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GAS TURBINE AND JET ENGINE FUELS

PROGRESS REPORT NO. 1

NAVY BUWEP CONTRACT RESEARCH

MARCH, 1961

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PHILLIPS PETROLEUM COMPANY

ASTIA

Progress Report No. 1
Navy Contract NO(w)61-0590-d

GAS TURBINE AND JET ENGINE FUELS

by

W. L. Streets

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S U M M A R Y

The first bimonthly period under Contract NO(w)61-0590-d has been spent continuing the study of the effects of sulfur in jet fuels on flame tube durability, which was started under Contract NOas58-310-d, Amendments 1 and 2, and continued under Contract NOas 60-6009-c. Efforts during this period have included preliminary evaluation of the combined effect of sulfur and ingested sea water on jet combustor flame tube corrosion using the Phillips 2-inch Research Combustor. Initiation of this study has been brought about as a result of reports of markedly decreased life of jet engine "hot section" components in engines operating on sulfur-containing fuels in sea water laden atmospheres. Results of testing carried on to date in this laboratory have indicated the following:

1. Synthetic sea water (ASTM D655) showed no significant tendency to increase or decrease flame tube metal loss above or below the values observed for operation on 1 per cent sulfur fuel without sea water injection, even at concentrations as high as 5000 times that indicated in the literature as representative of the concentration of airborne sea water vapor at an altitude of 50 feet over the ocean.
2. Natural sea water (Gulf of Mexico) did cause increased metal loss both with operation on 1 per cent sulfur fuel and with nearly sulfur-free fuel. However, the magnitude of these increases was nearly the same without sulfur as with sulfur, indicating that the corrosive effects of sulfur and this particular sea water were not synergistic but independent.

APR 24 1961

PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

Progress Report No. 1
Navy Contract NO(w)61-0590-d

GAS TURBINE AND JET ENGINE FUELSI. INTRODUCTION

The first bimonthly period under Navy Contract NO(w)61-0590-d has been spent continuing the study of the effects of sulfur in jet fuels on combustor flame tube durability, which was started under Contract NOas 58-310d, Amendments 1 and 2, and continued under Contract NOas 60-6009c. Efforts during this period have included evaluation of the effect of sea water on flame tube durability during operation with both low sulfur and high sulfur fuels. Initiation of this program has been brought about as a result of the reports of several observers of markedly decreased life of combustor and turbine "hot section" components in engines operating in the presence of sea water laden air. These reports have indicated an even greater acceleration of corrosion rates in cases where these engines were also operating with fuels containing sulfur at concentrations within the specification maximum of 0.4 per cent. It is therefore the purpose of the present investigation to establish under controlled conditions in the laboratory the effects of sea water and sea water plus fuel sulfur on jet engine "hot section" components. This report will discuss the results of preliminary experiments involving operation with and without synthetic and/or natural sea water and with and without sulfur in the fuel.

II. TEST PROGRAM

The apparatus utilized in this investigation was the Phillips 2-inch Research Combustor which has been described in complete detail in previous reports (1). Briefly, this is a 2-inch diameter axial flow combustor embodying the principal features of modern jet engine combustion systems. Air is supplied to this combustor in controlled amounts from a compression and heating plant described in (1), while fuel is supplied to the swirl type nozzle by nitrogen pressurization. The design of the combustor is such as to allow ready removal of flame tubes for inspection, weighing, etc.

The flame tube metal loss test procedure consists of cleaning and weighing a new flame tube before each test, installing it in the combustor test assembly and measuring the weight loss (by difference) following each of three consecutive one-hour test periods.

Test conditions employed for the present program were identical to those used for previous investigations of the effect of sulfur type and concentration on flame tube durability which have been reported on in (2). Combustor pressure was held at 350 in. Hg abs., inlet air temperature at 700 F and inlet reference velocity at 100 fps, providing a severity level which is reasonably realistic for high compressor ratio turbojets operating at relatively low altitudes. Fuel-air ratio remained at 0.010 lb fuel per lb of air for the complete sequence of tests.

