of Sample on H_2O_2	Effect of H_2O_2 on Sample
Permeable		
Cotton, Drill	Moderate decomposition	Burns readily when soiled
Cotton, Rayon (50-50)	Moderate decomposition	Burns readily when soiled
Dacron, Viscose (50-50)	Moderate decomposition	Weakens considerably
Leather	—	Burns readily
Linen, Bleached	Moderate decomposition	Burns readily
Linen, Unbleached	Moderate decomposition	Burns readily when soiled
Rayon	Moderate decomposition	Burns readily when soiled
Silk, Degummed Fiber	—	Dissolved
Wool	Moderate decomposition	Weaks considerably; crumbles when touched
Impermeable		
Aluminized Cotton Duck	Moderate decomposition	Burns readily when soiled

[1] Data taken from Ref. 4.25

TABLE 4.19

COMPATIBILITY OF VARIOUS METALS WITH 98 W/O HYDROGEN PEROXIDE AT HIGH TEMPERATURES[1]

(Exposure at 270 F for 1 Hour)

Material	Weight Change During Test[2], gram	H_2O_2 Concentration Change, percent	Appearance After Test[3]
Inconel 718[5]	-0.0003	11.7	Light bronzing of the metal
304 Stainless Steel[4]	None	14.5	Heavily bronzed
304 Stainless Steel[5]	Not measured	--	Sample of H_2O_2 decomposed violently upon reaching 270 F. No change in specimen appearance.
316 Stainless Steel[4]	-0.0008	6.8	Heavily bronzed
316 Stainless Steel[4]	+0.0013	1.2	No change in specimen appearance
347 Stainless Steel[5]	-0.0002	11.2	Lightly bronzed
347 Stainless Steel[5]	+0.0003	1.3	No change in specimen appearance
Hastelloy-C[4]	-0.0014	9.0	Slightly bronzed
Hastelloy-X[4]	-0.0036	51.8	No apparent change
Equipment Test (Pyrex)	No metal sample	0.6	No change in specimen appearance

TABLE 4.19

(Concluded)

(1) Data taken from Ref. 4.29.

(2) Weight changes of less than 0.004 gram are not considered significant.

(3) All specimens were examined at 100X after testing. In no case was there any discernible difference in the surfaces of the blanks and the treated specimens other than the reported color change.

(4) The specimens were passivated by treatment for 4 hours in 70-percent HNO_3 at room temperature, washed with tap water, rinsed with distilled water, blotted dry with filter paper, and then oven-dried at 220 F.

(5) The specimens were passivated by treatment for 2 hours in 2-percent $Na_2Cr_2O_7$ solution at room temperature, washed with water, immersed in a 20-percent HNO_3 solution, rinsed with distilled water, and then oven-dried at 220 F.

TABLE 4.20

COMPATIBILITY OF 90-PERCENT HYDROGEN PEROXIDE WITH 1060 AND 1100 ALUMINUM ALLOYS[1]

Material Form[2]	Surface Condition	Exposure		Percent		Exposure Response
		Temperature, F	Time, days	AOL	Stability	
1060 Alloy	Unanodized RMS 90	110	10	0.2	92.3	No effect
1060 Alloy, H12 Temper	Unanodized RMS 89	110	10	0.2	92.4	No effect
1060 Alloy	Anodized RMS 90	110	10	0.3	97.2	No effect
1060 Alloy, H12 Temper	Anodized RMS 89	110	10	0.3	97.5	No effect
1060 Alloy	Unanodized	75	10	0.6	98.8	No effect
1060 Alloy	Unanodized	40	10	0.7	99.0	Discolored
1100 Alloy	Unanodized RMS 20	110	10	1.4	95.2	White coating
1100 Alloy	Anodized RMS 20	110	10	2.0	96.7	Grey coating

(1) Data taken from Ref. 4.10, 4.12, and 4.13.

(2) Passivation procedure CVA10-62a; no surface treatment; surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.21

COMPATIBILITY OF 90 W/O HYDROGEN PEROXIDE WITH 6061-T6 ALUMINUM SHEET[1][2]

Surface Condition	Passivation Procedure	Surface Posttreatment	Percent		Exposure		Exposure Response
			AOL	Stability	Temperature, F	Time, days	
Unanodized RMS 11-14	CVA 10-62a	None	5.4	94.2	151	7	Frosty sheen
Unanodized RMS 47	North American LA 0110-003	None	3.1	93.8	151	7	Spotty, dull
Unanodized RMS 65	North American LA 0110-003	None	2.9	96.2	151	7	Spotty, dull
Unanodized RMS 91	North American LA 0110-003	None	2.3	97.3	151	7	Spotty, dull
Unanodized RMS 207	North American LA 0110-003	None	2.3	97.0	151	7	Spotty, dull
Unanodized RMS 351	North American LA 0110-003	None	3.4	96.3	151	7	Spotty, dull
Unanodized	North American LA 0110-003	None	2.9	92.4	151	7	No effect
Unanodized	CVA 10-62a	1 AOL cycle exposure	1.8	96.9	151	7	Dull discoloration
Unanodized	CVA 10-62a	2 AOL cycles exposure	0.5	98.5	151	7	Light smutting
Unanodized	CVA 10-62a	"Farrelok" 2 AOL cycles	1.7	95.5	151	7	No effect

(1) Data taken from Ref. 4.14, 4.15.

(2) Thickness = 0.063 in.; surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.21

(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Percent		Exposure		Exposure Response
			AOL	Stability	Temperature, F	Time, days	
Unanodized	FMC Bulletin 104	1 AOL cycle 7 days at 151 F	1.5	95.7	151	7	Spotted
Unanodized	FMC Bulletin 104	2 AOL cycles 7 days at 151 F	1.6	97.2	151	7	Spotted, frosted
Unanodized	North American LA 0110-003	None	2.9	92.4	151	7	No effect
Unanodized	North American LA 0110-003	1 AOL cycle 7 days at 151 F	1.3	97.9	151	7	Dull grey color
Unanodized	North American LA 0110-003	2 AOL cycles 7 days at 151 F	1.0	98.3	151	7	No effect
Unanodized	North American LA 0110-003	None	12.0	86.0	151	7	No effect
Unanodized RMS 21	FMC Bulletin 104	None	1.1	97.3	110	10	No effect
Unanodized RMS 21	North American LA 0110-003	None	0.9	97.7	110	10	No effect
Unanodized RMS 21	Walter Kidde 520007	None	1.5	97.7	110	10	No effect
Unanodized RMS 21	McDonnell 13002	None	2.2	92.9	110	10	White deposit
Unanodized RMS 21	CVA 10-62a	None	2.3	97.4	110	10	White deposit

TABLE 4.21

(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Percent		Exposure		Exposure Response
			AOL	Stability	Temperature, F	Time, days	
Unanodized RMS 66	CVA 10-62a	None	2.6	82.4	110	10	No effect
Unanodized RMS 100	CVA 10-62a	None	2.4	85.4	110	10	No effect
Anodized RMS 13-18	CVA 10-62a	None	6.2	91.7	151	7	Frosty, spotty
Anodized RMS 7	North American LA 0110-003	None	0.7	97.7	151	7	Uniformly dulled
Anodized RMS 44	North American LA 0110-003	None	0.9	97.5	151	7	Uniformly dulled
Anodized RMS 87	North American LA 0110-003	None	1.2	97.7	151	7	Uniformly dulled
Anodized RMS 202	North American LA 0110-003	None	1.1	97.8	151	7	Uniformly dulled
Anodized RMS 380	North American LA 0110-003	None	1.1	97.8	151	7	Uniformly dulled
Anodized	CVA 10-62a	None	2.9	96.8	151	7	No effect
Anodized	CVA 10-62a	1 AOL cycle 7 days at 151 F	2.1	97.6	151	7	No effect
Anodized	CVA 10-62a	2 AOL cycles 7 days at 151 F	1.5	98.2	151	7	No effect
Anodized	CVA 10-62a	"Farrellok"	64.6	0.0	151	7	No effect

TABLE 4.21
(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Percent		Exposure		Exposure Response
			AOL	Stability	Temperature, F	Time, days	
Anodized	CVA 10-62a	"Farrellok" 1 AOL cycle 7 days at 151 F	7.3	0.0	151	7	No effect
Anodized	CVA 10-62a	"Farrellok" 2 AOL cycles 7 days at 151 F	1.4	95.4	151	7	No effect
Anodized	North American LA 0110-003	None	2.7	97.2	151	7	No effect
Anodized	North American LA 0110-003	1 AOL cycle 7 days at 151 F	1.7	97.7	151	7	No effect
Anodized	North American LA 0110-003	2 AOL cycles 7 days at 151 F	1.4	98.0	151	7	No effect
Anodized	CVA 10-62a	2 weeks storage in N_2 gas	2.1	95.3	151	7	No effect
Anodized	CVA 10-62a	2 weeks storage in polyethylene at 160 F	2.6	93.8	151	7	No effect
Anodized	CVA 10-62a	2 weeks storage in 100 percent RH at 160 F	5.1	90.3	151	7	No effect
Anodized *S/V Ratio 0.38 $in.^{-1}$	North American LA 0110-003	None	1.8	76.9	110	10	Spotty, frosted surface

TABLE 4.21

(Concluded)

Surface Condition	Passivation Procedure	Surface Posttreatment	Percent		Exposure		Exposure Response
			AOL	Stability	Temperature, F	Time, days	
Anodized S/V Ratio 0.76 $in.^{-1}$	North American LA 0110-003	None	3.5	67.3	110	10	Frosted surface
Anodized S/V Ratio 1.15 $in.^{-1}$	North American LA 0110-003	None	5.6	43.8	110	10	Frosted surface
Anodized S/V Ratio 1.53 $in.^{-1}$	North American LA 0110-003	None	7.8	26.8	110	10	Spotty, frosted surface
Anodized S/V Ratio 1.91 $in.^{-1}$	North American LA 0110-003	None	7.8	0.0	110	10	Frosted surface
Anodized MS 66	CVA 10-62a	None	5.5	64.4	110	10	No effect
Anodized MS 100	CVA 10-62a	None	3.8	80.8	110	10	No effect

TABLE 4.22

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH 304 STAINLESS STEEL[1]

Material Form[2]	Surface Condition	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
Sheet	RMS 7	35-percent H_2O_2[3]	151	7	9.0	86.8	Spotty bronzing
Sheet	RMS 45	35-percent H_2O_2[3]	151	7	12.3	81.9	Spotty bronzing
Sheet	RMS 66	35-percent H_2O_2[3]	151	7	10.0	85.9	Spotty bronzing
Sheet	RMS 174	35-percent H_2O_2[3]	151	7	10.7	83.4	Spotty bronzing
Sheet	RMS 256	35-percent H_2O_2[3]	151	7	11.4	80.1	Spotty bronzing
Sheet	RMS 5-8	None	151	7	6.5	95.9	Slight bronzing
Annealed Sheet	RMS 14	None	110	10	4.6	90.3	Mottled bronzing
Annealed Sheet	RMS 14	35-percent H_2O_2[3]	110	10	3.7	90.1	Light bronzing

[1]Data taken from Ref. 4.14 and 4.15

[2]Passivation procedure CVA 10-62a; surface/volume ratio = 0.38 $in.^{-1}$

[3]Posttreatment was in 35-percent hydrogen peroxide inhibited with 0.03-percent phosphoric acid

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH 316L STAINLESS STEEL(1)(2)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
Sheet Stock t = 0.063							
RMS 48	CVA 10-62a	None	110	10	4.2	85.5	Spotty bronze
RMS 80	CVA 10-62a	None	110	10	3.6	87.1	Spotty bronze
RMS 48	CVA 10-62a	35-percent H_2O_2	110	10	2.2	83.3	Spotty bronze
RMS 80	CVA 10-62a	35-percent H_2O_2	110	10	2.0	86.1	Spotty bronze
RMS 13	FMC Bulletin 104	None	110	10	5.4	95.7	Slightly bronzed
RMS 13	North American LA 0110-003	None	110	10	4.6	96.7	Slightly bronzed
RMS 13	Walter Kidde 520007	None	110	10	7.0	95.2	Slightly bronzed
RMS 13	McDonnell A/C 13002	None	110	10	7.8	95.4	Slightly bronzed
RMS 13	CVA 10-62a	None	110	10	7.5	95.1	Slightly bronzed
Emery Paper Buffed	CVA 10-62a	35-percent H_2O_2	75	10	1.4	97.6	Uniformly bronzed
Emery Paper Buffed	CVA 10-62a	35-percent H_2O_2	40	10	1.2	99.0	Lightly bronzed

TABLE 4.23

(Concluded)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
Tubing							
RMS 8	CVA 10-62a	35-percent H_2O_2	110	10	3.3	95.5	Uniformly bronzed
RMS 8	Walter Kidde 520007	None	110	10	4.1	93.6	Uniformly bronzed
RMS 8	CVA 10-62a	35-percent H_2O_2	110	7	2.3	95.5	Lightly bronzed
RMS 8	Walter Kidde 520007	None	110	7	3.0	92.8	Lightly bronzed
RMS 8	CVA 10-62a	35-percent H_2O_2	110	5	1.1	97.3	Lightly bronzed
RMS 8	CVA 10-62a	35-percent H_2O_2	110	3	0.6	98.8	Lightly bronzed
RMS 8	Walter Kidde 520007	None	110	3	1.1	97.6	Lightly bronzed

(1) Data taken from Ref. 4.11, 4.12, and 4.18

(2) Sheet stock; surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.24

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH 321 STAINLESS STEEL(1)(2)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
0.063-Inch Sheet Stock							
Emery Paper Buffed	CVA 10-62a	None	151	7	10.3	87.5	Spotty bronze
Emery Paper Buffed	CVA 10-62a	1 AOL cycle 7 days at 151 F	151	7	3.7	97.8	Spotty bronze
Emery Paper Buffed	CVA 10-62a	2 AOL cycles 7 days at 151 F	151	7	3.6	98.6	Blue-bronze
Emery Paper Buffed	CVA 10-62a	35-percent H_2O_2	151	7	7.0	93.1	No effect
Emery Paper Buffed	CVA 10-62a	35-percent H_2O_2, 1 AOL cycle 7 days at 151 F	151	7	3.1	97.8	Light bronze
Emery Paper Buffed	CVA 10-62a	35-percent H_2O_2, 2 AOL cycles 7 days at 151 F	151	7	2.6	98.6	Light bronze
Emery Paper Buffed	CVA 10-62a	"Farrellok"	151	7	14.6	76.6	Uniform bronze
Emery Paper Buffed	CVA 10-62a	"Farrellok," 1 AOL cycle 7 days at 151 F	151	7	4.4	97.6	Uniform bronze

TABLE 4.24

(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
0.063-Inch Sheet Stock							
Emery Paper Buffed	CVA 10-62a	"Farrellok" + 2 AOL cycles 7 days at 151 F	151	7	3.8	98.3	Orange-bronze
Emery Paper Buffed	North American LA 0110-003	None	151	7	18.5	59.1	Uniform bronze
Emery Paper Buffed	North American LA 0110-003	1 AOL cycle 7 days at 151 F	151	7	6.4	96.5	Spotty bronze
Emery Paper Buffed	North American LA 0110-003	2 AOL cycles 7 days at 151 F	151	7	4.7	97.8	Brown-bronze
Emery Paper Buffed	CVA 10-62a	2 weeks storage in dry N_2 gas	151	7	5.2	94.7	Spotty bronze
Emery Paper Buffed	CVA 10-62a	2 weeks storage polyethylene bag at 160 F	151	7	4.8	94.1	Uniform bronze
Emery Paper Buffed	CVA 10-62a	2 weeks storage 100-percent RH at 160 F	151	7	4.8	94.9	Uniform bronze
RMS 4-6	CVA 10-62a	None	151	7	7.9	94.3	Light bronze
RMS 96	CVA 10-62a	None	110	10	2.9	85.7	Bronzed
RMS 50	CVA 10-62a	None	110	10	3.6	83.2	Irregular bronze
RMS 96	CVA 10-62a	35-percent H_2O_2	110	10	1.7	86.9	Spotty bronze

TABLE 4.24

(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
0.063-Inch Sheet Stock							
RMS 50	CVA 10-62a	35-percent H_2O_2	110	10	2.9	82.8	Spotty bronze
Buffed, S/V Ratio 0.38 $in.^{-1}$	LTV 308-20-3	None	110	10	10.0	55.5	Severely bronzed
Buffed, S/V Ratio 0.76 $in.^{-1}$	LTV 308-20-3	None	110	10	20.6	11.6	Severely bronzed
Buffed, S/V Ratio 1.15 $in.^{-1}$	LTV 308-20-3	None	110	10	35.2	0.0	Severely bronzed
Buffed, S/V Ratio 1.53 $in.^{-1}$	LTV 308-20-3	None	110	10	51.6	0.0	Severely bronzed
Buffed, S/V Ratio 1.91 $in.^{-1}$	LTV 308-20-3	None	110	10	88.2	0.0	Severely bronzed

TABLE 4.24

(Continued)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
0.25-Inch Tubing							
Emery Paper Buffed	Detergent clean	None	110	10	2.9	90.2	Yellow-bronze
Emery Paper Buffed	LTV 308-20-3	None	110	10	2.7	93.5	Faint yellow
Emery Paper Buffed	LTV 308-20-3 HNO_3 Sol. 75 F	Oven-baked at 750 F	110	10	1.4	94.3	Mottled tan-blue
Emery Paper Buffed	Detergent clean	Oven-baked at 750 F	110	10	2.6	89.4	Iridescent straw-copper
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 600 F	110	10	5.0	74.7	Iridescent gray-bronze
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 700 F	110	10	3.3	81.9	Iridescent gray-bronze
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 750 F	110	10	2.2	88.2	Iridescent gray-orange
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 800 F	110	10	0.7	97.6	Light pink-straw color
RMS 12	CVA 10-62a	35-percent H_2O_2	110	10	2.4	95.1	Slightly bronzed
RMS 12	Walter Kidde 520007	None	110	10	2.8	94.8	Slightly bronzed
Buffed, S/V Ratio, $in.^{-1}$ 1.91	LTV 308-20-3	None	110	10	16.4	0.0	Light bronzing

TABLE 4.24
(Concluded)

Surface Condition	Passivation Procedure	Surface Posttreatment	Exposure		Percent		Exposure Response
			Temperature, F	Time, days	AOL	Stability	
0.25-Inch Tubing							
Buffed, S/V Ratio, 1.91 in.$^{-1}$	North American LA 0110-003	None	110	10	22.5	0.0	Severely bronzed
RMS 12	CVA 10-62a	35-percent H_2O_2	110	7	1.8	95.5	Slightly bronzed
RMS 12	Walter Kidde 520007	None	110	7	2.2	96.9	Slightly bronzed
RMS 12	CVA 10-62a	35-percent H_2O_2	110	5	1.3	96.0	Lightly bronzed
RMS 12	Walter Kidde 520007	None	110	5	1.4	96.6	Lightly bronzed
RMS 12	CVA 10-62a	35-percent H_2O_2	110	3	0.7	98.3	No effect
RMS 12	Walter Kidde 520007	None	110	3	1.1	97.6	No effect

(1) Data taken from Ref. 4.13, 4.14, and 4.15

(2) Surface/volume ratio = 0.38 in.$^{-1}$

TABLE 4.25

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SELECTED STAINLESS STEEL ALLOYS(1) (2)

Stainless-Steel Alloy	Surface Condition	Passivation Procedure	Surface Posttreatment	Percent AOL	Percent Stability	Exposure		Exposure Response
						Temperature, F	Time, days	
17-H PH Sheet	RMS 7-8	CVA 10-62a	None	55.7	0.0	151	7	No effect
17-4 PH Sheet, HT R-900	RMS 87	Walter Kidde 520007	None	10.7	65.3	110	10	No effect
17-4 PH Sheet, HT R-900	RMS 40	Walter Kidde 520007	None	13.0	30.3	110	10	No effect
17-4 PH Sheet, HT R-900	RMS 113	Walter Kidde 520007	None	19.7	21.2	110	10	Darkened, spotty
17-4 PH Sheet HT R-900	RMS 113	Walter Kidde 520007	None	18.9	24.3	110	10	Heavily bronzed
17-7 PH Sheet, HT TH-1050	RMS 58	CVA 10-62a	35-percent H_2O_2	15.8	24.8	110	10	Heavily bronzed
17-7 PH Sheet, HT TH-1050	RMS 57	CVA 10-62a	None	13.3	58.5	110	10	Heavily bronzed

(1) Data taken from Ref. 4.15
(2) Surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.25

(Concluded)

Stainless-Steel Alloy	Surface Condition	Passivation Procedure	Surface Posttreatment	Percent AOL	Percent Stability	Exposure		Exposure Response
						Temperature, F	Time, days	
302 Cold Drawn Wire	RMS 94	CVA 10-62a	35-percent H_2O_2	4.3	92.8	110	10	Slightly bronzed
302 Cold Drawn Wire	RMS 94	CVA 10-62a	None	3.7	90.1	110	10	Severely bronzed
347 Sheet	RMS 88	CVA 10-62a	None	3.4	86.5	110	10	Bronzed
347 Sheet	RMS 88	CVA 10-62a	35-percent H_2O_2	2.2	83.0	110	10	Bronzed
347 Sheet	RMS 39	CVA 10-62a	None	4.0	84.9	110	10	Bronzed
347 Sheet	RMS 39	CVA 10-62a	35-percent H_2O_2	3.5	83.6	110	10	Dull bronze

TABLE 4.26

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH VICONE 185 ELASTOMER(1) (2)

Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
		Temperature F	Time, days			
North American LA 0110-003	None	160	7	2.5	98.9	Bleached
CVA 10-64a	None	110	10	0.9	92.0	Bleached
CVA 10-64a	5-percent HNO_3	110	10	0.9	93.6	Bleached
FMC Bulletin 104	None	110	10	0.4	99.4	Bleached
North American LA 0110-003	None	110	10	0.9	99.5	Bleached
Walter Kidde 520007	None	110	10	0.2	99.4	Bleached
McDonnell A/C 3002	None	110	10	0.5	99.4	Bleached
CVA 10-64a	None	110	10	0.3	99.4	Bleached
CVA 10-64a	5-percent HNO_3	75	10	0.8	98.9	Bleached
CVA 10-64a	5-percent HNO_3	40	10	0.8	98.7	Bleached

(1) Data taken from Ref. 4.12 and 4.16
(2) 0.063-inch sheet stock; surface condition as fabricated

TABLE 4.27

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SILASTIC 9711 ELASTOMER SHEET(1) (2)

Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
		Temperature, F	Time, days			
North American LA 0110-003	None	160	7	6.5	98.8	Slight blister
CVA 10-64a	None	151	7	5.3	99.2	No effect
CVA 10-64a	1 AOL cycle 7 days at 151 F	151	7	5.8	98.9	Dimpled, spotty
CVA 10-64a	2 AOL cycles 7 days at 151 F	151	7	5.5	99.1	Opaque blisters
CVA 10-64a	"Farrellok"	151	7	3.4	99.2	No effect
CVA 10-64a	"Farrellok" 1 AOL cycle 7 days at 151 F	151	7	4.1	99.2	Spotty
CVA 10-64a	"Farrellok" + 2 AOL cycles 7 days at 151 F	151	7	4.1	99.1	Opaque blisters
FMC Bulletin 104	None			4.8	99.2	No effect
FMC Bulletin 104	1 AOL cycle 7 days at 151 F	151	7	4.8	99.2	Dimpled, spotty
FMC Bulletin 104	2 AOL cycles 7 days at 151 F	151	7	4.6	99.2	Opaque blisters
Walter Kidde 520007	None	151	7	5.2	99.4	No effect

