Abridged

Aerojet
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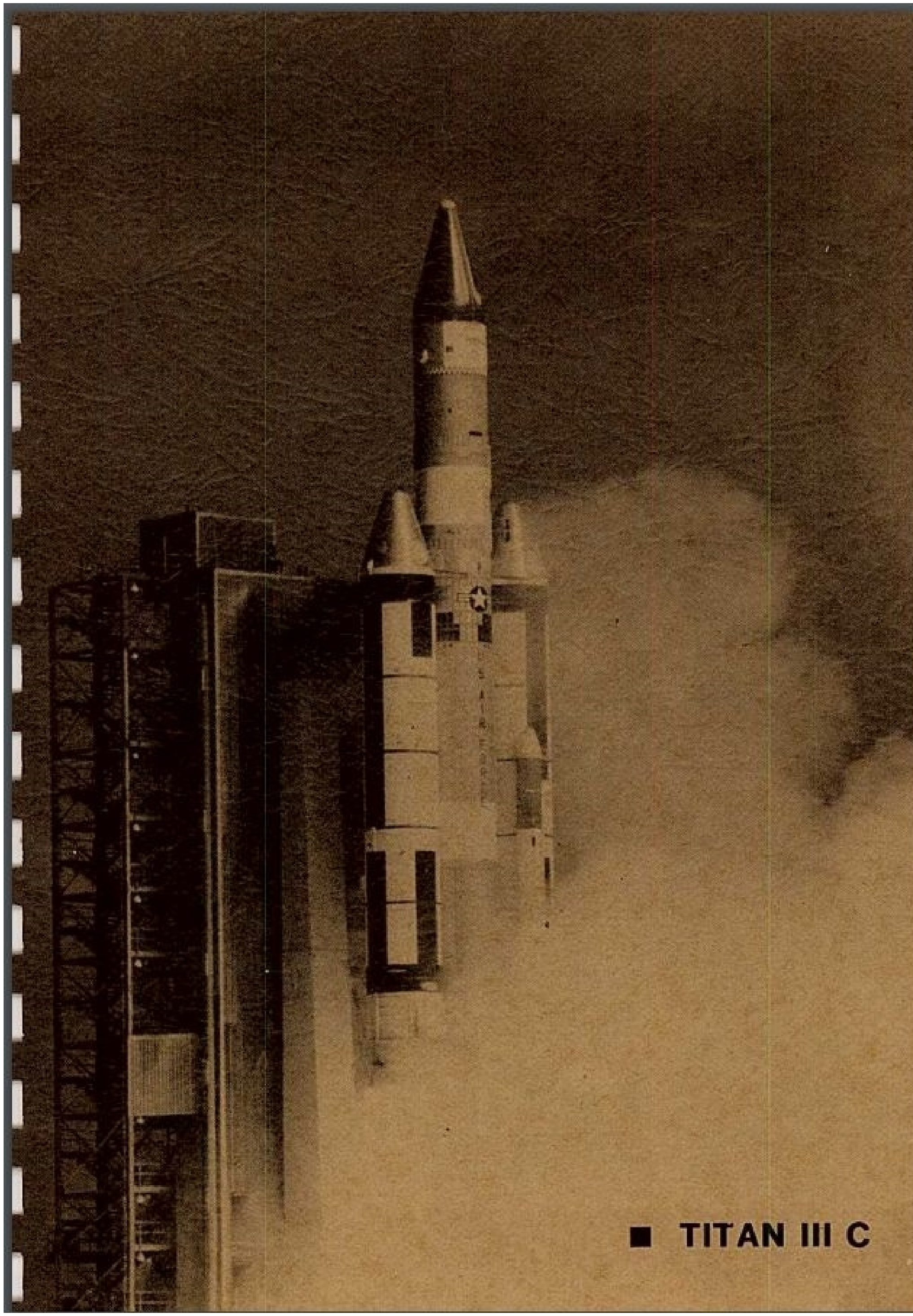
Company

Properties And Performance Of Liquid Rocket Propellants



■ TITAN III C

Compliments of:

ROCKET
APPLICATIONS

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I. DISCUSSION

A. GENERAL PROPERTIES

The molecular weight, freezing point, normal boiling point, critical temperature, critical pressure, heat of vaporation (at nbp), and the heat of formation are single values and are listed on respective charts. The techniques used to obtain them are as follows:

The molecular weight can be obtained from standard atomic weight tables. For mixtures, the additive atomic weight from mole fractions is obtained, i.e., the summation of mole fractions times molecular weight of each individual component.

