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DEVELOPMENT OF LOW TEMPERATURE GAS GENERATOR TECHNOLOGY

Quarterly Report

Prepared By:

Dr. Donald R. Poole

Rocket Research Corporation
520 South Portland Street
Seattle, Washington 98108

April, 1966

Air Force Rocket Propulsion Laboratory
Research and Technology Division
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Edwards, California

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FOREWORD

This technical report was prepared for the Air Force Rocket Propulsion Laboratory, Research and Technology Division, Edwards Air Force Base, California, by Rocket Research Corporation, Seattle, Washington under Contract AF 04(611)-11376. This Quarterly Report covers the period January 3, 1966 through March 31, 1966. The Air Force Project Officer was Capt. Joel A. Tolson. The Rocket Research Corporation Program Manager was Dr. Donald R. Poole.

This report has been assigned a secondary report number of RRC-66-R-58 by Rocket Research Corporation.

This report contains no classified information extracted from other classified documents.

Publication of this report does not constitute Air Force Approval of the report's findings or conclusions. It is published only for the exchange of ideas.

Joel A. Tolson, Capt., USAF
Project Officer

ABSTRACT

The objective of Contract AF 04(611)-11376 is to characterize monopropellant hydrazine based propellants which, by the use of ammonia and ammonia-water diluents, are capable of producing clean outlet gases in the temperature range of 175°F to 2,200°F when passed through a catalytic decomposition chamber.

During the report period thermochemical calculations were performed on a large number of cases involving various compositions of hydrazine, ammonia and water. The effect of varying the amount of ammonia dissociation was investigated in the above calculations. The results of these calculations are presented in this report in tabular and graphical form. In addition, equipment was assembled for the preparation of solutions of hydrazine, ammonia, and water and for the measurement of vapor pressures and freezing points of these solutions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I

CONTRACT SCOPE

1.1 General

The Program is being conducted in three phases. Phase I involves conducting thermochemical calculations which will provide theoretical data to aid in the selection of systems to be investigated experimentally. Phase II will be the actual experimental physical and chemical characterization of these systems. Preliminary delivered performance data will be determined in Phase III using a heavyweight experimental reactor. This Program is basically a propellant study and does not involve development of gas generator hardware.

1.2 Thermochemical Calculations (Phase I)

Thermochemical calculations will be performed on various compositions for the hydrazine-ammonia-water system. The effect of varying amounts of ammonia dissociation will be investigated in addition to the effect of varying the chamber pressure.

1.3 Physical and Chemical Characterization (Phase II)

Solubility limits and vapor pressures of ammonia in hydrazine and ammonia-water mixtures in hydrazine will be determined. This information and the theoretical performance information from Phase I will permit selection of several optimum mixtures. The number and composition of the optimum mixtures will be selected subject to AFRPL approval. The density, freezing point, vapor pressure, and viscosity of the optimum mixtures will then be determined.

1.4 Reactor Testing (Phase III)

A laboratory scale test reactor will be designed and fabricated which will produce gases at the rate of 60 standard cubic feet per minute. It will operate at a nominal chamber pressure of 300 psia and is to be constructed so that the catalyst bed can be easily varied. Tests will be run with the reactor using the optimum mixtures selected in Phase II.

SECTION II

THERMOCHEMICAL CALCULATIONS

2.1 Computer Program Description

The computer facilities of the Service Bureau Corporation, Palo Alto, California, were utilized for Phase I thermochemical equilibrium analyses. The NASA computational procedure was used for solution of the basic problem, as published in NASA Report No. 1037. The thermochemical data employed in this analysis was obtained from the joint Army, Navy, Air Force (JANAF) Interim Thermochemical Tables.

2.2 Chamber Conditions

The decomposition of hydrazine may be considered to take place according to the following consecutive reactions:

$$3N_2H_4 \longrightarrow 4NH_3 + N_2 \qquad (1)$$

$$2NH_3 \longrightarrow N_2 + 3H_2 \qquad (2)$$

For the purpose of calculating the relative amounts of the reactants, it was assumed that equation (1) goes to completion. The extent to which reaction (2) takes place is determined by the efficiency of the catalyst used and the design details of the reaction chamber.

Reactions (1) and (2) may be combined as follows:

$$N_2H_4 \longrightarrow 4/3\,(1 - X)\,NH_3 + \left(\frac{2X + 1}{3}\right) N_2 + 2XH_2 \qquad (3)$$

Where

X = fraction of NH_3 dissociated.

For the cases in which various concentrations of ammonia in hydrazine were considered, X represents only the fraction dissociation of the ammonia which was derived from the decomposing hydrazine and Y represents the fraction of the added ammonia which has dissociated.

The input compositions were calculated in units of gram-atoms per 100 grams of reactant for hydrogen, oxygen, and nitrogen and gram-moles per 100 grams of reactant for ammonia by means of the following equations:

$$\frac{4(1-X)}{3}\left(\frac{P_h}{32.048}\right) + (1-Y)\left(\frac{P_{am}}{17.032}\right) = (NH_3) \quad (4)$$

$$\frac{2(1-X)}{3}\left(\frac{P_h}{32.048}\right) + Y\left(\frac{P_{am}}{17.032}\right) = (N) \quad (5)$$

$$\frac{2P_w}{18.016} + \frac{4P_h X}{32.048} + \frac{3P_{am} Y}{17.032} = (H) \quad (6)$$

$$\frac{P_w}{18.016} = (0) \quad (7)$$

Where:

P_h = weight percent hydrazine in reactants

P_{am} = weight percent ammonia in reactants

P_w = weight percent water in reactants

X = fraction ammonia (derived from hydrazine) dissociated

Y = fraction of added ammonia dissociated

Calculations were performed for numerous propellant compositions where arbitrary amounts of ammonia were impressed upon the reaction products in the chamber. In these cases, ammonia was not allowed to dissociate and the formation of additional ammonia was not permitted. For practical purposes this condition specifies the composition of the chamber gases for these reactants. Numerous calculations were also performed in which complete chemical equilibrium was allowed to exist. Equilibrium conditions were applied whenever $X = Y = 1$.

All calculations were carried out under frozen flow conditions. Calculations under shifting flow conditions were not necessary since the results would be identical to frozen flow conditions for all practical purposes.

2.3 Thermochemical Data

The heats of formation used in the thermochemical calculations are listed in Table I.

These values were derived from the standard heat of formation of each component of the solutions and the heats of solution of ammonia and water in hydrazine.

Values of the heat of solution for various concentrations of ammonia in hydrazine were obtained from the data given in Reference 1. After conversion to the appropriate units this information was plotted as shown in Figure 1. This graph indicate that the heat of solution is essentially constant for concentrations greater than about 5%. The value -0.07 kcal/100 g was therefore applied as a correction in all cases involving ammonia solutions, even though a correction of this magnitude has very little influence on the results.

Corrections for the heat of solution for the various concentrations of water in hydrazine were obtained from Figure 2. Information was obtained for this figure from References 2 and 3.

For those solutions containing both ammonia and water in hydrazine, the heats of solution were estimated from values for the two component systems. The constant value of -0.07 kcal/100 g was applied to correct for the heat of solution of ammonia in hydrazine. The concentration of water in hydrazine was calculated as though no ammonia was in the solution and the corresponding heat of solution was then obtained from Figure 2.

Thermochemical calculations were performed on a test case in an effort to determine the significance of the heat of solution corrections. The test case consisted of 30% ammonia and 70% hydrazine with X = .4 and Y = 0 and was calculated both with and without the heat of solution correction. When the correction was applied, the chamber temperature was 931.08°K and the characteristic exhaust velocity was 3559 ft/sec. Without the correction, these values were 932.11°K and 3561 ft/sec. From these values it was concluded that any errors which may have been introduced by the described methods of correcting for the heat of solution would not influence the results significantly.

2.4 Discussion of Results

The results of the thermochemical calculations are summarized in Tables II, III, and IV and in Figures 3 through 15. These figures illustrate the wide ranges of chamber temperatures and performance which are theoretically possible through use of mixtures of ammonia, water and hydrazine.

It is interesting to note the abrupt changes in slopes of the curves in Figure 5. These changes are assumed to be due to the (theoretical) condensation of liquid water in the chamber. Figure 5 also shows that there is very little to be gained by examining solutions containing more than about 50% water. It may be seen from Figures 6 and 7 that 50% diluent is also approximately the upper limit for solutions containing equal weight percentages of ammonia and water.

SECTION III

PROPELLANT CHARACTERIZATION

Phase II of this program calls for the physical and chemical characterization of a number of solutions of hydrazine with ammonia and water diluents. The initial task of Phase II is to provide enough information about the physical properties of these solutions to permit a reasonable selection of the mixture compositions which will be subjected to further study. The information of primary concern in the initial task is the mutual solubilities of the three components hydrazine, ammonia, and water. Solubility is taken here to mean the maximum concentration of additive which may be contained in the solution without the appearance of some undesirable feature such as a second liquid phase, a solid phase, or a high vapor pressure. The solubility of a condensed gas such as ammonia is strongly dependent upon both pressure and temperature. The vapor pressures of solutions of ammonia in hydrazine were calculated at 70°F and 150°F from the vapor pressures of ammonia and hydrazine assuming Raoult's law to be applicable. This information is shown in Figure 16.

Thomas (Reference 1) has measured the freezing points of solution of ammonia in hydrazine and reports that the results fit the equation:

$$\ln (1 - N) = - \frac{L_f}{R} \left(\frac{1}{T} - \frac{1}{T_m} \right) \qquad (8)$$

Where:

N = mole fraction of NH_3

R = gas constant

L_f = heat of fusion = 3,175 cal/gm mole

T_m = freezing point of 96 percent hydrazine

This equation was used to derive the curve shown in Figure 17.

Thomas also measured vapor pressures of solutions of ammonia in hydrazine but unfortunately these measurements were limited to vapor pressures less than one atmosphere. More important, however, was his conclusion that for temperatures above -40°C there will only be one liquid phase.

Since ammonia has been shown to be miscible with hydrazine at lower temperatures and pressures, only one or two tests are needed to establish whether or not these two compounds are miscible at higher temperatures and pressures.

Mixtures of up to about 60% ammonia in hydrazine will be made up in Hoke cylinders. The vapor pressure of each mixture will be measured at various temperatures by a temperature compensated bourdon tube pressure gauge which is included in a temperature controlled oven. This apparatus has been set up and is being checked out with pure ammonia. This apparatus will also be used for measuring the vapor pressures of solutions containing both ammonia and water in hydrazine where high pressures will be encountered.

In order to establish the solubility of mixtures of both ammonia and water in hydrazine, it is planned to prepare solutions of various concentrations in heavy walled glass tubes which will be sealed to prevent loss of ammonia. The freezing points will be determined and then the solutions will be warmed and observed to establish whether more than one liquid phase appears.

During this reporting period the apparatus for these experiments was set up and one hydrazine solution was prepared which contains 14.4% NH_3 and 4.5% H_2O. This solution has a freezing point of +4°F.

SECTION IV

FUTURE WORK

More solutions will be mixed and vapor pressures and freezing point measurements will be performed. These results and the thermochemical calculations will be considered carefully and certain optimum compositions will be selected. These solutions will then be prepared and more detailed physical property measurements will be undertaken in order to fully characterize the propellants.

REFERENCES

1. Thomas, D. D., "Liquid-Vapor-Solid Equilibria for Ammonia-Hydrazine System" Memorandum No. 9-12, Jet Propulsion Laboratory, California Institute of Technology, April 26, 1948. (U)

2. Rossini, F. D., et al, "Selected Values of Chemical Thermodynamic Properties," Circular of the National Bureau of Standards 500, U. S. Government Printing Office, Washington D. C., February 1, 1952. (U)

3. Bushnell, V. C., Hughes, A. M., and Gilbert, E. C., "Studies on Hydrazine: Heats of Solution of Hydrazine and Hydrazine Hydrate at 25°." Journal of the American Chemical Society 59, 2142 (1937). (U)

APPENDIX

TEST DATA

(Reverse Side Blank)