(1) Data taken from Ref. 4.16 and 4.17
(2) Sheet thickness = 0.063 inch; surface/volume ratio (S/V) = 0.38 $in.^{-1}$ except where otherwise noted

TABLE 4.27

(Continued)

Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
		Temperature, F	Time, days			
Walter Kidde 520007	1 AOL cycle 7 days at 151 F	151	7	5.5	99.0	Spotty
Walter Kidde 520007	2 AOL cycles 7 days at 151 F	151	7	5.2	98.6	Opaque Blisters
CVA 10-64a	2 weeks storage in dry N_2 gas	151	7	5.7	99.0	No effect
CVA 10-64a	2 weeks storage polyethylene bag at 160 F	151	7	5.7	99.0	No effect
CVA 10-64a	2 weeks storage 100-percent RH at 160 F	151	7	5.2	98.9	No effect
CVA 10-64a	None	151	7	4.3	98.8	No effect
CVA 10-64a	None	151	7	3.7	97.4	Bleached
CVA 10-64a	5-percent HNO_3	110	10	2.8	96.9	Bleached
North American LA 0110-003	None	110	10	2.9	99.2	Bleached
Walter Kidde 520007	None	110	10	1.7	99.4	No effect
Walter Kidde 520007 (S/V = 0.76/in.)	None	110	10	3.2	99.3	No effect

TABLE 4.27

(Concluded)

Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
		Temperature, F	Time, days			
Walter Kidde 520007 (S/V = 1.15/in.)	None	110	10	5.3	99.2	No effect
Walter Kidde 520007 (S/V = 1.53/in.)	None	110	10	6.9	98.0	No effect
Walter Kidde 520007 (S/V = 1.91/in.)	None	110	10	7.9	99.1	No effect

TABLE 4.28

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SELECTED VITON ELASTOMERIC MATERIALS(1) (2)

Material Form	Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
			Temperature, F	Time, days			
Fluorel 2141 1/16-Inch Sheet	North American LA 0110-003	None	160	7	4.3	98.2	Blistered, swelled
Fluorel 2141 1/16-Inch Sheet	North American LA 0110-003	None	110	10	1.1	98.8	No effect
Parker V359-7 Batch 04107	CVA 10-64a	None	151	7	11.5	91.9	Blistered, exudate
Parker 77-545 Batch 03888	CVA 10-64a	None	151	7	5.9	95.6	Blistered, distorted
Stillman SR-27-770	CVA 10-64a	None	151	7	2.4	98.6	Light blister
Viton A Parker V359-7	CVA 10-64a	None	110	10	2.5	95.0	Bleached black to grey
Viton A Parker V359-7	CVA 10-64a	5-percent HNO_3	110	10	2.4	85.8	Bleached black to grey

(1) Data taken from Ref. 4.16 and 4.17
(2) Surface condition as fabricated; surface/volume ratio = 0.39 $in.^{-1}$

TABLE 4.29

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SELECTED PLASTICS[1]

Material Form[2]	Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
			Temperature, F	Time, days			
Aclar 22C 5-Mil Sheet	North American LA 0110-003	None	160	7	0.5	98.7	No effect
Aclar 22C 2-Mil Sheet	CVA 10-64a	None	110	10	0.5	92.4	No effect
Aclar 22C 2-Mil Sheet	CVA 10-64a	5-percent HNO_3	110	10	0.1	91.5	No effect
Aclar 22C 5-Mil Sheet	FMC Bulletin 104	None	110	10	0.0	99.3	No effect
Aclar 22C 5-Mil Sheet	North American LA 0110-003	None	110	10	0.0	99.2	No effect
Aclar 22C 5-Mil Sheet	Walter Kidde 520007	None	110	10	0.2	99.4	No effect
Aclar 22C 5-Mil Sheet	McDonnell A/C 13002	None	110	10	0.0	99.2	No effect
Aclar 22C 5-Mil Sheet	CVA 10-64a	None	110	10	0.0	99.5	No effect

(1) Data taken from Ref. 4.17
(2) Surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.29
(Concluded)

Material Form[2]	Passivation Procedure	Surface Posttreatment	Exposure		Percent AOL	Percent Stability	Exposure Response
			Temperature F	Time, days			
Aclar 22C 20-Mil Sheet	North American LA 0110-003	None	110	10	0.1	99.1	No effect
Aclar 33C 5-Mil Sheet	CVA 10-64a	None	110	10	1.2	98.7	No effect
Aclar 33C 5-Mil Sheet	CVA 10-64a	5-percent HNO_3	110	10	2.1	97.9	No effect
"Fluorogold" Polytetra-fluoroethylene	CVA 10-64a	None	151	7	2.7	98.8	Bleached gold to white

TABLE 4.30

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SELECTED COMPOSITE MATERIALS[1] [2]

Composite	Surface Condition	Passivation Procedure	Exposure		Percent AOL	Percent Stability	Exposure Response
			Temperature, F	Time, days			
6061-T6 Al	Unanodized	North American LA 0110-003	160	7	10.6	87.2	No effect
+							
Aclar 22C	As fabricated						No effect
6061-T6 Al	Unanodized	North American LA 0110-003	160	7	10.2	92.9	Silastic adhered to aluminum
+							
Silastic 9711	As fabricated						
6061-T6 Al	Unanodized	North American LA 0110-003	160	7	15.2	83.0	Slight adhesion, Al-Vicone
+							
Vicone 185	As fabricated						
6061-T6 Al	Unanodized	North American LA 0110-003	160	7	10.2	90.6	Al etched, Fluorel blistered
+							
Fluorel 2141	As fabricated						
1060 Al	Anodized	FMC Bulletin 104	151	7	3.3	95.4	Frosted Al surface
+							
6061-T6 Al	Anodized						
6061-T6 Al	Anodized	FMC Bulletin 104	151	7	14.1	78.4	White oxide
+							
321 SS	Buffed						Bronzed severely
6061-T6 Al	Anodized	FMC Bulletin 104	151	7	14.0	30.6	White oxide
+							
316L SS	Buffed						Bronzed

(1) Data taken from Ref. 4.11
(2) Surface/volume ratio = 0.38 $in.^{-1}$

TABLE 4.30

(Concluded)

Composite	Surface Condition	Passivation Procedure	Exposure		Percent AOL	Percent Stability	Exposure Response
			Temperature, F	Time, days			
321 SS	Buffed	FMC Bulletin 104	151	7	24.0	45.2	Severely bronzed
+							
316L SS	Buffed						
1060 Al	Anodized	FMC Bulletin 104	110	10	0.4	98.3	No effect
+							
6061-T6 Al	Anodized						No effect
6061-T6 Al	Anodized	FMC Bulletin 104	110	10	3.7	89.8	Thin oxide
+							
321 SS	Buffed						Bronzed
6061-T6 Al	Anodized	FMC Bulletin 104	110	10	2.4	91.5	Thin oxide
+							
316L SS	Buffed						Bronzed
321 SS	Buffed	FMC Bulletin 104	110	10	4.9	85.6	Severely bronzed
+							
316L SS	Buffed						

TABLE 4.31

HETEROGENEOUS DECOMPOSITION RATE OF HYDROGEN PEROXIDE AS A FUNCTION OF SURFACE PREPARATION[1]

H_2O_2, w/o	Surface		S/V cm^{-1}	Decomposition Rate at 212 F		
	Type	Preparation[2]		Overall day^{-1}	Blank[3] day^{-1}	k_2,[5] cm/day
90[4]	1260 Aluminum	a,b,h	1.90	0.0626	0.0009	0.032
90	1260 Aluminum	a,b,g,h	2.29	0.0309	0.0144	0.0072
90	1260 Aluminum	a,b,i	1.71	0.0168	0.0008	0.0094
90	1260 Aluminum	a,b,g,i	2.18	0.0164	0.0042	0.0056
90	1260 Aluminum	a,b,j	2.06	0.0148	0.0009	0.0067
90	1260 Aluminum	a,b,j,g	2.66	0.0093	0.0048	0.0017
90	1260 Aluminum	a,b,k	1.65	0.0135	0.0009	0.0077
90	1260 Aluminum	a,b,g,k	2.19	0.0098	0.0053	0.0021
90	1260 Aluminum	q	2.01	0.0459	0.0051	0.020
90	1260 Aluminum	g,q	2.08	0.0325	0.0111	0.0103
90	301-T Stainless Steel	a,c,j	1.85	3.84	0.0019	2.07
90	301-T Stainless Steel	a,l	2.15	3.03	0.0011	1.41
90	301-T Stainless Steel	a,c,m	2.25	5.47	0.0009	2.42
90	2014 Aluminum	a,b,e,f	1.01	0.150	0.0066	0.141
90	2014 Aluminum	a,b,e,f,g	0.95	0.0156	0.0139	0.0018
90	2219 Aluminum	a,b,e,f	0.95	1.8	0.008	1.9
90	2219 Aluminum	a,b,e,f,g	1.02	0.296	0.142	0.053

TABLE 4.31

(Continued)

H_2O_2, w/o	Surface		S/V cm^{-1}	Decomposition Rate at 212 F		
	Type	Preparation		Overall day^{-1}	Blank day^{-1}	k_2,(5) cm/day
90	7039 Aluminum	a	2.29	0.343	0.0010	0.149
90	7039 Aluminum	a,g	2.97	0.0856	0.0127	0.024
90	7039 Aluminum	a,b,e,f	2.49	0.0709	0.0008	0.028
90	7039 Aluminum	a,b,e,f,g	4.53	0.0723	0.0090	0.0140
90	7039 Aluminum	a,b,e,f	1.07	0.0562	0.0063	0.047
90	7039 Aluminum	a,b,e,f,g	1.05	0.0204	0.0063	0.0134
99	7039 Aluminum	a,b,e,f,g	2.32	0.0364	0.0013	0.0151
98(6)	7039 Aluminum	a,b,e,f,g	4.30	0.0682	0.0314	0.0086
90	7039 Aluminum	a,b,e,f,g	4.24	0.0589	0.0063	0.0124
98	7039 Aluminum	a,b,e,f,g	4.39	0.0960	0.0050	0.0207
98	7039 Aluminum	a,b,e,f,g	4.67	0.124	0.006	0.0252
90	1260 Aluminum	a,b,e,f,g	2.07	0.0066	0.0032	0.0016
98	1260 Aluminum	a,b,e,f,g	1.97	0.0108	0.0024	0.0043
98	1260 Aluminum	a,b,e,f,g	2.22	0.0098	0.0025	0.0033
90	5052 Aluminum	a,b,e,f,g	2.93	0.0124	0.0065	0.0020
98	5052 Aluminum	a,b,e,f,g	2.22	0.0168	0.0024	0.0065
98	5052 Aluminum	a,b,e,f,g	2.97	0.0145	0.0047	0.0033
90	Kel-F	f	3.75	0.0191	0.0011	0.0048
90	Kel-F	f,g	4.68	0.0202	0.0015	0.0040
90	Teflon FEP	f	6.02	0.0717	0.0027	0.0115
90	Teflon FEP	f,g	6.97	0.0783	0.0011	0.0111
90	Tin on 5052 Aluminum	s	2.00	0.0536	0.0009	0.026
90(6)	Tin on 5052 Aluminum	g,s	3.05	0.0397	0.0126	0.0089
90(6)	Tin on 5052 Aluminum	s,t	1.77	0.0154	0.0068	0.0049
90(6)	Tin on 5052 Aluminum	g,s,t	2.33	0.0210	0.0015	0.0084

TABLE 4.31
(Continued)

H_2O_2, w/o	Surface		S/V	Decomposition Rate at 212 F		
	Type	Preparation	cm^{-1}	Overall day^{-1}	Blank day^{-1}	k_2,[5] cm/day
90[7]	Tin on 1260 Aluminum	u	2.61	0.0541	0.0041	0.0191
90[7]	Tin on 1260 Aluminum	g,u	2.62	0.0712	0.0395	0.0121
90[7]	Tin on 1260 Aluminum	u	2.15	0.0315	0.0047	0.0124
90[7]	Tin on 1260 Aluminum	g,u	2.22	0.0397	0.0261	0.0061
				Decomposition Rate at 176 F		
98	301-T Stainless Steel	a,g	1.68	1.37	0.000	0.82
98	301-T Stainless Steel	a,g	2.10	1.31	0.004	0.62
90	301-T Stainless Steel	a,c,e,f,g	1.83	1.12	0.001	0.61
90	301-T Stainless Steel	a,c,e,f,g	1.83	1.29	0.659	0.34
90	347 Stainless Steel	a,c,e,f,g	1.72	0.944	0.001	0.55
90	347 Stainless Steel	a,c,e,f,g	1.72	1.38	0.544	0.48
90	AM355 Stainless Steel	a,c,e,f	1.74	1.13	0.000	0.64
90	AM355 Stainless Steel	a,c,e,f,g	2.39	2.15	0.146	0.84
90	Almar 18-250	a,c,e,f	1.85	0.074	0.001	0.039
90	Almar 18-250	a,c,e,f,g	2.15	0.095	0.006	0.041
90	Almar 18-250	a,c,e,f,g	1.95	0.187	0.006	0.093
98	Almar 18-250	a,c,e,f,g	2.11	0.189	0.004	0.088
90	Almar 18-250	a,c,e,f,g	2.14	0.086	0.005	0.038
98	Almar 18-250	a,c,e,f,g	2.05	0.112	0.002	0.054
90	301-T Stainless Steel	a,c,j	1.85	1.68	0.000	0.91
90	301-T Stainless Steel	a,c,g,j	2.24	1.63	0.029	0.72
90	301-T Stainless Steel	a,g,l	2.76	1.21	0.088	0.41
90	301-T Stainless Steel	a,c,m	2.25	1.49	0.000	0.66
90	301-T Stainless Steel	a,c,g,m	2.76	3.11	0.243	1.04
90	301-T Stainless Steel	n,p	2.15	1.16	0.001	0.54

TABLE 4.31
(Concluded)

H_2O_2, w o	Surface		S/V cm^{-1}	Decomposition Rate at 77 F		
	Type	Preparation		Overall day^{-1}	Blank day^{-1}	k_2,[5] cm/day
90	347 Stainless Steel	a,c,e,f,g	1.72	0.00588	0.00182	0.00236
				Decomposition Rate at 32 F		
90	301-T Stainless Steel	a,c,e,f,g	1.83	0.00035	0.00010	0.00014

(1) Data taken from Ref. 4.9

(2) Surface preparation according to Table 4.31a

(3) For samples without treatment g, the blank is determined before addition of the test sample. With treatment g after repeated replacement of H_2O_2, the blank is determined after test and removal of the sample. The blank includes the homogeneous decomposition by contaminants and the heterogeneous decomposition due to the vessel walls, including any contaminants absorved there.

(4) 90 w/o H_2O_2 containing 3.4×10^{-5} mg/l $Na_2Sn(OH)_6$ and 6.9×10^{-5} mg/l HNO_3 stabilizer

(5) K_2 represents a specific rate constant for an assumed first order reaction at the liquid-surface interface

(6) 98 w/o H_2O_2 containing 8.4×10^{-6} mg/l tin stabilizer

(7) 90 w/o H_2O_2 containing no stabilizer

TABLE 4.31a

PROCEDURES USED FOR SURFACE PREPARATION IN TABLE 4.31

Note	Preparation Procedure
a	Sample degreased in aromatic solvent followed by a rinse in acetone, all at room temperature
b	Sample submerged in 1-percent NaOH for 10 minutes at room temperature
c	Sample submerged in 10-percent NaOH for 16 hours at room temperature
d	Sample submerged in 1-percent HNO_3 for 5 minutes at room temperature
e	Sample submerged in 35-percent HNO_3 for 16 hours at room temperature
f	Sample submerged in HP-90 until used for test, at room temperature
g	Sample submerged in stabilized HP-90 at the temperature of the test for 1- to 16-hour periods, followed by repeat treatments with fresh HP-90 until steady-state conditions appear to be achieved
h	Sample submerged in fused stearic acid for 1 hour at 80 to 100 C immediately after treatment by Procedure b
i	Sample submerged in 2-percent ethylene-diaminetetraacetic acid in 30-percent H_2SO_4 for 30 minutes at 80 to 90 C
j	Sample submerged in 1-percent disodium ethylenediaminetetraacetic acid in 35-percent HNO_3
k	Sample submerged in fused phthalic anhydride for 1 hour at 140 to 150 C immediately after treatment by Procedure b
l	Sample submerged in Viscasil 100,000, then wiped dry with absorbent tissue
m	Sample submerged in 85-percent H_3PO_4 for 16 hours at room temperature

TABLE 4.31a

(Concluded)

Note	Preparation Procedure
n	Sample submerged in 35-percent HNO_3 for 1 hour at 50 to 70 C
p	Sample submerged in 1-percent Viscasil in benzene, dried, re-submerged, and dried
q	Sample anodized in 25-percent H_3PO_4 at 1 amp/sq decimeter for 6 minutes at room temperature
s	Samples submerged in 2-percent NaOH for 2 hours, then in 2-percent HNO_3 for 10 minutes, then zincated. Samples zincated in 16-percent Na_2ZnO_2 - 40-percent NaOH solution for 30 seconds at room temperature. Samples were then rinsed well and submerged in 2-percent HNO_3 for 1 minute. Samples were then zincated again, rinsed, and submerged in 2-percent HNO_3 for 1 minute again. Samples were then electroplated by submerging in 6.4-percent stannous sulfate, 5.0-percent sulfamic acid, 0.5-percent dihydroxydiphenyl sulfone solution with the current on and maintained for 6 minutes at room temperature at 0.022 amp/cm^2 (20 amp/sq ft). Samples were then rinsed well and submerged in HP-90 for 20 hours.
t	Samples previously plated by procedure s were given an additional tin plate by submerging in 5.0-percent stannous sulfate, 5.0-percent sulfuric acid, 5.0-percent sodium sulfate, 0.4-percent gelatin, 0.2-percent m-cresol solution with the current on and maintained for 6 minutes at room temperature at 0.022 amp/cm^2. Samples were then rinsed well and submerged in HP-90 for 20 hours.
u	Samples were treated as in procedure s through the first zincating step. Samples were then zinc electroplated in 0.05-percent zinc chloride, 0.05-percent sodium cyanide, 1-percent sodium hydroxide solution for 1 minute at room temperature at 0.022 amp/cm^2. Samples were then rinsed and submerged in 2-percent HNO_3 for 1 minute and then tin electroplated as in s. The tin plate was then fused in a furnace at 265 C and then tin electroplated a second time. Samples were then rinsed well and submerged in HP-90 for 20 hours.

TABLE 4.32

COMPARISON OF THE VARIOUS METHODS OF TANK TEMPERATURE MEASUREMENT IN ORDER OF INCREASING COST (REF.4.64)

Methods	Advantages	Disadvantages	Approximate Cost
1. Bare hand on tank surface	A. Low cost B. Unlimited number of sensing points	A. Poor accuracy	
2. Temperature-sensitive paint on tank surface	A. Low cost B. Large areas could be covered	A. Limited number of sensitive temperatures B. Adversely affected by H_2S, SO_2 and NH_3	$25 to $50
3. Spot surface temperature consisting of bimetallic dial thermometer with sensitive part in aluminum block affixed to lower section of tank surface and insulated (used by Shell Chemical without alarm)	A. Low cost B. Actual temperature indication C. Linear temperature scale D. Not affected by high vapor space temperature	A. Some ambient temperature effects	$50 to $75
4. Same as No. 3 but installed in thermal well below liquid level	A. Relatively inexpensive B. Measures actual liquid temperature C. Linear temperature scale D. Not affected by high vapor space temperature E. Not affected by ambient temperature	A. Nozzle required	$75 to $100
5. Spot surface or thermal well installation using gas-filled thermal system with or without alarm contacts	Same as 3 and 4	Same as 3 and 4	$200 to $350
6. Surface temperature consisting of gas-filled dial thermometer with sensitive part in contact	A. Nozzle not required B. Measures average surface temperature C. Linear temperature scale	A. Same ambient effects B. Vapor space temperature would affect temperature indication at low liquid	$300 to $400

5. Spot surface or thermal well installation using gas-filled thermal system with or without alarm contacts	Same as 3 and 4	Same as 3 and 4	$200 to $350
6. Surface temperature consisting of gas-filled dial thermometer with sensitive part in contact with a section of the tank from horizontal centerline to bottom of the tank. Insulation applied.	A. Nozzle not required B. Measures average surface temperature C. Linear temperature scale	A. Same ambient effects B. Vapor space temperature would affect temperature indication at low liquid level	$300 to $400
7. Surface temperature (Belly-Band type) recorder consisting of vapor tension capillary and insulated	A. Nozzle not required B. Contacts large surface area C. Permanent temperature record	A. Thermal system tends to record warmest temperature along capillary 1. Would record vapor space temperature any time vapor is warmer than liquid B. Cost C. Temperature scale not linear and very difficult to read in lower range D. Good surface contact required E. Some ambient effect	$400 to $500
8. Same as 7 except using gas-filled capillary system	Same as 7 plus D. Linear temperature scale E. Indicates average surface temperature	A. Would average vapor space and liquid surface temperature B. Good surface contact required C. Some ambient effect D. Cost	$300 to $500
9. Weston Average Resistance Tank Temperature System consisting of an indicator switch to dial in the proper resistance corresponding to the liquid level	A. Up to six liquid levels B. Average temperatures below liquid level	A. Cost B. Maintenance C. Must enter tank with probe D. Must know liquid level	$1,000+
10. Multi-Point Temperature Recorder with or without alarm contact. (Used by Shell Chemical without alarm.)	A. Could also record ambient temperature B. Permanent visual record of all temperatures C. Linear scale	A. Cost B. Maintenance	$2,000 to $2,500