The freezing temperature is obtained experimentally in every case. The authors know of no technique for calculating the freezing temperature of substances.

The normal boiling point is best measured, but a fair estimate can be obtained, in some cases, from structural considerations.

The critical constants are very important quantities in the emperical calculation of many of the other physical properties. The generalized correlations and many other calculation techniques employed in this compilation used the reduced temperature and pressure (temperature and/or pressure divided by critical temperature and pressure).

The heat of vaporization at the normal boiling point is often useful in other calculations and is given in the compilation. This value can be calculated by several techniques which are based on the Clapeyron equation. The generalized plot obtained from this equation by Meissner and Paddison was used to calculate the heat of vaporization where experimental data were not available. For mixtures, the pseudo-critical point was used.

The heat of formation was obtained from references in every case, although it was often calculated or estimated from bond energies by the authors of these references. For this compilation an attempt is made to give the heat of formation of the liquid at 298.16°K (77°F) for all but liquids which had a normal boiling point below 77°F. For low boiling liquids the heat of formation of the liquid at its normal boiling point is given. In some cases the heat of vaporization and sensible enthalpy, from 77°F to the normal boiling point from separate references, were added to the gaseous heat of formation at 77°F to obtain the heat of formation liquid at nbp.

The heat of formation of mixtures was obtained by sum, weighed by mole fraction, without consideration of heat of mixing, which data are not readily available for most mixtures.

B. VAPOR PRESSURE

The vapor pressures, where no referenced data were available, were calculated by the method of Riedel. This method is based on the reduced temperature and pressure and thus requires knowledge of the critical constants of the material. Use of the Riedel equation involves the evaluation of a constant and thus requires one vapor pressure point at one temperature. The normal boiling point is usually used as the one point. The Riedel equation, in order to solve for vapor pressure, also requires evaluation of rather complex functions of the reduced temperature. This technique is quite accurate, but is of course, limited by the accuracy of the critical constants used.

C. VISCOSITY

Viscosity data can be extrapolated from one or more experimental points by the method of Uyehara and Watson. This is one of the techniques based on the "generalized plot" approach. The value required is related to reduced pressure and temperature and is obtained from a generalized curve which is correct for all substances. This technique is simple and has proved quite successful in evaluation of many physical and thermodynamic properties. As with most generalized plots involving any given physical property, the results are often greatly in error in those cases where the nature of the given substance, such as large dipole moment or high degree of association, cause its properties to diverge from "normal." The viscosities obtained from this method are good estimates (most data are in error 10% or less) although some substances are probably much more in error.

D. THERMAL CONDUCTIVITY

Although theory and experiment in transport properties are in a poor state, thermal conductivity is the least well known of these properties. Many techniques have been proposed for calculation of thermal conductivity in both gaseous and liquid phases. These techniques are often based on the best kinetic theory and experimental method; however, general calculation techniques of even reasonably high accuracy have met with very limited success. In this light the simple method of Weber which has shown very good accuracy when compared with the limited experimental data available was used in this compilation. The correlation of Weber is, in itself, not very good since it employs the liquid heat capacity which is quite difficult to calculate. The results presented for thermal conductivity are very often only estimates.

