

AD-A066 119

ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERD--ETC F/G 19/1
SENSITIVITY OF BURNING RATE TO INITIAL TEMPERATURE FOR A BINARY--ETC(U)
DEC 78 R C STRITTMATER, H E HOLMES, J R WARD

UNCLASSIFIED

ARBRL-ME-02889

SBIE-AD-E430 186

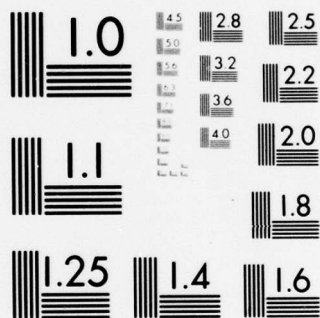
NL

1 OF 1
AD
A066119



END
DATE
FILMED
5-79

DOC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

✓
(12) LEVEL III

AD-E430 186

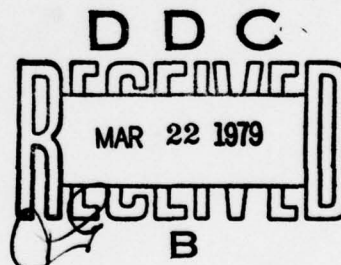
MEMORANDUM REPORT ARBRL-MR-02889

AD A0 66119

SENSITIVITY OF BURNING RATE TO INITIAL
TEMPERATURE FOR A BINARY
MAGNESIUM-SODIUM NITRATE MIX

Richard C. Strittmater
Hughes E Holmes
J. Richard Ward

December 1978



DDC FILE COPY



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

79 02 23 06 0

Destroy this report when it is no longer needed.
Do not return it to the originator.

Secondary distribution of this report by originating
or sponsoring activity is prohibited.

Additional copies of this report may be obtained
from the National Technical Information Service,
U.S. Department of Commerce, Springfield, Virginia
22161.

The findings in this report are not to be construed as
an official Department of the Army position, unless
so designated by other authorized documents.

*The use of trade names or manufacturers' names in this report
does not constitute indorsement of any commercial product.*

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 9 MEMORANDUM REPORT ARBRL-MR-02889	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Sensitivity of Burning Rate to Initial Temperature for a Binary Magnesium-Sodium Nitrate Mix.		5. TYPE OF REPORT & PERIOD COVERED
7. AUTHOR(s) 10 Richard C. Strittmater, Hughes E. Holmes J. Richard Ward		6. PERFORMING ORG. REPORT NUMBER
8. CONTRACT OR GRANT NUMBER(s)		12 22 p.
9. PERFORMING ORGANIZATION NAME AND ADDRESS USA Ballistic Research Laboratory ATTN: DRDAR-BLP Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS RDT&E/1L161102AH43 16
11. CONTROLLING OFFICE NAME AND ADDRESS USA Armament Research and Development Command USA Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE 11 DEC 1978
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 18 SBIE 19 AD-E430186		13. NUMBER OF PAGES 24
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES φ.φφ22/K and φ.φφ28/K		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Pyrotechnics Combustion Models Magnesium Sodium Nitrate Burning Rate Temperature Coefficient		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (meg) The temperature sensitivity of the burning rate of a mixture of magnesium and sodium nitrate (60/40 by weight) was determined at 0.1 and 1.0 MPa. The temperature sensitivity was 0.0021K ⁻¹ and 0.0028K ⁻¹ at 0.1 MPa and 1.0 MPa, respectively. A standard JANNAF composite propellant illustrated the same trend in temperature sensitivity with increasing pressure leading one to suggest the models used for composite propellant combustion are the starting point for modeling pyrotechnic combustion. (CONT'D)		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DDC

RECEIVED
MAR 22 1979

B

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. Abstract (Cont'd):

Analysis of various combustion models suggests the dependence of temperature sensitivity with initial temperature as an additional tool to determine the capability of various models to describe combustion. At present the temperature sensitivity is assumed to be independent of initial temperature; experiments need to be performed over large temperature intervals in order to test this hypothesis. Pyrotechnics offer an attractive test case, since the initial temperature of a pyrotechnic can be raised to nearly 1000K before decomposition of the oxidizer or phase changes take place.



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES.	5
I. INTRODUCTION	7
II. EXPERIMENTAL PROCEDURES AND APPARATUS.	8
III. RESULTS AND DISCUSSION	8
IV. CONCLUSIONS.	16
REFERENCES	17
DISTRIBUTION LIST.	19

ACCESSION BY	
NTIS	Write Section ☒
DDC	Duff Section ☐
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	ANAL. and/or SPECIAL
A	

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Schematic of System Used to Conduct Combustion Studies to Determine Initial Temperature Sensitivity of Burning Rate.	9
2	Schematic of Sample Positioned on Heat Exchanger.	10
3	Copy of Visicorder Record Showing Response of Thermo- couples	12
4	Burning Rate <u>vs</u> Initial Temperature at 0.1 MPa and 1.0 MPa	14

I. INTRODUCTION

Pyrotechnics are used in a wide range of military applications, all of which depend on the controlled ignition and combustion of a pyrotechnic mix. The Engineering Design Handbook Series on Military Pyrotechnics reviews the range of effects from a burning pyrotechnic that are of military use¹. These effects include production of heat (incendiary rounds), production of light (tracers and illuminating shells) and production of smoke (smoke grenades and smoke rounds). Pyrotechnics are also used as solid propellant igniters and primers. A novel role of pyrotechnics is to increase the range or decrease the time-of-flight of projectiles by reducing base drag^{2,3}.