HEAT OF SOLUTION

AMMONIA - HYDRAZINE SOLUTIONS

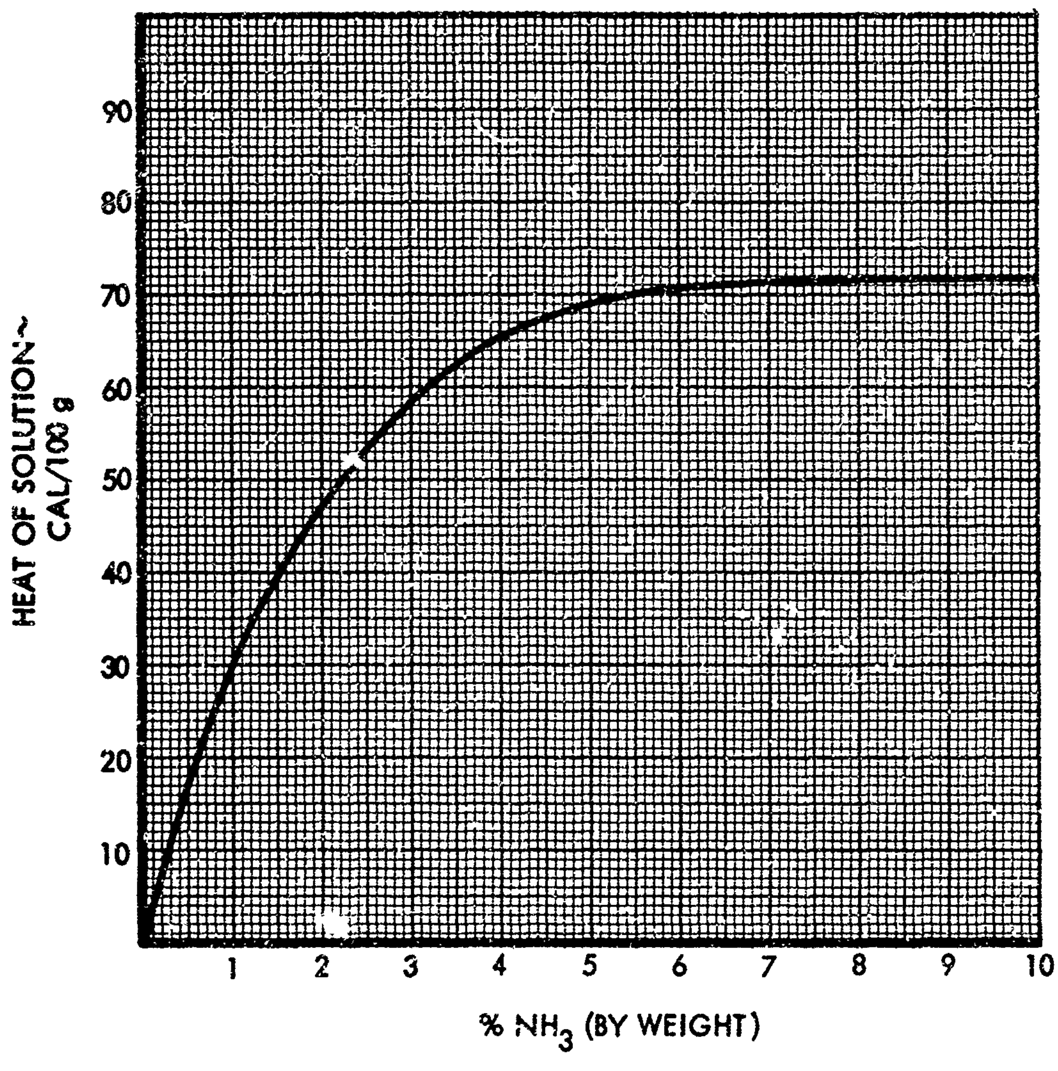

FIGURE 1

HEAT OF SOLUTION
WATER - HYDRAZINE SOLUTIONS

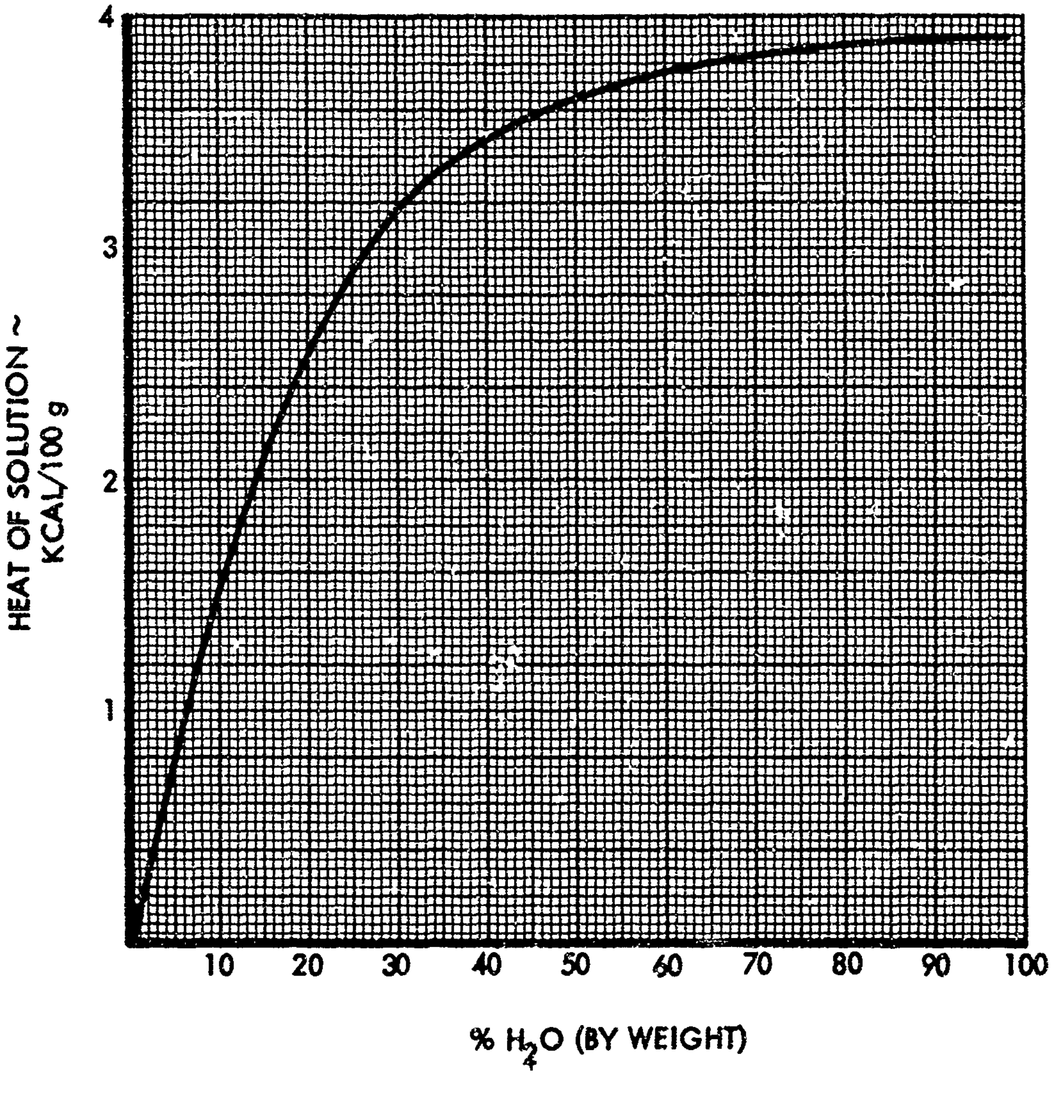

FIGURE 2

HYDRAZINE - AMMONIA SYSTEM
CHAMBER TEMPERATURE VS % NH_3 FOR VARYING AMMONIA DISSOCIATION

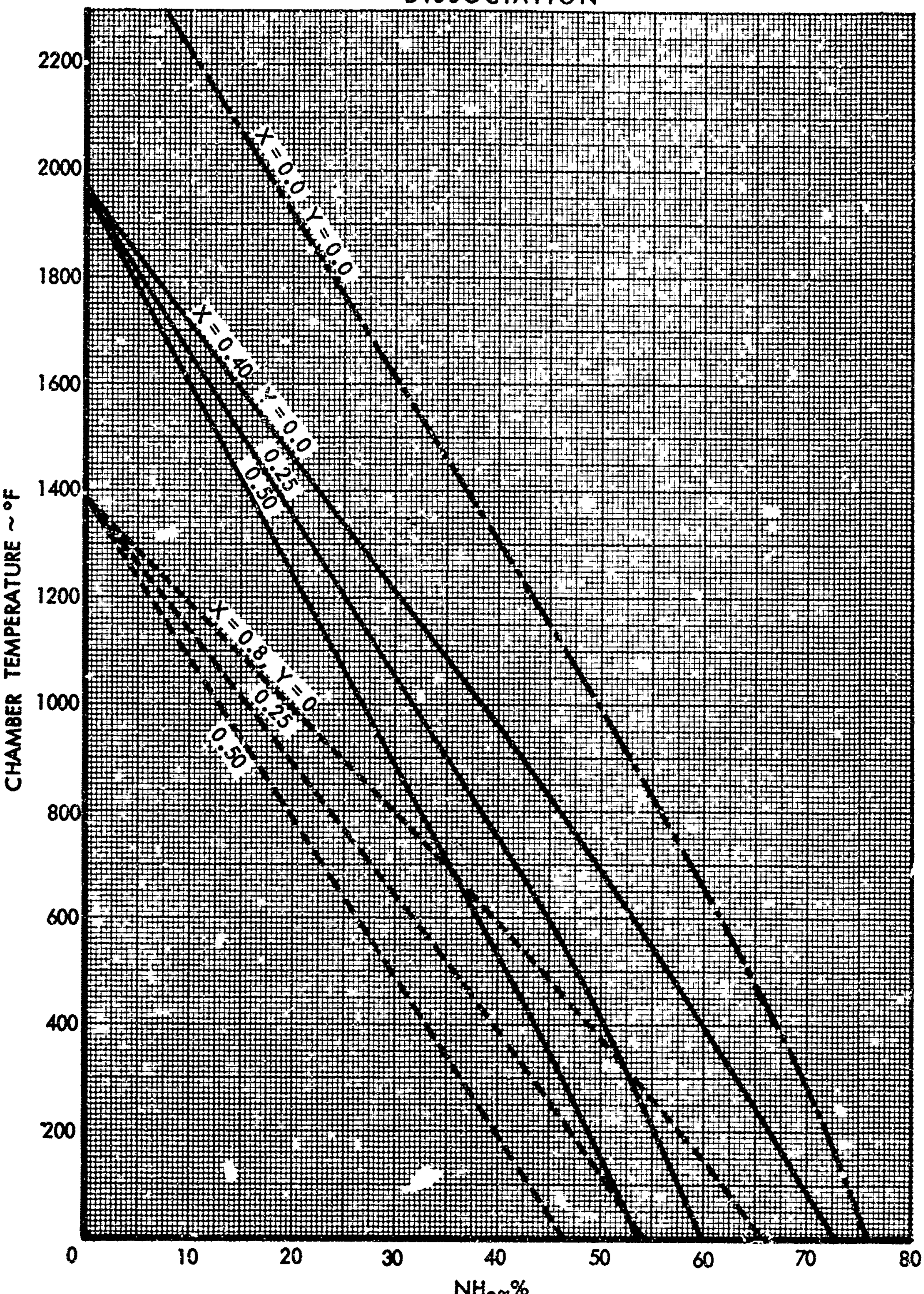

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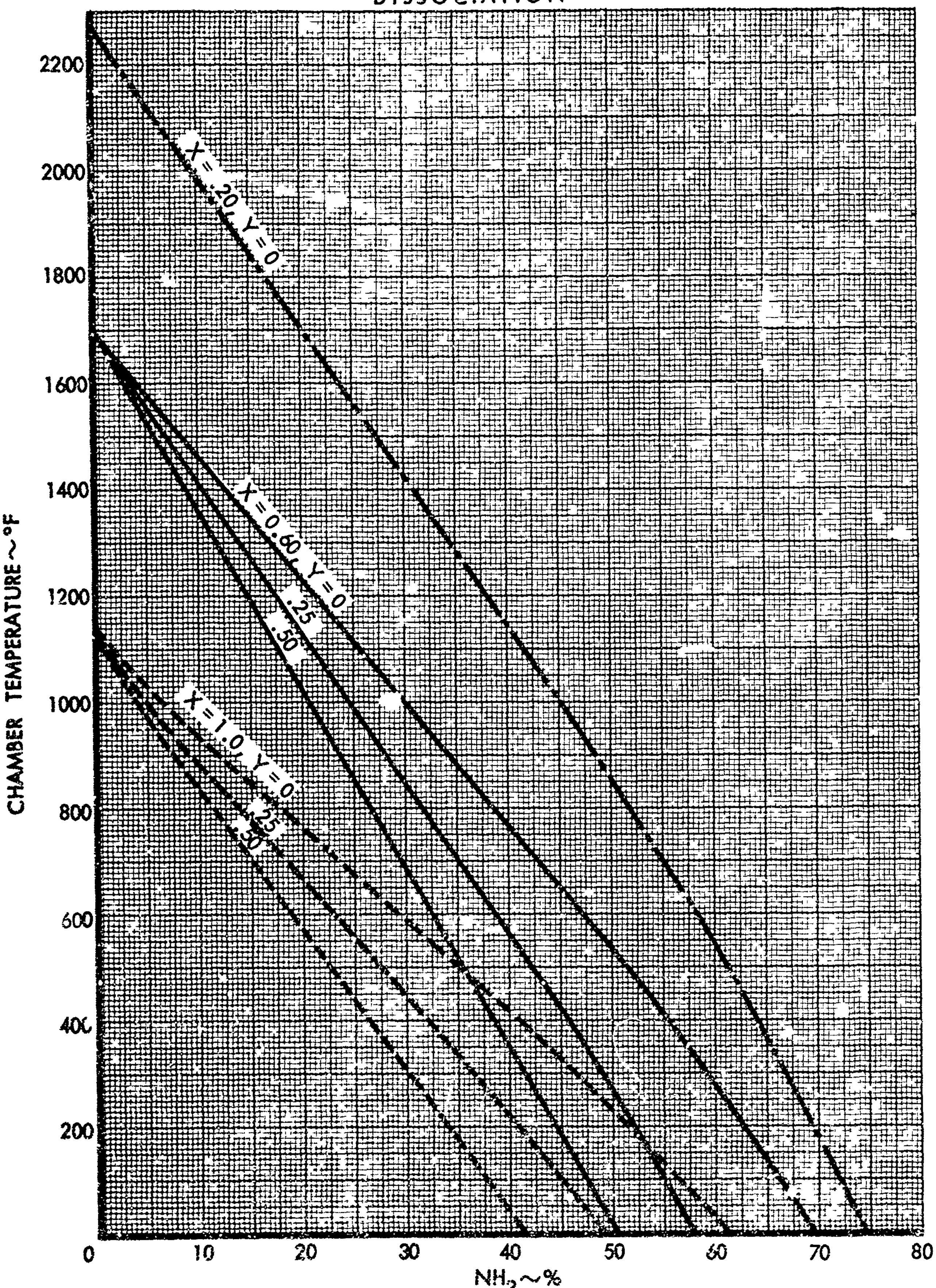
FIGURE 3