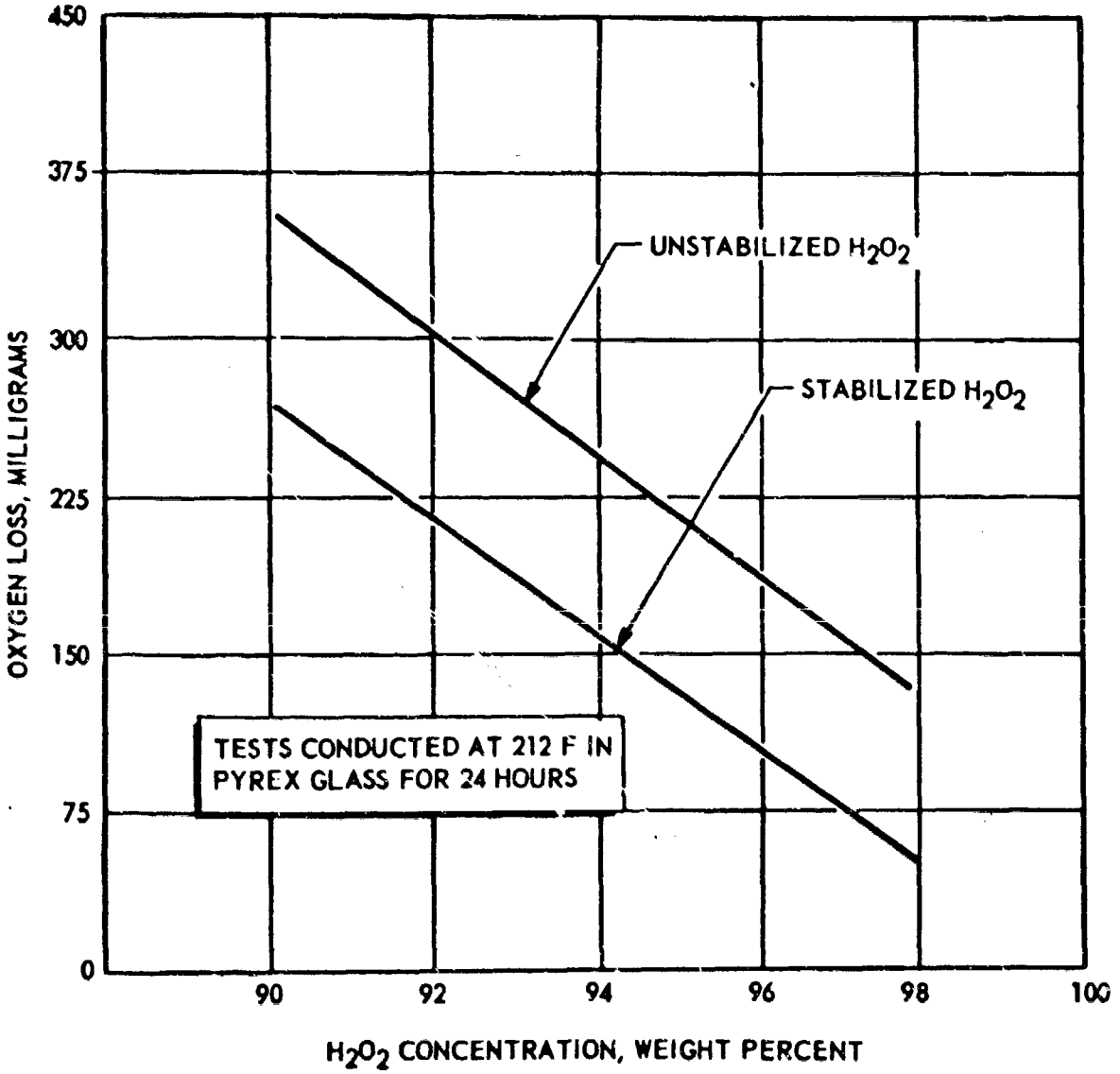


Figure 4.1. Stability of Hydrogen Peroxide as a Function of Concentration (Ref. 4.2)

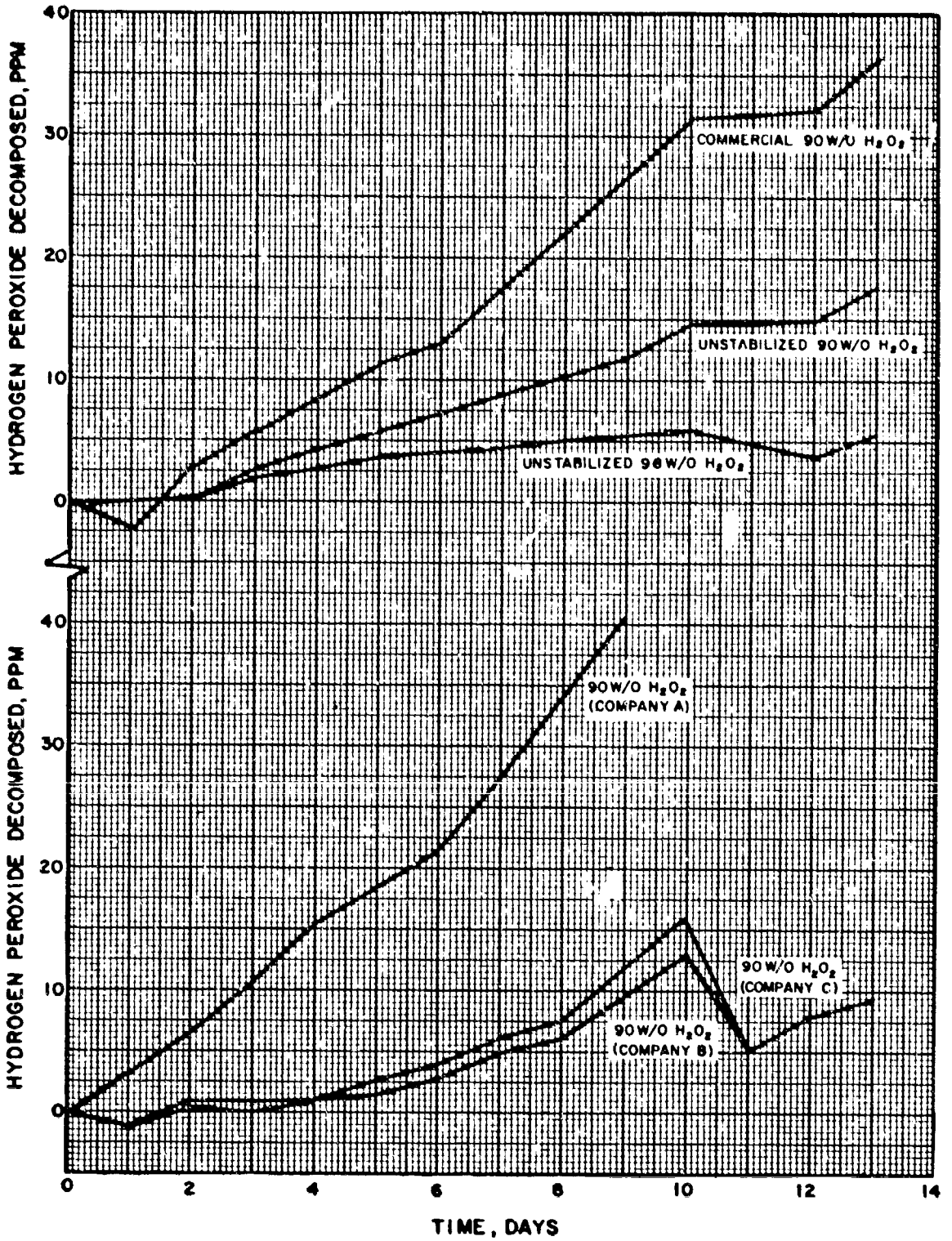


Figure 4.2. Typical Decomposition Rates for Various Hydrogen Peroxide Samples at 32 F (Ref. 4.6)

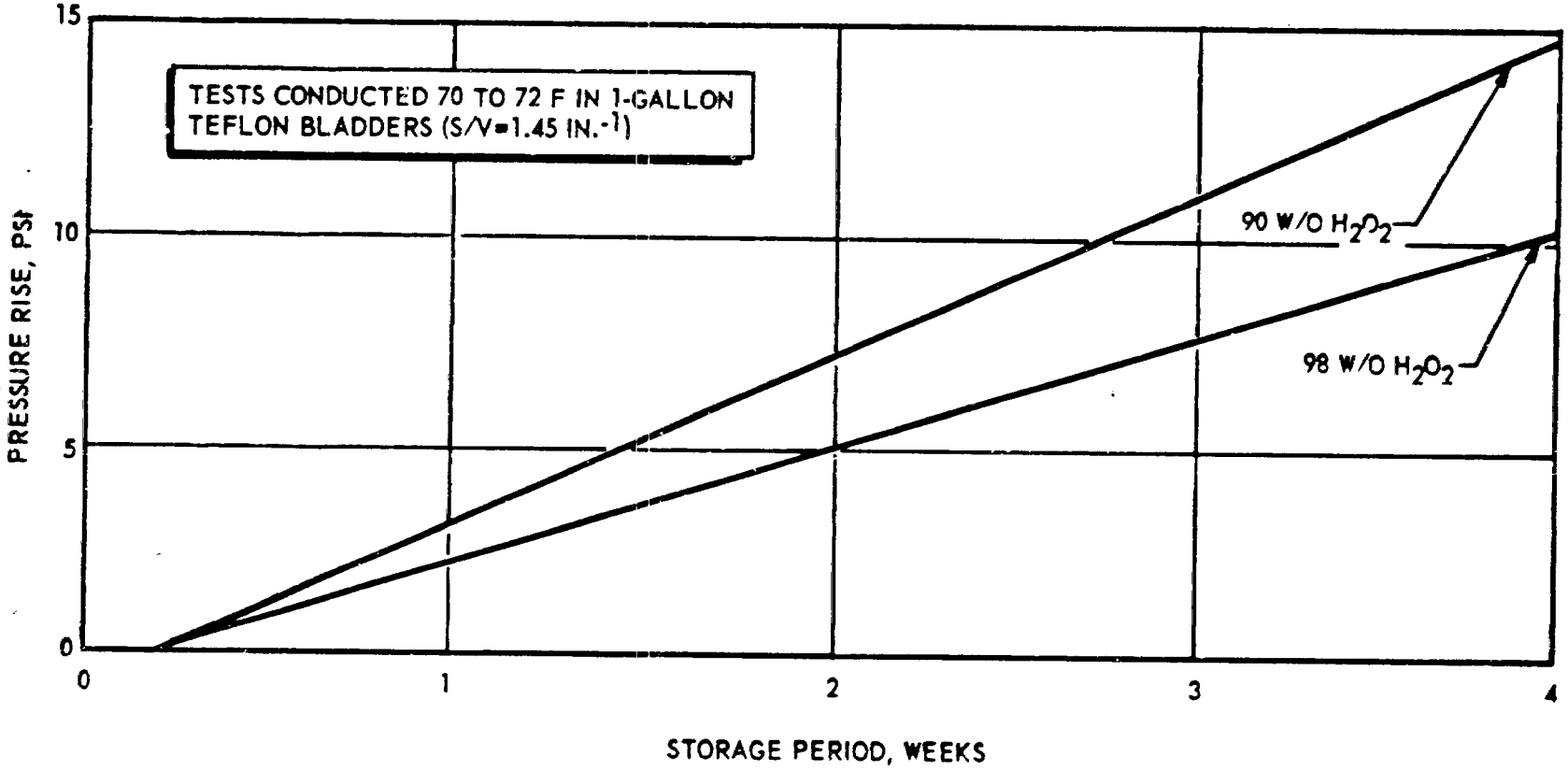


Figure 4.3. Results of Sealed Storage Tests With Unstabilized 90 w/o and 98 w/o H_2O_2 (Ref. 4.7)

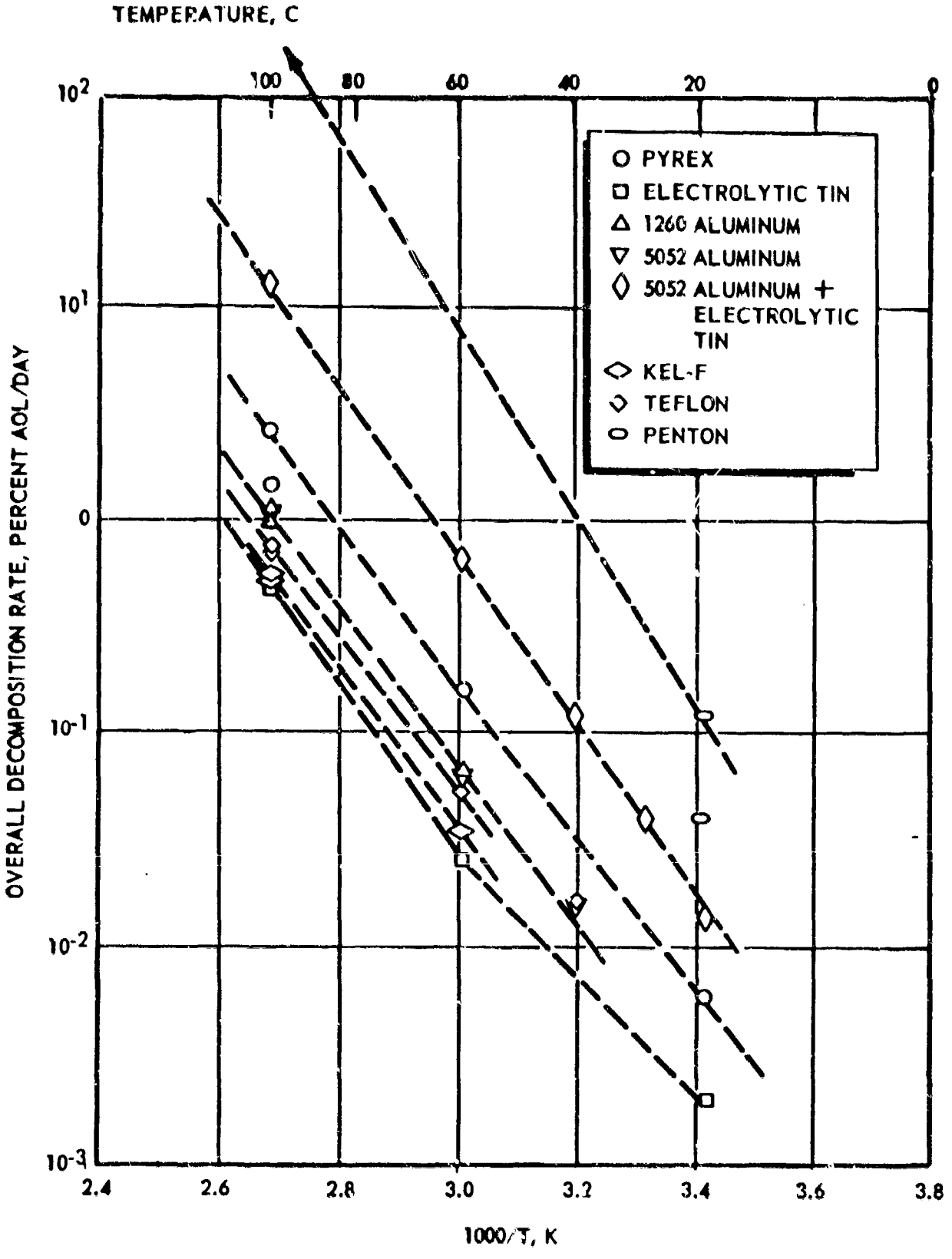
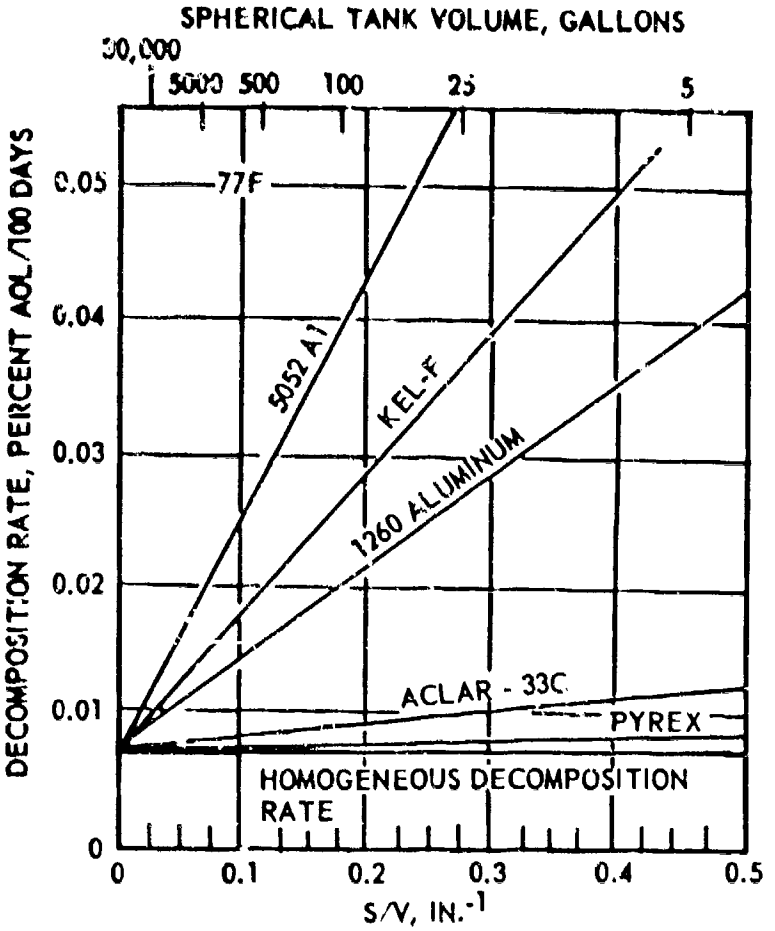
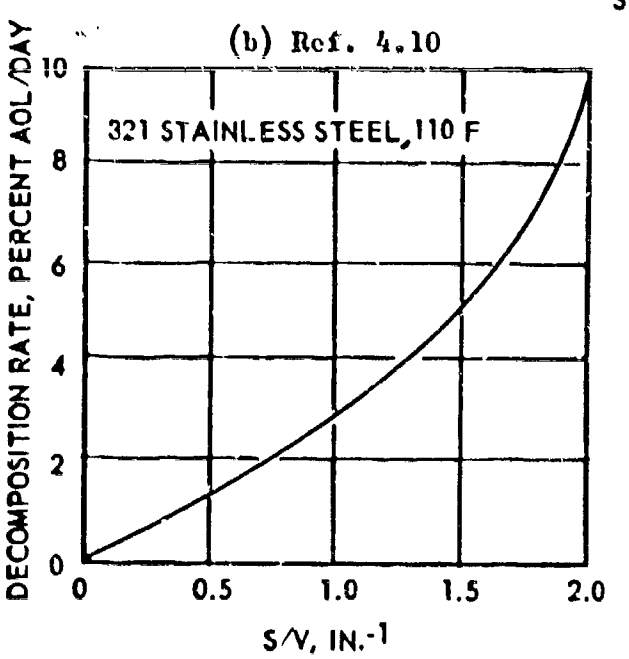


Figure 4.4. Heterogeneous Decomposition of 90 w/o Hydrogen Peroxide at Various Temperatures (Ref. 4.1)

(a) Ref. 4.1



(b) Ref. 4.10



(c) Ref. 4.10

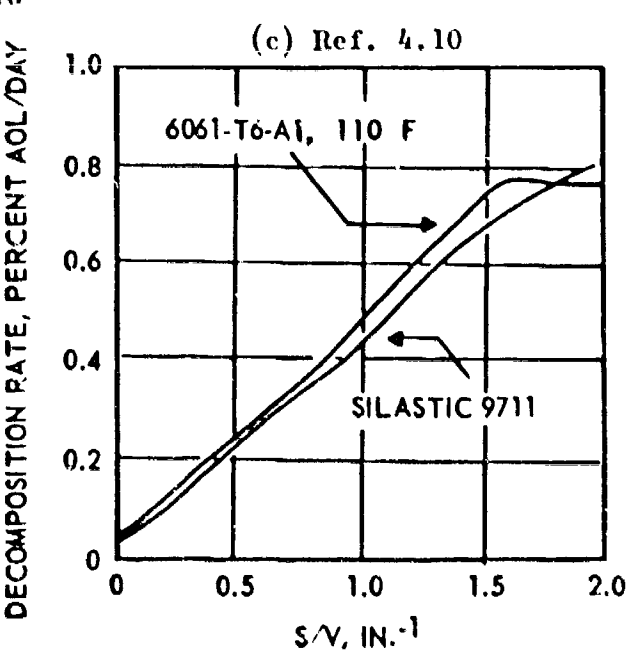


Figure 4.5. Decomposition Rates of 90 Weight Percent Hydrogen Peroxide-Water Solutions as a Function of Surface-to-Volume Ratio

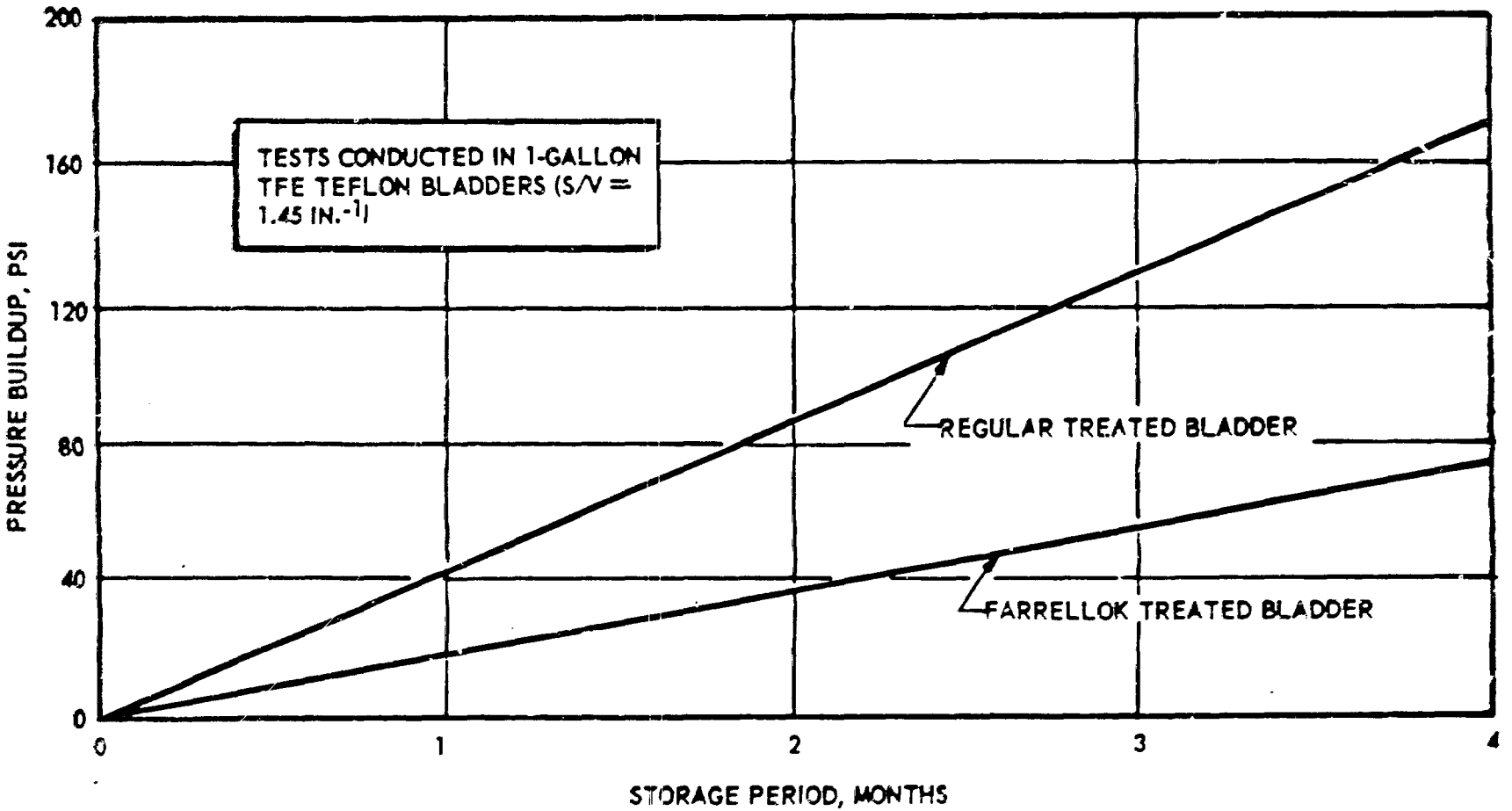


Figure 4.6. Results of Sealed Storage Tests at 72 F With Unstabilized 98 Weight Percent H_2O_2 in Bladders Treated by Various Techniques (Ref. 4.7)