Despite the wide role of pyrotechnics in munitions, investigations of the combustion and ignition of these substances have lagged behind similar work on composite solid propellants and homogeneous propellants. The Engineering Design Handbook on Theory and Application of Pyrotechnics⁴ illustrates the gap between propellant combustion modeling and pyrotechnic combustion modeling.

In an effort to begin closing the gap between pyrotechnics and propellant combustion, an experimental program is underway to obtain burning rate data on pyrotechnic mixes. This report discusses measurements of the temperature sensitivity of the burning rate of a mixture (60/40 by weight) of magnesium and sodium nitrate. The organic binder normally found in pyrotechnic mixes was deleted in the hope of simplifying modeling efforts.

The desire to examine temperature sensitivity was prompted by work on modeling composite propellant combustion. A 1972 JANNAF workshop⁵

1. "Military Pyrotechnics Series, Part Four, Design of Ammunition for Pyrotechnic Effects", AMC Pamphlet AMCP 706-188, March 1974.
2. J.R. Ward, F.P. Baltakis, and S.W. Pronchick, "Wind Tunnel Study of Base Drag Reduction by Combustion of Pyrotechnics", BRL Report No. 1745, October 1974. (AD #B000431L)
3. K. Anderson, N.E. Gunnars, and R. Hellgren, "Swedish Base Bleed - Increasing the Range of Artillery Projectiles Through Base Flow", Propellants and Explosives, 1, pp. 69-73 (1976).
4. "Military Pyrotechnic Series, Part One, Theory and Application", AMC Pamphlet AMCP 706-185, April 1967.
5. L. Caveny, "Workshop Report on Temperature and Pressure Sensitivity of Burning Rates", Proceedings of the Ninth JANNAF Combustion Meeting, Volume II, CPIA Publication 231, December 1972.

concluded that the ability of various models to predict temperature sensitivity may serve to validate such models better than the conventional prediction of burning rate vs pressure. This was demonstrated recently by Condon, Renie, and Osborn⁶ who used prediction of temperature sensitivity to illustrate the superiority of the petite ensemble model for modeling composite propellant combustion.

II. EXPERIMENTAL PROCEDURES AND APPARATUS

A low pressure combustion chamber was used to conduct propellant burning rate studies as a function of initial temperature and pressure. A schematic of the chamber, heat exchanger and auxiliary apparatus is shown in Figure 1. The chamber was chosen to accommodate the burning of the pyrotechnic samples used in this study without increasing the initial pressure of 0.1 MPa of nitrogen more than ten percent. The volume of the chamber is 0.08 cubic meter and has a maximum operating pressure of 1 MPa. The nitrogen was circulated along the sides of the propellant sample, as shown in Figure 1, to inhibit flame spread. The propellant holder was machined from aluminum because of its high thermal conductivity. Both alcohol and water were used as the temperature conditioning fluid.

The samples were prepared in the following way. A mixture of forty percent magnesium and sixty percent sodium nitrate was poured into a mold and pressed to a pressure of 345 MPa with a hydraulic press. The sample was removed from the press and its density determined. The sample was then placed in a clamping apparatus that positioned it at the proper angle for drilling three holes (#80 drill) for receiving thermocouples. Chromel-Alumel thermocouples made of 0.05mm diameter wires were inserted into the holes. The thermocouples were used to measure the initial temperature of the propellant and the time of transit of the combustion zone. The temperature profile measured by the thermocouples could also be used for qualitative impressions of temperatures at various points in the combustion zone. Figure 2 shows the prepared sample mounted on the holder with dimensions. After purging and filling the chamber to the desired pressure with nitrogen, the temperature was adjusted to the desired value. The sample was ignited and the temperatures were recorded on a Honeywell Visicorder.

III. RESULTS AND DISCUSSION

Twenty-nine samples were prepared and burned. A large variation in burning rate was detected which depended on the density of the sample. The theoretical density of forty percent magnesium and sixty percent sodium nitrate is 2.02 grams per cubic centimeter. Only samples

6. J.A. Condon, J.P. Renie, and J.R. Osborn, "Temperature Sensitivity of Propellant Burning Rates", *Combustion and Flame*, 30, pp. 267-276 (1977).