HYDRAZINE - AMMONIA SYSTEM

CHAMBER TEMPERATURE VS % NH_3 FOR VARYING AMMONIA DISSOCIATION



51046

FIGURE 4

HYDRAZINE - WATER SYSTEM

CHAMBER TEMPERATURE VS % H_2O FOR VARIOUS AMMONIA DISSOCIATION

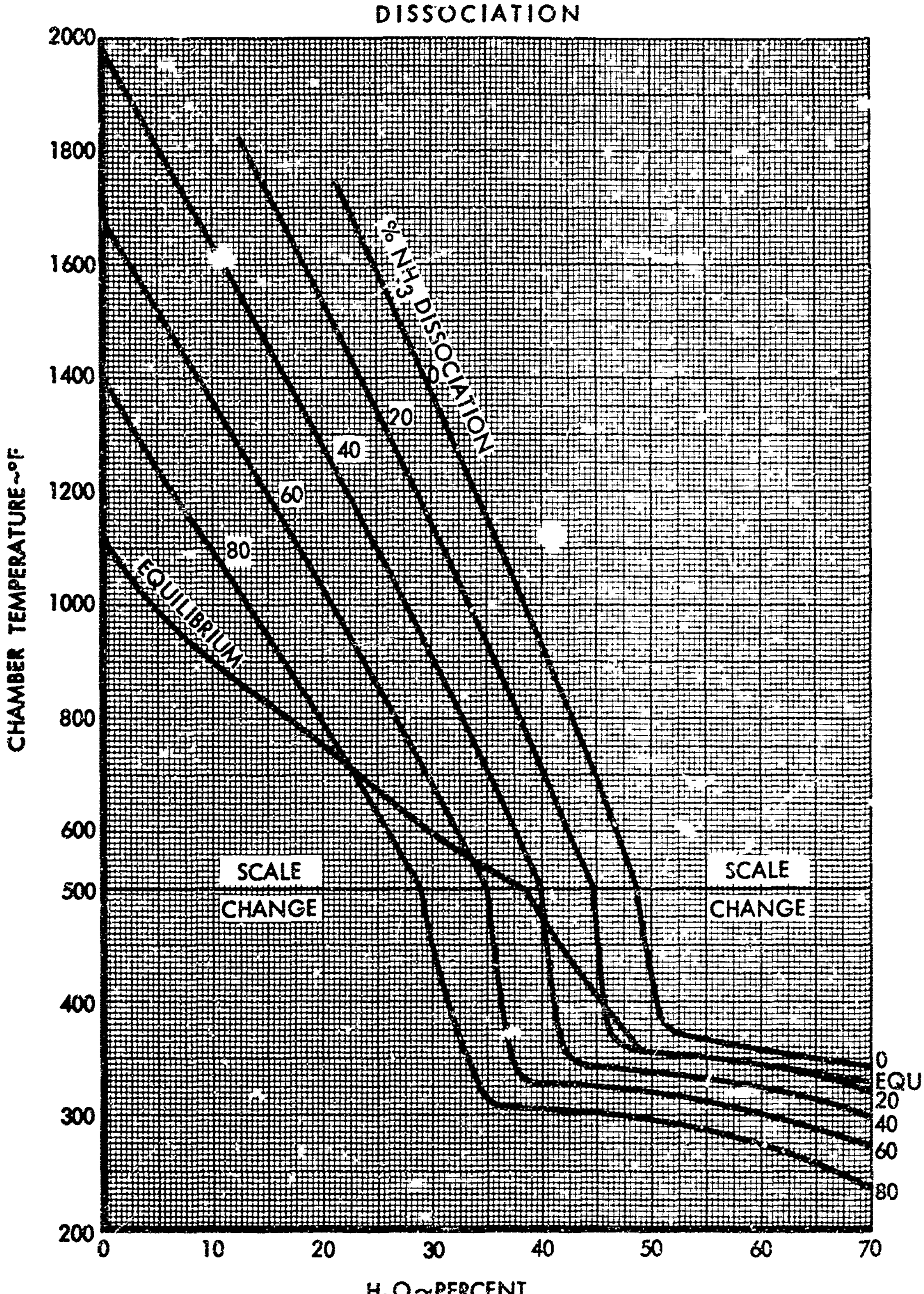


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FIGURE 5

HYDRAZINE - EQUAL WEIGHT
% H_2O AND NH_3 SYSTEM

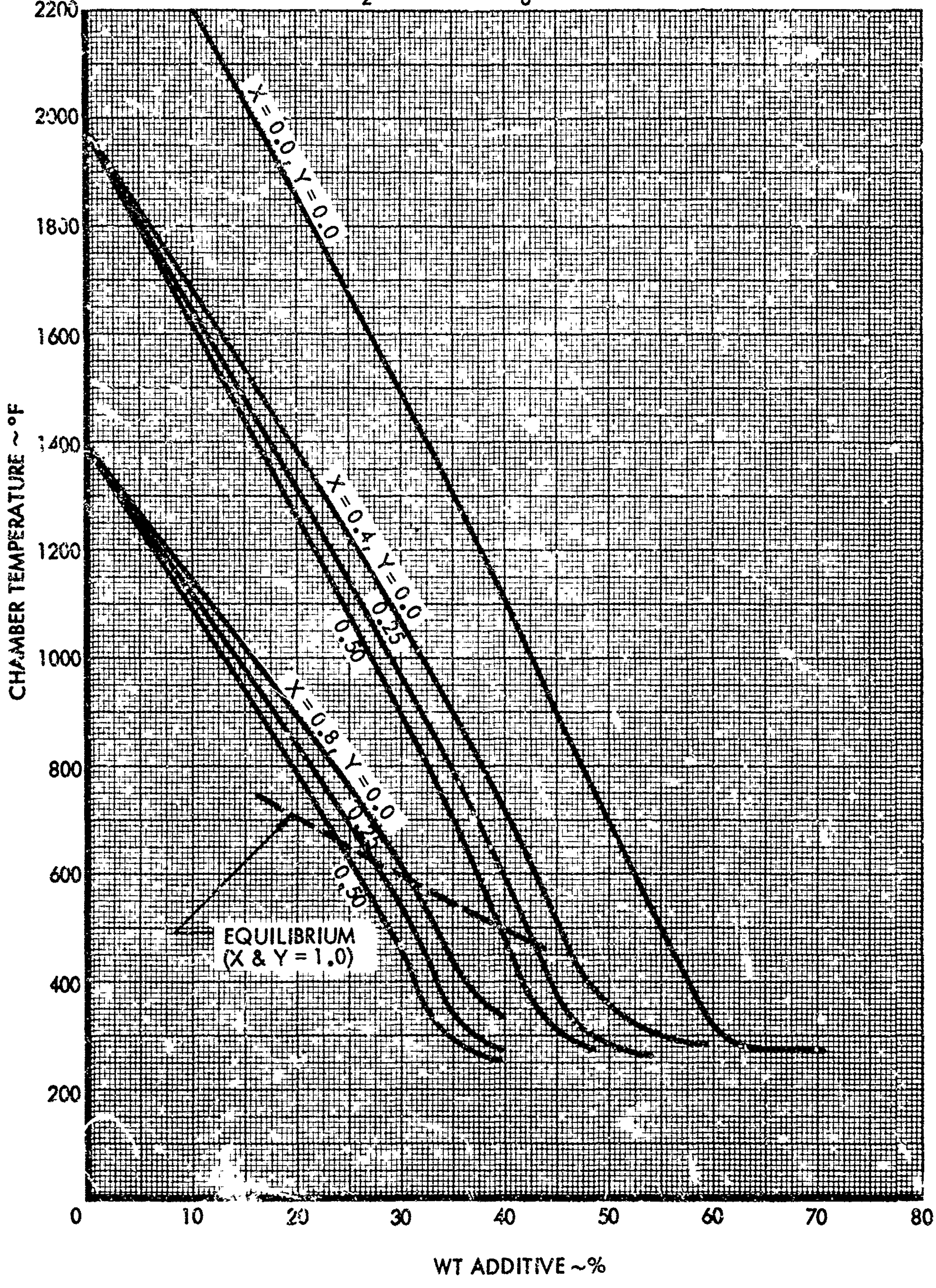

FIGURE 6

HYDRAZINE - EQUAL WEIGHT % H_2O AND NH_3 SYSTEM

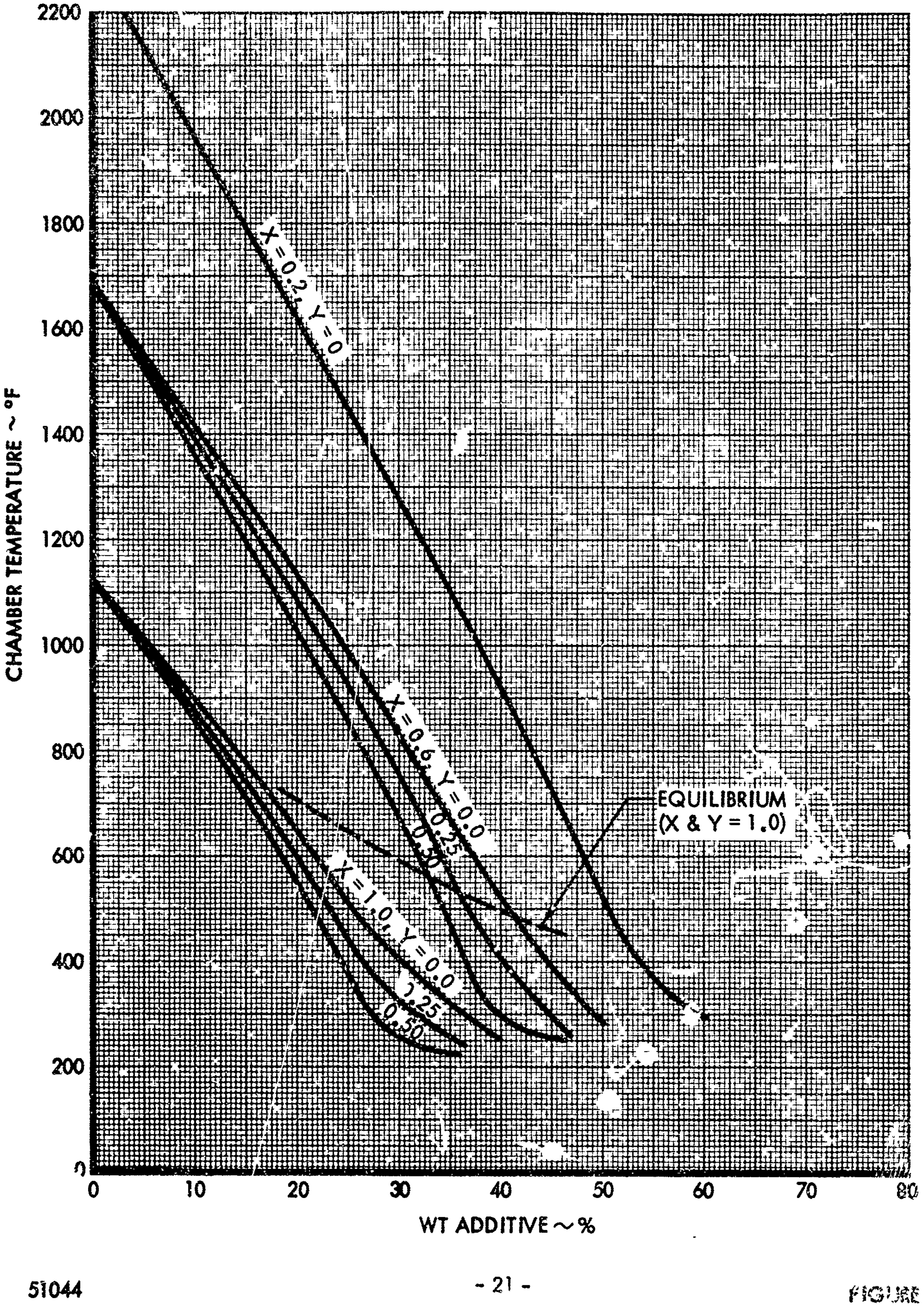

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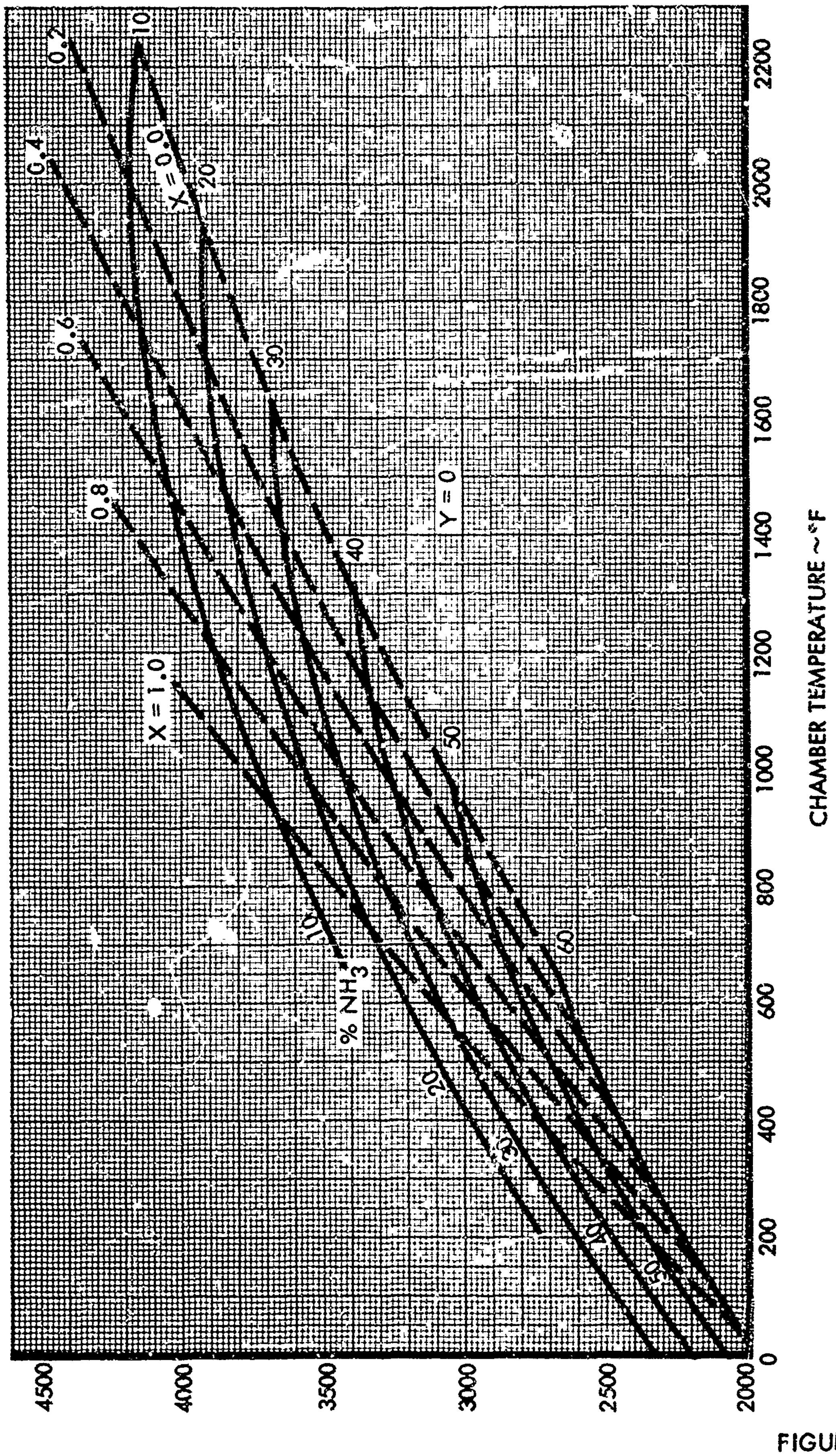
FIGURE