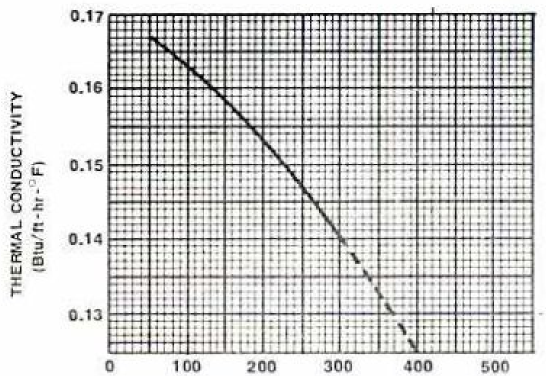
E. HEAT CAPACITY

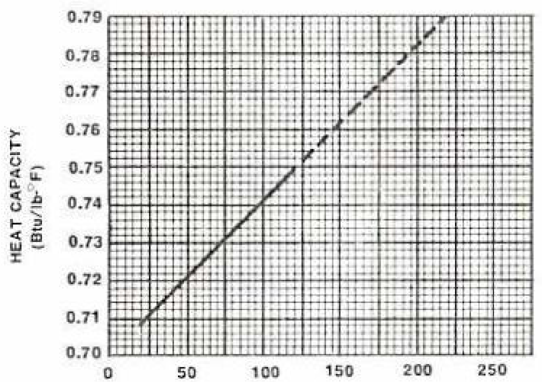
The rigorous calculation of heat capacity is a difficult and tedious process involving extensive data concerning the molecule under consideration. Most of the propellants considered in this compilation have not been very thoroughly studied; consequently, sufficient spectroscopic and structural data are not available. As a result, more emperical techniques have been used by the authors to obtain heat capacity data for the liquids over a reasonably wide range of temperature.

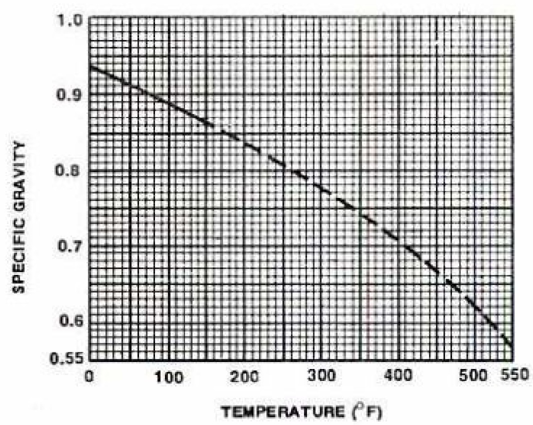
The technique employed to extrapolate the data is based on the assumption of Chow and Bright that the variation of liquid heat capacity with temperature can be correlated to Watson's density expansion factor.