Since previous investigations (2) of the effect on flame tube durability of a variety of sulfur compounds added to a nearly sulfur-free base fuel had shown sulfur compound type to be unimportant as compared to sulfur concentration, it was decided for purposes of the present test program to use just the single compound ditertiary butyl disulfide, which is relatively inexpensive and readily available at high purities. In order to exaggerate the sulfur severity for testing purposes it was decided to employ this compound at sufficient concentration to realize 2.5 times the jet fuel specification sulfur limit of 0.4 per cent, or, in other words, 1.0 per cent sulfur, since considerable previous data were available at this concentration.

The base fuel selected for this work was, as in the case of the previous investigations, a JP-5 type isoparaffinic alkylate containing 0.005 per cent or less sulfur. Typical properties of this base fuel are shown in Table 1.

Pilot tests were undertaken at the beginning of this test program to determine the best means for injecting the sea water into the combustion system. Since, in the case of the engines themselves, the sea water enters as vapor in the air stream, attempts were initially made to simply spray the sea water into the air stream at a point just upstream of the combustor nozzle holder. This method was found to be unsatisfactory due to deposition of most of the salt on the upstream side of the nozzle holder and associated hardware before it had a chance to enter the combustion zone. Next, an attempt was made to inject the sea water directly into one of the primary air ports of the combustor. Again, however, most of the salt deposited on the walls of the port before entering the combustion zone and, additionally, channeling along one side of the flame tube wall was observed when some salt did manage to enter the combustion zone. Since these techniques did not seem promising enough to explore further, the next method considered was that of injecting the sea water into the fuel stream by means of a mixing tee placed just outside the combustor, or, in the case of very small quantities, by including it in the fuel using suitable emulsifiers. Pilot tests were conducted using both of these methods and the results seemed to be operationally quite satisfactory. It was then decided to use the emulsification route where the desired sea water input was so small as to be difficult to meter by the usual means and to use the mixing tee system when flow rates were sufficient to be readily measurable.

It was, of course, desirable prior to beginning the test work in this program, to attempt to establish from the available literature a realistic magnitude of sea salt intake for low-level flight over the ocean. For this purpose reference was made to the work of Woodstock and Gifford (3) in which air borne sea salt samples were obtained at altitudes ranging from 50 feet to 3800 feet over the ocean near Bermuda. Inspection of their data indicated that of the several sampling altitudes involved a maximum concentration of salts was observed at an altitude of 50 feet. This altitude also seemed to coincide reasonably well with typical carrier aircraft operation and so it was decided to employ the salt concentration data obtained at 50 feet. Conversion of Woodstock's data to a corresponding salt intake for the Phillips 2-Inch Research Combustor operating under the conditions cited above indicated a salt flow rate of 8.86×10^{-6} lb/hr of salt. Conversion of this value to the necessary flow rate of a 4.2% (wt.) salts solution (synthetic sea water to be described later herein) showed that a synthetic sea water flow rate of 2.11×10^{-4} lb/hr. would be required. However, since it had been arbitrarily decided to use 2.5 times the specification maximum for sulfur, it was also decided to arbitrarily increase this sea water input by 2.5 times in the hope of increasing the severity for test purposes. Additionally, since it had been decided to emulsify the sea water in the fuel for such small salt input rates it was necessary to determine the necessary concentration of sea water in the fuel corresponding to the above sea water flow rate (calculated in air) consistent with the desired fuel flow rate for the intended conditions of operation of the combustor. This worked out to be 17 parts (wt.) of synthetic sea water per million parts of fuel. As will be explained later, this very low synthetic sea water input proved to have no measurable effect on flame tube durability, so it was decided to carry out some tests using the mixing tee arrangement with very much higher sea water input rates. For these tests the synthetic sea water flow rate of 2.11×10^{-4} lb/hr. suggested by the data of Woodstock and Gifford was multiplied by a factor of approximately 5000 to arrive at a greatly increased rate of 1 lb/hr. of sea water. This rate corresponds to 3.1% of the fuel plus sea water input and these tests are therefore identified in the data of Table 2 in this way.