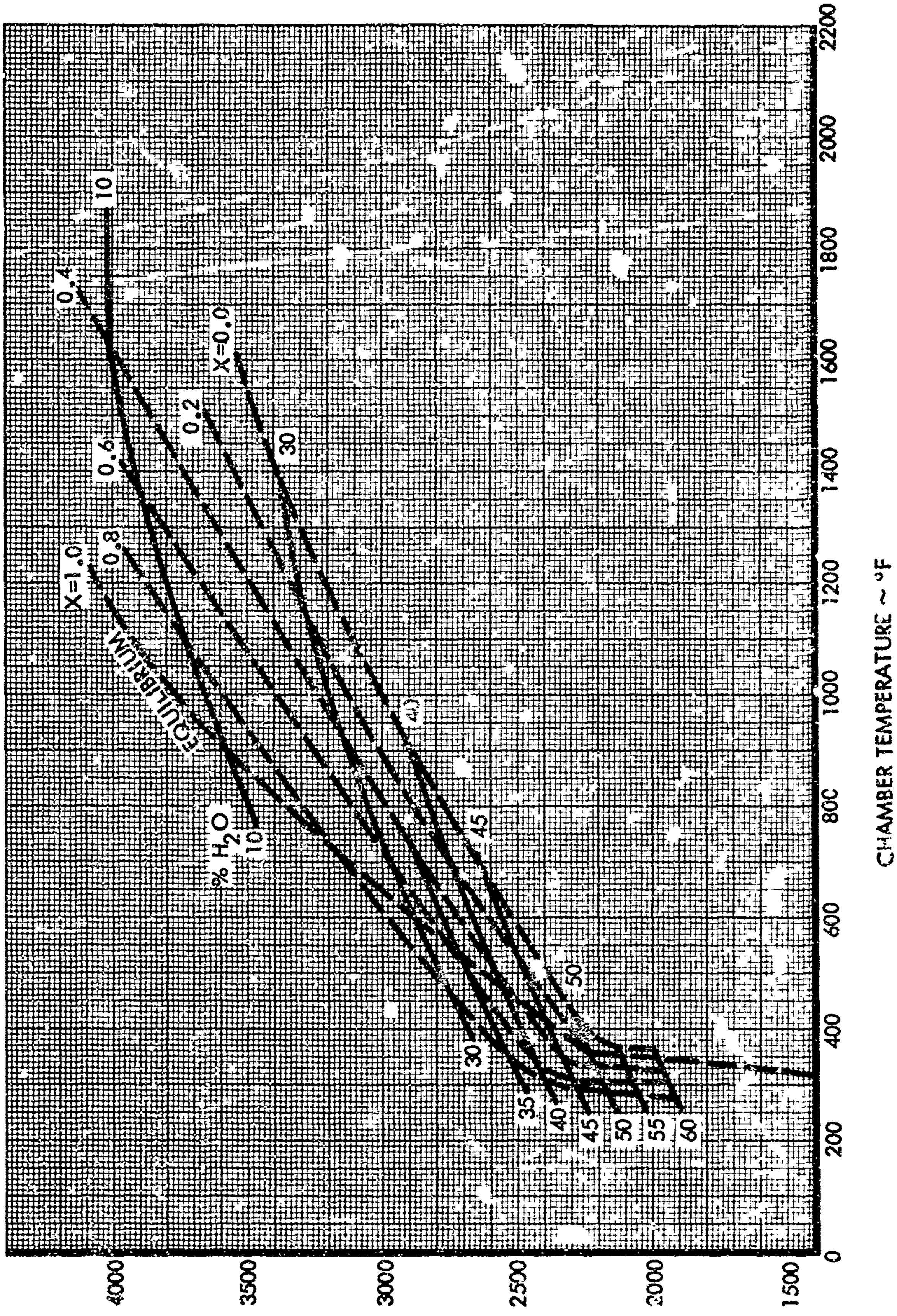
PERFORMANCE OF THE HYDRAZINE - AMMONIA SYSTEM AS A FUNCTION OF TEMPERATURE AND NH_3 DISSOCIATION



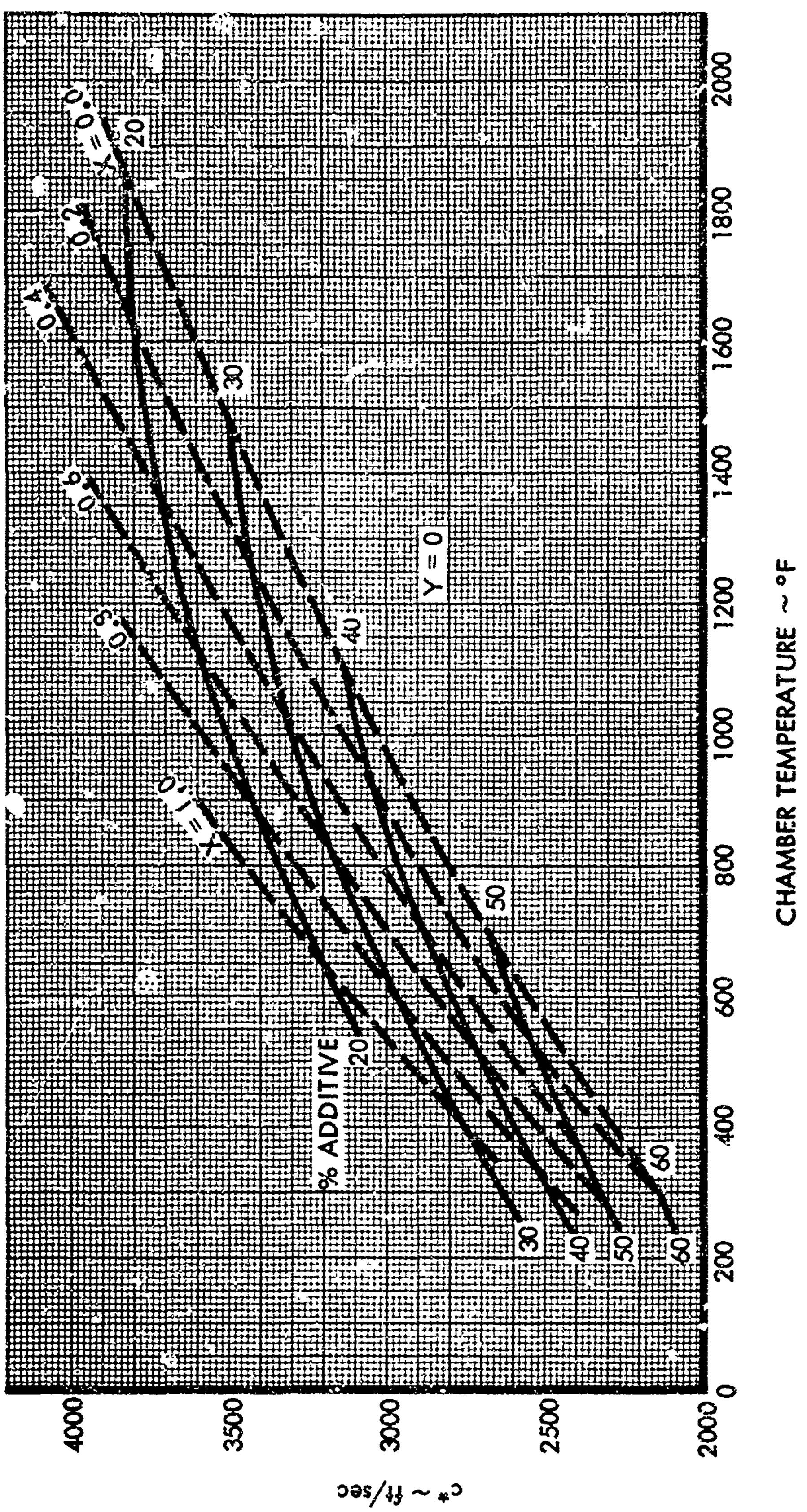
51039-1

FIGURE 8

PERFORMANCE OF THE HYDRAZINE - H_2O SYSTEM AS A FUNCTION OF TEMPERATURE AND NH_3 DISSOCIATION

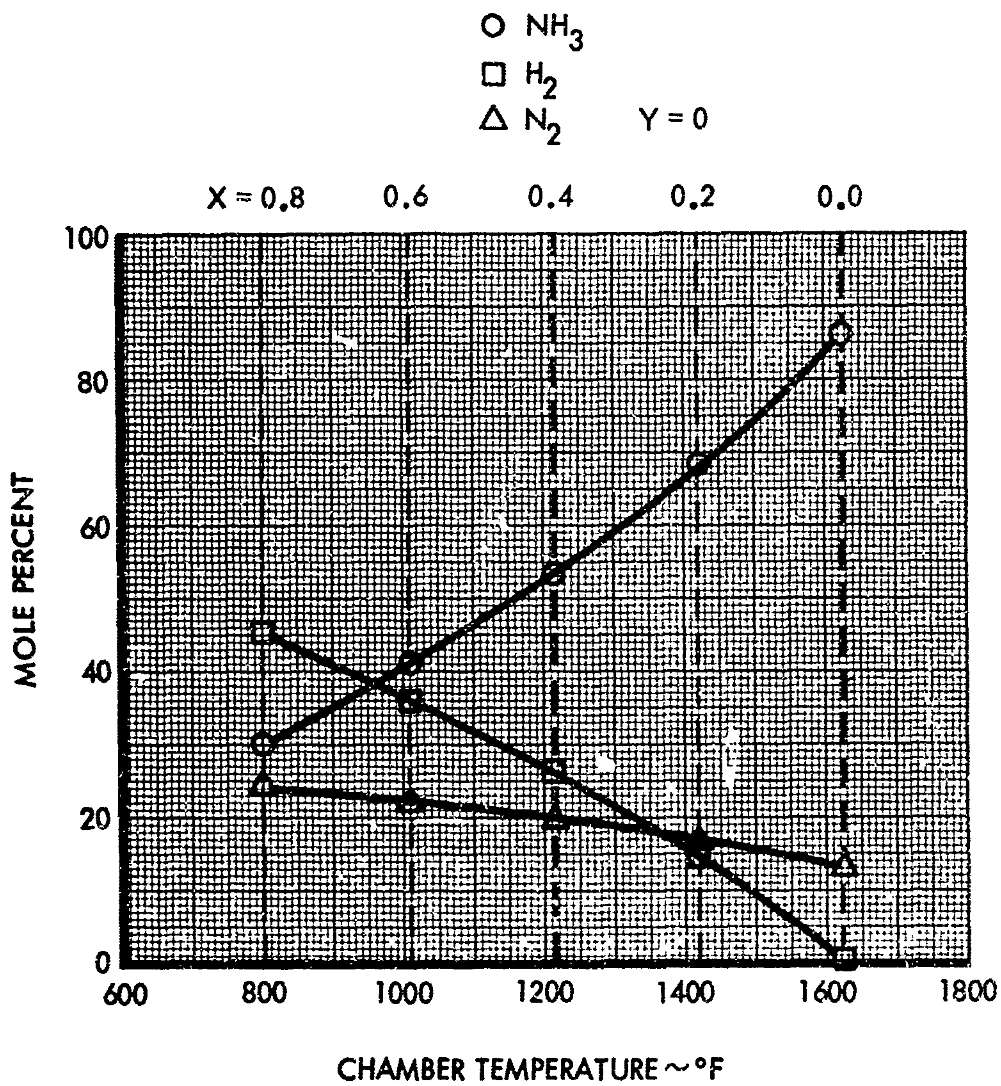


PERFORMANCE OF THE HYDRAZINE - EQUAL WT % H_2O AND NH_3 SYSTEM AS A FUNCTION OF TEMPERATURE AND NH_3 DISSOCIATION



70% HYDRAZINE - 30% NH_3 SYSTEM

REACTION PRODUCT COMPOSITION



50% HYDRAZINE - 50% NH_3 SYSTEM

REACTION PRODUCT COMPOSITION

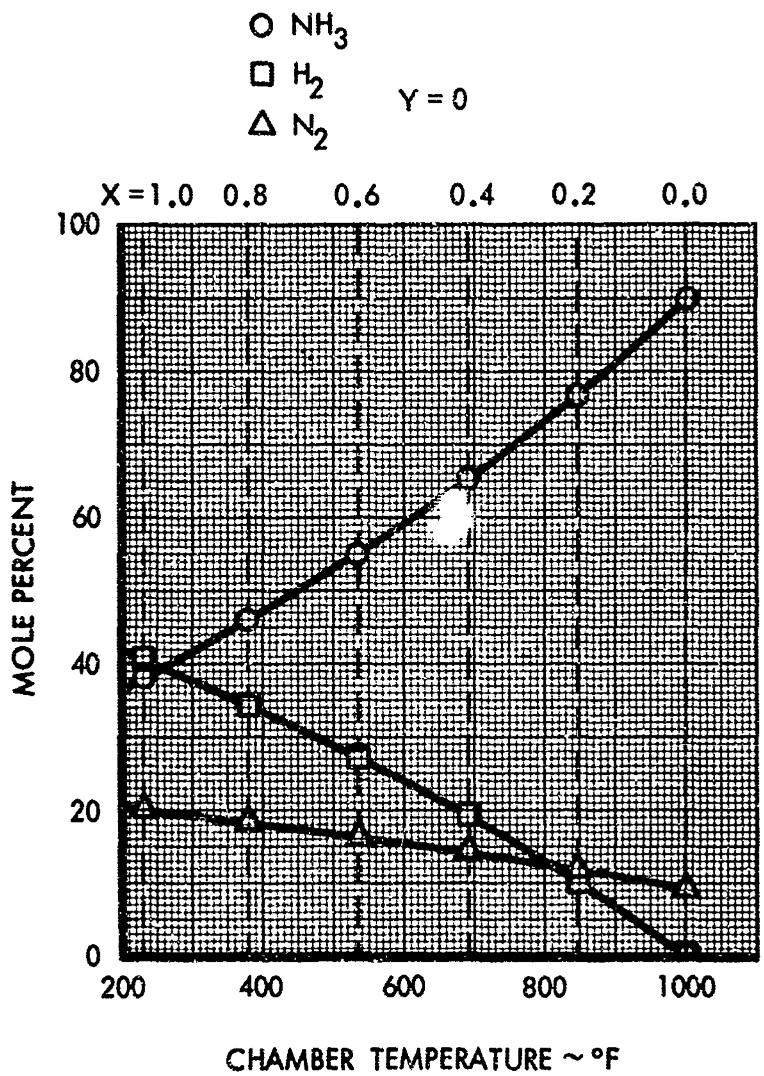
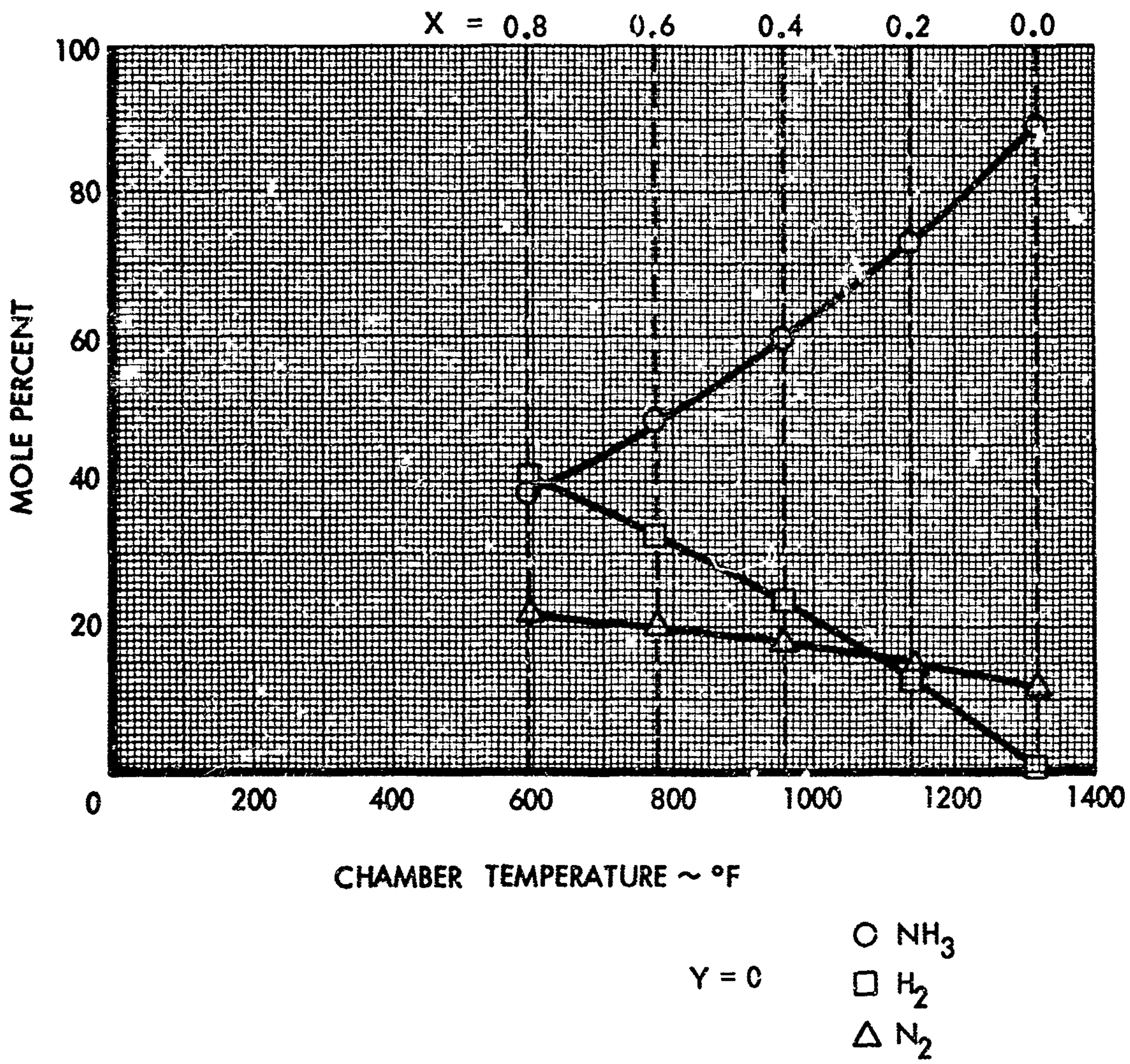