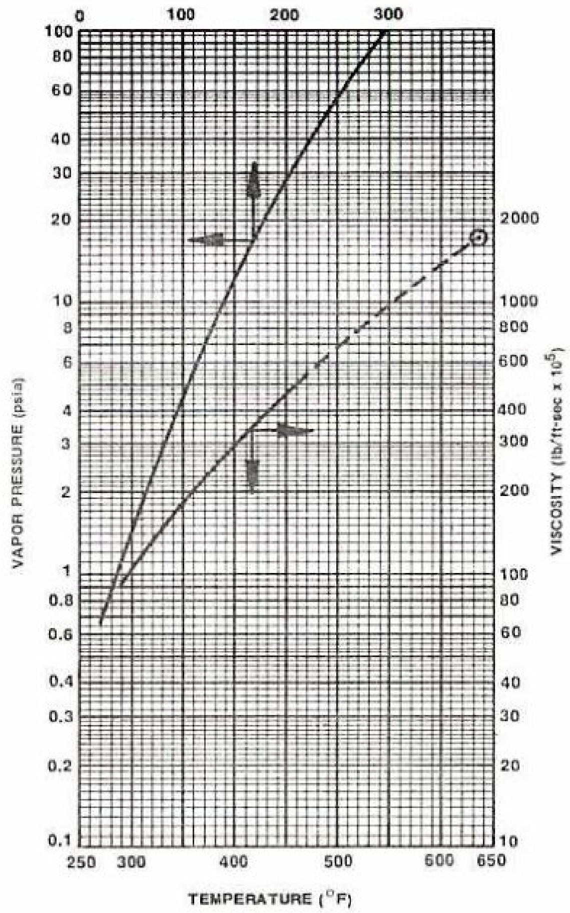
F. SPECIFIC GRAVITY

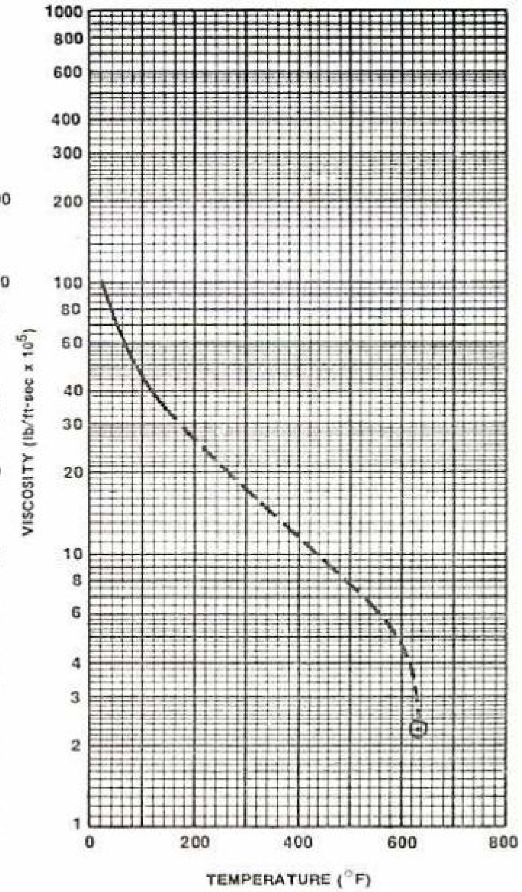
Having one data point, the specific gravity can be calculated over the entire liquid range using the Watson density expansion factor. This method is quite accurate and with few exceptions (very polar or highly associated liquids) the accuracy is within about 1% of the true value, except in the region of the critical point.









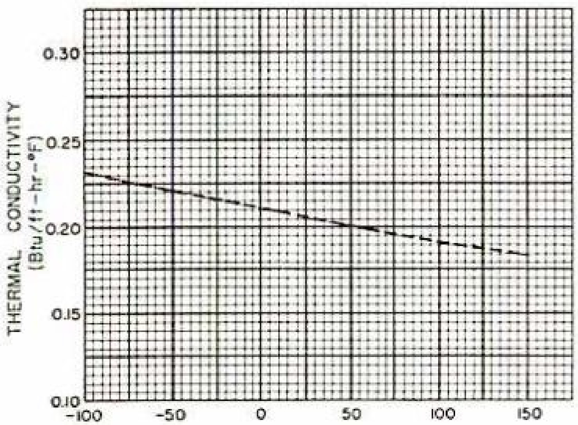


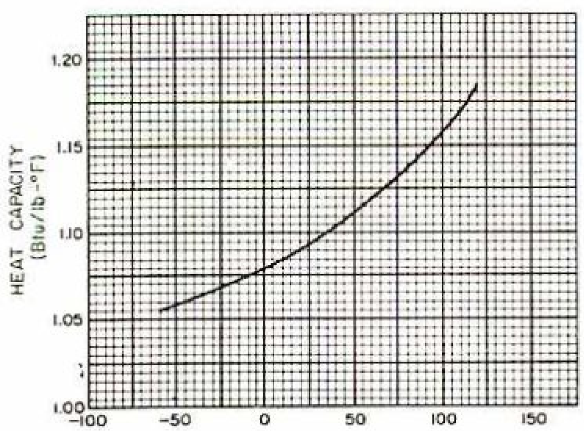
PHYSICAL PROPERTIES OF AEROZINE-50: 50% N_2H_4 – 50% UDMH, b.w.

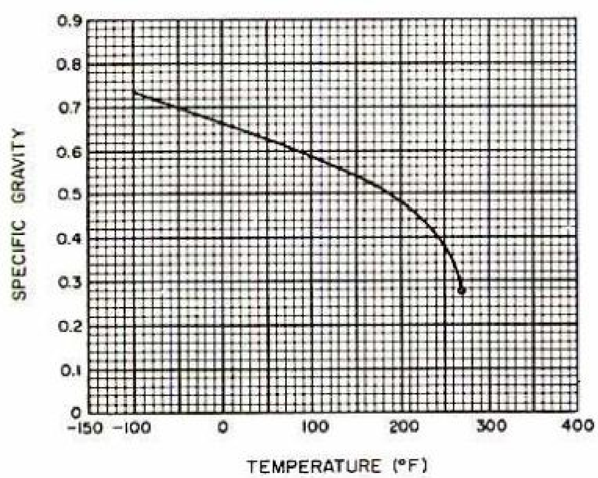
MOLECULAR WEIGHT	41.802
FREEZING TEMPERATURE (°F)	22
NORMAL BOILING POINT (°F)	158
CRITICAL TEMPERATURE (°F)	633
CRITICAL PRESSURE (psia)	1731
HEAT OF FORMATION (cal/mole liq @ 298.16°K)	12,310
HEAT OF VAPORIZATION (Btu/lb @ NBP)	346.5