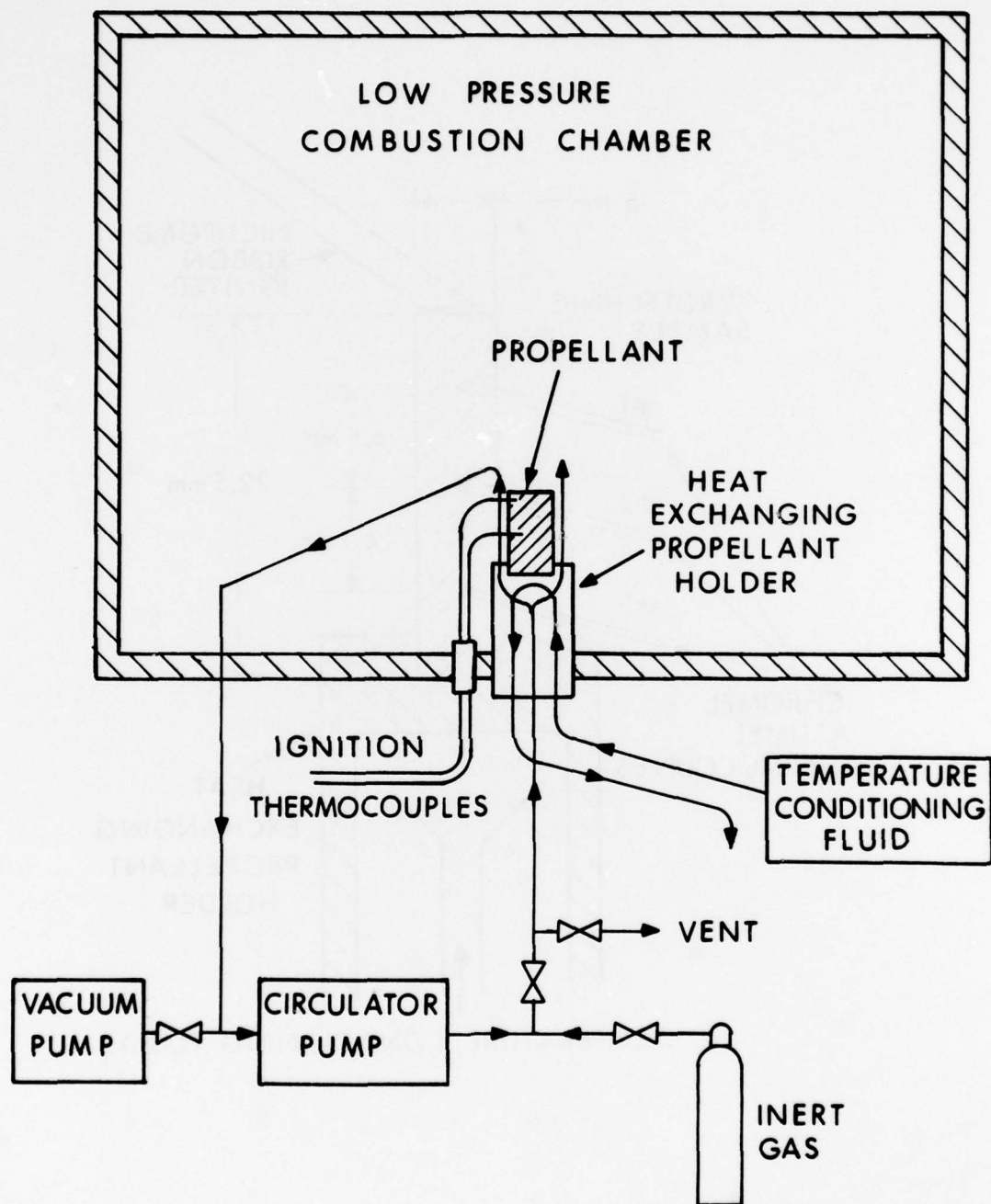


Figure 1. Schematic of System Used to Conduct Combustion Studies to Determine Initial Temperature Sensitivity of Burning Rate

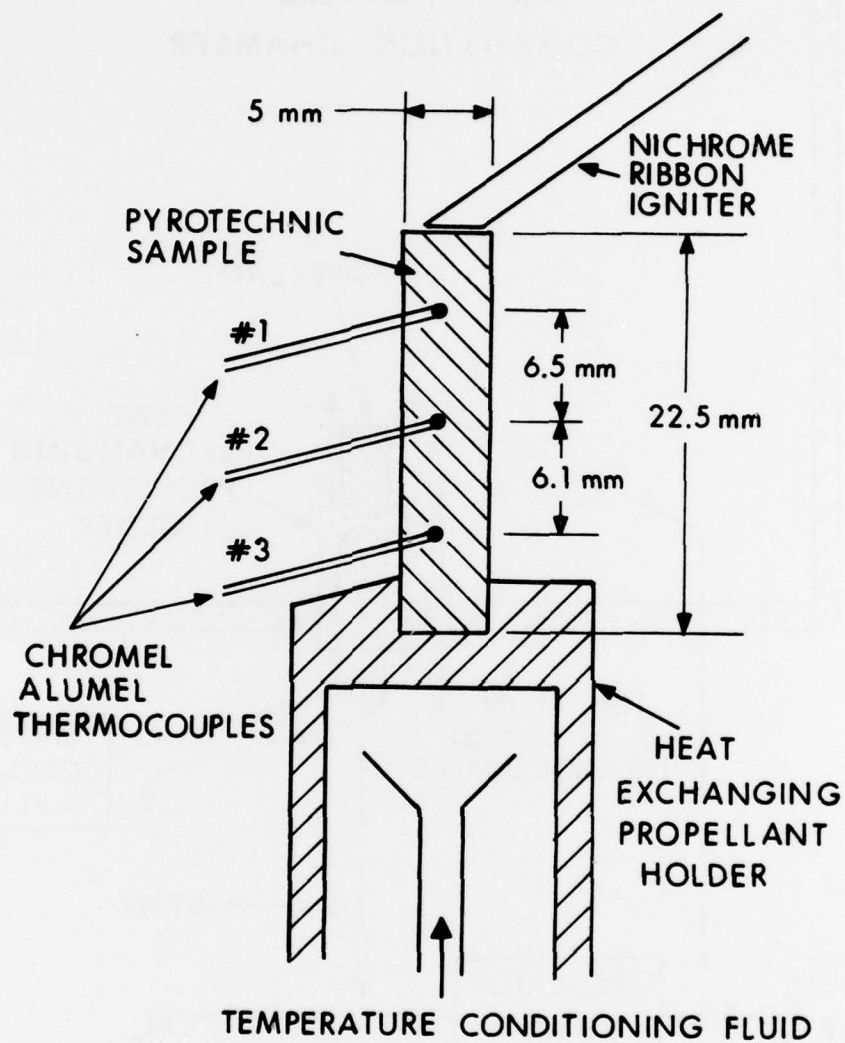


Figure 2. Schematic of Sample Positioned on Heat Exchanger

whose densities were between 1.9 and 2.02 grams per cubic centimeter burned in a fairly reproducible manner, so only firings of samples in this density range were used in the analysis.