FIGURE 12

60% HYDRAZINE - 40% NH_3 SYSTEM

REACTION PRODUCT COMPOSITION



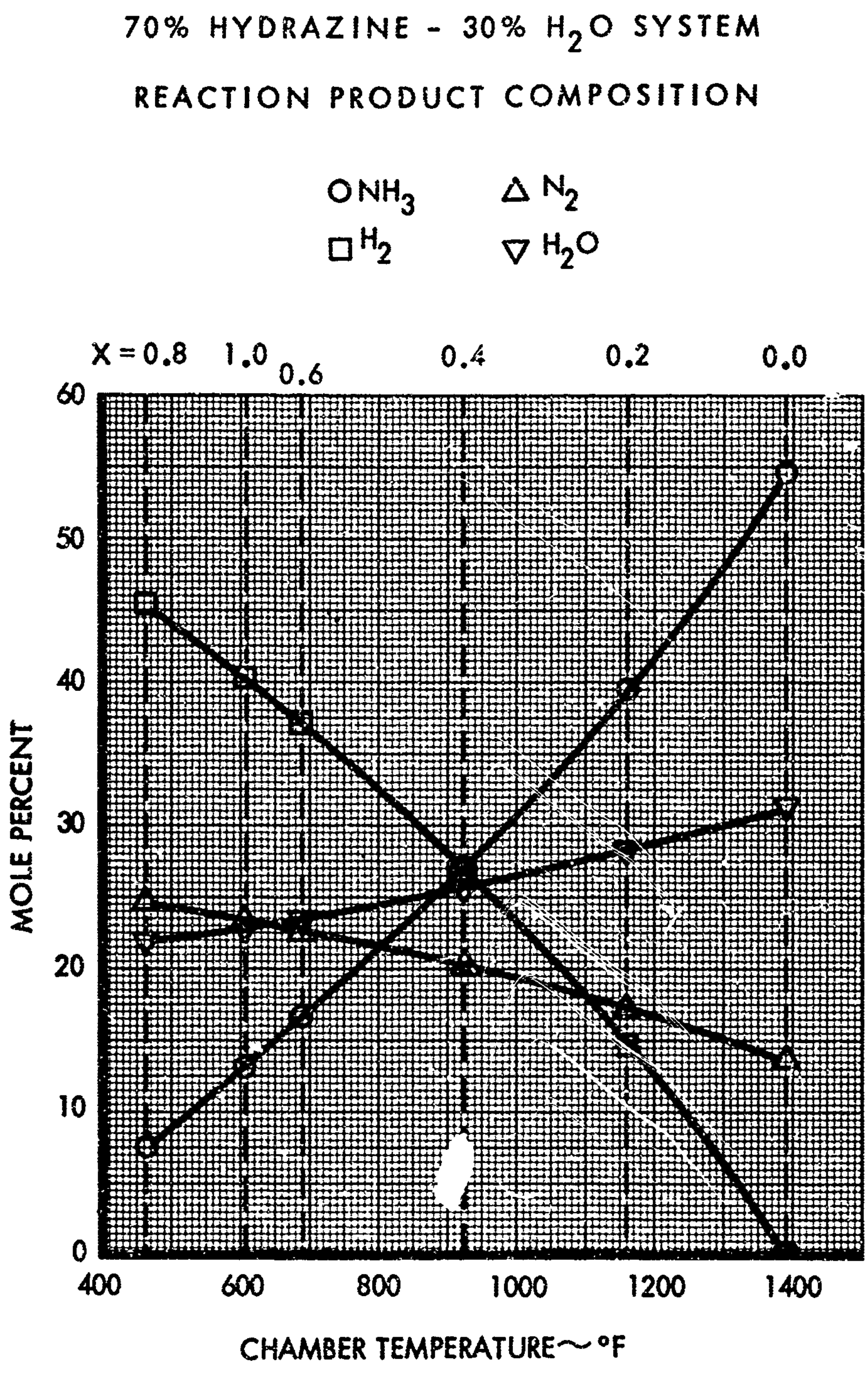

70% HYDRAZINE - 30% H2O SYSTEM
REACTION PRODUCT COMPOSITION
O NH3
Δ N2
□ H2
∇ H2O
X = 0.8
1.0
0.6
0.4
0.2
0.0
60
50
40
30
20
10
0
MOLE PERCENT
400
600
800
1000
1200
1400
CHAMBER TEMPERATURE ~ °F

FIGURE 14

55% HYDRAZINE - 45% H_2O SYSTEM

REACTION PRODUCT COMPOSITION

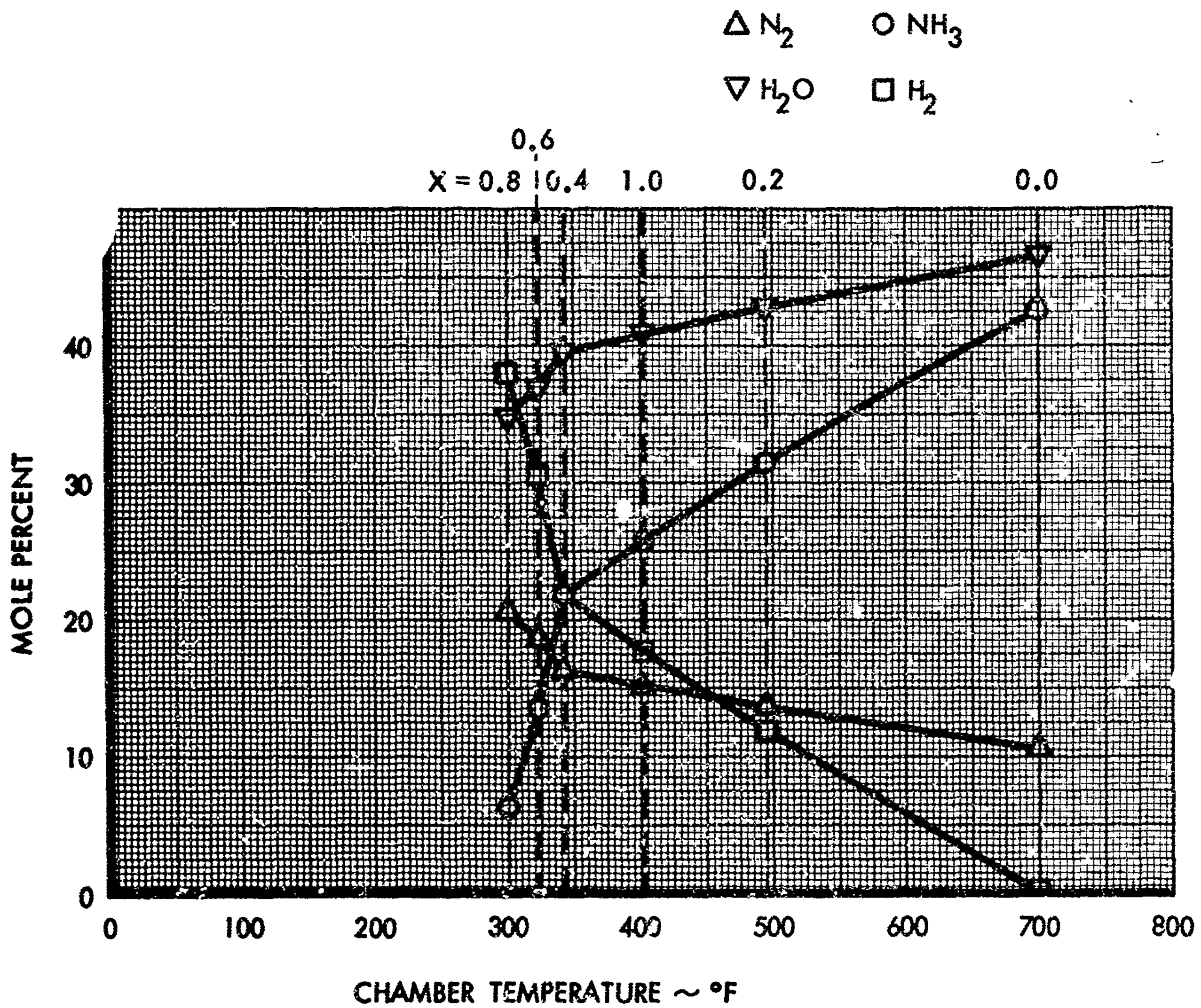


FIGURE 15

CALCULATED VAPOR PRESSURES
OF
AMMONIA-HYDRAZINE SOLUTIONS

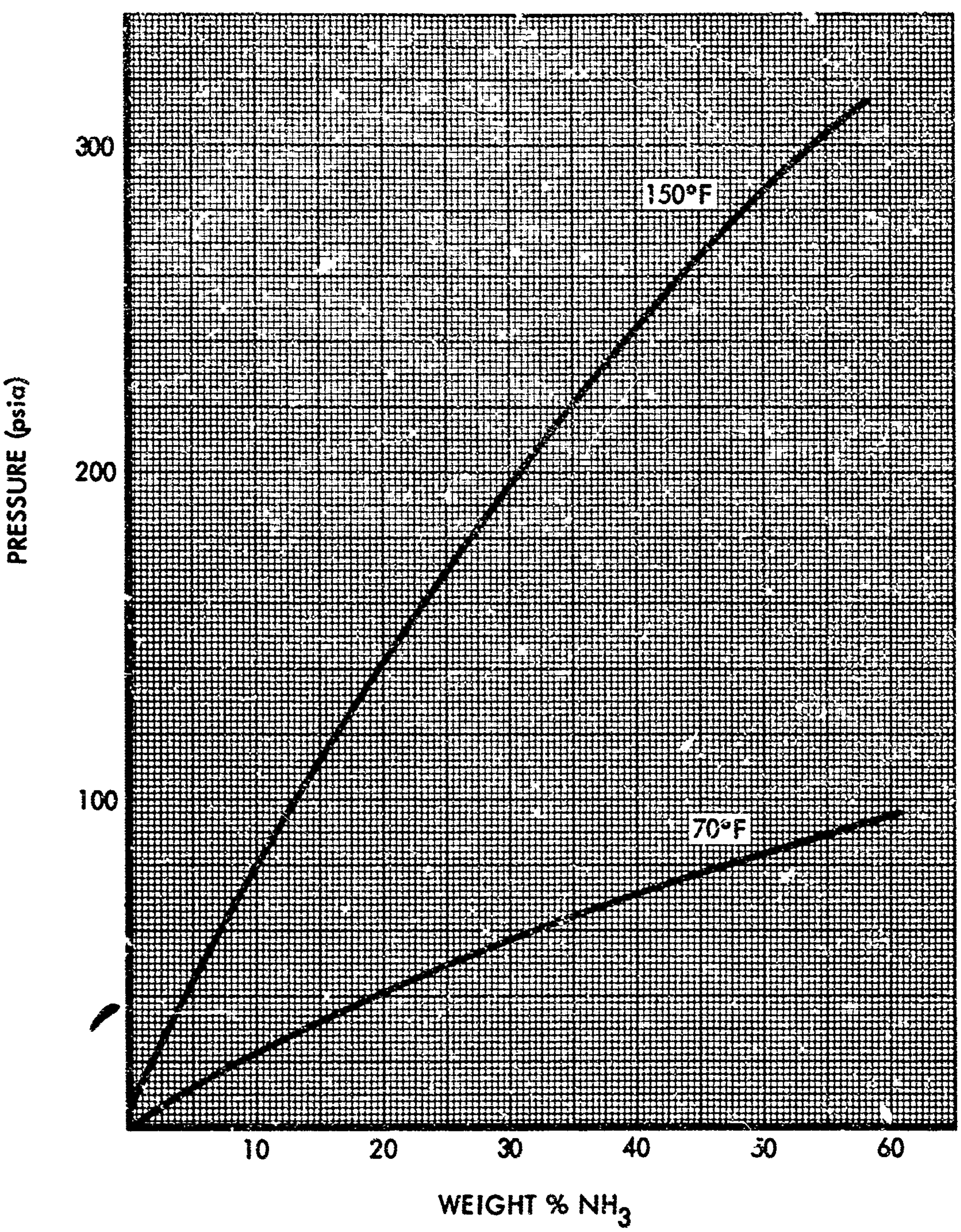
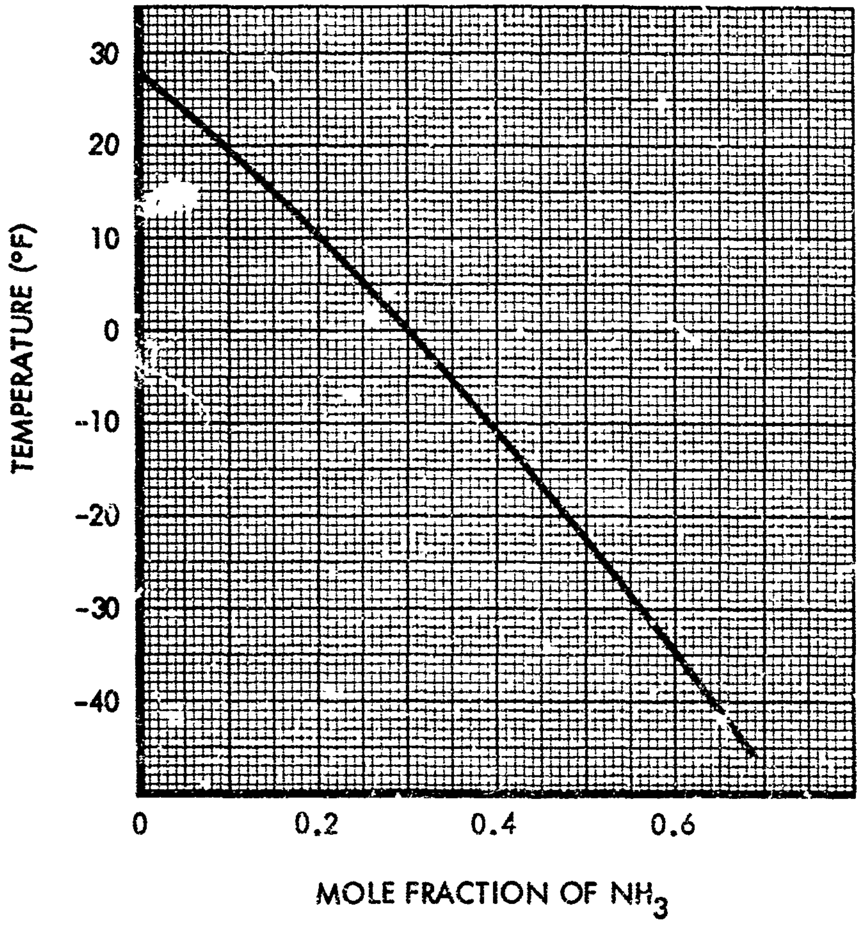