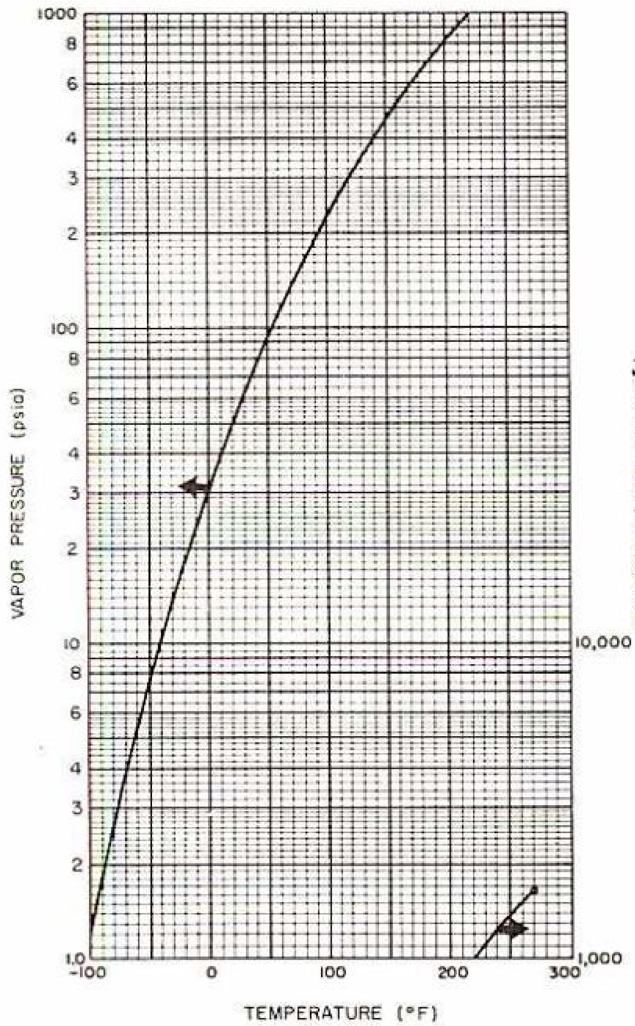
REFERENCE DATA ———
EXTRAPOLATED DATA – – – –
CRITICAL POINT O ⊙

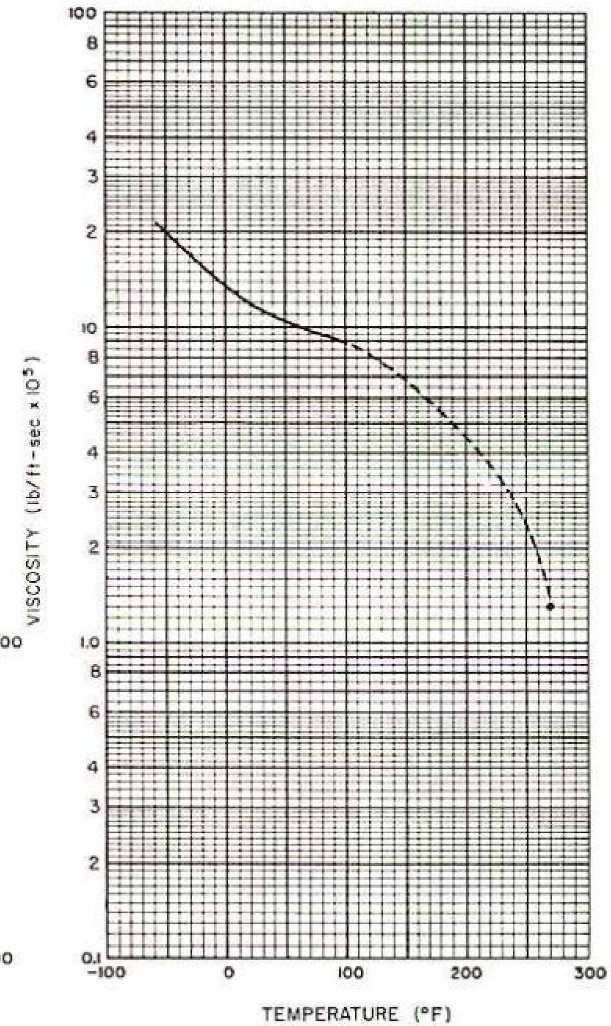
REVISED NOV. 1974











PHYSICAL PROPERTIES OF AMMONIA – NH_3

MOLECULAR WEIGHT	17.032
FREEZING TEMPERATURE (°F)	−107.9
NORMAL BOILING POINT (°F)	−28.05
CRITICAL TEMPERATURE (°F)	270.1
CRITICAL PRESSURE (psia)	1636
HEAT OF FORMATION (cal / mole liq @ nbp)	−17,140
HEAT OF VAPORIZATION (Btu / lb)	596.2