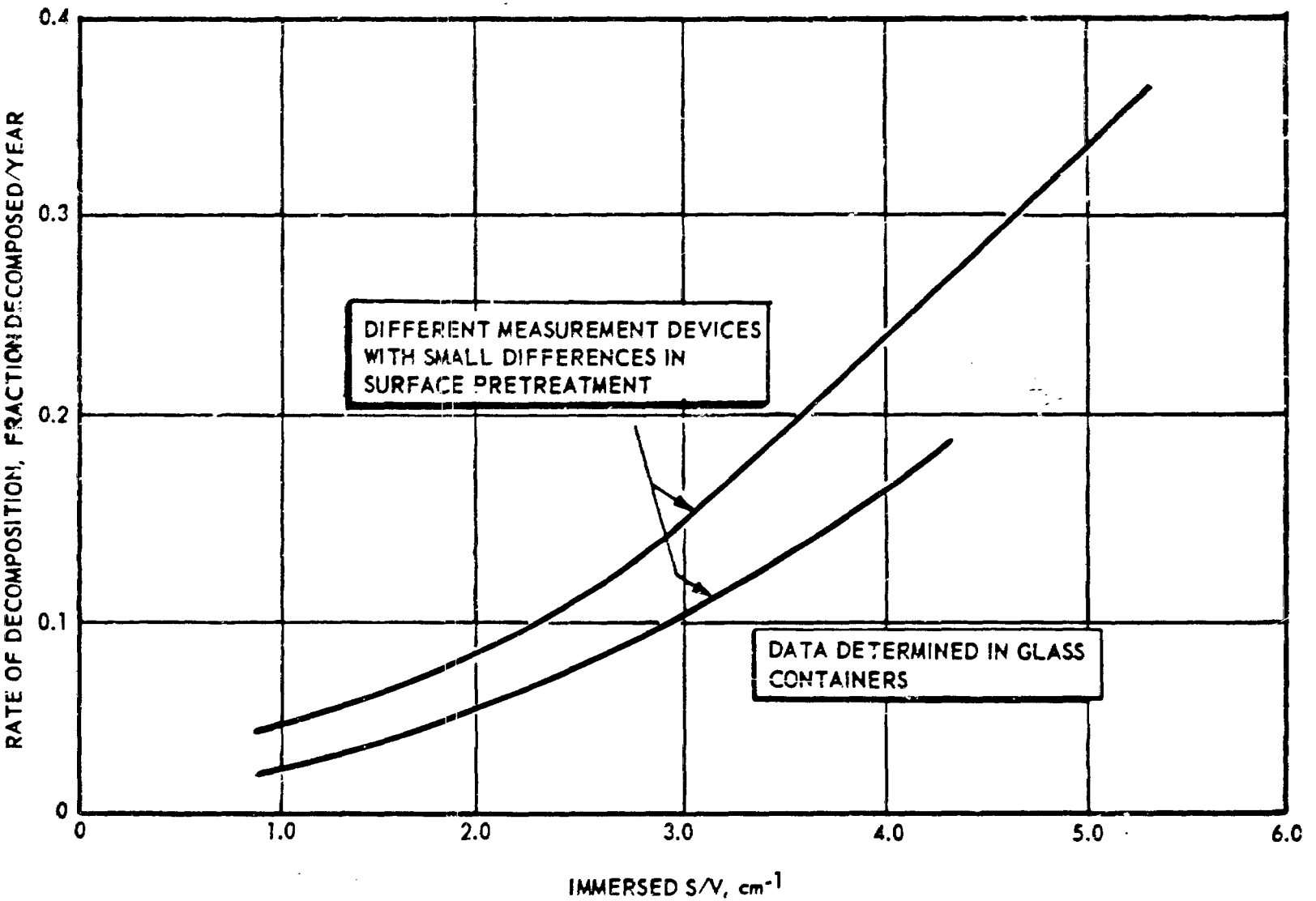


Figure 4.7. Effect of Surface to Volume Ratio on the Decomposition Rate of 99 + Weight Percent Hydrogen Peroxide During Storage (Ref. 4.5)

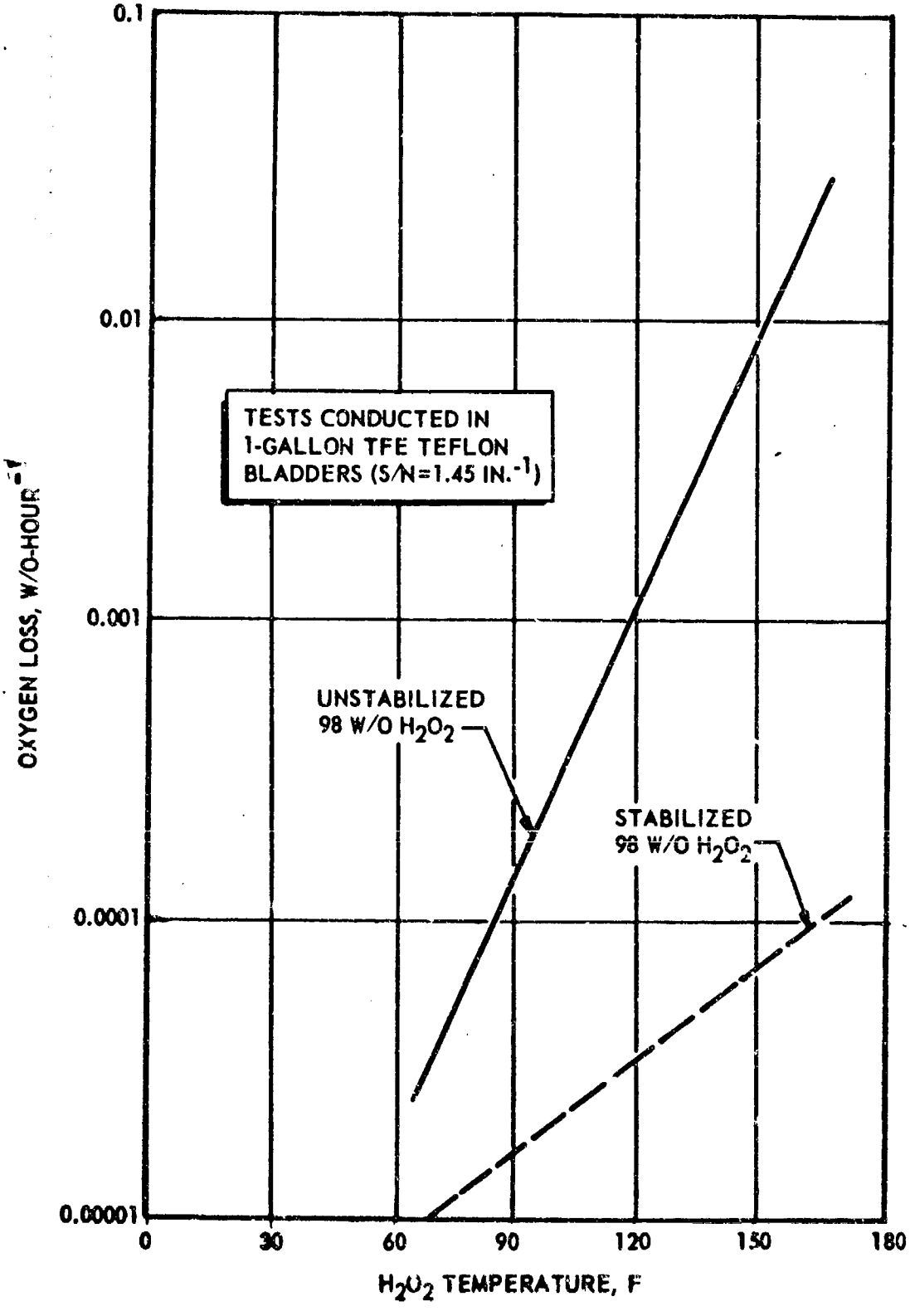


Figure 4.8. Effect of Stabilization of 98 Weight Percent H_2O_2 as a Function of Temperature (Ref. 4.7)

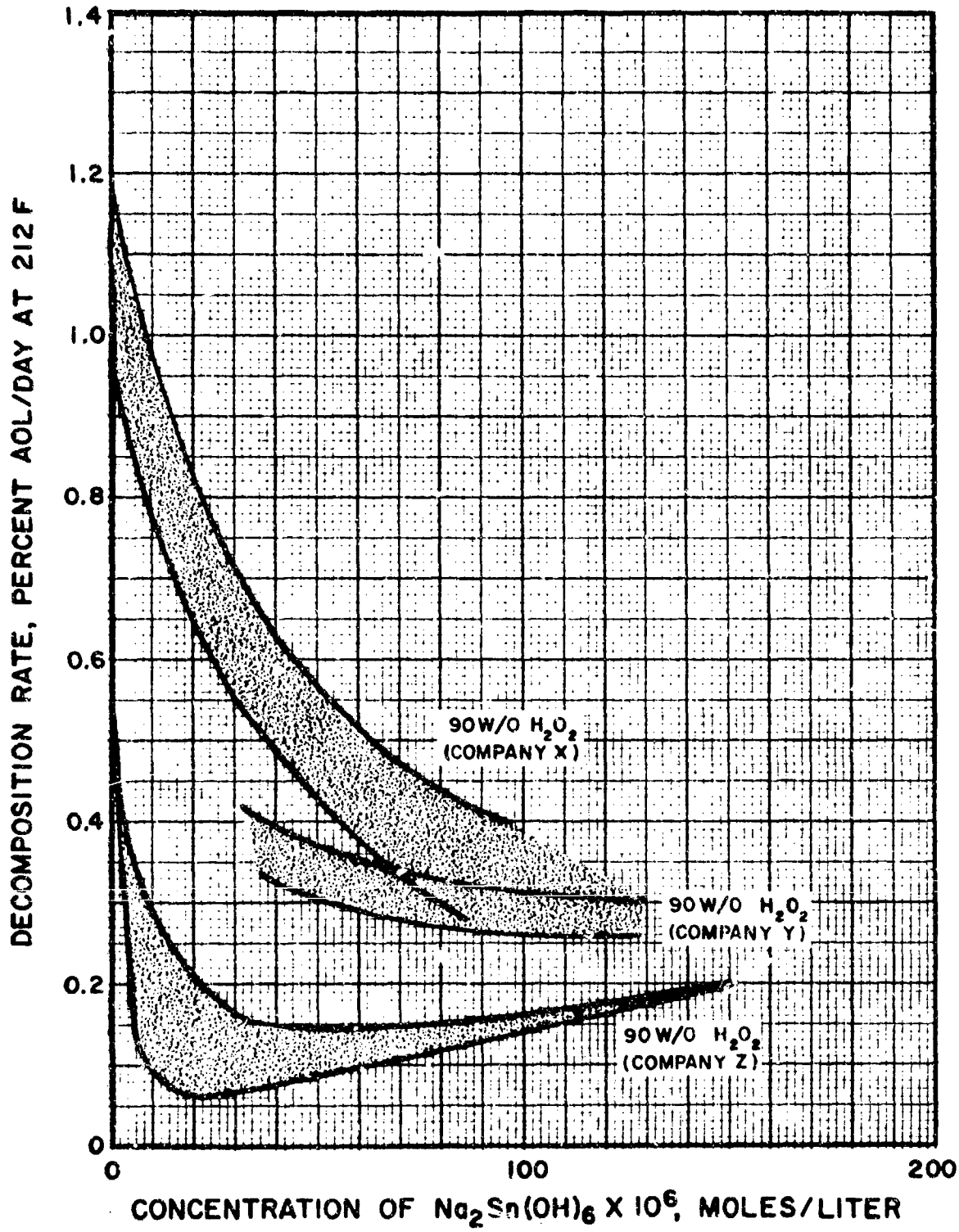


Figure 4.9. Effect of Stabilization of 90 w/o H_2O_2 as a Function of Stabilizer Concentration at 212 F (Ref. 4.8)

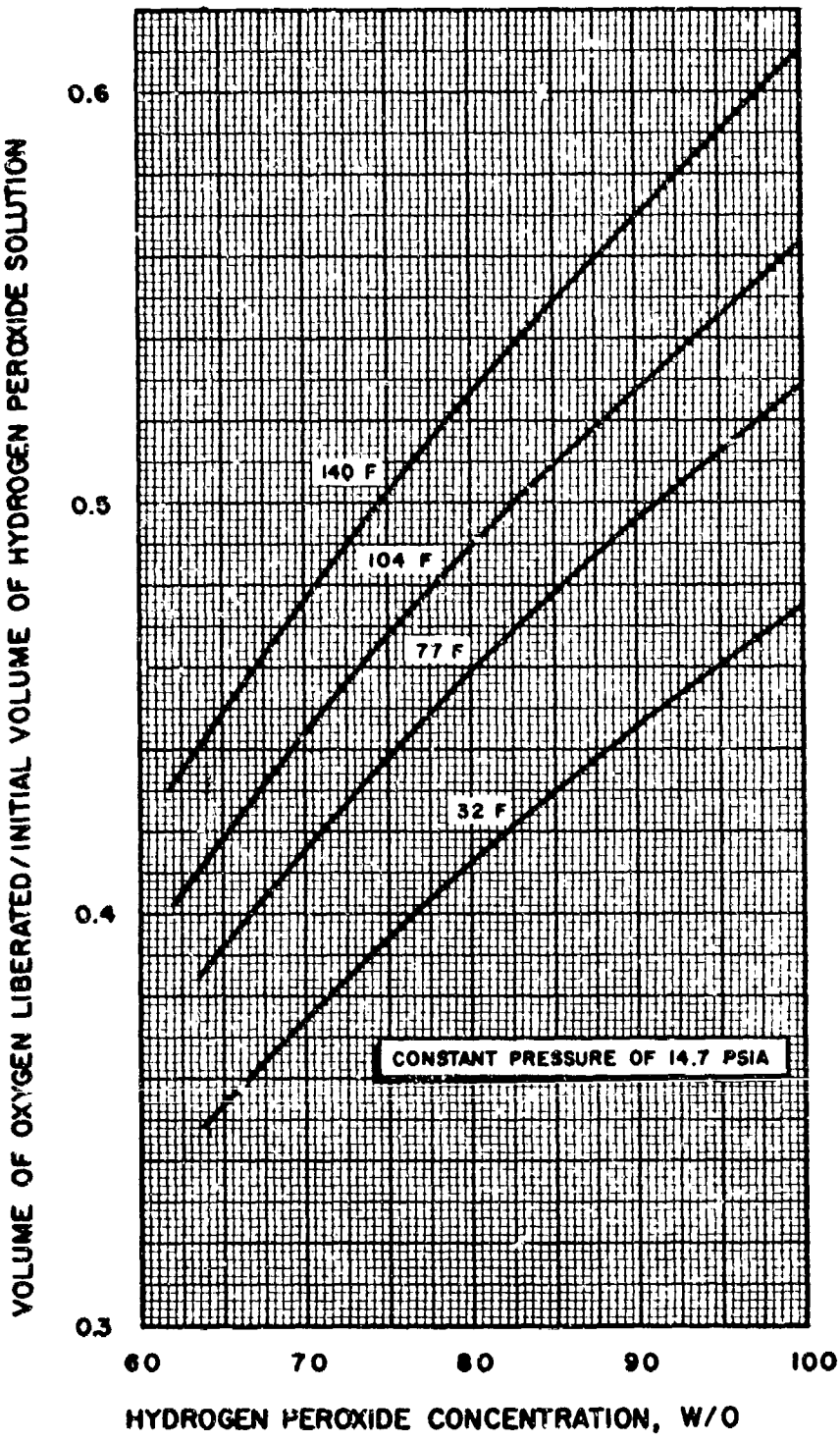


Figure 4.10. Volume of Oxygen Liberated per Year From the Decomposition of Hydrogen Peroxide at a Rate of 0.1 Percent AOL/Year

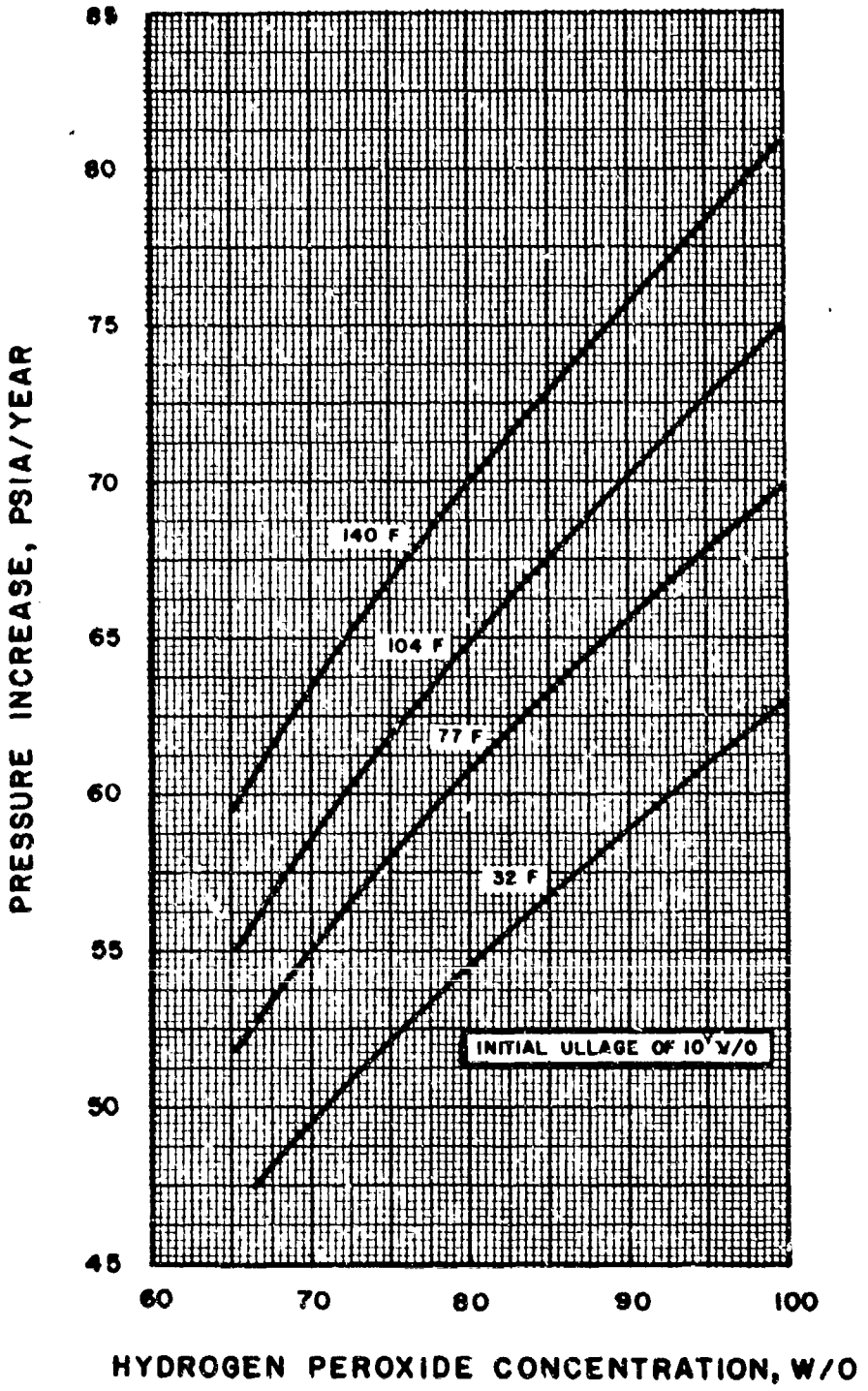


Figure 4.11. Pressure Increase in a Sealed Container Resulting From Hydrogen Peroxide Decomposition at a Rate of 0.1 Percent AOL/Year

SECTION 5: TRANSPORTATION

5.1 SHIPPING CONTAINERS AND VEHICLES

Approved hydrogen-peroxide shipping containers are available in the following capacities (Ref. 5.1, 5.2):

Reagent quantities: 1 pint (3/4 pound) (I.C.C. Regulation 73.266)

Drum quantities: 30 gallons (300 pounds) (I.C.C. Regulation 42D)

Tank cars: 4000, 6000, and 8000 gallons (I.C.C. Regulation 103-A-AL-W)

Tank trucks: 2000 and 4000 gallons (I.C.C. Regulation MC 310-H_2O_2)

Portable tanks: any desirable size (I.C.C. Special Permit)

All hydrogen peroxide storage or shipping containers are equipped with a dustproof vent to release oxygen produced from decomposition and to prevent the possibility of contamination.

5.1.1 Reagent Quantity Containers

Reagent quantity containers are glass bottles with dustproof vents on top. For concentrations above 52 w/o H_2O_2, the glass container capacity should not exceed 1 quart (Ref. 5.3). When packing these containers for shipping, I.C.C. Regulation 73.266, Specifications 15A, 15B, 15C, 16A, and 19A apply (Ref. 5.2). The applicable reagent bottles must be packed in a metal container vented at the bottom and packed in another metal container vented at top. Cushioning material shall be used between the bottle and inner container

and between the inner and outer metal containers. Cushioning material shall be vermiculite or the equivalent in an amount at least 10 times the volume of the solution shipped, and shall be wet with at least 10-percent water by volume to which a stabilizing agent has been added (Ref. 5.2). These containers should then be crated in a wooden box.

5.1.2 Drums

There are two types of drums available for shipping concentrated hydrogen peroxide. One is a double-head drum suitable for all freight shipment, and the other is a single-head drum suitable only for full-carload and full-truckload shipments. The vent on the double-head drum opens into the compartment between the two heads. This compartment will trap any H_2O_2 lost through splashing or leakage (Ref. 5.4, 5.5).

Both types of drums are fabricated according to I.C.C. Specification 42D (Ref. 5.2). Each of these drums is made of high-purity aluminum with a vented closure in the top head. The rated capacity does not exceed 30 gallons, and side openings are not permitted. The closure is sealed to prevent removal in transit. The top head should be plainly marked "KEEP THIS END UP" or "KEEP PLUG UP TO PREVENT SPILLAGE." For shipments other than carload or truckload lots loaded by consignor and unloaded by consignee, the drums must be of a design and venting arrangement approved by the Bureau of Explosives.

The approximate tare weight of a single compartment drum is 42 pounds, and that of a double compartment drum is 50 pounds. The net filling weights of 70 and 90 percent hydrogen peroxide are 280 and 300 pounds, respectively. These weights correspond to about 26 or 27 gallons of liquid in the drum. The volume will vary with temperature (Ref. 5.4).

5.1.3 Tank Cars

Tank cars suitable for hydrogen peroxide use are available in 4000-, 6000-, and 8000-gallon capacities. These cars, constructed according to I.C.C. Specification 103A-AL-W (Ref. 5.2), are cylindrical, fusion-welded aluminum tanks with a dome containing a manhole, a vent with a porous-stone filter to exclude dust, an unloading dip-pipe, a fill connection, and a bursting disk designed to blow out a 45-psig pressure. The temperature of the hydrogen peroxide is measured by a thermometer or thermocouple carried in a protective aluminum tube inside the tank or fastened to the tank's outside wall below the liquid level; the outside thermometer or thermocouple is insulated with glass wool (Ref. 5.1). All fittings, gaging, venting, loading, discharging, and air-inlet devices are constructed of materials compatible with hydrogen peroxide. Venting devices are of a type approved by the Bureau of Explosives.

5.1.4 Tank Trucks

I.C.C. Specification MC-310-H_2O_2 (Ref. 5.2) applies to shipment by tank trucks with 2000- to 4000-gallon capacity. These trucks, which have been specially constructed for hydrogen peroxide service, are equipped with complete unloading facilities, including a connecting hose and fittings for attachment to the consignee's storage system (Ref. 5.1, 5.4).