A copy of a typical record from the Visicorder illustrating the response of the three thermocouples is shown in Figure 3. The burning rate was determined from the time intervals bounded by the sharp increases in temperature seen in Figure 3. Table I summarizes the burning rates measured in this set of experiments. The reproducibility of the burning rates measured at each thermocouple interval is taken as evidence of uniform burning for a given run. In a number of cases, thermocouple 2 or thermocouple 3 failed to register; the data from those runs which gave burning rates in agreement with the rates in the runs with uniform burning are also included in Table I. The burning rates chosen for further analysis are taken from the time interval between thermocouples one and three except for the runs 8, 10, and 24, in which thermocouple three failed to function.

The temperature sensitivity at constant pressure is defined as the following

$$\sigma = \left. \frac{\partial(\ln r)}{\partial T_0} \right|_p, \quad (1)$$

where

σ = temperature sensitivity, K^{-1}

r = burning rate, mm/s

T_0 = initial temperature, K.

For the mixture of magnesium and sodium nitrate under study, the plot of $\ln r$ vs T_0 is shown in Figure 4. The straight line determined from a linear least-squares fit to the data is also shown in Figure 4. The values of σ determined from the least-squares analysis are $0.0021 K^{-1}$ and $0.0028 K^{-1}$ at 0.1 and 1.0 MPa, respectively. The standard estimate of error determined from the least-squares analysis is 1.5 mm/s and 1.3 mm/s at 0.1 and 1.0 MPa respectively. All the experimental points fall within the standard estimate of error.

The values of σ for the pyrotechnics mix are similar to the temperature sensitivities measured by Condon and co-workers. At 1.0 MPa they report a σ of $0.002 K^{-1}$ for the composite propellant in comparison to the value of $0.003 K^{-1}$ estimated from the few runs at the higher pressure for the pyrotechnic mix. The temperature sensitivity of the composite propellant decreases as the pressure is reduced, which is the same trend seen for the pyrotechnic mix. This trend in temperature sensitivity vs pressure reinforces one's intuition that composite propellant combustion and pyrotechnic combustion are similar, and one should use the composite propellant combustion models Condon found