FIGURE 16

FREEZING-POINT CURVE
FOR
AMMONIA-HYDRAZINE SYSTEM*



* FROM REFERENCE 1

TABLE I

HEAT OF FORMATION OF HYDRAZINE SOLUTIONS

$\%N_2H_4$	$\%NH_3$	$\%H_2O$	Hf°
100	0	0	+ 37.5998
90	0	10	- 5.5018
70	0	30	- 90.7060
65	0	35	-111.4167
60	0	40	-132.9876
55	0	45	-153.5183
50	0	50	-174.4393
45	0	55	-195.3601
40	0	60	-216.2509
30	0	70	-258.0026
95	5	0	+ 30.399
90	10	0	+ 24.508
80	20	0	+ 11.486
70	30	0	- 1.552
60	40	0	- 14.558
55	45	0	- 21.069
50	50	0	- 27.580
40	60	0	- 40.602
35	65	0	- 47.113
30	70	0	- 53.624
80	10	10	- 18.691

TABLE II

THEORETICAL PERFORMA

HYDRAZINE - WATER SY

CHAMBER PRESSURE = 300 psia - EXHAUST

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	Δ
300	1.1.40	100	--	0	0.4	--	1,356	1,981	4,395	190.6	-41
	1.1.60	100	--	0	0.6	--	1,192	1,687	4,309	185.7	-39
	1.1.80	100	--	0	0.8	--	1,028	1,392	4,160	178.4	-36
	1.1.100	100	--	0	1.0	--	881	1,126	3,975	170.0	-33
	3.1.40	90	--	10	0.4	--	1,170	1,646	4,030	174.4	-34
	3.1.60	90	--	10	0.6	--	1,017	1,371	3,913	168.4	-32
	3.1.80	90	--	10	0.8	--	864	1,096	3,740	160.3	-29.
	3.1.100	90	--	10	1.0	--	757	903	3,585	153.4	-27.
	3.3.00	70	--	30	0.0	--	1,026	1,387	3,390	147.6	-25.
	3.3.20	70	--	30	0.2	--	896	1,154	3,301	142.7	-23.
	3.3.40	70	--	30	0.4	--	768	923	3,167	136.2	-21.
	3.3.60	70	--	30	0.6	--	638	689	2,981	128.0	-18.
	3.3.80	70	--	30	0.8	--	510	458	2,750	118.0	-16.
	3.3.100	70	--	30	1.0	--	589	600	2,896	124.3	-17.
	3.35.60	65	--	35	.6	--	539	510	2,710	116.5	-15.
	3.35.80	65	--	35	.8	--	429	312	2,496	107.2	-13.
	3.35.100	65	--	35	1.0	--	557	544	2,742	117.9	-15.
	3.4.00	60	--	40	0.0	--	773	932	2,922	126.3	-18.
	3.4.20	60	--	40	0.2	--	654	717	2,776	119.6	-16.
	3.4.40	60	--	40	0.4	--	534	503	2,589	111.5	-14.
	3.4.60	60	--	40	0.6	--	437	327	2,413	103.9	-12.
	3.4.80	60	--	40	0.8	--	425	306	2,405	104.3	-12.
	3.4.100	60	--	40	1.0	--	519	475	2,563	110.3	-13.
	3.45.00	55	--	45	0	--	645	701	2,652	114.4	-15.
	3.45.20	55	--	45	.2	--	531	496	2,481	107.0	-13.
	3.45.40	55	--	45	.4	--	446	343	2,337	100.8	-11.

TABLE II
AL PERFORMANCE
E - WATER SYSTEM
ia - EXHAUST PRESSURE = 14.7 psia

I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
190.6	-41.767	14.567	1.237	2.496	1.872	2.496	--	--
185.7	-39.630	12.992	1.282	3.744	2.288	1.664	--	--
178.4	-36.568	11.725	1.328	4.993	2.704	0.832	--	--
170.0	-33.230	10.774	1.370	6.122	3.081	0.0789	--	--
174.4	-34.973	14.852	1.248	2.247	1.685	2.247	.555	--
168.4	-32.579	13.365	1.291	3.370	2.059	1.498	.555	--
160.3	-29.519	12.149	1.335	4.493	2.434	.749	.555	--
153.4	-27.060	11.409	1.365	5.295	2.701	.215	.555	--
147.6	-25.035	18.848	1.209	--	.728	2.912	1.665	--
142.7	-23.416	16.984	1.245	.874	1.019	2.330	1.665	--
136.2	-21.334	15.455	1.285	1.747	1.310	1.747	1.665	--
128.0	-18.833	14.178	1.326	2.621	1.602	1.165	1.665	--
118.0	-16.015	13.097	1.362	3.495	1.893	.582	1.665	--
124.3	-17.766	13.757	1.341	2.945	1.710	.949	1.665	--
116.5	-15.591	14.398	1.340	2.434	1.437	1.082	1.943	--
107.2	-13.196	13.357	1.356	3.245	1.758	0.541	1.898	0.045
117.9	-15.973	14.570	1.334	2.311	1.446	1.164	1.943	--
126.3	-18.335	18.725	1.242	--	.624	2.496	2.220	--
119.6	-16.438	17.124	1.282	.749	.874	1.997	2.220	--
111.5	-14.283	15.775	1.323	1.498	1.123	1.498	2.220	--
103.9	-12.398	14.623	1.332	2.247	1.373	.998	2.120	.100
104.3	-12.506	13.628	1.274	2.996	1.622	.499	1.557	.663
110.3	-13.987	15.615	1.328	1.595	1.156	1.433	2.220	--
114.4	-15.050	18.663	1.267	--	0.572	2.288	2.498	--
107.0	-13.152	17.195	1.308	0.686	0.801	1.831	2.498	--
100.8	-11.687	15.940	1.311	1.373	1.030	1.373	2.355	0.143

TABLE II (Cont'd)

THEORETICAL PERFORMANC

HYDRAZINE - WATER SYSTE

CHAMBER PRESSURE = 300 psia - EXHAUST PI

P_c psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	ΔH_R
300	3.45.60	55	--	45	.6	--	435	324	2,329	101.3	-11.78
	3.45.80	55	--	45	.8	--	423	302	2,312	101.1	-11.74
	3.34.100	55	--	45	1.0	--	481	407	2,397	103.3	-12.26
	3.5.00	50	--	50	0.0	--	491	424	2,300	99.4	-11.34
	3.5.20	50	--	50	0.2	--	452	355	2,243	97.4	-10.89
	3.5.40	50	--	50	0.4	--	443	338	2,232	97.5	-10.93
	3.5.60	50	--	50	0.6	--	432	319	2,218	97.4	-10.90
	3.5.80	50	--	50	0.8	--	419	295	2,195	96.8	-10.75
	3.5.100	50	--	50	1.0	--	453	356	2,247	97.5	-10.91
	3.55.00	45	--	55	0	--	459	366	2,143	93.7	-10.08
	.20	45	--	55	.2	--	450	351	2,128	93.5	-10.05
	.40	45	--	55	.4	--	440	333	2,108	93.1	- 9.95
	.60	45	--	55	.6	--	428	312	2,086	92.4	- 9.81
	.80	45	--	55	.8	--	414	286	2,062	91.6	- 9.64
	.100	45	--	55	1.0	--	451	352	2,129	93.5	-10.05
	3.60.00	40	--	60	0	--	456	361	1,996	88.4	- 8.99
	.20	40	--	60	.2	--	447	344	1,978	87.9	- 8.88
	.40	40	--	60	.4	--	436	325	1,957	87.2	- 8.74
	.60	40	--	60	.6	--	423	302	1,936	86.5	- 8.59
	.80	40	--	60	.8	--	408	275	1,915	85.6	- 8.42
	.100	40	--	60	1.0	--	448	347	1,982	88.0	- 8.90
	3.70.00	30	--	70	0.0	--	445	343	1,612	72.9	- 6.10
	.20	30	--	70	.2	--	434	321	1,600	72.4	- 6.02
	.40	30	--	70	.4	--	421	298	1,591	72.0	- 5.95
	.100	30	--	70	1.0	--	438	329	1,604	72.5	- 6.04

ABLE II (Cont'd)
TICAL PERFORMANCE
INE - WATER SYSTEM
0 psia - EXHAUST PRESSURE = 14.7 psia

	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
9	101.3	-11.787	14.857	1.258	2.059	1.259	0.915	1.824	0.674
2	101.1	-11.740	13.911	1.222	2.746	1.487	0.458	1.325	1.173
7	103.3	-12.264	16.625	1.322	0.986	0.901	1.631	2.498	--
0	99.4	-11.346	18.603	1.301	--	.520	2.080	2.775	--
3	97.4	-10.895	17.266	1.269	.624	.728	1.664	2.424	.351
2	97.5	-10.930	16.109	1.227	1.248	.936	1.248	1.936	.839
8	97.4	-10.900	15.097	1.199	1.872	1.144	0.832	1.494	1.280
5	96.8	-10.759	14.205	1.177	2.496	1.352	0.416	1.063	1.712
7	97.5	-10.917	17.311	1.274	0.602	0.721	1.679	2.467	0.309
3	93.7	-10.082	18.542	1.225	--	0.468	1.872	2.437	0.615
8	93.5	-10.050	17.338	1.193	0.562	0.655	1.498	1.994	1.058
8	93.1	- 9.956	16.281	1.170	1.123	0.842	1.123	1.572	1.481
6	92.4	- 9.817	15.346	1.154	1.685	1.030	0.749	1.177	1.876
2	91.6	- 9.642	14.512	1.141	2.247	1.217	0.374	0.814	2.238
9	93.5	-10.056	17.438	1.196	0.512	0.639	1.531	2.032	1.020
6	88.4	- 8.990	18.482	1.154	--	0.416	1.664	1.918	1.413
8	87.9	- 8.885	17.411	1.139	0.499	0.582	1.331	1.554	1.776
7	87.2	- 8.744	16.458	1.127	0.999	0.749	0.998	1.202	2.128
6	86.5	- 8.592	15.603	1.118	1.498	0.915	0.666	0.877	2.454
5	85.6	- 8.429	14.833	1.112	1.997	1.082	0.333	0.586	2.744
2	86.0	- 8.906	17.566	1.141	0.423	0.557	1.332	1.610	1.720
2	72.9	- 6.104	18.363	1.073	--	0.312	1.248	0.967	2.918
0	72.4	- 6.022	17.558	1.070	0.375	0.437	0.998	0.741	3.144
1	72.0	- 5.956	16.821	1.068	0.749	0.562	0.749	0.539	3.347
4	72.5	- 6.048	17.828	1.071	0.246	0.394	1.084	0.817	3.069

TABLE II (Cont'd)

THEORETICAL PERFORM

HYDRAZINE - WATER SY

CHAMBER PRESSURE = 300 psia - EXHAUS

P_c psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	[illegible]
100	1.1.100	100	--	0	1.0	--	871	1.109	3,961	144.7	-24
600	1.1.100	100	--	0	1.0	--	893	1,148	3,991	181.7	-37
1,000	1.1.100	100	--	0	1.0	--	905	1,170	4,009	189.1	-41
100	3.1.100	90	--	10	1.0	--	734	861	3,548	129.6	-19
	3.3.100	70	--	30	1.0	--	549	530	2,825	103.2	-12
	3.4.100	60	--	40	1.0	--	486	415	2,503	91.4	- 9
	3.50.100	50	--	50	1.0	--	411	280	2,166	79.0	- 7
600	3.1.100	90	--	10	1.0	--	778	942	3,618	164.9	-31
	3.3.100	70	--	30	1.0	--	616	649	2,942	134.8	-20
	3.4.100	60	--	40	1.0	--	541	516	2,601	119.6	-16
	3.50.100	50	--	50	1.0	--	484	412	2,299	107.7	-13
1,000	3.1.100	90	--	10	1.0	--	798	977	3,647	172.3	-34
	3.3.100	70	--	30	1.0	--	637	688	2,977	141.5	-23
	3.4.100	60	--	40	1.0	--	558	546	2,630	125.6	-18
	3.50.100	50	--	50	1.0	--	510	459	2,336	114.9	-15

ABLE II (Cont'd)
TICAL PERFORMANCE
ZINE - WATER SYSTEM
0 psia - EXHAUST PRESSURE = 14.7 psia

	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
61	144.7	-24.052	10.716	1.373	6.197	3.106	0.029	--	--
91	181.7	-37.962	10.845	1.367	6.031	3.050	0.140	--	--
99	189.1	-41.107	10.922	1.363	5.933	3.018	0.205	--	--
18	129.6	-19.298	11.259	1.371	5.469	2.759	0.098	0.555	--
25	103.2	-12.242	13.422	1.352	3.217	1.800	0.768	1.665	--
13	91.4	- 9.610	15.275	1.336	1.809	1.227	1.290	2.220	--
6	79.0	- 7.178	17.425	1.312	0.545	0.702	1.717	2.740	0.036
8	164.9	-31.266	11.552	1.359	5.132	2.647	0.323	0.555	--
2	134.8	-20.872	13.996	1.333	2.759	1.648	1.073	1.665	--
1	119.6	-16.440	15.848	1.321	1.454	1.109	1.527	2.220	--
9	107.7	-13.324	17.227	1.245	0.644	0.735	1.651	2.243	0.532
7	172.3	-34.138	11.683	1.354	4.986	2.598	0.420	0.555	--
7	141.5	-23.014	14.187	1.326	2.614	1.599	1.169	1.665	--
0	125.6	-18.021	16.030	1.315	1.347	1.073	1.598	2.220	--
6	114.9	-1[illegible].162	17.163	1.222	0.676	0.745	1.629	2.045	0.730