5.1.5 Portable Tanks

Portable tanks, commonly of 500- and 1300-gallon capacity, are subject to I.C.C. Special Permits. These tanks, which can be filled at the plant and used as storage vessels at the user's site, offer many advantages, particularly for remote, overseas, or temporary sites.

5.2 SHIPPING REGULATIONS

For shipping, the I.C.C. has classified concentrated H_2O_2 as a corrosive, "white label," liquid. Each container must be clearly marked "THIS SIDE UP" or "KEEP PLUG UP TO AVOID SPILLAGE." In addition, each container must carry the specification marking and number and the statement of the contents. "FOR HYDROGEN PEROXIDE USE ONLY" must be stenciled above the specification markings.

5.2.1 Commercial Air (Federal Aviation Agency)

When hydrogen peroxide is shipped by commercial air travel, the Official Air Transport of Restricted Articles, Tariff and Civil Air Regulations No. 49 regulates packaging and handling information.

5.2.2 Military Air (Department of Defense)

Regulations noted in AFM 71-4, Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft, and NAVWEPS 15-03-500 govern all hydrogen peroxide shipments by military aircraft.

5.2.3 Waterways (U.S. Coast Guard)

Hydrogen peroxide shipments on Coast Guard-controlled waterways are controlled by I.C.C. Regulations and U.S. Coast Guard Regulations NAV-CG-108, which note packaging and handling information.

5.3 OPERATION AND MAINTENANCE OF EQUIPMENT

5.3.1 Drums

To prevent spillage through the venting device, drums containing hydrogen peroxide should not be tilted or rolled during loading, transfer, or handling; they must be moved and stored in an upright position.

Siphoning or pumping are the recommended methods for emptying drums. The siphoning system is used when small quantities of hydrogen peroxide are involved. A siphon known commercially as the Model D Golden Thief Vacuum Pump (manufactured by the W&W Manufacturing Co., Box 9311, Chicago, Illinois) or its equivalent is usually used for transferring or sampling of small quantities of liquid. Although the vacuum portion of the noted device contains aluminum alloys unsuitable for peroxide use, the only part that contacts the solution is a compatible plastic tube. This siphon can be used for sampling tanks as well as drums and can deliver liquid from a considerable height. The plastic tubing and the sampling pump should be properly cleaned and passivated before use. Suitable cleaning and packaging between use times is also required. A combination of glass and plastic tubing is also possible in a siphon arrangement. Pouring or gas pressurization should be avoided in emptying drums containing hydrogen peroxide. (Gas pressurization can introduce contaminants or overpressurize the drum.) (Ref. 5.4).

Although direct pouring is not a recommended technique, a special hydrogen peroxide drum valve suitable for attachment to the standard 30-gallon drum is available from the Shell Chemical Company. This valve enables a direct pour from the drum and is suitable for short use times only (1 to 2 days) (Ref. 5.4).

After being emptied, the drum (and compartments) should be completely flushed with clean water and drained. The bung cap should be replaced immediately and tightened securely. All pipelines and hoses should be drained when transfers are complete.

When emptying a drum by pumping or vacuum, a trap should be placed in the suction line to prevent feedback of the hydrogen peroxide into the container after withdrawal.

5.3.2 Tank Cars and Trucks

Tank cars and tank trucks may be unloaded by either pumping or pressurization with clean, dry, hydrocarbon-free nitrogen gas. The use of a self-priming pump is quite common and is particularly desirable when fast delivery under pressure is required. The majority of the pumps are a centrifugal design, although air-driven reciprocating pumps are also available. Pump unloading is recommended for both tank cars and trucks.

The pressure fed system (sometimes called the ejector system) is a method of feeding by gas pressurization and should not be used on drums or smaller containers. There are mixed feelings about pumping by this technique. In addition to the possibility of overpressurization that exists with this technique, it is felt by some organizations that the possible introduction of water or oil with the pressurant gas and/or the insertion of the pump inlet line into the supply tank offers the possibility of vehicle container contamination. Thus if this unloading system is used, it is recommended that the compressed air or nitrogen used for pressurization be filtered for entrained solids as well as water (water-pumped gas is preferred to oil-pumped gas), and its pressure carefully controlled.

The standard tank car compressed gas fitting has been designed for nitrogen. The gas pressurization line should be equipped

with a suitable pressure reduction valve, a safety relief valve (set for approximately 15 psig), and a pressure gage. A pressure of 5 to 10 psig is normally sufficient to unload a 4000-gallon tank car in 2 hours. This will consume about 6- to 10-cu ft/min nitrogen. Pressures in excess of 15 psig should not be used. The compressed-gas feed line should be blown out before introduction into the hydrogen peroxide supply. Details of the unloading procedures should be obtained from the particular hydrogen peroxide manufacturer that supplies the tank car.

Tank truck unloading is normally handled by the hydrogen peroxide producer or his carrier. Each tank comes equipped with the necessary fittings, a hose, and a pump designed for hydrogen peroxide service. Trained drivers and/or other qualified personnel representing the producer are present to make the necessary connections for the unloading operation. After unloading a tank with pressure, the vent shall be opened at once. When pressure transfer is used on tanks, a line shall be attached to the safety vent and extended to the ground so that the vent may be quickly opened to stop the flow in an emergency. The tank should not be flushed after emptying unless it is to be entered for inspection or repair.

When either the tank car or truck have been emptied, the outside of the tank and the ground should be washed thoroughly wherever spillage of the hydrogen peroxide could have occurred during the unloading. All lines, hoses, and the pump should be drained free of hydrogen peroxide and flushed with clean water. All lines and hoses should then be covered with aluminum blind flanges or polyethylene bags to prevent contamination from dust (Ref. 5.4).

5.3.3 Handling

When transporting hydrogen peroxide, the following handling procedures and safety precautions should be followed:

1. At least two trained operators should always be assigned to any operation involving the handling, transfer, or storage of hydrogen peroxide.

2. Drivers and operators involved in deliveries of hydrogen peroxide should be instructed to identify the material as hydrogen peroxide of the correct concentration and grade. Carelessly calling it by another name such as "acid" may result in its being unloaded into the wrong tank with possible serious consequences.

3. Leaking pipes, hoses, pumps, etc., from concentrated hydrogen peroxide tank trucks or tank cars are fire hazards. The presence of combustible materials, especially wood, paper, or cotton waste, at the filling or unloading site, should be avoided. Spilled hydrogen peroxide should be immediately removed by flushing with copious quantities of water.

4. Operators unloading hydrogen peroxide should wear protective clothing and use only the designated equipment.

5. There should be water hoses, showers, and eye fountains in the immediate vicinity of the unloading area. The location and proper function of this equipment should be checked before beginning operation.

6. Sampling of hydrogen peroxide, if necessary, should be done only under very carefully controlled conditions and only by authorized personnel. All samples should be discarded after use and never returned to the storage container.

7. Sampling devices or any other material should not be inserted into a hydrogen peroxide container. Samples should be taken by pumping or draining from system feed lines.

8. If, for some reason, it is necessary to put some instrument, device, sampler, etc., into a hydrogen peroxide solution, the device must undergo the appropriate cleaning and passivation procedure. With each addition of a foreign body to hydrogen peroxide, the chance of contamination is increased.

9. Freezing may cause localized concentrations of contaminants which, on thawing, may result in accelerated decomposition.

10. Freezing will cause concentration gradients to develop as the material thaws. Thorough agitation is required to ensure uniform concentration of the solution. Hydrogen peroxide solutions are difficult to freeze, and supercooling of 70 to 90 F is not uncommon. Handling, vibration, or motion of any kind should be avoided during possible supercooling periods to avoid freezing and subsequent concentration stratification.

11. Pressure vents should be shielded so that the possibility of dust return or other contamination is minimized.

12. Routine inspection of storage facilities should include hosing down storage containers as well as the storage area at regular intervals to minimize the accumulation of dust, dirt, debris, etc.

13. The outside of storage containers should be thoroughly cleaned before removal of outlet covers. This may be accomplished by means of an air hose, a water hose, or a combination of these.

14. Cleaning of the threaded sections before connection of the mating parts should be carefully done to minimize the possibility of contamination.

15. In the opening of a pipe line or similar item that has previously been used in transferring hydrogen peroxide, it should always be assumed that there may be some hydrogen peroxide left in the line, and a supply of water should be available.

14. Storage of equipment such as transfer hoses should provide for venting any pressure built up from decomposition of residual peroxide. All drained materials should be diluted and discarded.

5.4 REFERENCES

5.1 United States Government, Office of the Director of Defense Research and Engineering, Washington, D.C., The Handling and Storage of Liquid Propellants, January 1963.

5.2 General Services Administration, National Archives and Records Service, Federal Register Division, Code of Federal Regulations, Title 49, Chapter I, "Interstate Commerce Commission," Parts 71 to 90, revised 1956.

5.3 Schumb, W. C., C. N. Satterfield, and R. L. Wentworth, Hydrogen Peroxide, A.C.S. Monograph 128, Reinhold Publishing Corporation, New York, 1955.

5.4 Shell Chemical Company, New York, New York, Concentrated Hydrogen Peroxide, H_2O_2. Properties, Uses, Storage, Handling, 2nd Edition, Report No. SC: 62-23, 1962.

5.5 McCormick, James C., Buffalo, New York, Hydrogen Peroxide Rocket Manual, F.M.C. Corporation, 1965.

SECTION 6: SAFETY

6.1 HAZARDS

The potential safety hazards in dealing with hydrogen peroxide fall into the following general categories: detonation and/or explosion, uncontrolled decomposition, fires, and personnel injury. While these hazards may sound ominous, it must be remembered that similar hazards exist for various other compounds which are in widespread use and are safely handled by industry. If operating personnel are armed with knowledge of the potential hazards and how to avoid them, there is no reason why concentrated hydrogen peroxide cannot be safely employed in commercial processes.

6.1.1 Physiological Effects

6.1.1.1 Vapor Inhalation. Hydrogen peroxide solutions and vapors are nontoxic, but they are irritating to body tissue. This irritation can vary from mild to severe, depending upon the concentration of hydrogen peroxide. Concentrated hydrogen peroxide has little odor unless deliberately inhaled. The sensation is then somewhat like that produced by ozone or the halogens (Ref. 6.1).

Inhalation of hydrogen peroxide vapors causes irritation and inflammation of the respiratory tract and may result in burning of the nose and throat, running of the nose, and coughing. Prolonged breathing can produce swelling of the respiratory membranes or accumulation of fluid in the sinuses and lungs. Short-time exposure will not cause lasting harm, but a physician should be notified in extreme exposure cases (Ref. 6.2. and 6.3). The toxicity level for 90 w/o hydrogen peroxide is expressed as a threshold limit value (TLV) of 1 ppm (1.4 mg/cu m) (Ref. 6.4

and 6.5). The TLV represents the average concentration over a normal work day to which the average human can be safely exposed on a daily basis without adverse effects.

The vapors can also irritate the eyes, producing burning, redness, and watering. The effect is short-lived except in extreme or continuous exposure. When hydrogen peroxide contacts the eyes, the eyes should be flushed immediately with water.

6.1.1.2 Cutaneous Exposure. The vapors, mists, and solutions of hydrogen peroxide are very irritating to body tissues. When the liquid touches the skin, there is a burning sensation and the areas affected are bleached. If contact is brief, the effects will usually disappear within 2 or 3 hours. Continued exposure, however, will result in slight water blister formation which should heal quickly. Contact of the hydrogen peroxide with the more sensitive parts of the body, such as the thighs, neck, or under the fingernails, will cause more severe effects than contact with the hands. If hydrogen peroxide contacts the skin, the area affected should be flooded immediately with large quantities of water (Ref. 6.2 and 6.3). If the irritation does not subside after flushing with water and burns persist, a physician should be notified.

Various experiments have been conducted with animals to show the effect of hydrogen peroxide on skin surfaces. With rabbits, it was observed that 90 w/o hydrogen peroxide applied to the skin was absorbed and caused death by gas embolism (rabbits are susceptible to embolism, however). Cats, guinea pigs, rats, pigs, and dogs, although much less susceptible to embolism, showed a greater reaction on the skin (Ref. 6.1). (There were no results showing possible lethal effects of H_2O_2 on these animals, however.)

In studies on human skin, 90 w/o hydrogen peroxide on the palms and fingertips, where the keratin is thick and nerve endings are abundant, causes strong prickling and formation of opaque white patches. This is extremely painful under the fingernails. "On other skin areas where the keratin is thinner, irritation occurs, but with less itching and the white appearance is confined to a few areas at the base of hairs. There is no evidence of penetration deeper than the first layer of skin, or stratum corneum, and all these effects disappear without trace" (Ref. 6.1, page 426).

6.1.1.3 Ingestion. If hydrogen peroxide is swallowed, e.g., during pipetting, it may cause bleeding and severe distention of the stomach due to the liberation of oxygen. In some cases, injection or ingestion of hydrogen peroxide can be fatal, depending upon the amount and concentration. Intravenous injections of dilute hydrogen peroxide solutions are more lethal than concentrated solutions, since the dilute solutions are able to penetrate the system more deeply before decomposition and blocking of the circulation occur (Ref. 6.1).

In the mouth, an effervescence occurs as the hydrogen peroxide decomposes, giving a prickling sensation. At high concentrations, the effects in the mouth are heightened, to the point of painfulness, to say nothing of the hazard of burns; and such contact is to be avoided.

6.1.2 Fire Hazards

Hydrogen peroxide by itself is not flammable, but solutions of high concentration may react with combustible materials and generate enough heat to cause ignition. When involved in a fire, hydrogen peroxide actively supports combustion by liberating oxygen, and this results in a "flare" fire that may terminate in explosion. Elimination of air, however, does not control or put out the fire. Hot, concentrated, liquid hydrogen

peroxide (> 65 w/o), once ignited, will "burn" rapidly as a continuous, hot, nearly invisible vapor decomposition flame close to the surface of the liquid. Such a decomposition flame will continue without an external source of heat until the liquid is entirely consumed, unless the liquid concentration is reduced or the liquid is cooled sufficiently to extinguish the flame (Ref. 6.2).

Hydrogen peroxide solutions greater than 65 w/o can release enough energy to heat the decomposition products to a relatively high temperature (1382 F for 90 w/o solutions). Ignition of nearly inflammable material may then be expected. Solutions of less than 65 w/o may also cause fires due to the fact that upon exposure to air, water in the solution may evaporate faster than the peroxide, increasing the concentration of the latter. Naturally, the lower the initial concentration, the less likely this would happen (Ref. 6.2).

Fires can be started easily by dampening combustible materials with hydrogen peroxide solutions stronger than about 70 w/o, provided that the proper catalyst is present. In the absence of catalysts, many materials such as clean cotton or wood may not even react with 90 w/o hydrogen peroxide. (The absence of any catalytic material, however, is rather unlikely according to Ref. 6.6.) Secondary fires may also occur. Consumption of the hydrogen peroxide does not necessarily eliminate the fire. If the ignition temperature limit of any fuel-air mixture in the immediate vicinity has been achieved, combustion of these materials will continue. This may, however, occur at a considerably different burning rate.

An empirical test was devised (Ref. 6.7) to compare the flammability hazard of the various concentrations of propellant-grade hydrogen peroxide. A spill test was developed using a green felt of 90-percent wool and 10-percent vegetable fiber. (Numerous other organic materials were tried, but this was the first

material to give reproducible results.) The test simply consists of placing two drops of concentrated hydrogen peroxide on the piece of felt and measuring the time to visible flame. The ignition time decreases with increasing concentration as shown in Fig. 6.1.

Ignition (i.e., initiation of rapid decomposition) limits have been determined for hydrogen peroxide vapor (Ref. 6.8 and 6.9) for pressures above atmospheric; these data are presented in Fig. 6.2. The ignition limits of hydrogen peroxide are actually the ignition limits of the vapor and are, therefore, a function of the vapor-phase composition. In turn, this vapor-phase composition is a function of the liquid temperature and the total pressure on the system. The ignition limits are not sharply defined but are general areas, as illustrated by the positive and negative test results shown in Fig. 6.2.

General areas where the vapor phase in contact with the liquid phase has reached the probable ignition level are shown in Fig. 6.3 (Ref. 6.10).

6.1.3 Explosion Hazards

Although hydrogen peroxide solutions are not ordinarily classed as explosives (see Section 4.4.1.1.2), certain conditions can exist in which a detonation or an explosive-like release of energy can occur. Typically, most "explosions" involving hydrogen peroxide are a result of decomposition of the hydrogen peroxide, which may occur as a result of gross contamination and/or excessive temperature rise of the hydrogen peroxide. The decomposition reaction produces large amounts of heat (which further accelerates the decomposition reaction) and gas with subsequent effects of gas overpressurization in any confining areas. The "explosion" usually results from the rupture of the confining surface and release of the gas pressure.

Normally, this decomposition process is relatively slow, and the final pressure release is preceeded by a slow thermal and pressure buildup. However, there are also conditions in which the decomposition process reaches an explosive rate. Although such conditions are usually associated with the vapor phase, separation of the cause-effect relationship between the liquid and vapor phases is difficult. In addition to the normal liquid-vapor equilibrium, the entrapment of vapor (and a subsequent vapor-phase decomposition within the liquid phase) is always possible with a material that decomposes so readily into liquid and gaseous products.

6.1.3.1 Vapor-Phase Hazards. When the concentration of hydrogen peroxide in the vapor phase exceeds 26 mole percent (40 w/o) at atmospheric pressure, an explosive decomposition reaction is possible (Ref. 6.8 and 6.9). This limit is increased with decreasing pressures (43 w/o at 200 mm Hg and 70 w/o at 40 mm Hg) and decreased with pressures above ambient. Ignition of these concentrations may occur as a result of a spark, contact with a catalytic surface, or contact with a heat source in excess of 300 F.

During vapor detonation velocity measurements (Ref. 6.8), a detonation velocity of 6700 ft/sec was recorded at atmospheric pressure in a minimum concentration of 50 w/o hydrogen peroxide. No detonations were observed in hydrogen peroxide vapor at total pressures of 42.6 and 99.5 psia. Measurements of detonation velocities in higher concentrations at atmospheric pressure were generally unobtainable because of spontaneous decomposition or premature ignition of the test gases.

Under ordinary storage and handling conditions, explosive vapor concentrations are not reached. However, when heated under atmospheric pressure to temperatures of ~ 264 F, liquid concentrations above 75 w/o will produce vapor concentrations in the explosive range. These explosive regions correspond to the ignitable regions shown in Fig. 6.3 as a function of liquid composition, liquid temperature, and pressure.

6.1.3.2 Liquid-Phase Hazards. Although earlier experimental efforts, particularly those of the Germans, had indicated that liquid hydrogen peroxide solutions with concentrations greater than 88 w/o could be detonated, more recent efforts have demonstrated the absence of shock sensitivity in the liquid phase below concentrations of 95 w/o. However, there are still more conflicts in the data obtained from a variety of shock sensitivity tests on hydrogen peroxide concentrations greater than 95 w/o. Consequently, these higher concentrations are still considered (Ref. 6.11) potentially explosive under certain conditions. In addition, concentrated hydrogen peroxide solutions are thermally sensitive (see Section 6.1.3.1) although the direct participation of the liquid phase in detonations involving the heated vapor phase is questionable.

The validity of positive results from some types of sensitivity tests used in the early efforts on the hydrogen peroxide liquid phase are questionable (Ref. 6.12) for the following reasons:

1. Shock sensitivity in earlier work was usually done by setting off relatively large explosive charges in the hydrogen peroxide. This technique is questionable because the mixture of organic vapors from the explosive charge may have initiated the reaction, and the heat liberated by the explosive charge may vaporize enough hydrogen peroxide to result in a vapor explosion.
2. Thermal tests in early work were limited to open containers. Because of localized heating and distillation effects, it was not known what concentration of hydrogen proxide was actually involved in the explosion.
3. Subsequent sensitivity tests (Ref. 6.9) on the vapor phase above a hydrogen peroxide liquid phase of 90 w/o indicated that none of the detonations found in this concentration range involved the liquid phase.

The results of various experimental efforts, which have involved three primary areas of sensitivity testing (thermal sensitivity, shock sensitivity, and detonation propagation), are summarized in the following paragraphs to provide a guide to the potential explosion hazards of the hydrogen peroxide liquid phase.

6.1.3.2.1 Thermal Sensitivity. To expand previously available liquid-phase thermal sensitivity data (summarized in Table 6.1) thermal sensitivity tests were conducted by duPont (Ref. 6.12) on hydrogen peroxide in open and in closed containers. The open-container tests (at atmospheric pressure) showed that the vapor above 90 w/o liquid hydrogen peroxide exploded at 248 to 284 F. The liquid did not explode but decomposed rapidly, producing temperatur ‹ up to 752 F. Similarly tested 98-percent hydrogen peroxide vapor exploded at 212 to 248 F and gave evidence of liquid participation in the reaction. Results from tests on 35-percent hydrogen peroxide were similar to those with 90-percent hydrogen peroxide. In sealed glass bulbs, 90-percent hydrogen peroxide explodec at 320 to 356 F and the liquid was involved in the reaction; however, the explosions were attributed to pressure buildup from relatively slow decomposition. A low-order explosion was produced with 95 and 98 w/o hydrogen peroxide at 248 to 284 F. The results of representative tests from these efforts are reprinted in Tables 6.2 through 6.4.

In a further effort to determine liquid-phase participation in vapor-phase detonations resulting from thermal sensitivity, field tests (Ref. 6.12) were conducted using larger quantities of material. These tests, which eliminated the possibility of complete vaporization of the liquid, consisted of placing approximately 2 gallons of concentrated hydrogen peroxide in old, well-used "Albone" (35 w/o stabilized H_2O_2) drums. These drums were placed in a pit with remote heat contol and temperature recording systems. The drums

were heated at a controlled rate, and the temperature-time profile of each was recorded. The following results were reported on the five tests run:

1. Two gallons of 90 w/o hydrogen peroxide. The drum started belching foam at 271 F. Much liquid was dispersed, but the stainless-steel container was undamaged.

2. Two gallons of 95 w/o hydrogen peroxide. Vapor ignited at 268 F and burned with several white puffs with no resulting damage to the stainless-steel container.

3. Two gallons of 35 w/o hydrogen peroxide. Vapors ignited at 248 F. Burning continued for 30 seconds. Both ends of the drum were bulging and the thermocouple had been ejected from the drum during the test.

4. Two gallons of 95 w/o hydrogen peroxide. Vapors ignited at 295 F and burned for 3 minutes. The drum was undamaged.

5. Two gallons of 95.2 w/o hydrogen peroxide. At 289.4, the drum ruptured, spewing high-strength liquid hydrogen peroxide. The maximum pressure recorded was 75 psi.

It was concluded (Ref. 6.12) as a result of these tests and the other available data that in concentrations up to 95 w/o the liquid, or at least a good part of the liquid, does not participate (except to form more vapor from heat feedback) when vapor-phase burning or explosion occurs. This is true even though the adjoining vapor temperature exceeds 572 F. However, concentrated liquid hydrogen peroxide is susceptible to overheating, which makes possible the formation of vapor within the liquid phase and consequent "belching." Thermal hazards increase for liquid hydrogen peroxide concentrations above 95 w/o, even though direct participation by the liquid phase in resulting detonations is questionable.