At this point it would seem well to mention that the original intention was to run all of these tests using type 304 stainless steel flame tubes. As testing progressed it was noticed that repeated tests conducted with the base fuel treated with 1% sulfur failed to check previously obtained metal loss values and were also poorly repeatable within themselves. Metallurgical examination of the used flame tubes revealed that the fabricator had accidentally made several of the tubes from type 316 rather than type 304 stainless steel. The remaining new flame tubes were checked by a spot test technique and further testing was carried on using only those tubes established as type 304 stainless steel. Although not too conclusive because of their poor repeatability the results of the tests in which type 316 tubes were used have been included herein since at this time they represent the only data available on the effect of a very low salt intake level. Although the accidental use of the type 316 stainless steel flame tubes would appear to be unfortunate, it does, nevertheless, point up the interesting fact that this material is considerably less predictable with regard to sulfur corrosion than type 304 stainless steel. It is intended in future work, however, to repeat the tests at the 17 ppm concentration using known type 304 tubes.

As previously mentioned, the decisions with regard to sea water flow rates, etc., were predicated upon the use of a synthetic sea water formulation. The formulation chosen for this study is that described in ASTM Test Method D665-60. A complete description of the components of this formulation and their concentrations is shown in Table 3. In addition to this synthetic sea water, a sample of natural sea water, obtained at the site of an offshore drilling rig in the Gulf of Mexico, was also employed. Emulsification of the synthetic sea water in the fuel was brought about through the use of 17 ppm of a 50/50 mixture of sorbitan monolaurate and polyoxyethylene sorbitan monolaurate ashless non-ionic surfactants. Since these surfactants were present at very small concentrations and since there is little reason to believe they would influence metal losses, no attempt was made during this initial testing to isolate their possible effects.

III. DISCUSSION OF EXPERIMENTAL RESULTS

Considering first the data plotted in Figure 1, which includes only those tests inadvertently run on type 316 stainless steel flame tubes, it would appear that the addition of synthetic sea water at an input level corresponding to 2.5 times that observed by Woodstock and Gifford at an altitude of 50 feet, failed to increase the rate of corrosion beyond that observed for operation on fuel containing 1% sulfur. Although these results are somewhat clouded by the erratic sulfur corrosion observed with the type 316 stainless steel tubes, it is apparent that the inclusion of the synthetic sea water did not cause metal losses to rise above the highest value observed for the tests on the 1% sulfur fuel alone. No data are available for comparison with the test on the base fuel plus synthetic sea water (no sulfur). However, based on previous experience with 304 stainless steel flame tubes operating on the isoparaffinic alkylate base fuel alone, it would appear doubtful that this low concentration of synthetic sea water had any appreciable effect on flame tube durability either with or without sulfur in the fuel.

Since the results of the tests described above had failed to show any positive deleterious effects of sea water, it was decided to increase the sea water input rate drastically to a level 5000 times that suggested by the data of Woodstock and Gifford and to include also some tests using natural sea water taken from the Gulf of Mexico. The results of these tests, using type 304 stainless steel flame tubes, are shown in Figure 2, again as plots of accumulated flame tube metal loss versus test time. Tests conducted at this greatly increased sea water input are identified as those in which the sea water was injected into the fuel stream at a rate corresponding to 3.1% of the combined sea water plus fuel input. Tests were run both with and without sulfur added to the base fuel and also on the base fuel alone with neither sulfur nor sea water.

Inspection of the data plotted in Figure 2 shows that the synthetic sea water formulation appeared to have very little effect on flame tube durability even at this exaggerated injection rate regardless of whether sulfur was present in the fuel or not.