TABLE III

THEORETICAL PERFORMAN

HYDRAZINE - AMMONIA SY

CHAMBER PRESSURE = 300 psia - EXHAUST P

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	ΔH
300	4.05.10.0	95	5	--	1.0		810	999	3,794	162.4	-30.2
	4.1.0.0	90	10	--	0	0	1,500	2,240	4,141	182.2	-38.1
	.2.0	--	--	--	.2	0	1,358	1,984	4,166	182.0	-38.0
	.4.0	90	10	--	.4	0	1,213	1,724	4,129	179.1	-36.8
	.4.25	90	10	--	.4	.25	1,184	1,672	4,114	178.2	-36.5
	.4.50	90	10	--	.4	.50	1,156	1,620	4,098	177.3	-36.1
	.6.0	90	10	--	.6	0	1,066	1,460	4,032	173.8	-34.7
	.6.25	90	10	--	.6	.25	1,037	1,408	4,007	172.5	-34.2
	.6.50	90	10	--	.6	.50	1,008	1,356	3,979	171.2	-33.6
	.8.0	90	10	--	.8	0	919	1,195	3,881	166.5	-31.8
	.8.25	90	10	--	.8	.25	890	1,143	3,845	164.8	-31.2
	.8.50	90	10	--	.8	.50	862	1,092	3,807	163.1	-30.5
	.10.0	90	10	--	1.0	0	774	933	3,679	157.5	-28.5
	.10.25	90	10	--	1.0	.25	745	882	3,634	155.5	-27.8
	.10.50	90	10	--	1.0	.50	718	832	3,588	153.5	-27.0
	4.10.10.10	90	10	--	1.0	1.0	729	852	3,607	154.4	-27.3
	4.20.0.0	80	20	--	0	0	1,329	1,933	3,916	172.1	-34.0
	.10.25	80	20	--	1.0	.25	616	649	3,191	136.7	-23.2
	.10.50	80	20	--	1.0	.5	571	568	3,188	136.5	-21.4
	4.3.0.0	70	30	--	0	0	1,159	1,626	3,669	160.9	-29.7
	.2.0	70	30	--	.2	0	1,046	1,423	3,635	158.3	-28.8
	.4.0	70	30	--	.4	0	931	1,216	3,559	154.0	-27.2
	.4.25	70	30	--	.4	.25	844	1,072	3,473	149.7	-25.7
	.4.50	70	30	--	.4	.5	757	902	3,364	144.6	-24.0
	.6.0	70	30	--	.6	0	816	1,008	3,441	148.1	-25.2
	.6.25	70	30	--	.6	.25	728	851	3,324	142.7	-23.4
	.6.50	70	30	--	.6	.5	642	695	3,185	136.7	-21.4

TABLE III
ICAL PERFORMANCE
E - AMMONIA SYSTEM
psia - EXHAUST PRESSURE = 14.7 psia

I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
162.4	-30.296	10.886	1.367	5.929	2.964	0.294	--	--
182.2	-38.184	18.984	1.164	--	0.936	4.331	--	--
182.0	-38.064	16.621	1.199	1.123	1.311	3.583	--	--
179.1	-36.853	14.781	1.236	2.247	1.685	2.834	--	--
178.2	-36.501	14.467	1.244	2.467	1.758	2.687	--	--
177.3	-36.115	14.166	1.251	2.687	1.831	2.540	--	--
173.8	-34.715	13.308	1.276	3.370	2.059	2.085	--	--
172.5	-34.205	13.053	1.284	3.590	2.133	1.938	--	--
171.2	-33.668	12.808	1.293	3.810	2.206	1.791	--	--
166.5	-31.857	12.102	1.319	4.493	2.434	1.336	--	--
164.8	-31.232	11.891	1.327	4.713	2.507	1.189	--	--
163.1	-30.590	11.687	1.335	4.934	2.581	1.042	--	--
157.5	-28.502	11.096	1.360	5.617	2.808	0.587	--	--
155.5	-27.803	10.919	1.368	5.837	2.882	0.440	--	--
153.5	-27.093	10.746	1.375	6.057	2.955	0.294	--	--
154.4	-27.380	10.815	1.372	5.968	2.925	0.353	--	--
172.1	-34.027	18.745	1.170	--	0.832	4.503	--	--
136.7	-23.230	11.700	1.367	5.433	2.937	0.881	--	--
136.5	-21.417	10.811	1.379	5.873	2.790	0.587	--	--
160.9	-29.743	18.512	1.178	--	0.728	4.674	--	--
158.3	-28.812	16.711	1.208	0.874	1.019	4.091	--	--
154.0	-27.267	15.228	1.240	1.747	1.311	3.509	--	--
149.7	-25.756	14.271	1.265	2.408	1.531	3.068	--	--
144.6	-24.019	13.428	1.293	3.068	1.751	2.628	--	--
148.1	-25.217	13.988	1.274	2.621	1.602	2.926	--	--
142.7	-23.420	13.176	1.302	3.282	1.822	2.486	--	--
136.7	-21.465	12.454	1.330	3.942	2.042	2.046	--	--

TABLE III (Cont'd)

THEORETICAL PERFORMANCI

HYDRAZINE - AMMONIA SYST

CHAMBER PRESSURE = 300 psia - EXHAUST PRE

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	$T_c \sim$ °K	$T_c \sim$ °F	c*	I_{sp}	ΔH_R
300	.8.0	70	30	--	.8	.0	700	801	3,281	140.9	-22.804
	.8.25	70	30	--	.8	.25	614	645	3,136	134.5	-20.806
	.8.50	70	30	--	.8	.5	529	493	2,974	127.5	-18.692
	.10.0	70	30	--	1.0	0	586	596	3,086	132.4	-20.134
	.10.25	70	30	--	1.0	.25	502	445	2,918	125.1	-17.990
	.10.50	70	30	--	1.0	.5	422	301	2,736	117.1	-15.769
	4.30.10.10	70	30	--	1.0	1.0	586	596	3,086	132.4	-20.243
	4.45.8.25	55	45	--	.8	.25	396	253	2,489	106.7	-13.083
	.8.50	55	45	--	.8	.5	277	039	2,149	92.1	- 9.750
	4.4.0.0	60	40	--	0	0	987	1,317	3,395	148.3	-25.288
	.2.0	60	40	--	.2	0	888	1,139	3,335	144.8	-24.098
	.4.0	60	40	--	.4	0	788	959	3,240	139.9	-22.488
	.4.25	60	40	--	.4	.25	669	745	3,082	132.6	-20.199
	.4.50	60	40	--	.4	.5	551	532	2,880	123.8	-17.605
	.6.0	60	40	--	.6	.0	687	777	3,109	133.8	-20.563
	.6.25	60	40	--	.6	.25	568	563	2,912	125.2	-18.010
	.6.50	60	40	--	.6	.5	453	355	2,682	115.1	-15.226
	.8.0	60	40	--	.8	0	586	595	2,944	126.6	-18.409
	.8.25	60	40	--	.8	.25	470	386	2,718	116.7	-15.653
	.8.50	60	40	--	.8	.5	361	190	2,459	105.3	-12.737
	.10.25	60	40	--	1.0	.25	376	225	2,502	107.1	-13.182
	.10.50	60	40	--	1.0	.5	275	035	2,195	94.0	-10.165
	.10.10	60	40	--	1.0	1.0	543	517	2,865	123.1	-17.421
	4.5.0.0	50	50	--	0	0	810	998	3,077	133.7	-20.548
	.2.0	50	50	--	.2	0	724	844	2,991	129.3	-19.221
	.4.0	50	50	--	.4	0	638	689	2,875	124.0	-17.667
	.4.25	50	50	--	.4	.25	484	412	2,610	112.4	-14.514

TABLE III (Cont'd)

RETICAL PERFORMANCE

ZINE - AMMONIA SYSTEM

300 psia - EXHAUST PRESSURE = 14.7 psia

c*	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
281	140.9	-22.804	12.934	1.311	3.495	1.893	2.343	--	--
136	134.5	-20.806	12.237	1.339	4.155	2.113	1.904	--	--
974	127.5	-18.692	11.611	1.363	[illegible]16	2.333	1.463	--	--
086	132.4	-20.134	12.028	1.347	[illegible]	2.184	1.761	--	--
918	125.1	-17.990	11.423	1.369	5.029	2.404	1.321	--	--
736	117.1	-15.769	10.876	1.382	5.689	2.625	0.881	--	--
086	132.4	-20.243	12.029	1.347	4.367	2.184	1.762	--	--
489	106.7	-13.083	12.510	1.350	3.737	1.818	2.439	--	--
149	92.1	- 9.750	11.555	1.379	4.727	2.148	1.779	--	--
395	148.3	-25.288	18.285	1.189	--	0.624	4.845	--	--
335	144.8	-24.098	16.756	1.217	0.749	0.874	4.345	--	--
240	139.9	-22.488	15.462	1.248	1.498	1.123	3.846	--	--
082	132.6	-20.199	14.175	1.288	2.378	1.417	3.259	--	-
880	123.8	-17.605	13.086	1.329	3.259	1.710	2.672	--	--
109	133.8	-20.563	14.354	1.282	2.247	1.373	3.347	--	--
912	125.2	-18.010	13.238	1.324	3.127	1.666	2.760	--	--
682	115.1	-15.226	12.284	1.355	4.008	1.960	2.173	--	--
944	126.6	-18.409	13.394	1.[illegible]	2.996	1.623	2.848	--	--
718	116.7	-15.653	12.418	1.352	3.876	1.916	2.261	--	--
459	105.3	-12.737	11.574	1.364	4.757	2.210	1.674	--	--
502	107.1	-13.182	11.693	1.363	4.625	2.166	1.761	--	--
195	94.0	-10.165	10.942	1.388	5.506	2.459	1.174	--	--
865	123.1	-17.421	13.018	1.332	3.319	1.730	2.632	--	--
077	133.7	-20.548	18.064	1.207	--	0.520	5.016	--	--
991	129.3	-19.221	16.801	1.235	0.624	0.728	4.600	--	--
875	124.0	-17.667	15.704	1.267	1.248	0.936	4.184	--	--
510	112.4	-14.514	14.081	1.323	2.349	1.303	3.450	--	--

TABLE III (Cont'd)

THEORETICAL PERFORMANC

HYDRAZINE - AMMONIA SYS

CHAMBER PRESSURE = 300 psia - EXHAUST PR

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~°K	T_c ~°F	c*	I_{sp}	ΔH_R
300	.4.50	50	50	--	.4	.5	340	152	2,281	97.9	-11.005
	.6.0	50	50	--	.6	0	550	531	2,733	117.8	-15.935
	.6.25	50	50	--	.6	.25	400	261	2,436	104.5	-12.558
	.6.50	50	50	--	.6	.5	264	015	2,052	88.0	- 8.910
	.8.0	50	50	--	.8	0	464	375	2,570	110.6	-14.061
	.8.25	50	50	--	.8	.25	322	120	2,229	95.7	-10.516
	.10.0	50	50	--	1.0	0	381	227	2,392	102.5	-12.083
	.4.6.0.0	40	60	--	0	0	621	659	2,682	116.0	-15.470
	.2.0	40	60	--	.2	0	548	527	2,571	111.1	-14.197
	.4.0	40	60	--	.4	0	475	395	2,444	105.6	-12.805
	.6.0	40	60	--	.6	0	403	266	2,307	99.3	-11.321
	.8.0	40	60	--	.8	0	336	145	2,145	92.2	- 9.764
	.10.0	40	60	--	1.0	0	270	027	1,959	84.2	- 8.147
	4.65.6.0	35	65	--	.6	0	332	168	1,950	84.0	- 7.959
	4.70.0.0	30	70	--	0	0	410	278	2,173	93.8	-10.122
	.2.0	30	70	--	.2	0	355	179	2,062	88.7	- 9.033
	.4.0	30	70	--	.4	0	302	084	1,922	82.9	- 7.892
100	4.10.10.10	90	10	--	1.0	1.0	697	796	3,553	129.8	-19.369
	4.30.10.10	70	30	--	1.0	1.0	543	518	3,001	109.6	-13.816
	4.40.10.10	60	40	--	1.0	1.0	503	446	2,787	101.8	-11.914
600	4.10.10.10	90	10	--	1.0	1.0	755	900	3,650	166.3	-31.786
	4.30.10.10	70	30	--	1.0	1.0	617	651	3,142	143.7	-23.729
	4.40.10.10	60	40	--	1.0	1.0	570	567	2,916	133.7	-20.554
1,000	4.10.10.10	90	10	--	1.0	1.0	778	941	3,686	174.0	-34.813
	4.30.10.10	70	30	--	1.0	1.0	641	694	3,184	151.1	-26.228
	4.40.10.10	60	40	--	1.0	1.0	591	605	2,954	140.6	-22.735

ABLE III (Cont'd)
TICAL PERFORMANCE
NE - AMMONIA SYSTEM
0 psia - EXHAUST PRESSURE = 14.7 psia

	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
31	97.9	-11.005	12.762	1.342	3.450	1.670	2.716	--	--
33	117.8	-15.935	[illegible] 40	1.300	1.872	1.144	3.768	--	--
36	104.5	-12.558	13.302	1.338	2.973	1.511	3.034	--	--
52	88.0	- 8.910	12.118	1.371	4.074	1.878	2.300	--	--
70	110.6	-14.061	13.889	1.328	2.496	1.352	3.352	--	--
9	95.7	-10.516	12.604	1.348	3.597	1.719	2.618	--	--
2	102.5	-12.083	13.130	1.338	3.120	1.560	2.93[illegible]	--	--
2	116.0	-15.470	17.848	1.240	--	0.416	5.187	--	--
1	111.1	-14.197	16.847	1.270	0.499	0.582	4.854	--	--
4	10[illegible]	-12.805	15.952	1.298	0.999	0.749	4.521	--	--
7	99.3	-11.321	15.148	1.311	1.498	0.915	4.188	--	--
5	92.2	- 9.764	14.421	1.316	1.997	1.082	3.856	--	--
9	84.2	- 8.147	13.761	1.351	2.496	1.248	3.523	--	--
0	84.0	- 7.959	17.429	1.292	4.369	0.801	4.399	--	--
3	93.8	-10.122	17.636	1.282	--	0.312	5.358	--	--
2	88.7	- 9.033	16.893	1.283	0.374	0.437	5.108	--	--
2	82.9	- 7.892	16.209	1.320	0.749	0.562	4.859	--	--
[illegible]	129.8	-19.369	10.623	1.380	6.218	3.009	0.186	--	--
[illegible]	109.6	-13.816	11.709	1.359	4.708	2.297	1.535	--	--
7	101.8	-11.914	12.688	1.344	3.619	1.830	2.432	--	--
[illegible]	166.3	-31.786	10.980	1.365	5.760	2.856	0.491	--	--
[illegible]	143.7	-23.729	12.260	1.338	4.132	2.105	1.919	--	--
[illegible]	133.7	-20.554	13.254	1.323	3.114	1.662	2.769	--	--
[illegible]	174.0	-34.813	11.124	1.359	5.583	2.797	0.609	--	--
[illegible]	151.1	-26.228	12.446	1.330	3.949	2.044	2.041	--	--
[illegible]	140.6	-22.735	13.442	1.316	2.956	1.609	2.374	--	--