6.1.3.2.2 Shock Sensitivity. Hydrogen peroxide and hydrogen peroxide-water solutions are considered non-impact sensitive in both the solid state (low-temperature studies) and the liquid state up to 212 F (Ref. 6.2, 6.4, 6.6, 6.12, and 6.13). No impact sensitivity was noted (Ref. 6.13) for 98 w/o hydrogen peroxide at 212 F and an impact height of 300 kg-cm.

Hydrogen peroxide grades of 90 and 98 w/o H_2O_2 have been subjected to adiabatic compression test loading rates of 231,000 lb/sec at 70 to 72 F and 160 F with no effect on the hydrogen peroxide. Loading rates of 3,000,000 lb/sec at 70 to 90 F have been achieved on 90 w/o hydrogen peroxide with no adverse effects (Ref. 6.3).

Shock tests with No. 20 PETN boosters set off in 30-gallon aluminum drums, and tests with 15 grams of Hercomite dynamite exploded in the same quantity at 70 to 72 F and 160 F showed no propellant detonation for 90 and greater w/o hydrogen peroxide solutions (Ref. 6.3).

Card gap tests, using an apparatus in which 30 gms of liquid sample was separated from a 30 gm tetryl charge by a thin (5 to 10 mils) aluminum membrane, indicated no evidence of detonation in 90, 95, and 98 w/o hydrogen peroxide (Ref. 6.12). The results of these tests are shown in Table 6.5, and are similar to those resulting from earlier tests conducted by the Navy (Ref. 6.3) to demonstrate the relative insensitivity of 90, 95.5, and 99.5 w/o hydrogen peroxide at ambient temperatures and 160 F.

Other types of shock sensitivity tests have also been conducted on 90, 95, and ~ 100 w/o hydrogen peroxide (Ref. 6.12 and Table 6.6). Although some of these data do indicate shock sensitivity in hydrogen peroxide concentrations above 95 w/o, the data are suspect (Ref. 6.12) because of potential vapor-phase detonation and contamination contributions.

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Hydrogen peroxide grades of 90 and 98 w/o H_2O_2 have been subjected to adiabatic compression test loading rates of 231,000 lb/sec at 70 to 72 F and 160 F with no effect on the hydrogen peroxide. Loading rates of 3,000,000 lb/sec at 70 to 90 F have been achieved on 90 w/o hydrogen peroxide with no adverse effects (Ref. 6.3).

Shock tests with No. 20 PETN boosters set off in 30-gallon aluminum drums, and tests with 15 grams of Hercomite dynamite exploded in the same quantity at 70 to 72 F and 160 F showed no propellant detonation for 90 and greater w/o hydrogen peroxide solutions (Ref. 6.3).

Card gap tests, using an apparatus in which 30 gms of liquid sample was separated from a 30 gm tetryl charge by a thin (5 to 10 mils) aluminum membrane, indicated no evidence of detonation in 90, 95, and 98 w/o hydrogen peroxide (Ref. 6.12). The results of these tests are shown in Table 6.5, and are similar to those resulting from earlier tests conducted by the Navy (Ref. 6.3) to demonstrate the relative insensitivity of 90, 95.5, and 99.5 w/o hydrogen peroxide at ambient temperatures and 160 F.

Other types of shock sensitivity tests have also been conducted on 90, 95, and ~ 100 w/o hydrogen peroxide (Ref. 6.12 and Table 6.6). Although some of these data do indicate shock sensitivity in hydrogen peroxide concentrations above 95 w/o, the data are suspect (Ref. 6.12) because of potential vapor-phase detonation and contamination contributions.

Although it is generally concluded that hydrogen peroxide solutions are not normally shock sensitive, it should be noted that hydrogen peroxide with additives (or contaminants) capable of being oxidized are highly impact sensitive. This sensitivity theoretically depends upon the concentration and type of additive and, in actual practice, upon the sample size and the method and type of impact. Various mixtures involving hydrogen peroxide of various concentrations with minimum (< 10 percent) quantities of organic materials such as ethylene glycol, ethyl alcohol, benzene, etc. have been found to be particularly hazardous (Ref. 6.11). These mixtures will detonate violently when subjected to the slightest mechanical shock with detonation velocities approaching those of nitroglycerine, TNT, RDX, etc.

6.1.3.2.3 Detonation Propagation. Under normal usage, it seems impossible to obtain a propagating detonation in hydrogen peroxide-water solutions. The only tests where a propagating detonation has been observed were under conditions of extreme confinement with an exceptionally heavy booster charge. Although these conditions are not likely to be encountered in any normal storage or handling condition, studies by the Navy (Ref. 6.11) have demonstrated some conditions at which hydrogen peroxide concentrations above 95 w/o will propagate a detonation.

In another study (Ref. 6.3) propagation tests were conducted on 98-percent hydrogen peroxide by placing explosives (having energy rates of 1,860,000,000 ft-lb per second and pressure generation rates of 576,000 atmospheres which develop within 12.5 microseconds) in a 1.5-inch schedule-80 stainless-steel pipe. The pipe was connected to an aluminum drum containing 250 pounds of hydrogen peroxide. Although a detonation was set off in the pipe, the hydrogen peroxide was unaffected.

Similar results were obtained (Ref. 6.3) by the Bureau of Mines in tests on 99 w/o hydrogen peroxide contained in 0.5-inch tubing. A large booster charge was located in 1-inch tubing of hydrogen peroxide, which was connected to the smaller tubing. The detonation of the booster charge, which detonated the material in the 1-inch tube, failed to propagate into the hydrogen peroxide in the smaller tubing.

6.1.3.3 Explosion Potential Criteria. A criterion (Ref. 6.14) has been developed for the estimation of the potential explosive and detonation hazard of hydrogen peroxide systems. This involves the calculation of what is called the "critical excess energy" of the system and is the heat of reaction for the formation of all gaseous products from all compounds in the mixture. Before continuing with the correlation procedure, a discussion of balancing combustion-explosion type reactions seem appropriate. Briefly, these are the rules for balancing these reactions:

1. Carbon is first oxidized to CO
2. If additional oxygen remains, form water
3. If additional oxygen remains, oxidize CO to CO_2

Addition of readily oxidizable metals to this system would introduce a step between 1 and 2; however, there are a number of qualifications to this procedure so that the reliability of this technique as a hazard criterion for metals is questionable.

After balancing the equation with the particular ratio of ingredients which are of interest, the heat of reaction is computed, assuming that all of the reaction products are in the vapor form. Heats of formation of the reactants in their actual form (solid,, liquid, or gas) and of the end products in their gaseous form, all based at 298 K, are used for this computation. A heat of reaction in

excess of 450 cal/gm implies a possible explosive hazard for that particular mixture. A heat of reaction in excess of 900 cal/gm predicts a possible detonation hazard. These "critical energy" values were selected after a very careful study of experimental data accumulated from explosive and detonation tests on mixtures of organic compounds with concentrated hydrogen peroxide. A heat of reaction can be computed for a number of compositions and the compositions for the "critical excess energy" values of 450 and 900 cal/gm determined. These computed compositions may then be plotted to map out hazard areas in the use of mixtures of these materials. It should be noted, however, that these values are not infallible. Mixtures should always be tested experimentally before actual handling operations begin.

Expressions, which may be solved by pure mathematics, have also been generated for the determination of the critical energy compositions (Ref. 6.15). However, for those handbook users who are willing to balance the chemical equation, the following heats of formation of the common products of combustion are given. The heats of formation of various concentrated hydrogen peroxide solutions are shown in Fig. 2.12 to 2.13a and are discussed in Section 2.2.3.1 of this report.

CO -26.417 kcal/mol at 293 K; molecular weight = 28.01

H_2O -57.80 kcal/mol at 298 K; molecular weight = 18.016

CO_2 -94.315 kcal/mol at 298 K; molecular weight = 44.010

Heats of formation or heats of combustion (from which heats of formation can be computed) of a large variety of organic compounds are available in practically all chemical handbooks.

In the computation of systems where the components are not mutually soluble or are not soluble in all proportions, consideration should be given to the possible existence of hazardous concentrations at

liquid-phase interfaces. The solubility of a large number of compounds in hydrogen peroxide is given in Table 4.14a, Section 4. This method of evaluation is not really appropriate for immiscible systems.

Despite the apparent success of the correlation methods, a safety hazard evaluation must always be obtained for a new system whenever the safety of personnel or equipment is concerned. These methods should only be used to define limits for experimental test design.

The explosive regions in systems of hydrogen peroxide and organic compounds surround the composition ratios of H_2O_2/organic compound which lead to complete reaction to carbon dioxide and water. Explosions are generally unobtainable if the final solution contains less than approximately 30 w/o hydrogen peroxide.

The sensitivity of these explosive mixtures toward explosion is of the same order of magnitude as that for molten TNT or nitroglycerine. Oxygen-deficient mixtures or water-rich mixtures are less sensitive (to mechanical impact, for example) than oxygen-balanced or oxygen-rich mixtures. Explosions can be initiated by mechanical shock, explosive shock, heat, electric discharges, hot surfaces, etc.

The following factors should not be overlooked in the investigation of a new system:

1. The possibility of reaction, such as the formation of performic acid in the system containing formic acid. In this case, the explosive region increases in area as a function of time because performic acid is generated at a measurable rate.

2. The addition of a new species such as sulfuric acid, which at high H_2SO_4/H_2O ratios caused the autodetonation of compositions which had yielded negative impact test results. This is usually a time-dependent reaction.

3. Immiscible systems can explode at interfaces. Increased dispersion may cause an immiscible system to be as dangerous as a miscible system.

4. Solids such as ion exchange resins, or plastics such as polyvinyl-chloride, can explode when saturated with concentrated hydrogen peroxide.

5. The first impact tests on a new system should probably be made at high hydrogen peroxide concentrations and low organic compound concentrations since this region is where the detonation limit is closest to the limit determined via impact test or cap-in-pipe test. For this same reason, definitive positive tests (as opposed to doubtful tests as often obtained with oxygen-deficient mixtures) will be obtained in this region (Ref. 6.14)

6.2 HAZARD PREVENTION

As described in the Hazards Section (6.1), spills and leakage of hydrogen peroxide can result in hazards to both personnel and facilities. The best possible means of avoiding these hazards is to eliminate or minimize the potential cause factors. Effective reduction of leakage, spills, contamination, and other potentially hazardous situations can be best accomplished by the use of properly designed equipment and thoroughly trained personnel.

6.2.1 System Integrity

The importance of the design integrity of propellant storage, transfer, and handling systems cannot be overemphasized. The systems should be reliable, operationally flexible, and easy to maintain. Some of the suggested design criteria that should be incorporated in a system are:

1. The system must be constructed of materials which are definitely known to be compatible with hydrogen peroxide.
2. The system will be designed and operated in such a manner as to prevent contamination of the system with known reactive materials.
3. The number of mechanical joints will be reduced to a minimum, thus reducing the probability of propellant leakage.
4. The system will be designed to safely withstand the maximum operating pressure.
5. The transfer lines will be free of liquid traps.
6. An inert-gas (moisture-free) system must be provided to purge the transfer lines without the necessity of dumping the residual hydrogen peroxide or disconnecting any system joints.
7. The system components must be reliable, compatible with hydrogen peroxide, and properly serviced (cleaned and passivated).
8. Sufficient remotely activated control equipment must be provided to isolate portions of the system during emergencies or component replacement.

The continual observation of an operational system for possible malfunctions can prevent serious propellant spills.

6.2.2 Trained Personnel

Properly trained personnel are required to handle propellant-grade hydrogen peroxide. All personnel concerned with the handling, storage, or transfer of hydrogen peroxide should be thoroughly familiar with the following:

1. The nature and properties of propellant-grade hydrogen peroxide
2. Compatible materials of construction and the necessity of essential passivation techniques
3. Operation of the transfer and storage system
4. Toxicity and physiological effects of hydrogen peroxide
5. Operation and use of safety equipment and clothing
6. Fire and spill prevention techniques
7. Fire and spill control measures
8. Disposal and decontamination techniques
9. Local operating procedures and regulations
10. First aid techniques

No person should be allowed to handle hydrogen peroxide unless thoroughly familiar with the previously listed items and should be confident that the propellant can be handled safely with the equipment and facilities available. In addition, all operations should be controlled by a procedures checklist, which has been prepared and thoroughly checked by personnel most familiar with the potential problem areas. As further safeguards, close supervision should be maintained to ensure adherence to safety practices, and all operations involving the handling of hydrogen peroxide should be performed by groups of two or more persons.

6.3 HAZARD CONTROL

6.3.1 Facility Safety Equipment

Equipment for facility protection should consist of a water deluge system and fire hoses (chemical fire extinguishers are not to be used on hydrogen peroxide fires). This equipment should be strategically located and easily accessible. Other facility items to be provided for personnel protection include safety showers, eye wash fountains, and appropriately located first aid kits.

All operating personnel should be thoroughly familiar with the location and operation of each piece of safety equipment. The operating condition of the equipment must be verified periodically.

6.3.2 Spill Control

A propellant spill can be most efficiently controlled by performing the following steps in the order listed:

1. Stop the propellant-handling operations
2. Isolate the propellant tanks from the transfer lines by closing the necessary valves (by remote control if possible)
3. Locate the source of the spill
4. Isolate the components affected by closing the necessary valves
5. Dispose of the spilled propellant

The performance of the first four steps should be automatic and can be performed in a very short time.

The disposition of the spilled propellant should not be too difficult, especially when propellant handling is performed during satisfactory weather conditions and the first four steps listed previously are quickly executed.

Hydrogen peroxide spills can best be controlled by deluging the spilled propellant with large quantities of water. After the spill is controlled, the entire area must be thoroughly cleaned to prevent the possibility of fire.

6.3.3 Fire and Explosion Control

Since most wooden flooring, straw, rags, clothing, leather, etc., contain enough catalytic material to cause rapid ignition with 90-percent hydrogen peroxide, proper precautions should be taken with this fact in mind. Storage areas for concentrated solutions should be of fireproof construction, and provision should be made for the flushing and draining of spillage.

Fires involving hydrogen peroxide should be controlled with water, because it dilutes the hydrogen peroxide and reduces the intensity of flare burning. The prompt application of copious amounts of water dilutes and cools, eliminating or minimizing the possibility of violent reaction. CHEMICAL FIRE EXTINGUISHERS SHOULD NOT BE USED.

To gain control, at least two parts of water for each part of hydrogen peroxide present should be applied. Because containers may burst, creating a fragmentation hazard, fighting these fires with hand lines is dangerous; therefore, prefire arrangements (i.e., the provision of fixed systems, etc.) should be made. In a hydrogen peroxide-fuel fire, every possible effort should be exerted to stop the flow of both fuel and hydrogen peroxide. If a fire breaks out nearby, containers of 90-percent hydrogen peroxide should be kept below 230 F to prevent vapor-phase explosions. A temperature-actuated sprinkler system on the storage tanks could be employed as a further precaution.

To prevent an explosion, hydrogen peroxide should be stored at a temperature low enough to prevent excessive gas formation due to decomposition. (A temperature below 145 F is recommended for

long-term storage as noted in Ref. 6.4). Hydrogen peroxide that has become contaminated or shows an abnormal temperature rise should be diluted and disposed of. Phosphoric acid (H_3PO_4) may be added as an emergency stabilizer to reduce decomposition (Ref. 6.4) before disposal.

6.4 PERSONNEL PROTECTION

6.4.1 Personnel Safety Equipment

The main personnel hazard in handling concentrated hydrogen peroxide is probably not from the contact of peroxide with the skin but the danger of burns caused by ignition of clothing. Protective clothing is necessary for all personnel handling concentrated hydrogen peroxide. Ordinary fabrics made of cotton, rayon, leather, or wool should not be used, because these are apt to ignite when splashed with hydrogen peroxide. Unnoticed splashes on ordinary clothing may cause fire sometime after the occurrence. Conventional permeable clothing of Dacron, Dynel, or Orlon, when used with eye goggles, gloves, and boots, normally gives adequate protection. For full body protection, vinyl coveralls or aprons of Koroseal or Neoprene should be used. The clothing must cover all parts of the operator's body and must be adjusted so as to prevent drainage into the gloves or boots. Permeable clothing wet with peroxide must be flushed with water and removed promptly, and the affected body parts must be thoroughly washed.

The hands and feet are always subject to contamination during the handling of liquid propellants or associated equipment. Gloves and boots will keep hydrogen peroxide from touching the skin. (Leather reacts quite readily with hydrogen peroxide, however.) The gloves used should protect against hydrogen peroxide and also should allow free movement of the fingers. The vinyl-coated gloves, Type R-1, Mil-G-4244 (Ref. 6.16) meet these requirements. Surgical rubber gloves or lightweight Neoprene gloves are suitable for handling small parts. Since boots of the approved protective materials

are not commercially available, an overboot, designed to be worn over regular safety footwear and high enough to fit comfortably under the protective trousers, is suitable. Boots made of natural or reclaimed rubber or GR-S may be used with reasonable safety if any contamination is washed off quickly. The boots should be frequently inspected to detect flaws which might result in personal injury. Severe foot burns can result from splashes on ordinary shoes.

Respiratory protection against vapors is not ordinarily required. Respirators approved for protection against hydrogen peroxide mists, however, should be available for use where exposure to the aerosol or mist is possible (Ref. 6.17 and 6.18).

In selection of protective clothing for H_2O_2 handling, the degree of hazard involved and the workers' comfort and agility must be considered. Overdressing and use of protective accessories when not warranted can actually be hazardous. A hood and full suit of impermeable clothing is only required where danger of gross spillage or spray directly on the worker is involved. In a pump transfer operation of hydrogen peroxide above 50 w/o, at least one man should be fully outfitted with impermeable clothing if detachable equipment such as a hose is being used. For handling hydrogen peroxide in drum quantities and in pump transfers in a permanent piping system, the permeable uniform worn with face shield, or eye goggles, rubber gloves, apron, and boots or rubbers will be sufficient. When wearing permeable Dacron or Dynel shirts and trousers, it is good practice to wear Dacron or Dynel underwear and socks. Goggles which afford complete eye protection should be worn during all handling and transfer operations. Water must always be available and two persons must always be present when high-strength hydrogen peroxide is handled even if protective clothing is worn.

Protective clothing and accessories recommended for personnel handling propellant-grade hydrogen peroxide are listed in Table 6.7.

6.4.2 First Aid

IF HYDROGEN PEROXIDE CONTACTS THE SKIN. Flood the area involved with water. If burns are present, refer to a physician.

IF HYDROGEN PEROXIDE CONTACTS THE EYES. Flush immediately and freely with water for at least 10 to 15 minutes; or if water is not available, saliva can be used to absorb the hydrogen peroxide and decrease the effect upon the tender eye membrane (Ref. 6.3). This should be done if even minute quantities of solution have entered the eyes. For any case of exposure involving the eyes, refer to an eye specialist.

IF HYDROGEN PEROXIDE IS SWALLOWED. Encourage vomiting. Give lukewarm water freely and encourage belching if there is evidence of distention. Call a physician.

IF HYDROGEN PEROXIDE VAPOR OR MIST IS INHALED. Remove victim immediately from further exposure. If irritation of the nose and throat is severe, refer to physician.

6.4.3 Medical Treatment

IN CASES OF EXTREME EXPOSURE OR CONTACT, OR PERSISTING IRRITATION, A PHYSICIAN SHOULD BE NOTIFIED.

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TABLE 6.1

90- TO 100-PERCENT HYDROGEN PEROXIDE THERMAL SENSITIVITY DATA*

Liquid Systems:				
Conditions of Test	Temperature, F	90 percent	95 percent	98 to 100 percent
Glass Vials in Wood Metal Bath 0.1 to 0.2 milliliter H_2O_2		Exploded at 302+ F	Slow explosion	Explodes at 270+ F
Aluminum Tube, Nichrome-Wound, 5 milliliters H_2O_2	383 302	Rapid decomposition	Slow explosion	Detonates
Melting Point Block—Aluminum and Glass Inserts		All decompose and explode at temperatures of 284 F and up		
Stainless-Steel Bomb		All slowly explode at temperatures above 248 F		

Vapor Systems:		H_2O_2 in Liquid, w/o	
Conditions of Test		90	100
Boiling Liquid in Glass at Atmospheric Pressure		Vapor Explodes at 284 to 302 F. Liquid rapidly decomposes.	Vapor and liquid explode at 307 F

*Data taken from work of various investigators and summarized in Ref. 6.12. These data, which were not referenced or otherwise detailed with regard to additional test parameters and techniques, are included as a general summary of the data preceeding the efforts reported in Ref. 6.12.

TABLE 6.2

THERMAL TESTS ON 90- TO 98-PERCENT H_2O_2 IN CLOSED CONTAINERS*

In Sealed Glass Bulbs 90-Percent H_2O_2 Only:				
H_2O_2, grams	Starting Temperature, F	Explosion Temperature, F	Time Heated, minutes	Remarks
0.438	356.0	374.0	5	Tests indicate liquid H_2O_2 does not detonate even at its boiling point. The explosion is probably due to relatively slow decomposition.
0.096	368.6	404.6	2	
0.461	348.8	404.6	3	
0.165	294.8	347.0	135	
0.235	336.2	345.2	4	
0.096	311.0	321.8	11	

In a Passivated Stainless-Steel Bomb With an Aluminum Liner:					
H_2O_2, w/o	Quantity, milliliters	Temperature, at Start, F	Temperature, Final, F	Pressure Rise, psi/sec	Reaction Time, seconds
90	30	275.0	519.8	1400	7.6
95	30	269.6	559.4	5450	1.6
98	30	287.6	609.8	9020	2.2

NOTE: These tests indicate that none of the H_2O_2 detonates, but 98 percent is sharply more hazardous.