Considering next the tests in which the natural sea water was used it may readily be seen from Figure 2 that this material did cause increases in flame tube metal loss. This was, however, evident both in tests where the fuel had been contaminated with 1% sulfur and in tests where it had not. Additionally, it will be observed from the 3-hour data of Figure 2 that the magnitude of the increase in metal loss when injecting the natural sea water was nearly the same with sulfur as without it. Thus, it would appear, on the basis of these preliminary results, that the corrosive effects of sulfur and of the natural sea water are independent. The composition of the natural sea water employed here is being checked by chemical analysis.

IV. CONCLUSIONS

Preliminary evaluations of the combined effect of sea water and jet fuel sulfur on jet combustor flame tube durability conducted using the Phillips 2-Inch Research Combustor have indicated the following:

1. Synthetic sea water injected into the combustor at rates 2.5 and 5000 times that indicated in the literature as representative of the concentration of airborne sea water vapor at an altitude of 50 feet over the ocean surface showed no significant change in flame tube metal loss values from those observed for operation on a synthetic 1% sulfur fuel without sea water injection.
2. Natural sea water taken from the Gulf of Mexico did cause increases in flame tube metal loss with operation on synthetic 1% sulfur fuel and with operation on a nearly sulfur-free fuel. However, the magnitude of these increases was nearly the same without sulfur as with sulfur, indicating that the corrosive effects of sulfur and this particular sample of sea water were not synergistic but independent.

V. OUTLINE OF PROJECTED WORK

It is intended to further investigate the effect of sea salts in combination with fuel sulfur on combustor durability during the second bimonthly period under Navy Contract NO(w)61-0590-d. It is expected that these efforts will include further testing with natural sea water at the 17 ppm level and attempts to establish the reason for the difference in corrosiveness observed between the synthetic sea water and natural sea water. Consideration will also be given to extending this study into the area of turbine blading corrosion. Additionally, it is intended during this

period to better establish the role of sulfur compounds on jet fuel thermal stability, using a low sulfur aviation grade kerosine as base fuel and various pure sulfur compounds as poisoning agents. The objectives will be to establish whether previous trends observed at 450 F temperature in the CFR Fuel Coker with alkylate base fuel, are confirmed with a less inherently stable base fuel at the 300 F specification temperature level -- and with total sulfur concentrations below specification maximum.

REFERENCES

1. Fromm, E. H.; "Design and Calibration of Phillips Jet Fuel Testing Facilities," Phillips Research Division Report 1252-55R, December, 1955.
2. Kittredge, G. D. and Streets, W. L.; "Gas Turbine and Jet Engine Fuels," Summary Report For Navy Contract NOas 60-6009-c, Phillips Research Division Report 2760-60R, January, 1961.
3. Woodstock, Alfred H. and Gifford, Mary M.; "Sampling Atmospheric Sea-Salt Nuclei Over the Ocean," Journal of Marine Research, Volume VIII, 1949.

TABLE I

TYPICAL PROPERTIES OF ISOPARAFFINIC ALKYLATES USED AS BASE FUEL
FOR FLAME TUBE DURABILITY TESTS WITH SEA WATER AND SULFUR

ASTM Distillation		
IBP, F		357
10% Evap.		367
50% Evap.		390
90% Evap.		472
EP		549
API Gravity		53.0
Bromine Number		1.4
Aniline Point, F		191.5
Copper Corrosion, 3 hrs. @ 212 F		1
Flash Point, F		145
Dector Test		Negative
Color, Saybolt		+30
Kinematic Viscosity, cs at 32 F		4.05
cs at 100 F		1.77
Sulfur Content, % Wt, Total		0.005
Mercaptans		0.001
Composition, Vol. %	Essentially 100% Paraffins	

TABLE II

EFFECT OF SEA WATER ON FLAME TUBE DURABILITY IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

Combustor Operating Conditions: P = 350 in. Hg abs.; V = 100 ft./sec; IAT = 700 F; F/A = 0.010