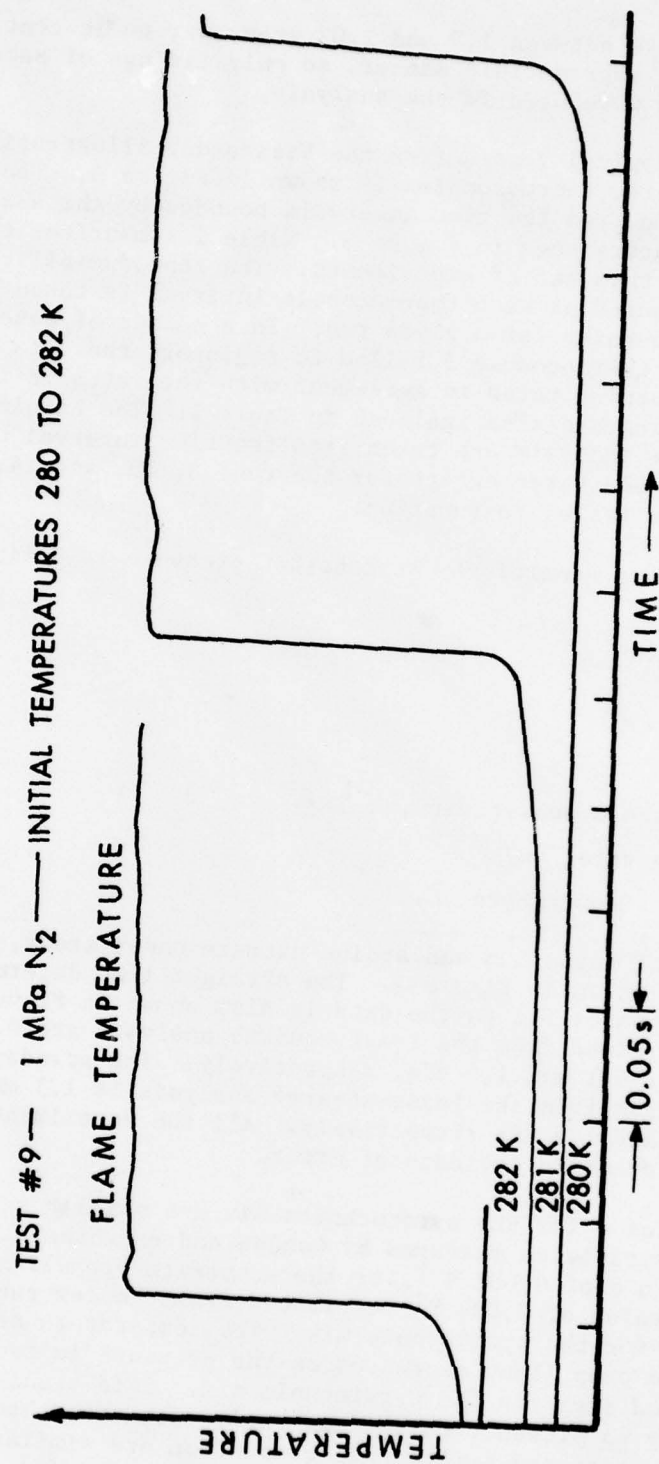


Figure 3. Copy of Visicorder Record Showing Response of Thermocouples

TABLE I. Summary of Burning Rate Measurements

Run	T _O , K	P, MPa	ρ , g/cm ³	Δt_1 , s	Δt_2 , s	Δt_{13} , s	r_1 , mm/s	r_2 , mm/s	r , mm/s ^a
22	293	0.10	1.95	0.32	0.32	0.64	20	19	20
25	293	.10	1.99	.37	.34	.71	18	18	18
29	324	.10	1.92	.31	.30	.61	21	20	21
28	324	.10	1.96	b	b	.62	b	b	20
24	350	.10	2.02	.30	c	c	22	c	22
23	353	.10	1.97	.31	.30	.61	21	20	21
19	355	.10	1.98	.30	.28	.58	22	22	22
9	281	1.0	1.91	.31	.28	.59	21	22	21
7	282	1.0	1.98	b	b	.58	b	b	22
8	282	1.0	2.01	.31	c	c	21	c	21
10	348	1.0	1.97	.26	c	c	25	c	25
6	349	1.0	1.95	.26	.23	.49	25	26	26

a - Burning rate for each run determined from Δt_{13} except for runs in which thermocouple three failed.

b - No data from thermocouple two.

c - No data from thermocouple three.

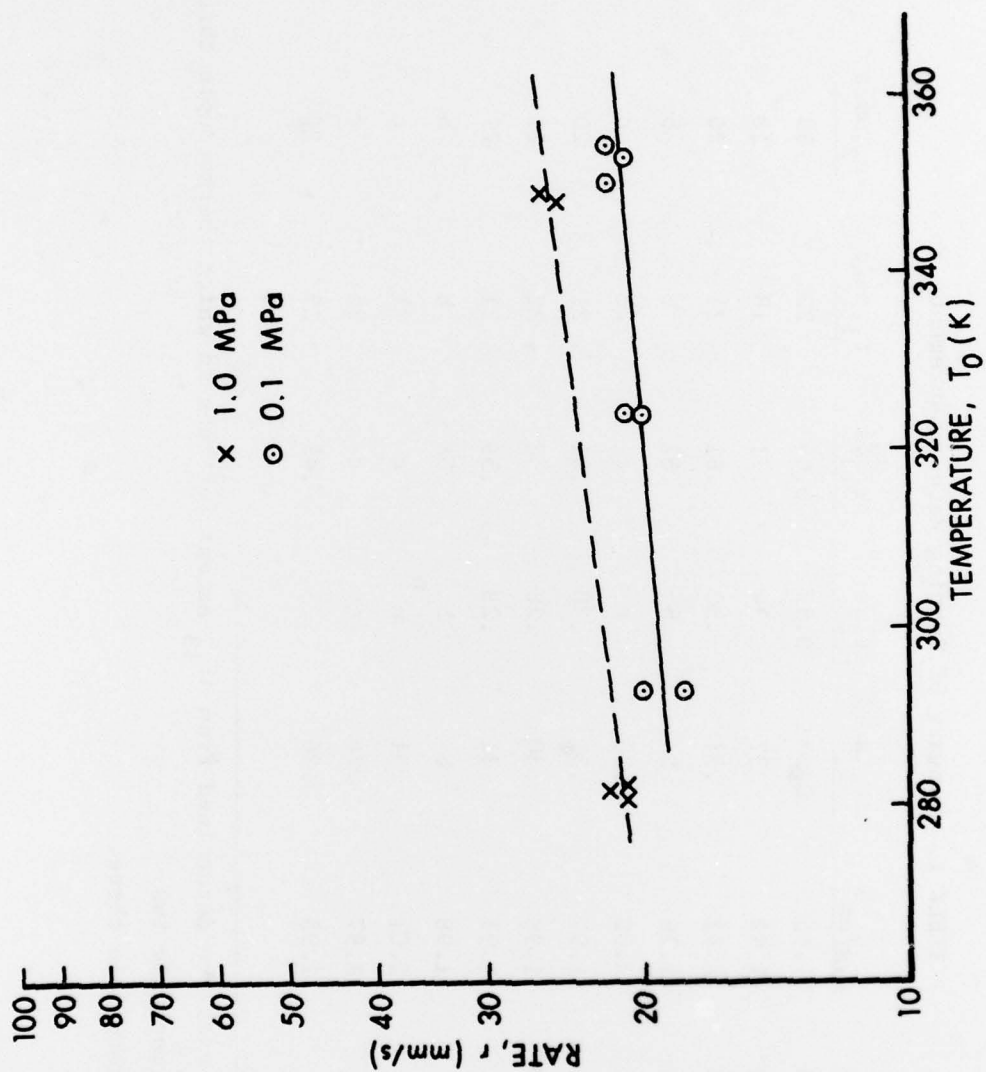


Figure 4. Burning Rate vs Initial Temperature at 0.1 MPa and 1.0 MPa

predicted the temperature sensitivity best. The two models were the petite ensemble model⁷ and the modified Beckstead, Derr, and Price (BDP) model⁸, although Condon and co-workers found the petite ensemble model predicted burning rate vs pressure closer to experimental values than did the modified BDP model.