*Ref. 6.12

TABLE 6.3

THERMAL-DECOMPOSITION TESTS OF HYDROGEN PEROXIDE*
(250-cc Round-Bottom Glass Flask)

Test No.	H_2O_2 Concentration, percent	Volume Charged, cc	Temperature Recorded	Initial Explosion Temperature, F	T_{max}, F	ΔT, F	Remarks
1	90	15	Vapor	266	>572	>306	Vapor explosion
2	90	15	Vapor	284	377.6	93.6	Vapor explosion
3	90	15	Vapor	287.6	370.4	82.8	Vapor explosion
4	90	15	Vapor	260.6	917.6	657.0	Vapor explosion
5	90	15	Vapor	255.2	465.8	210.6	Vapor explosion
6	90	12	Vapor	267.8	645.8	378	Vapor explosion
7	95	12	Vapor	235.4	458.6	223.2	Vapor explosion
8	95	12	Liquid	284.0	633.2	349.2	Vapor explosion
9	95	12	Liquid	—	—	—	Vapor explosion; blew thermocouple out
10	95**	12	Liquid	276.8	305.6	28.8	Vapor explosion
11	95**	12	Vapor	147.2	179.6	32.4	Vapor explosion; blew thermocouple out
12	95**	12	Liquid	264.2	858.2	594	Vapor explosion; two reports audible
13	95**	12	Vapor	276.8	392.0	115.2	Vapor explosion; two reports audible
14	98	12	Liquid	212	282.2	70.2	Vapor explosion
15	98	12	Liquid	203.0	309.2	106.2	Vapor explosion
16	98	12	Vapor	136.4	314.6	178.2	Vapor explosion; glass vessel ruptured
17	98**	12	Liquid	296.6	—	—	Vapor explosion; no temperature record
18	98**	12	Liquid	212	—	—	Vapor explosion; glass vessel ruptured

*Ref. 6.12
**Flask opening covered with aluminum sheet

TABLE 6.4

THERMAL-DECOMPOSITION TESTS OF HYDROGEN PEROXIDE*

(265-cc Closed Vessel)

Test No.	H_2O_2 Concentration, w/o	Volume Charged, cc	Initial Explosion Temperature, F	T_{max}, F	ΔT, F	P_{max}, psig	$(dp/dt)_{max}$, psi/sec	Time to P_{max}, seconds	Remarks
1	90	15	287.6	377.6	90	——	—	—	No pressure record available
2	90	15	262.4	388.4	126	660	—	—	No pressure rate or time
3	90	15	248.0	464	216	1000	1050	1.7	
4	90	25	280.4	528.8	248.4	——	—	—	No pressure record available
5	90	25	275.0	518	243	1450	1360	7.6	
6	95	15	284.0	485.6	201.6	——	—	—	No pressure record available
7	95	15	284.0	440.6	156.6	800	510	> 3.5	
8	95	25	294.8	536.0	241.2	1260	—	—	No pressure rate or time
9	95	25	269.6	559.4	289.8	2500	5450	1.6	
10	98	15	280.4	465.8	185.4	1000	1290	2.85	
11	98	25	287.6	609.8	322.2	3100	9020	> 2.2	

*Ref. 6.12

TABLE 6.5

SHOCK-SENSITIVITY TESTS OF HYDROGEN PEROXIDE*

(Modified Card-Gap Apparatus)

Test No.	Liquid Under Test	Volume Charged, cc	Tetryl Charge Weight, grams	Disk Thickness, mils	Results
1	Water	40	14	10	Fragmented apparatus; no apparent damage to "crusher"
2	90-percent H_2O_2	40	14	10	Fragmented apparatus; no apparent damage to crusher
3	95-percent H_2O_2	40	14	10	Fragmented apparatus; no apparent damage to crusher
4	98-percent H_2O_2	40	14	10	Fragmented apparatus; no apparent damage to crusher
5	98-percent H_2O_2	40	33	10	Fragmented apparatus; no apparent damage to crusher
6	95-percent H_2O_2	40	33	10	Fragmented apparatus; no apparent damage to crusher
7	90-percent H_2O_2	40	33	10	Fragmented apparatus; no apparent damage to crusher
8	90-percent H_2O_2	40	14	10	Fragmented apparatus; no apparent damage to crusher
9	98-percent H_2O_2	40	33	5	Fragmented apparatus; no apparent damage to crusher

*Ref. 6.12

TABLE 6.6

90- TO 100-PERCENT HYDROGEN PEROXIDE SHOCK SENSITIVITY DATA*

	H_2O_2, w/o		
	90	95	100
Impact Tests	← No explosions →		
Rifle Fire	← No explosions →		
No. 6 and 8 Blasting Caps Alone	← No detonations →		
No. 6 and 8 Blasting Caps With Pentaerythritol	Incomplete	detonation →	→ Complete
Ballistic Mortar	40 percent of TNF	80 percent of TNF	
Lead Block Enlargement	5 cc/gm	7 cc/gm	9 to 12 cc/gm
Explosion Velocity Aluminum Pipe	<100 meter/sec	4500 meter/sec	6200 meter/sec
Closed Steel Tubes, 175 milliliters H_2O_2 + 50 grams Penthrite Primed With Fulminate	No Detonation	Detonated	—

*Data taken from work of various investigators and summarized in Ref. 6.12. These data, which are not referenced or otherwise detailed with regard to additional test parameters and techniques, are included as a general summary of the efforts preceding the data reported in Ref. 6.12.

TABLE 6.7

PROTECTIVE CLOTHING AND ACCESSORIES RECOMMENDED FOR PERSONNEL HANDLING CONCENTRATED HYDROGEN PEROXIDE*

Item	Description	Source
Shirts, Trousers	Dacron fabric, Polystyrene buttons, no front or side pockets, no cuffs	Worklon, Inc., N.Y., N.Y.
	Dynel Fabric	Mine Safety Appl. Co.
	100-percent Dynel Chem-Weave, medium weight	Chem-Wear, Inc., Darien, Conn.
Belts	Vinyl plastic, with plastic buckle	Numerous commercial sources
Undershirts	Dacron	Alamac Knitting Mills, N.Y., N.Y., Special lot, minimum order, 10 dozen
	Dacron-cotton (can be ignited if soiled)	Carmi-Ainsbrooke Corp., Carmi, Illinois
Shorts	Dacron	Carmi-Ainsbrooke Corp. Manhattan Shirt Co., N.Y., N.Y.
Socks	Knit Dacron, no elastic, white Dynel fabric	Holston Mfg. Co., Knoxville, Tenn. Numerous commercial sources
Shoes	6-inch Neoprene Coated, No. 990 steel toe	Iron Age Div., Childs & Co., Inc., Pittsburgh, Pa.
Rubbers	Full, Neoprene with tongue	Numerous commercial sources
Boots	Neoprene, knee length	Numerous commercial sources
Goggles	No. 93 AV large nose, clear Willson Monogoggle	Willson Products, Inc., Reading, Pa.
	Model 293607 SAF-I-CHEM, Series 29 clear lens	U.S. Safety Service Co. Kansas City, Mo.
Face Shield	No. 324 clear Sellstrom face shield	Watson Co., Buffalo, N.Y.
Gloves	Sureseal, gauntlet, Vinyl or Neoprene, No. 116 lightweight for laboratory use. No. 136 medium weight for work use	Surety Rubber Co. Carrollton, Ohio
Apron	8-mil vinyl plastic. Surgeon's type, extra long, overlapping in back, ties in front.	Milburn Co. Detroit 7, Mich.

*Ref. 6.19

TABLE 6.7

(Concluded)

Item	Description	Source
Coveralls	Vinyl plastic. One-piece, light weight disposable unit. Grey color	Mine Safety Appliance Co.
Caps	Dacron fabric. Baseball type, with removable sunshade for neck.	Worklon, Inc.
	Dynel fabric	Chem-Wear Mine Safety Appliance Co.
Hood	8-mil vinyl methacrylate window, detachable head band, adjustable for size	Milburn Co. Detroit 7, Mich.
Impermeable Jacket	Fiberthin Raynster, Neoprene coated Nylon, MRS-107	U.S. Rubber Co. Washington, Ind.
Impermeable Overalls	Fiberthin Raynster, MRO-107	U.S. Rubber Co. Washington, Ind.
	OUTDOOR WINTER-WEIGHT PROTECTIVE CLOTHING	
Shirts	55-percent Dacron-45 percent wool Sport-type shirt, polystyrene buttons	Worklon, Inc. New York, N.Y.
Trousers	55-percent Dacron-45 percent wool No pockets, cuffs	Worklon, Inc. New York, N.Y.
Cap	100-percent Dacron pile lining, outer material	Borg Fabric Div. G. W. Borg Co. Delavan, Wisc.
Pants	100-percent Dacron pile lining, outer material	Borg Fabric Div.
Boots	Neoprene, insulated boots. Similar to U.S. Army all-rubber, insulated combat boots	Hood Rubber Co. Watertown, Mass.
Jacket	100-percent Dacron pile lining, outer material	Borg Fabric Div.

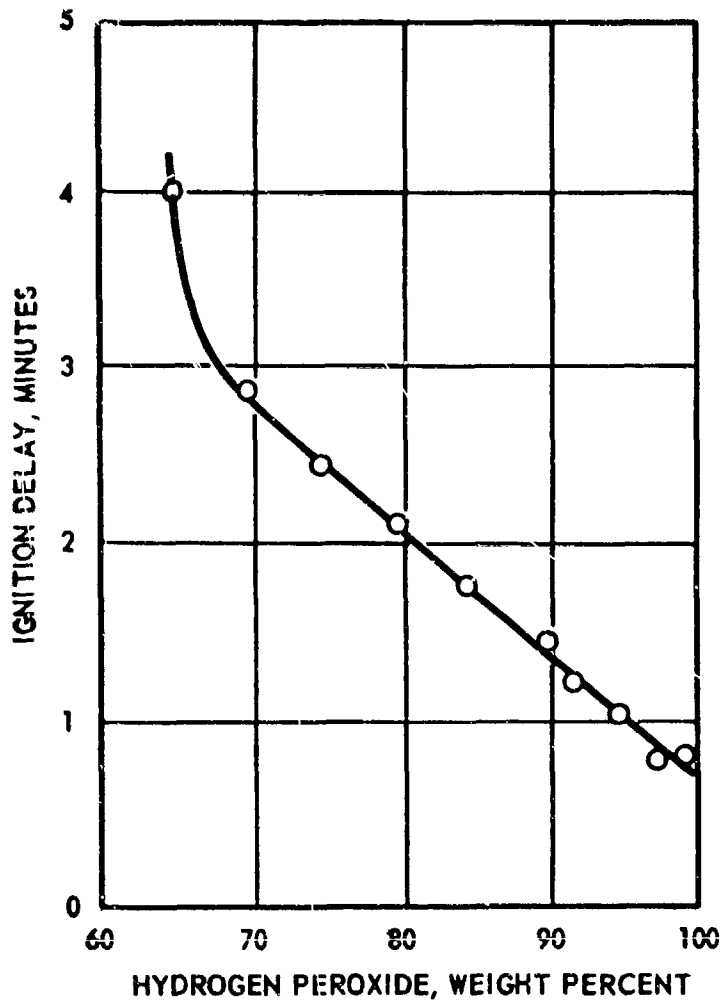


Figure 6.1. Ignition Delay of Hydrogen Peroxide With Felt (Ref. 6.7)

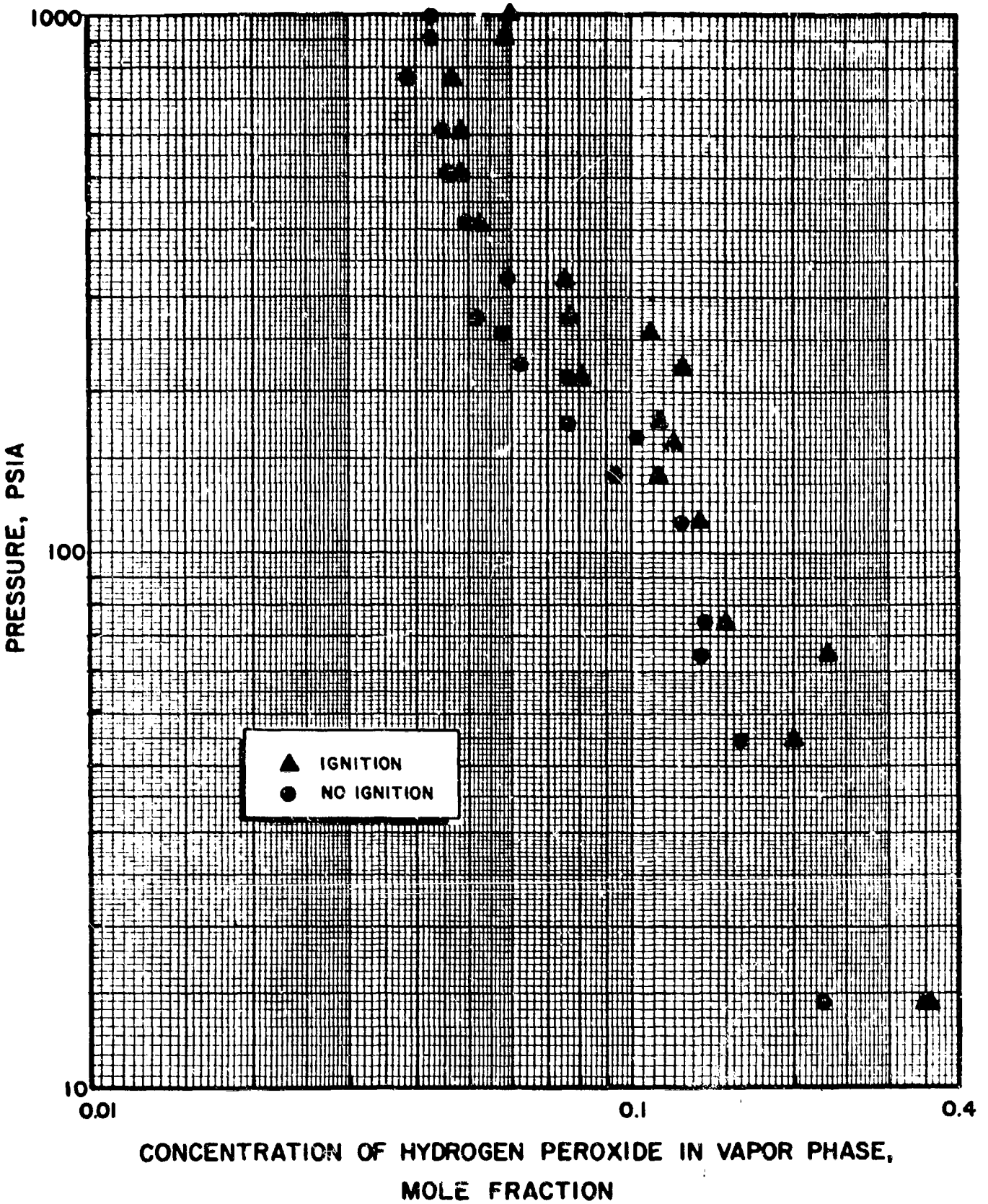


Figure 6.2. Ignition Limits of Hydrogen Peroxide Vapor (Ref. 6.8)

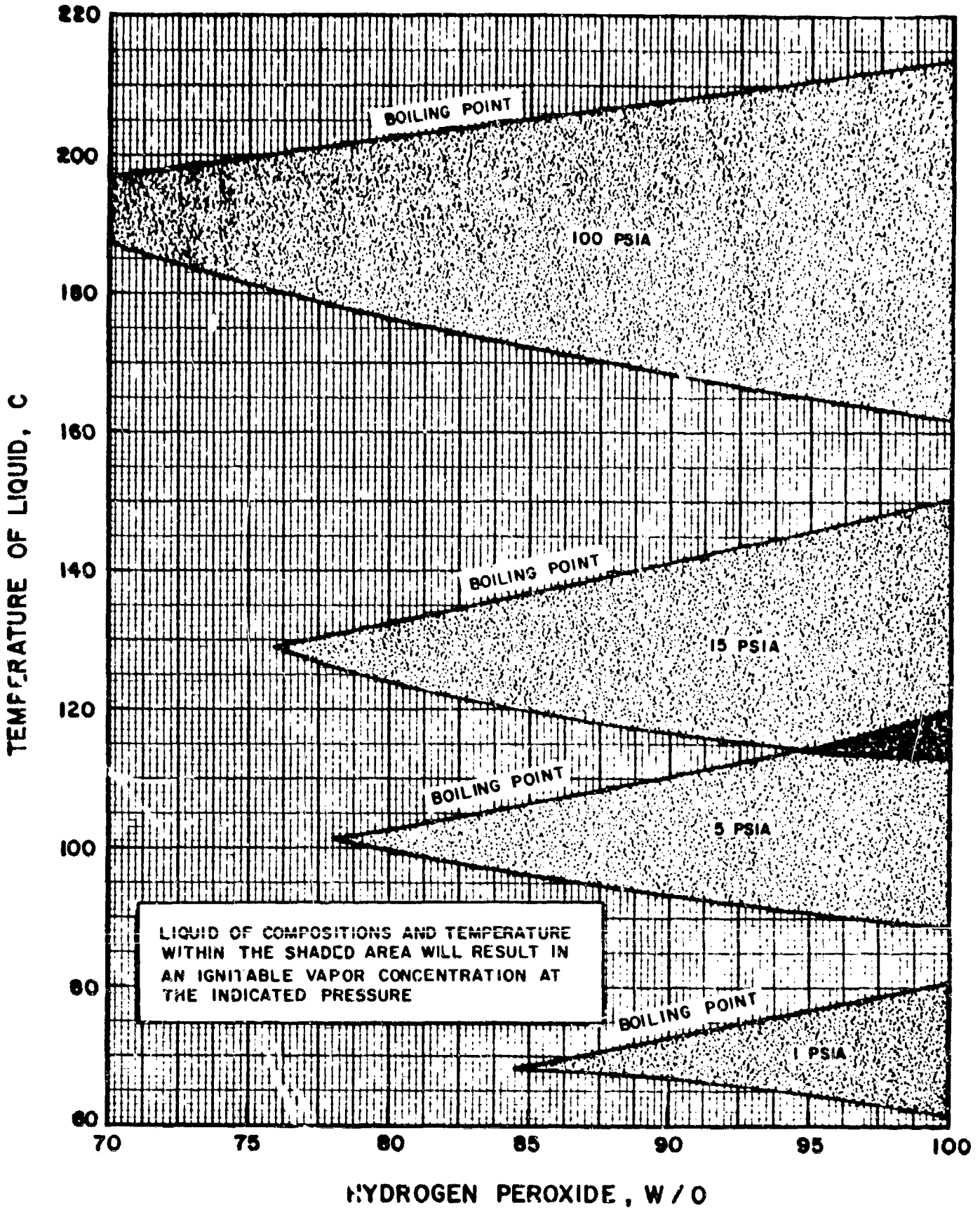


Figure 6.3 Liquid Compositions Which Result in Ignitable Vapor Concentrations (Ref. 6.10)

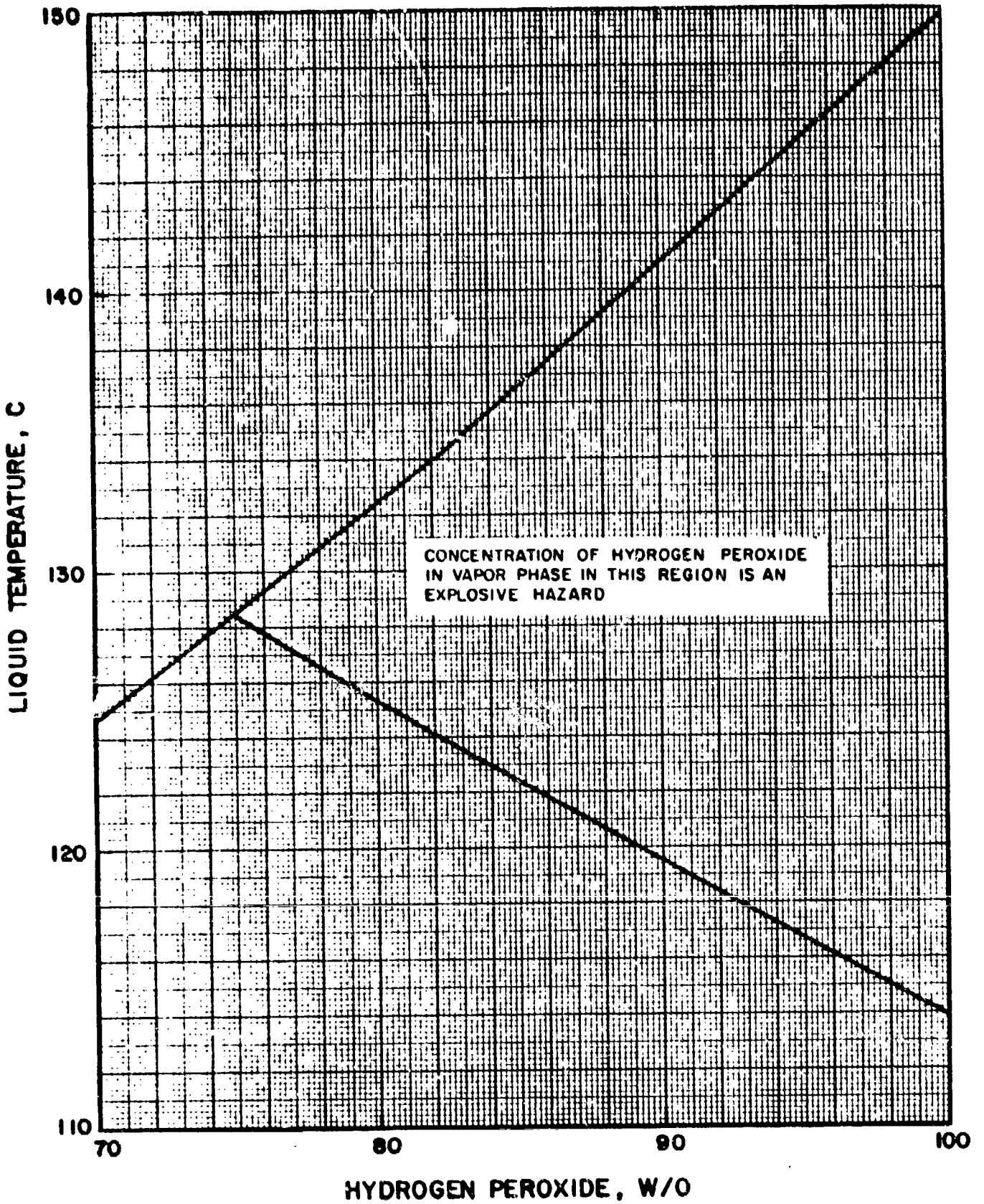


Figure 6.4. Hydrogen Peroxide Vapor Explosive Hazard Region (Ref. 6.11)

SECTION 7: DECOMPOSITION

7.1 DECOMPOSITION MECHANISM

The decomposition of hydrogen peroxide may be represented by the equation:

$$H_2O_2 \longrightarrow H_2O + 1/2\ O_2$$

This decomposition process is irreversible. Kineticists studying this particular decomposition process can theoretically illustrate 10 to 20 intermediate reactions which may exist in hydrogen peroxide decomposition; however, the above equation is the effective result of these intermediate steps in the decomposition. Although the rate controlling reaction has not been identified, it is generally believed that it is one involving an electron transfer.

Since its discovery, when Thenard (Ref. 7.1) reported on the effect of over a hundred materials on the decomposition reaction, many decomposition studies have been conducted on hydrogen peroxide in attempts to characterize the decomposition process. Throughout these studies, it has been recognized that hydrogen peroxide decomposition is a result of both homogeneous and heterogeneous reactions. This decomposition, when both the liquid and vapor phases of hydrogen peroxide exist, has been considered as the sum of five types of reactions: (1) homogeneous reaction in the liquid phase between the hydrogen peroxide and dissolved catalytic or oxidizable components; (2) heterogeneous reaction of the liquid phase with surfaces of the container and/or suspended particles; (3) heterogeneous reaction of a film of condensed hydrogen peroxide on surfaces in contact with the vapor phase; (4) heterogeneous reaction of the vapor phase on dry surfaces; and (5) homogeneous decomposition of the vapor phase (Ref. 7.1).

In a recent investigation (ef. 7.2) to define the contributions of these individual reactions to the ambient temperature decomposition of 90 w/o hydrogen peroxide, reaction types (4) and (5) were ignored. Reaction type (4) probably does not occur when the temperature of the surfaces is below the hydrogen peroxide boiling point and the effects of reaction type (3) were considered insignificant at the temperatures under consideration. In addition, it was indicated that reaction type (1) could probably be separated into further types of reactions; however, for the purpose of the particular study, the liquid phase homogeneous decomposition was considered as being essentially ionic catalysis. The differences between reaction types (2) and (3) were considered to be in the effective concentration of hydrogen peroxide on the surfaces, the concentration of contaminants which may build up in this condensed liquid film, and in the concentration of inhibitors which would be present in the condensed film (unless agitation of the vessel caused frequent wetting and washing of all surfaces with the hydrogen peroxide liquid phase).