Flame Tube Metal Type	Test Fuel Blend	Time, Hrs.	Combustor ΔT , F	Metal Loss, g.	Flame Tube Temperature, F (Station 2)	Flame Total Radiant Energy, Btu/hr ft. ² , (Station 2)
316	JP-5 Type Alkylate + 1% (Wt) Sulfur as Ditertiary Butyl Disulfide - Run 1	1	560	4.9	---	170,000
		2	600	14.0	1885	---
		3	565	28.0	---	175,000
316	Same as above - Run 2	1	575	2.2	---	200,000
		2	625	8.6	1770	---
		3	590	21.1	---	190,000
316	Same as above - Run 3	1	600	5.3	---	155,000
		2	680	21.7	1860	---
		3	640	42.4	---	180,000
316	JP-5 Type Alkylate + 1% (Wt) Sulfur as Ditertiary Butyl Disulfide + 17 ppm Synthetic Sea Water + 17 ppm Emulsifier	1	560	5.8	---	190,000
		2	620	18.3	1813	---
		3	585	34.9	---	185,000
316	JP-5 Type Alkylate + 17 ppm Synthetic Sea Water + 17 ppm Emulsifier	1	610	2.7	---	175,000
		2	690	8.0	1813	---
		3	588	14.4	---	190,000
304	JP-5 Type Alkylate	1	605	3.6	---	190,000
		2	705	11.6	1837	---
		3	630	19.1	---	165,000
304	JP-5 Type Alkylate w/3.1% (Wt) Synthetic Sea Water	1	628	4.5	---	132,000
		2	695	9.9	1767	---
		3	632	16.7	---	140,000
304	JP-5 Type Alkylate w/3.1% (Wt) Natural Gulf Sea Water	1	595	8.5	---	140,000
		2	680	17.9	1797	---
		3	625	28.9	---	135,000
304	JP-5 Type Alkylate + 1% (Wt) Sulfur as Ditertiary Butyl Disulfide - Run 1	1	600	14.8	---	180,000
		2	645	32.8	1847	---
		3	600	51.8	---	172,000
304	JP-5 Type Alkylate + 1% (Wt) Sulfur as Ditertiary Butyl Disulfide	1	610	13.7	---	182,000
		2	670	32.7	1857	---
		3	635	56.2	---	185,000

(Continued)

TABLE II (Cont'd)

EFFECT OF SEA WATER ON FLAME TUBE DURABILITY IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

Flame Tube Metal Type		Time, Hrs.	Combustor ΔT , F	Metal Loss, g.	Flame Tube Temperature, F (Station 2)	Flame Total Radiant Energy, Btu/hr ft ² (Station 2)
304	JP-5 Type Alkylate + 1% (Wt) Sulfur as	1	615	13.3	---	135,000
	Ditertiary Butyl Disulfide w/3.1% (Wt)	2	685	27.5	1810	---
	Synthetic Sea Water	3	645	51.8	---	120,000
304	JP-5 Type Alkylate + 1% (Wt) Sulfur as	1	625	13.8	---	140,000
	Ditertiary Butyl Disulfide w/3.1% (Wt)	2	720	36.0	1797	---
	Natural Gulf Sea Water	3	605	64.6	---	147,000

TABLE III

SYNTHETIC SEA WATER FORMULATION USED IN EVALUATION OF EFFECT OF
SEA WATER AND SEA WATER PLUS SULFUR ON FLAME TUBE DURABILITY

Source: ASTM Method D665-60

<u>Component</u>	<u>Concentration, Grams/liter</u>
NaCl	24.54
MgCl ₂ ·6H ₂ O	11.10
Na ₂ SO ₄	4.09
CaCl ₂	1.16
KCl	0.69
NaHCO ₃	0.20
KBr	0.10
H ₃ BO ₃	0.03
SrCl ₂ ·6H ₂ O	0.04
NaF	0.003