Another way to use temperature sensitivity measurements is to examine the dependence of σ with initial temperature.¹³ Many of the theories of steady combustion⁹⁻¹² yield an expression¹³ for the sensitivity of the burning rate to initial temperature of the form

$$\sigma = \frac{K_1}{(Q/C_p + T_o)} + \frac{EK_2}{2R(Q/C_p + T_o)^2}, \quad (2)$$

where

- σ = temperature sensitivity, K^{-1}
- Q = heat of reaction, J/g
- C_p = specific heat, J/g-K
- E = activation energy, J/mole
- R = gas constant, J/mole-K
- T_o = initial temperature, K
- K_1 and K_2 = dimensionless constants which range in value from 1 to 5 for K_1 and from 1/2 to 1 for K_2 .

7. R.L. Glick and J.A. Condon, "Statistical Analysis of Polydisperse Heterogeneous Propellant Combustion - Steady-State", Proceedings of the Thirteenth JANNAF Combustion Meeting, CPIA Publication 281, December 1976.
8. M.W. Beckstead, R.L. Derr, and C.F. Price, "A Model of Composite Solid Propellant Combustion Based on Multiple Flames", *AIAAJ*, 8, pp. 2200-2207 (1970).
9. R.G. Parr and B.L. Crawford, "A Physical Theory of Burning of Double-Base Rocket Propellants", *J. Physical Chem.*, 54, p. 929 (1950).
10. R.L. Coates, "An Analysis of a Simplified Laminar Flame Theory for Solid Propellant Combustion", *Combustion Science and Technology*, 4, p. 1 (1971).
11. M.W. Beckstead and N.S. Cohen, "Temperature and Pressure Sensitivity of Composite Propellants", Proceedings of the Seventh JANNAF Combustion Conference, CPIA Publication 204, February 1971.
12. T. von Karman and G. Millan, "The Thermal Theory of Constant Pressure Deflagration", Anniversary Volume on Applied Mechanics, Dedicated to C.B. Biezeno, pp. 59-69, N.V. Technische Uitgeverij: H. Stam, (Holland) 1953.
13. R.C. Strittmater, H.E. Holmes, and E. Wineholt, "The Temperature Sensitivity of Gun Propellants", BRL Memorandum Report No. 2593, February 1976. (AD #A022200)

Equation (2) shows that σ should be reduced as the initial temperature increases. Since σ is the slope of a plot of $\ln r$ vs T_0 , one should see curvature downward of such a plot at the higher values of T_0 . If the $\ln r$ vs T_0 is curved, then this deviation from the usually assumed straight line may be useful as a guide to testing the suitability of a model. To date plots of σ vs P have been used to discriminate between different models as Condon and his collaborators did. Pyrotechnics, such as magnesium and sodium nitrate, offer a chance to see if a plot of σ vs T_0 could serve to distinguish models, since the initial temperature can be raised to nearly 1000K before decomposition or phase changes occur in the condensed phase in comparison to conventional propellants where the decomposition can take place at 500-600K. For the data gathered in this report, $\ln r$ vs T_0 may be represented by a straight line; future experiments will be done at higher values of initial temperature to see if curvature of the $\ln r$ vs T_0 line can be observed.

IV. CONCLUSIONS

1. The temperature sensitivity of a 60/40 by weight mixture of magnesium and sodium nitrate was determined to be 0.0021 K^{-1} at 0.1 MPa, and 0.0028 K^{-1} at 1.0 MPa.
2. The trend for the pyrotechnics temperature sensitivity to increase with pressure is similar to the dependence of composite propellant temperature sensitivity with pressure. This analogy suggest combustion models applicable to composite propellants should be the starting point for modeling pyrotechnic combustion.
3. At present the dependence of temperature sensitivity with pressure is used to determine the capability of combustion models to describe propellant burning. Another way to test combustion models with information from burning rate at various initial temperatures is to examine the dependence of temperature sensitivity with initial temperature rather than pressure. The change in temperature sensitivity with temperature will be reflected by curvature in the plot of $\ln r$ vs T_0 . Measurements of temperature sensitivity are needed over a larger temperature range than is presently employed.