TABLE IV

THEORETICAL PERFORMANCE

HYDRAZINE - EQUAL WEIGHT PERCENT WATER -

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	$T_c \sim$ °K	$T_c \sim$ °K	c*	I_{sp}	ΔH_R
300	7.1.1.0.0	80	10	10	0	0	1,289	1,861	3,835	168.2	-32.504
	.2.0	80	10	10	.2	0	1,156	1,622	3,812	166.0	-31.663
	.4.0	80	10	10	.4	0	1,021	1,378	3,736	161.6	-29.994
	.4.25	80	10	10	.4	.25	991	1,324	3,712	160.3	-29.530
	.4.5	80	10	10	.4	.5	961	1,270	3,685	158.9	-29.035
	.6.0	80	10	10	.6	.0	885	1,133	3,607	155.1	-27.657
	.6.25	80	10	10	.6	.25	855	1,079	3,572	153.5	-27.070
	.6.5	80	10	10	.6	.5	825	1,025	3,534	151.7	-26.463
	.8.0	80	10	10	.8	0	749	888	3,429	147.0	-24.842
	.8.25	80	10	10	.8	.25	719	835	3,384	145.0	-24.175
	.8.5	80	10	10	.8	.5	690	782	3,336	143.0	-23.494
	.10.0	80	10	10	1.0	0	616	650	3,208	137.4	-21.712
	.10.25	80	10	10	1.0	.25	588	598	3,155	135.1	-20.991
	.10.5	80	10	10	1.0	.5	559	547	3,100	132.8	-20.260
	7.10.10.10.10	80	10	10	1.0	1.0	647	706	3,26[illegible]	139.8	-22.461
	7.15.15.0.0	70	15	15	0	0	1,086	1,495	3,520	153.8	-27.180
	.2.0	70	15	15	.2	0	965	1,277	3,458	150.1	-25.878
	.4.0	70	15	15	.4	0	842	1,057	3,350	144.5	-23.993
	.4.25	70	15	15	.4	.25	796	973	3,297	142.0	-23.159
	.4.5	70	15	15	.4	.5	749	889	3,238	139.2	-22.272
	.6.0	70	15	15	.6	.0	719	836	3,197	137.3	-2[illegible].676
	.6.25	70	15	15	.6	.25	673	752	3,127	134.3	-20.720
	.6.5	70	15	15	.6	.5	627	670	3,052	131.0	-19.728
	.8.0	70	15	15	.8	.0	597	617	3,001	128.8	-19.069
	.8.25	70	15	15	.8	.25	553	535	2,918	125.2	-18.024
	.8.5	70	15	15	.8	.5	508	455	2,831	121.5	-16.955
	.10.0	70	15	15	1.0	0	460	405	2,773	118.9	-16.253
	.10.25	70	15	15	1.0	.25	438	328	2,680	114.8	-15.151

TABLE IV

TICAL PERFORMANCE

HT PERCENT WATER - AMMONIA SYSTEM

	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
35	168.2	-32.504	18.859	1.179	--	0.832	3.916	0.555	--
12	166.0	-31.663	16.755	1.212	0.998	1.165	3.250	0.555	--
36	161.6	-29.994	15.074	1.249	1.997	1.498	2.584	0.555	--
2	160.3	-29.530	14.748	1.258	2.217	1.571	2.437	0.555	--
35	158.9	-29.035	14.435	1.266	2.437	1.645	2.291	0.555	--
07	155.1	-27.657	13.700	1.289	2.995	1.831	1.919	0.555	--
72	153.5	-27.070	13.429	1.298	3.216	1.904	1.772	0.555	--
34	151.7	-26.463	13.170	1.307	3.436	1.977	1.625	0.555	--
29	147.0	-24.842	12.555	1.329	3.994	2.163	1.253	0.555	--
34	145.0	-24.175	12.327	1.338	4.214	2.237	1.106	0.555	--
6	143.0	-23.494	12.108	1.347	4.434	2.310	0.959	0.555	--
8	137.4	-21.712	11.586	1.367	4.992	2.496	0.587	0.555	--
5	135.1	-20.991	11.393	1.374	5.213	2.570	0.440	0.555	--
0	132.8	-20.260	11.205	1.380	5.433	2.643	0.294	0.555	--
3	139.8	-22.461	11.812	1.358	4.745	2.414	0.752	0.555	--
0	153.8	-27.180	18.679	1.193	--	0.728	3.793	0.833	--
8	150.1	-25.878	16.846	1.226	0.874	1.019	3.210	0.833	--
0	144.5	-23.993	15.341	1.262	1.747	1.311	2.628	0.833	--
7	142.0	-23.159	14.840	1.276	2.078	1.421	2.408	0.833	--
8	139.2	-22.272	14.370	1.291	2.408	1.531	2.188	0.833	--
7	137.3	-21.676	14.082	1.301	2.621	1.602	2.046	0.833	--
7	134.3	-20.720	13.659	1.316	2.951	1.712	1.825	0.833	--
2	131.0	-19.728	13.260	1.330	3.282	1.822	1.605	0.833	--
1	128.8	-19.069	13.015	1.339	3.495	1.893	1.463	0.833	--
8	125.2	-18.024	12.652	1.352	3.825	2.003	1.243	0.833	--
1	121.5	-16.955	12.309	1.364	4.155	2.113	1.023	0.833	--
3	118.9	-16.253	12.098	1.369	4.368	2.184	0.881	0.833	--
0	114.8	-15.151	11.784	1.376	4.692	2.294	0.661	0.833	--

(Reverse Side Blank)

TABLE IV (Cont'd)

THEORETICAL PERFORMAN

HYDRAZINE - EQUAL WEIGHT PERCENT WATE

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	ΔH
300	.10.5	70	15	15	1.0	.5	397	254	2,582	110.5	-14.
	.10.10	70	15	15	1.0	1.0	584	591	2,975	127.7	-18.7
	7.18.18.10.25	64	18	18	1.0	.25	391	244	2,491	107.1	-13.1
	.10.5	64	18	18	1.0	.5	379	272	2,470	106.5	-13.0
	7.20.20.0.0	60	20	20	0	0	874	1,113	3,152	136.9	-21.5
	.2.0	60	20	20	.2	0	765	917	3,050	131.7	-19.9
	.4.0	60	20	20	.4	0	655	720	2,908	125.2	-18.0
	.4.25	60	20	20	.4	.25	590	603	2,806	120.7	-16.7
	.4.5	60	20	20	.4	.5	526	488	2,693	115.9	-15.4
	.6.0	60	20	20	.6	0	545	522	2,728	117.4	-15.8
	.6.25	60	20	20	.6	.25	482	408	2,610	112.2	-14.4
	.6.5	60	20	20	.6		421	298	2,484	106.6	-13.0
	.8.0	60	20	20	.8	.0	439	330	2,522	108.3	-13.4
	.8.25	60	20	20	.8	.25	403	266	2,451	105.3	-12.7
	.8.50	60	20	20	.8	.5	392	245	2,435	105.0	-12.6
	.10.0	60	20	20	1.0	0	395	252	2,441	105.2	-12.70
	7.23.23.6.25	54	23	23	.6	.25	408	275	2,368	102.1	-11.9
	.6.5	54	23	23	.6	.5	395	251	2,349	101.7	-11.8
	7.24.24.4.25	52	24	24	.4	.25	418	294	2,347	101.0	-11.71
	.4.50	52	24	24	.4	.50	407	272	2,335	101.0	-11.71
	7.25.25.0.0	50	25	25	0	0	644	700	2,687	116.1	-15.4
	.2.0	50	25	25	.2	0	547	524	2,541	109.7	-13.8
	.4.0	50	25	25	.4	0	450	350	2,372	102.2	-12.00
	.6.0	50	25	25	.6	0	413	283	2,311	99.9	-11.46
	7.28.28.4.0	44	28	28	.4	0	415	288	2,212	96.2	-10.62

TABLE IV (Cont'd)
ORETICAL PERFORMANCE
EIGHT PERCENT WATER - AMMONIA SYSTEM

c*	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
,582	110.5	-14.033	11.486	1.379	5.029	2.404	0.440	0.833	--
,975	127.7	-18.741	12.902	1.344	3.956	1.927	1.396	0.833	--
,491	107.1	-13.188	12.032	1.332	4.390	2.129	0.793	0.712	0.287
,470	106.5	-13.039	11.611	1.310	4.787	2.261	0.528	0.480	0.519
,152	136.9	-21.549	18.502	1.214	--	0.624	3.670	1.110	--
,050	131.7	-19.944	16.938	1.247	0.749	0.874	3.171	1.110	--
,908	125.2	-18.007	15.617	1.285	1.[illegible]98	1.123	2.672	1.110	--
,806	120.7	-16.753	14.932	1.308	1.938	1.270	2.378	1.110	--
,693	115.9	-15.429	14.306	1.330	2.378	1.417	2.085	1.110	--
,728	117.4	-15.832	14.488	1.324	2.247	1.373	2.173	1.110	--
,610	112.2	-14.467	13.896	1.342	2.687	1.520	1.879	1.110	--
484	106.6	-13.056	13.352	1.352	3.127	1.666	1.585	1.110	--
522	108.3	-13.483	13.510	1.350	2.996	1.623	1.674	1.110	--
451	105.3	-12.747	12.995	1.336	3.436	1.769	1.380	0.963	0.147
435	105.0	-12.675	12.518	1.307	3.876	1.916	1.086	0.681	0.429
441	105.2	-12.708	12.657	1.315	3.744	1.872	1.174	0.763	0.347
368	102.1	-11.988	14.043	1.306	2.528	1.404	1.911	1.007	0.270
349	101.7	-11.894	13.407	1.276	3.035	1.573	1.574	0.679	0.597
347	101.0	-11.718	15.008	1.326	1.826	1.150	2.355	1.303	0.030
335	101.0	-11.715	14.254	1.287	2,355	1.326	2.003	0.936	0.396
687	116.1	-15.485	18.329	1.252	--	0.520	3.548	1.388	--
541	109.7	-13.829	17.030	1.289	0.624	0.728	3.132	1.388	--
372	102.2	-12.005	15.904	1.319	1.248	0.936	2.716	1.388	--
311	99.9	-11.466	14.917	1.289	1.872	1.144	2.300	1.074	0.314
312	96.2	-10.627	16.081	1.251	1.098	0.824	2.742	1.030	0.524

TABLE IV (Cont'd)

THEORETICAL PERFORMAN

HYDRAZINE - EQUAL WEIGHT PERCENT WATE

P_c, psi	Code No.	N_2H_4	NH_3	H_2O	X	Y	T_c ~ °K	T_c ~ °F	c*	I_{sp}	ΔH
300	7.30.30.0.0	40	30	30	0	0	431	316	2,157	93.7	-10.
	.2.0	40	30	30	.2	0	420	296	2,143	93.5	-10.
100	7.10.10.10.10	80	10	10	1.0	1.0	605	631	3,187	116.4	-15.
	7.15.15.10.10	70	15	15	1.0	1.0	542	576	2,897	105.8	-12.
	7.20.20.10.10	60	20	20	1.0	1.0	492	427	2,629	96.1	-10.
600	7.10.10.10.10	80	10	10	1.0	1.0	677	760	3,314	151.3	-26.
	7.15.15.10.10	70	15	15	1.0	1.0	613	643	3,027	138.5	-22.
	7.20.20.10.10	60	20	20	1.0	1.0	554	538	2,743	126.0	-18.
1,000	7.10.10.10.10	80	10	10	1.0	1.0	701	803	3,354	158.8	-28.
	7.15.15.10.10	70	15	15	1.0	1.0	635	689	3,065	145.6	-24.
	7.20.20.10.10	60	20	20	1.0	1.0	573	572	[illegible].777	132.4	-20.

TABLE IV (Cont'd)
RETICAL PERFORMANCE
IGHT PERCENT WATER - AMMONIA SYSTEM

c*	I_{sp}	ΔH_R	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gas)	Moles H_2O (Liquid)
157	93.7	-10.082	18.159	1.262	0.0001	0.416	3.426	1.418	0.247
143	93.5	-10.048	17.124	1.231	0.499	0.582	3.093	1.060	0.605
187	116.4	-15.582	11.523	1.369	5.064	2.520	0.540	0.555	--
397	105.8	-12.874	12.570	1.355	3.902	2.029	1.191	0.833	--
629	96.1	-10.606	13.994	1.339	2.612	1.495	1.929	1.110	--
314	151.3	-26.317	12.027	1.350	4.518	2.338	0.904	0.555	--
027	138.5	-22.061	13.140	1.335	3.385	1.857	1.536	0.833	--
743	126.0	-18.244	14.574	1.321	2.185	1.352	2.214	1.110	--
54	158.8	-28.982	12.204	1.343	4.337	2.278	1.024	0.555	--
65	145.6	-24.362	13.331	1.328	3.222	1.802	1.645	0.833	--
77	132.4	-20.152	14.763	1.314	2.054	1.309	2.301	1.110	--

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Low Temperature						
Gas Generator						
Propellants						
Monopropellant						
Hydrazine						

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Air Force Rocket Propulsion Laboratory
Research & Technology Division
Air Force Systems Command,
Edwards, California

13. ABSTRACT

The objective of Contract AF 04(611)-11376 is to characterize monopropellant hydrazine based propellants which, by the use of ammonia and ammonia-water diluents, are capable of producing clean outlet gases in the temperature range of 175°F to 2,200°F when passed through a catalytic decomposition chamber.

During the report period thermochemical calculations were performed on a large number of cases involving various compositions of hydrazine, ammonia, and water. The effect of varying the amount of ammonia dissociation was investigated in the above calculations. The results of these calculations are presented in this report in tabular and graphical form. In addition, equipment was assembled for the preparation of solutions of hydrazine, ammonia, and water and for the measurement of vapor pressures and freezing points of these solutions.

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