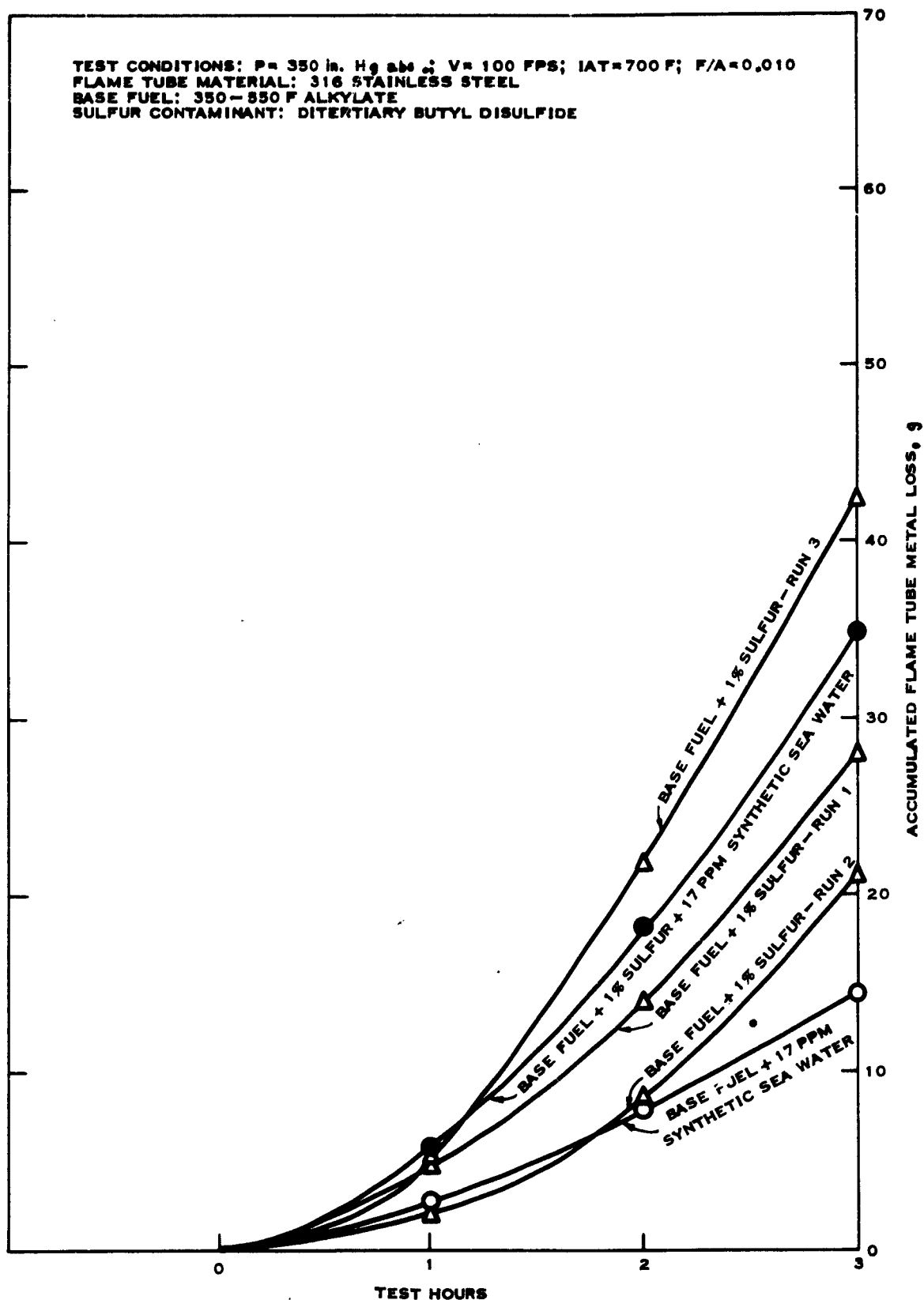


FIGURE 1
EVALUATION OF THE EFFECT OF SEA WATER AND FUEL SULFUR ON THE
DURABILITY OF TYPE 316 STAINLESS STEEL FLAME TUBES