REFERENCES

1. "Military Pyrotechnics Series, Part Four, Design of Ammunition for Pyrotechnic Effects", AMC Pamphlet AMCP 706-188, March 1974.
2. J.R. Ward, F.P. Baltakis, and S.W. Pronchick, "Wind Tunnel Study of Base Drag Reduction by Combustion of Pyrotechnics", BRL Report No. 1745, October 1974. (AD #B000431L)
3. K. Anderson, N.E. Gunners, and R. Hellgren, "Swedish Base Bleed - Increasing the Range of Artillery Projectiles Through Base Flow", Propellants and Explosives, 1, pp. 69-73 (1976).
4. "Military Pyrotechnic Series, Part One, Theory and Application", AMC Pamphlet AMCP 706-185, April 1967.
5. L. Caveny, "Workshop Report on Temperature and Pressure Sensitivity of Burning Rates", Proceedings of the Ninth JANNAF Combustion Meeting, Volume II, CPIA Publication 231, December 1972.
6. J.A. Condon, J.P. Renie, and J.R. Osborn, "Temperature Sensitivity of Propellant Burning Rates", Combustion and Flame, 30, pp. 267-276 (1977).
7. R.L. Glick and J.A. Condon, "Statistical Analysis of Polydisperse Heterogeneous Propellant Combustion - Steady-State", Proceedings of the Thirteenth JANNAF Combustion Meeting, CPIA Publication 281, December 1976.
8. M.W. Beckstead, R.L. Derr, and C.F. Price, "A Model of Composite Solid Propellant Combustion Based on Multiple Flames", AIAAJ, 8, pp. 2200-2207 (1970).
9. R.G. Parr and B.L. Crawford, "A Physical Theory of Burning of Double-Base Rocket Propellants", J. Physical Chem., 54, p. 929 (1950).
10. R.L. Coates, "An Analysis of a Simplified Laminar Flame Theory for Solid Propellant Combustion", Combustion Science and Technology, 4, p. 1 (1971).
11. M.W. Beckstead and N.S. Cohen, "Temperature and Pressure Sensitivity of Composite Propellants", Proceedings of the Seventh JANNAF Combustion Conference, CPIA Publication 204, February 1971.
12. T. von Karman and G. Millan, "The Thermal Theory of Constant Pressure Deflagration", Anniversary Volume on Applied Mechanics, Dedicated to C.B. Biezeno, pp. 59-69, N.V. Technische Uitgeverij: H. Stam, (Holland) 1953.
13. R.C. Strittmatter, H.E. Holmes, and E. Wineholt, "The Temperature Sensitivity of Gun Propellants", BRL Memorandum Report No. 2593, February 1976. (AD #A022200)

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
12	Commander Defense Documentation Center ATTN: DCC-DDA Cameron Station Alexandria, VA 22314	1	Commander US Army Communications Rsch and Development Command ATTN: DRDCO-PPA-SA Ft. Monmouth, NJ 07703
1	Director Defense Advanced Research Projects Agency ATTN: C.R. Lehner 1400 Wilson Boulevard Arlington, VA 22209	1	Commander US Army Missile Research and Development Command ATTN: DRDMI-R Redstone Arsenal, AL 35809
2	Director Institute for Defense Analyses ATTN: H. Wolfhard R.T. Oliver 400 Army-Navy Drive Arlington, VA 22202	1	Commander US Army Missile Materiel Readiness Command ATTN: DRSMI-AOM Redstone Arsenal, AL 35809
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST, N. Klein 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander US Army Tank Automotive Rsch and Development Command ATTN: DRDTA-UL Warren, MI 48090
1	Commander US Army Aviation Research and Development Command ATTN: DRSV-E P.O. Box 209 St. Louis, MO 63166	1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib Rock Island, IL 61299
1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035	2	Commander US Army Armament Research & Development Command ATTN: DRDAR-TSS Dover, New Jersey 07801
1	Commander US Army Electronics Research & Development Command Technical Support Activity ATTN: DELSD-L Ft. Monmouth, NJ 07703	5	Commander US Army Armament Research and Development Command ATTN: DRDAR-LCE-CI, J. Lannon DRDAR-LC, J.P. Picard DRDAR-LCE, C. Lenchitz DRDAR-LCE, R.F. Walker SCA-PP, L. Stiefel Dover, New Jersey 07801

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Commander US Army White Sands Missile Range ATTN: STEWS-VT WSMR, NM 88002	2	Commander US Naval Surface Weapons Center ATTN: S.J. Jacobs/Code 240 Code 730 Silver Spring, MD 20910
1	Commander US Army Watervliet Arsenal ATTN: Code SARWV-RD, R. Thierry Watervliet, NY 12189	1	Commander US Naval Surface Weapons Center ATTN: Library Br, DX-21 Dahlgren, VA 22448
1	Commander US Army Materials and Mechanics Research Center ATTN: DRXMR-ATL Watertown, MA 02172	1	Commander US Naval Underwater Systems Center Energy Conversion Department ATTN: R.S. Lazar/Code 5B331 Newport, RI 02840
1	Commander US Army Natick Research and Development Command ATTN: DRXRE, D. Sieling Natick, MA 01762	2	Commander US Naval Weapons Center ATTN: R. Derr C. Thelen China Lake, CA 93555
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib WSMR, NM 88002	1	Commander US Naval Research Laboratory ATTN: Code 6180 Washington, DC 20375
1	Commander US Army Research Office ATTN: Tech Lib P.O. Box 12211 Research Triangle Park, NC 27706	3	Superintendent US Naval Postgraduate School ATTN: Tech Lib D. Netzer A. Fuhs Monterey, CA 93940
1	Chief of Naval Research ATTN: Code 473 800 N. Quincy Street Arlington, VA 22217	2	Commander US Naval Ordnance Station ATTN: Dr. C. Dale Tech Lib Indian Head, MD 20640
1	Commander US Naval Sea Systems Command ATTN: J.W. Murrin (NAVSEA-0331) National Center, Bldg. 2, Rm 6E08 Washington, DC 20360	2	AFOSR ATTN: J.F. Masi B.T. Wolfson Bolling AFB, DC 20332