Assuming these three types of reactions are the only contributing effects to hydrogen peroxide decomposition in the ambient temperature range, the rate of decomposition can be represented by the following expression:

$$\frac{d(HP)}{dt} = k_1 (HP) + k_2 (HP) (S/V)_{liq.} + k_3 (HP) (s/V)_{vapor}$$

where HP = concentration of hydrogen peroxide

k_1 = liquid phase homogeneous reaction rate

k_2 = liquid phase heterogeneous reaction rate

k_3 = vapor phase heterogeneous reaction rate

S/V surface to volume ratio of the liquid phase

s/V = surface to volume ratio of the vapor phase

t = time

Through the use of various purification techniques, relatively inert surfaces, and the absence of a vapor phase, the experimenters of Ref. 7.2 were able to isolate, for all practical purposes, the effective homogeneous reaction rates of the liquid from 20 to 100 C (68 to 212 F). Using these data, the effects of soluble additives (such as stabilizers) on the liquid phase were also determined. Although the data resulting from this work varied from test to test and as a function of stabilizer concentration and type, temperature, and manufacturing process, the homogeneous decomposition rate of the stabilized and unstabilized liquid was generally found to be less than $\sim$ 0.03 w/o active oxygen loss (AOL) per year at 100 C (212 F). In addition, it was indicated that for future comparisons of results at different temperatures or the estimation of decomposition rates at various temperatures, the activation energy for the homogeneous decomposition of hydrogen peroxide can be assumed to be 18 kcal/mole.

As a result of this work, the experimenters indicated that the predicted homogeneous decomposition rate of hydrogen peroxide would correspond to the following expression:

$$D_l = 10^{7.2} e^{-\frac{1800}{1.987T}}$$

where D_l = homogeneous decomposition rate in weight fraction/year

and T = temperature in K.

Using an overall decomposition rate with a correction for the effect of the homogeneous rate, heterogeneous decomposition rates were also determined in this study. Values were calculated for k_2 using experimental decomposition rates obtained for hydrogen peroxide storage in 5-gallon storage tanks fabricated from different materials. In these tests it was assumed that the rate constants for both vapor phase and liquid phase heterogeneous decomposition were equivalent at the lower temperatures

(on the basis that the rate of decomposition was sufficiently slow so that mass transfer of hydrogen peroxide to the vapor space surface was not the controlling rate); thus the heterogeneous decomposition rate for both phases was equivalent to k_2 (S/V) where (S/V) represented the total exposed surface area of the tank relative to the volume of the liquid hydrogen peroxide. Results of these tests indicated that k_2 for the different materials at 25 C (77 F) appeared to be as follows:

1260 aluminum	= 0.0065 weight fraction AOL, cm/year
5052 aluminum	= 0.0160 weight fraction AOL, cm/year
tin plate	= 0.286 weight fraction AOL, cm/year
Kel-F	= 0.0031 weight fraction AOL, cm/year

Additional studies in this and the homogeneous area are being conducted by the same investigators and have been reported thus far in Ref. 7.3 and 7.4.

A study of hydrogen peroxide homogeneous decomposition rates in the complete absence of catalytic surface effects (Ref. 7.5) was attempted through the use of solid hydrogen peroxide as the container wall. Unfortunately, during the period of the contracted work, the desired experimental conditions were not obtained, although definitive techniques were proposed for future study. However, during the study, total decomposition rates were measured on several purified and stabilized grades of 90 and 98 w/o hydrogen peroxide in both the frozen (-60 and -30 C) and the cooled liquid (0 C) state. The resulting decomposition rates from these tests, which were effectively due to homogeneous decomposition effects, were below 0.023 w/o AOL/year.

Throughout the various decomposition studies that have been conducted on hydrogen peroxide, it has been generally indicated that the homogeneous decomposition rates of liquid hydrogen peroxide were found to be dependent upon:

1. Hydrogen peroxide concentration

2. Type of additives or contaminants present
3. Concentration of additives or contaminants
4. pH
5. Particular combinations of foreign materials present
6. Temperature

Similarly, the heterogeneous reaction rates were found to be dependent upon:

1. Hydrogen peroxide concentration
2. Temperature
3. Passivation or cleaning technique
4. Surface area
5. Surface finish (area ratio)
6. Localized concentrations of impurities in the solid surface
7. Pressure (under certain conditions)

Numerous investigators have reported decomposition and stability data for hydrogen peroxide as a function of these variables and with hundreds of various materials. Because of the uncertainty involved in trying to segregate any one of the contributing parameters in the decomposition process, illustrations of the individual paremeters are not presented in this handbook. However, these decomposition data are summarized as total effects relative to engineering parameters such as storability (Section 4.1), materials compatibility (Section 4.2), passivation effectiveness (Section 4.3), etc., in other parts of this handbook.

For those users of this handbook who are interested in more details of various reaction rates and other aspects in the decomposition of hydrogen peroxide, the use of the previously referenced literature (Ref. 7.1, 7.2, 7.3, 7.4, and 7.5) as well as the use of references to literature on decomposition provided in the attendant bibliography (Section 8.9) will provide the basis for further investigation.

7.2 CONTROLLED DECOMPOSITION

The hydrogen peroxide decomposition process is used under controlled conditions to provide a high temperature gas as the working fluid for reaction control systems, auxiliary power units, turbopump drive, underwater propulsion, etc. Ordinarily, to achieve effective use of the decomposition process for these applications, the hydrogen peroxide must undergo a rapid and complete decomposition to H_2O and O_2 within the confines of a combustion chamber; the decomposition must be immediately initiated upon entry to the chamber and must be completed upon exit. The process must occur smoothly without radical surges or oscillations in the working pressure. There have been two primary methods employed to initiate and maintain this type of a controlled decomposition of hydrogen peroxide in a combustion chamber: (1) catalytic decomposition and (2) thermal decomposition.

7.2.1 Catalytic Decomposition

Catalytic decomposition of hydrogen peroxide is, as implied, dependent on the use of a catalyst, either as a liquid in a fluid-type catalytic chamber or as a solid in a fixed bed chamber. In the use of a liquid catalyst, a suitable catalytic liquid is continuously injected into the combustion chamber with the hydrogen peroxide and ejected out of the combustion chamber with the decomposition gases. The liquid catalysts normally employed are aqueous solutions of calcium or potassium permanganate.

Solid catalyst beds normally consist of packed columns of porous materials or screens, which have been coated with the catalytic agent. The solid porous materials are usually referred to as catalytic stones and are activated by impregnation

with the catalytic agent contained in a solvent with subsequent removal of the solvent (usually by drying). Materials that have been commonly used for this type of solid catalyst are aqueous solutions of calcium or potassium permanganate, or the metallic nitrates. Calcium permanganate is usually prefered to potassium permanganate, primarily due to its higher solubility in water. The most effective results from this type of catalyst are usually obtained with alumina or carborundum particles as the porous carrier medium.

Silver is probably the best known and the most active catalyst for the decomposition of hydrogen peroxide. This catalytic material is usually applied in a screen type of configuration. Since pure silver has proven somewhat undesirable from a physical integrity standpoint (especially at the temperatures obtained in this type of application) and because of its high cost, the silver catalyst is also used as a plating on brass, nickel, or stainless steel screens. To further reduce the cost imposed by the silver, stainless or nickel screens are intermingled with the silver or silver coated screens, without reducing catalyst effectiveness; of course a minimum number (which is dependent on the particular configuration) of catalyst screens, is required for satisfactory operation. The use of the silver plated screens usually offers better initial starting characteristics than the catalyst does and provides more structural integrity in the bed; however, such screens are more subject to catalyst stripping during operation. Because the initial activity of previously unused silver catalysts is normally low, they are usually "activated" by pretreatement with samarium nitrate (by immersion) and hot fired in a furnace prior to their use in the catalyst pack.

Although the silver and the permanganate catalysts have been the catalysts of choice for most of the controlled decomposition concepts, there are a number of other types of materials which have been investigated as hydrogen peroxide catalysts. Identification of these different materials and a more detailed discussion of the catalytic decomposition process are contained in Ref. 7.1, 7.6, 7.7, and 7.8. A complete bibliography of other data in this area has been compiled in Ref. 7.9.

7.2.1.1 Catalyst Pack Design and Descriptions. The permanganate liquid catalyst was initially used by the Germans during World War II for application in torpedo propulsion and in a gas generator to drive the turbopumps for the V-2 rocket. Although the liquid permanganate catalyst is still used for some underwater propulsion applications, the solid catalysts have proven to be more applicable to most of the present monopropellant hydrogen peroxide propulsion and gas generation concepts.

The first effective application of the solid catalyst concept was in the Redstone Missile gas generator system. This catalyst (Ref. 7.10) was used to decompose a 76 w/o hydrogen peroxide solution to provide working gases for a turbine which was used to drive the main propellant pumps of the missile system. The catalyst was a polysurfaced silicon carbide "stone" which had been impregnated with calcium permanganate. These "permanganate stones" (PMS) were screened to +16 mesh and packed into a catalyst bed of approximately 3 inches depth, where they were held in place by an inlet screen of 16 mesh and outlet screens of 16 and 80 mesh, supported by rigid perforated steel plates. A hydrogen peroxide flow rate of $\sim$6.0 lbs/sec resulted in a bed loading rate of $\sim$ 10 lb/sq in.-min and a 20- to 30-psi bed

pressure drop. The catalyst was required to give suitable operation for 600 seconds; the start transient was ~70-150 ms from propellant entry into the chamber to 90% Pc.

Although the PMS catalyst provided a suitable catalyst for 76 w/o hydrogen peroxide, the use of concentrations in excess of 85 w/o H_2O_2 stripped the catalytic material from the porous carrier. In addition, the PMS catalyst had a tendency toward fracturing or "dusting" in handling with a resultant loss in catalytic efficiency. Thus the development of a more suitable catalyst for higher hydrogen peroxide concentrations was sought.

In the middle 1950's, silver catalyst screens were developed for use with 90 w/o H_2O_2. Since then, there have been a number of different types of silver catalysts developed for different applications. Each bed is unique to the application for which it is developed, thus each particular design may be slightly different. Because there are a number of different catalyst beds for decomposition of 90 w/o H_2O_2 in existence today, a listing of each in this handbook would be prohibitive. Therefore the description of a catalyst pack for 90 w/o H_2O_2 given in the succeeding paragraph represents a general description of the silver screen catalyst pack and does not represent any single design.

Silver catalyst screens may be (as mentioned previously) fabricated from pure silver or from silver plated-brass, -nickel, or -stainless steel screens. The screens are usually 16 to 20 mesh with a wire diameter of ~0.014 inches. Some specifications for catalyst screens call for a 66 to 71 percent light-transmission. After "activation" by samarium nitrate immersion and baking, the screens are packed into the combustion chamber (with a light force fit against the walls) at right angles to the combustion chamber. Usually

the packing is such that a stainless steel or nickel screen (inactive screen) is placed between two catalyst screens. The number of catalyst screens is dependent on system requirements (operational life, bed size, throughput, pressure drop limitations, start transients, etc.) and may vary from 15 to as many as 100 catalyst screens.

Usually, the bed is terminated with several "inactive" screens. Perforated stainless steel supports are used as screen retainers, and also may be placed at different points in the bed to act as anti-channel baffles. The entire column is compressed to some specified compacting pressure to limit pressure oscillations and assure reproducible performance (pressure drop, flow rate, temperature gradient, etc.) from bed to bed in the same hardware. Most silver screen catalyst beds are operated at bed-loadings of $\sim$ 20 lb/sq in-min; these bed loading rates may vary although it should be noted that higher catalyst bed loading rates will result in higher bed pressure drops and silver erosion rates. Bed pressure drops usually run from 75 to 125 psi.

The standard silver and silver-plated screen catalysts were found to be inadequate for sustained decomposition of 90 w/o H_2O_2 that is pre-heated to temperatures above 100 to 150 F, or for concentrations of hydrogen peroxide with adiabatic decomposition temperatures above 1400 to 1500 F. Because many present applications involve preheating of the hydrogen peroxide (as a result of its use as a regenerative coolant) and the use of 98 w/o H_2O_2 which decomposes at $\sim$ 1800 F, the development of a catalyst which retains physical strength and chemical reactivity above this temperature has been pursued.

The initial development of a high temperature hydrogen peroxide catalyst was undertaken by Rocketdyne, first under company-sponsored funding and later under Contract NOas 56-1052J. Although this catalyst, which is described in Ref. 7.11, has been used successfully at Rocketdyne for several years in the decomposition of 98 w/o H_2O_2, the catalyst's physical and chemical stability at temperatures of 2000 F is questionable. Thus under Air Force Contract AF04(611)-11208, FMC initiated the development of new decomposition catalysts for 98 w/o H_2O_2. Their progress in these efforts have been reported in Ref. 7.12.

For those users of this handbook who are interested in the detailed design of catalyst beds for various concentrations of propellant-grade hydrogen peroxide, the use of data contained in Ref. 7.13, 7.14, 7.15, and 7.16, in addition to those already cited, are suggested.

7.2.1.3 Catalyst Poisoning. There are a number of impurities that may be contained in hydrogen peroxide, which will cause catalyst poisoning or catalyst pack malfunction. Although these impurities are normally associated with those additives used in stabilization, any non-volatile contaminant or additive in the hydrogen peroxide is a potential catalyst poison. Residual or nongaseous products from the decomposition process, such as tin or aluminum, may act as a catalyst poison by depositing on the catalyst to decrease the effective catalytic surface or by physically plugging the flow paths. Other materials such as the nitrates, chlorides, and phosphates may cause excessive erosion and loss of catalytic material, which reduces the effective activity of the catalyst. Additives which act as stabilizers during hydrogen peroxide storage by complexing and "tying up" the activity of heavy metal ions also tend to complex with the catalyst material in the combustion chamber.

Although the particular details of catalyst poisoning by various potential contaminants are not completely understood, most of the important hydrogen peroxide catalyst poisoners have been identified. Attempts at characterizing limitations for each of the individual species and the contributions and limitations of their interaction have met with little success. However, the limitations (which were determined under an extensive Navy "crash" program and further refined through extensive use) placed on inorganic contaminants in the hydrogen peroxide by the procurement specification MIL-P-16005D (see Section 3.3) for 90 w/o hydrogen peroxide have been effective in controlling poisoning of catalysts used for decomposition of propulsion grade hydrogen peroxide.

7.2.1.3.1 Effect of Organics. For some time there has been considerable controversy over possible differences between hydrogen peroxide produced by the various production techniques with respect to silver-screen catalyst performance and failure. Organic contaminants found in hydrogen peroxide produced by the organic process (namely the anthraquinone and propane-derivative oxidation processes) were suspected of being responsible for various catalyst pack failures that occurred periodically in various hydrogen peroxide decomposition systems (Ref. 7.15). Although there were a few catalyst pack failures (in contrast to the many successful operations) during operation of the packs with organically derived hydrogen peroxide, there was a lack of clear-cut analytical evidence indicating that the organic contaminants were contributing causes.

Because there was a belief that the higher carbon content of the organic materials either caused the reaction to exceed the melting point of the catalyst or caused a carbonate formation on the surface of the catalyst (to effectively poison it), a study was conducted by Rocketdyne (Ref. 7.11) to determine the potential effect of carbon content on

catalyst performance. The performances of three types of organically derived hydrogen peroxide were compared with that from the electrolytic process in silver screen catalyst packs of the configuration used in the Rocketdyne Super Performance Aircraft Rocket Engine (Models AR-1, -2). The results from these tests indicated that the performance of one of the organically-derived hydrogen peroxides (with a carbon content of 150 to 200 mg/l) was equivalent or better than that of the electrolytically-produced reference hydrogen peroxide. The failure of the catalyst in the use of the other two organically-derived hydrogen peroxides (with similar carbon contents of 120 to 270 and 194 to 212 mg/l, respectively) was theorized to be a result of either (1) the specific nature of the carbon compounds present, (2) synergistic effects of organic and inorganic contaminants, or (3) synergistic effects of the purely inorganic impurities.

Later, after apparent improvements in the process for the manufacture of organically-derived hydrogen peroxide, production models of the Rocketdyne AR-2 engine system were qualified using 90 w/o hydrogen peroxide (which met the requirements of Mil-P-16005C)* from the three manufacturers of propellant-grade hydrogen peroxide. No catalyst failures were experienced during these tests that were attributable to any particular type of hydrogen peroxide, either organically-or electrolytically-derived.

Recently, studies were conducted by the Air Force Rocket Propulsion Laboratory (Ref. 7.17), in which 90 w/o hydrogen peroxide (procured under Mil-P-16005D from the various manufacturing processes) was catalytically decomposed in an LR-99 gas generator using a simulated flight feed system. No differences were observed in the operation or performance between the three types of propellant-grade hydrogen peroxide.

*NOTE: Mil-P-16005C was superceded by MIL-P-16005D

It was concluded that "there was no evidence to indicate a desirability of a change in the current hydrogen peroxide specification".

As a result of these recent comparisons of hydrogen peroxide catalyst performance with both organically-derived and electrolytically-derived hydrogen peroxide, it is concluded that the propellant procured according to Mil-P-16005D requirements should not be detrimental to the performance of the present silver-screen catalysts. However, the roles of the individual contaminants of both types as well as their inter-relationship in catalyst poisoning are still not completely defined.

7.2.1.4 Operational Problems. Although reviews of the operational problems that frequently occur in the catalytic decomposition of hydrogen peroxide appear in many sources (including in particular, Ref. 7.1 and 7.15), a very adequate and concise discussion of the problems is given in Ref. 7.18 as follows:

> "It is now opportune to consider the various factors which lead to a loss of efficiency of a (catalyst-Ed.) pack.
>
> The first is that of increase in pressure drop across the pack during use. In this case, although the pack is still active, it may become impossible to maintain the desired rate of flow of H.T.P. (propellant-grade hydrogen peroxide-Ed.) due to the increase of resistance to flow through the pack. Such increased resistance may be caused by the deposition of large amounts of non-catalytic material such as tin stabilizer. The deposition of precipitated silver dissolved from the entry end of the pack can also cause an increase in pressure drop if the amount of free space provided downstream is small. Increased pressure drops have also been observed when large amounts of silver were provided on the downstream gauzes (screen-Ed.). This effect may result from the partial fusion of the silver, causing the gauzes to become 'welded' together and is likely to be accentuated when H.T.P. of high concentration is used.

A second factor leading to the loss of catalyst pack efficiency is the erosion of silver. This may occur in two principal ways: (1) When the adhesion of the silver plating to the base metal of the gauze is poor, mechanical stripping of silver may occur at high flow rates of H.T.P. through the interstices of the gauzes. The type of silver catalyst known as 'activated silver' which is a loose powdery deposit of silver made by dipping copper gauze in ammoniacal silver nitrate solution, is particularly prone to mechanical stripping. (2) Erosion occurs by solution of silver metal in the liquid H.T.P. near the entry end of the pack: most of the dissolved silver is redeposited downstream but a small fraction is blown out, and this leads to a gradual reduction in the total amount of silver available. However, more important than the gradual overall loss of silver is the fact that the gauzes at the entry end of the pack eventually become completely stripped of silver and then cease to contribute towards the decomposition of the H.T.P. This leads to a gradual shortening of the effective length of the pack, the liquid phase penetrating further towards the downstream end. Eventually the penetration reaches the downstream end and the efficiency of the pack falls rapidly.

The use of H.T.P. at low ambient temperatures, and the repeated stopping and restarting of the decomposer when cold, both accelerate the loss of efficiency of a pack, due to an increased rate of erosion of silver. Since the rate of decomposition of hydrogen peroxide at a silver surface decreases with decrease in temperature, the use of a decomposer at low temperatures involves a greater penetration of the pack by liquid H.T.P. and in consequence a higher overall rate of solution of silver. As mentioned above, the rapid starting of a decomposer involves a greater penetration of H.T.P. than occurs during steady 'running,' and there is in consequence a higher rate of solution of silver during the starting period. Repeated stopping of the decomposer and restarting when it has cooled down will therefore lead to an overall higher rate of loss of silver than occurs during a continuous 'run.' It is also a consequence of the greater penetration of liquid during a start that a decomposer which is losing efficiency, but is still usable, may not restart satisfactorily from cold if the 'run' is stopped at a late stage during its potential life under continuous 'running' conditions.

In connection with the erosion of silver it is necessary to consider the phenomenon known as 'channeling,' which is the term given to the preferential erosion of silver over certain parts of the gauze area. As a result of 'channeling' the gauzes become completely stripped of silver over certain areas whilst the rest of the gauze still retains silver. This process in turn, leads to penetration by undecomposed H.T.P. along the channels. This condition brings about very inefficient usage of the available silver on the pack, since once a 'channel' has been produced the H.T.P. begins to flow more freely along it than through other parts of the gauze area.*

'Channeling' is caused by two principal factors, (1) irregular distribution of H.T.P. on the gauzes by the injector, and (2) the cooling effect at the periphery of the gauzes due to loss of heat to the surroundings. The presence of 'channeling' due to irregular distribution of H.T.P. is noticeable when an injector consisting of a number of holes in a plate is used, as each hole in the injector is matched by a channel on the gauze in the entry end of the pack. The cooling effect at the periphery of the gauze leads to a somewhat lower rate of decomposition in this region and a greater distance of penetration. This leads to more rapid erosion of silver at the periphery, and 'channeling' along the walls of the decomposer.

Finally, it is necessary to consider a third factor which can lead to loss of decomposition efficiency, namely loss of activity of the silver catalyst. This may occur in two major ways, (1) by the catalyst becoming covered with a layer of non-catalytic material, or (2) by direct chemical 'poisoning' of the catalytic surface. The first type of effect occurs whenever non catalytic material, such as alumina and tin oxide, is deposited on the gauzes downstream thereby reducing the efficiency of contact of H.T.P. with the catalyst surface. The second type of effect occurs when the H.T.P. contains contaminants which reduce the rate of decomposition at the catalyst surface."

*Editor's Note: It is also believed that channeling can cause recirculation of the hot decomposition gases within the catalyst chamber. These gases can preheat the liquid stream entering the catalyst bed, which results in an increase in the normal decomposition temperatures in the bed. This increase in temperature is a probable major contributor to the failure of the present silver-screen catalyst packs.

7.2.2 Thermal Decomposition

The use of self-heating thermal chambers to maintain controlled decomposition of hydrogen peroxide has been limited to laboratory studies. In the thermal concept, the design of the decomposition chamber is similar to that employed in packed bed catalytic chambers, except that the chamber material is selected on the basis of thermal conductivity criteria rather than for catalytic activity. The thermal pack is heated with a "pilot light" either by diverting a small flow of hydrogen peroxide through a small catalyst chamber (and directing the decomposition gases into the thermal bed) or by hypergolic ignition slugs of fuel and oxidizer. When the thermal bed achieves a suitable temperature level, the main flow of hydrogen peroxide is initiated and the pilot flow is terminated. The assumed advantage of this operation is an elimination of most of the problems associated with the effects of temperature, poisoning, and erosion in the catalyst bed.

This concept was investigated with both 98 w/o (Ref. 7.19) and 90 w/o (Ref. 7.11) hydrogen peroxide and found to have limited usefulness. Although decomposition could be maintained with small bed loading rates, large propellant flows usually quenched the decomposition process within 3 to 5 seconds after "pilot light" termination. It was concluded that the slow rate of thermal decomposition of hydrogen peroxide cannot compete with the rates obtainable with catalytic decomposition.

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13 ABSTRACT

This handbook is a compilation of the engineering properties and handling characteristics of propellant-grade hydrogen peroxide. The handbook includes data and information on hydrogen peroxide physicochemical properties, production, storability, materials compatibility, materials treatment and passivation, facilities and equipment, disposal, transportation, safety, and decomposition.

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