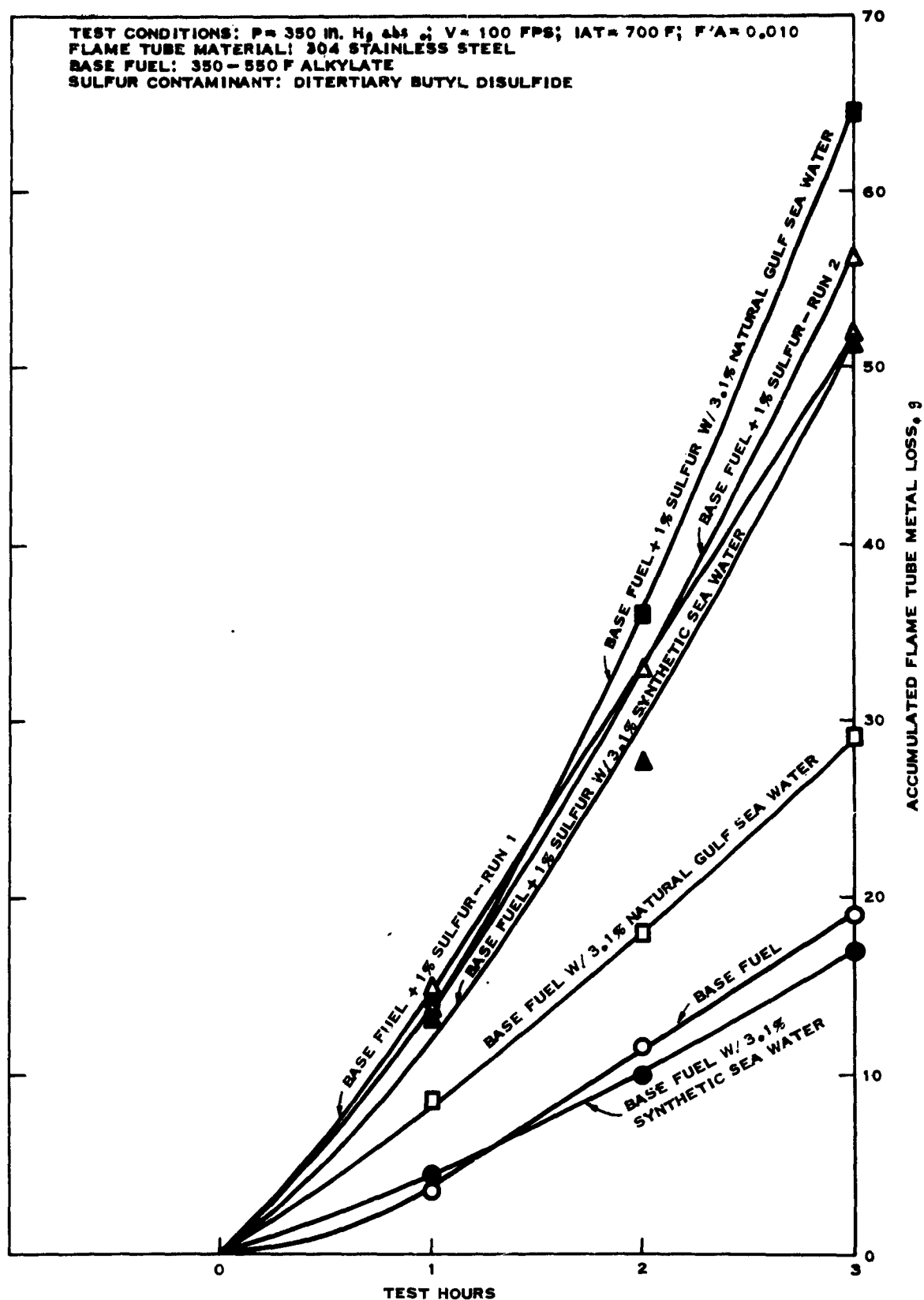


FIGURE 2
EVALUATION OF THE EFFECT OF SEA WATER AND FUEL SULFUR ON THE DURABILITY OF
TYPE 304 STAINLESS STEEL FLAME TUBES