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
2	AFRPL (DYSC) ATTN: D. George J.N. Levine Edwards AFB, CA 93523	1	General Electric Company Armament Department ATTN: M.J. Bulman Lakeside Avenue Burlington, VT 05402
1	Lockheed Palo Alto Rsch Labs ATTN: Tech Info Ctr 3521 Hanover Street Palo Alto, CA 94304	1	General Electric Company Flight Propulsion Division ATTN: Tech Lib Cincinnati, OH 45215
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813	2	Hercules Incorporated Alleghany Ballistic Lab ATTN: R. Miller Tech Lib Cumberland, MD 21501
1	ARO Incorporated ATTN: N. Dougherty Arnold AFS, TN 37389	1	Hercules Incorporated Bacchus Works ATTN: M. Beckstead Magna, UT 84044
1	Atlantic Research Corporation ATTN: M.K. King 5390 Cherokee Avenue Alexandria, VA 22314	1	IITRI ATTN: M.J. Klein 10 West 35th Street Chicago, IL 60615
1	AVCO Corporation AVCO Everett Research Lab Div ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149	1	Olin Corporation Badger Army Ammunition Plant ATTN: J. Ramnarace Baraboo, WI 53913
2	Calspan Corporation ATTN: E.B. Fisher A.P. Trippe P.O. Box 235 Buffalo, NY 14221	2	Olin Corporation New Haven Plant ATTN: R.L. Cook D.W. Riefler 275 Winchester Avenue New Haven, CT 06504
1	ENKI Corporation ATTN: M.I. Madison 9015 Fulbright Avenue Chatsworth, CA 91311	1	Paul Gough Associates, Inc. ATTN: P.S. Gough P.O. Box 1614 Portsmouth, NH 03801
1	Foster Miller Associates, Inc. ATTN: A.J. Erickson 135 Second Avenue Waltham, MA 02154		

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Physics International Company 2700 Merced Street Leandro, CA 94577	2	Thiokol Corporation Wasatch Division ATTN: J. Peterson Tech Lib P.O. Box 524 Brigham City, UT 84302
1	Pulsepower Systems, Inc. ATTN: L.C. Elmore 815 American Street San Carlos, CA 94070	1	TRW Systems Group ATTN: H. Korman One Space Park Redondo Beach, CA 90278
1	Science Applications, Inc. ATTN: R.B. Edelman 23146 Cumorah Crest Woodland Hills, CA 91364	2	United Technology Center ATTN: R. Brown Tech Lib P.O. Box 358 Sunnyvale, CA 94088
2	Rockwell International Corp. Rocketdyne Division ATTN: C. Obert J.E. Flanagan 6633 Canoga Avenue Canoga Park, CA 91304	1	Universal Propulsion Co. ATTN: H.J. McSpadden P.O. Box 546 Riverside, CA 92502
2	Rockwell Internation Corp. Rocketdyne Division ATTN: W. Haymes Tech Lib McGregor, TX 76657	1	Battelle Memorial Institute ATTN: Tech Lib 505 King Avenue Columbus, OH 43201
1	Shock Hydrodynamics, Inc. ATTN: W.H. Anderson 4710-16 Vineland Avenue North Hollywood, CA 91602	1	Brigham Young University Dept of Chemical Engineering ATTN: R. Coates Provo, UT 84601
1	Thiokol Corporation Elkton Division ATTN: E. Sutton Elkton, MD 21921	1	California Institute of Tech 204 Karmar Lab Mail Stop 301-46 ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91125
3	Thiokol Corporation Huntsville Division ATTN: D. Flanagan R. Glick Tech Lib Huntsville, AL 35807	1	Case Western Reserve Univ. Division of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
3	Georgia Institute of Tech School of Aerospace Engineering ATTN: B.T. Zinn E. Price W.C. Strahle Atlanta, GA 30332	2	Purdue University School of Mechanical Engineering ATTN: J. Osborn S.N.B. Murthy TSPC Chaffee Hall West Lafayette, IN 47906
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616	1	Rutgers State University Dept of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Informa- tion Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20810	1	Southwest Research Institute Fire Research Section ATTN: W.H. McLain P.O. Drawer 28510 San Antonio, TX 78228
1	Massachusetts Institute of Technology Dept of Mechanical Engineering ATTN: T. Toong Cambridge, MA 02139	1	Stanford Research Institute Propulsion Sciences Division ATTN: Tech Lib 333 Ravenswood Avenue Menlo Park, CA 94024
1	Pennsylvania State University Applied Research Lab ATTN: G.M. Faeth P.O. Box 30 State College, PA 16801	1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
1	Pennsylvania State University Dept of Mechanical Engineering ATTN: K. Kuo University Park, PA 16801	1	University of California, San Diego AMES Department ATTN: F. Williams P.O. Box 109 La Jolla, CA 92037
3	Forrestal Campus Library Princeton University ATTN: M. Summerfield L. Caveny Tech Lib P.O. Box 710 Princeton, NJ 08540	1	University of Illinois Dept of Aeronautical Engineering ATTN: H. Krier Transportation Bldg, Rm 105 Urbana, IL 61801

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>
1	University of Minnesota Dept of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
2	University of Utah Dept of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: Dr. J. Sperrazza
DRXSY-MP, H. Cohen
Cdr, USATECOM
ATTN: DRSTE-SG-H