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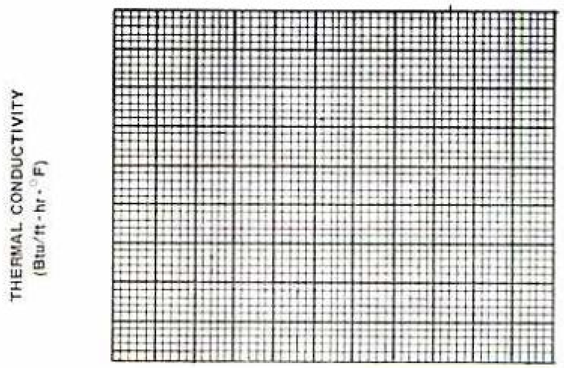
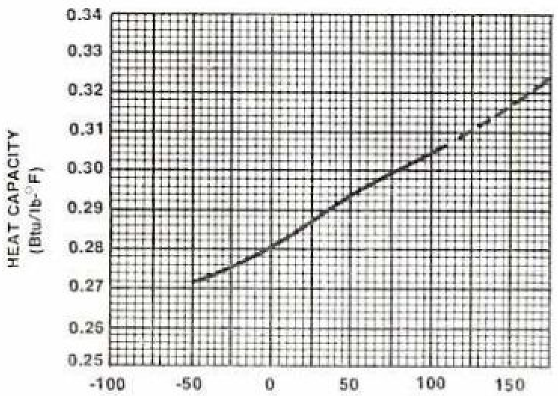
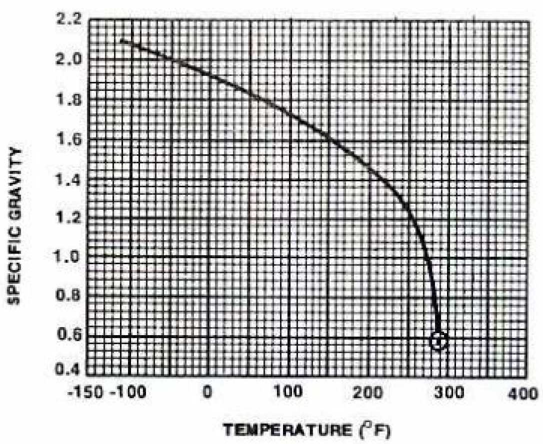
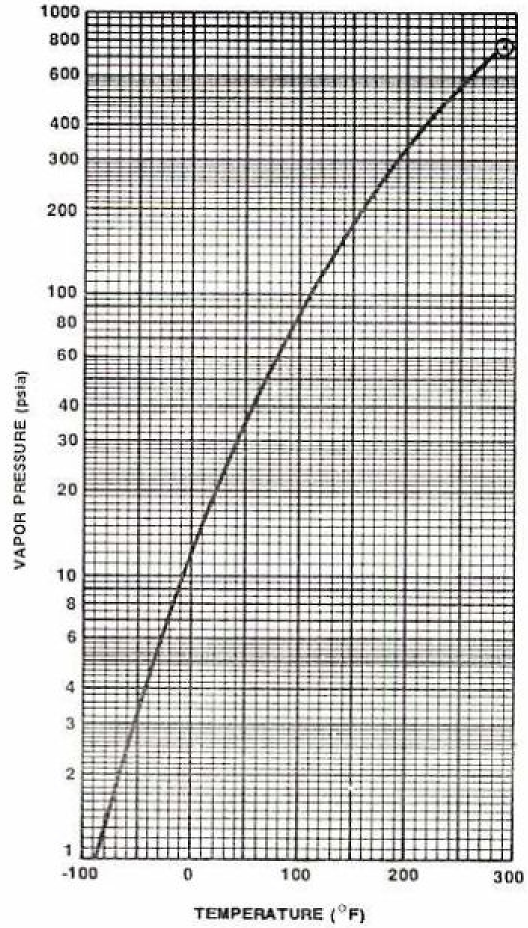
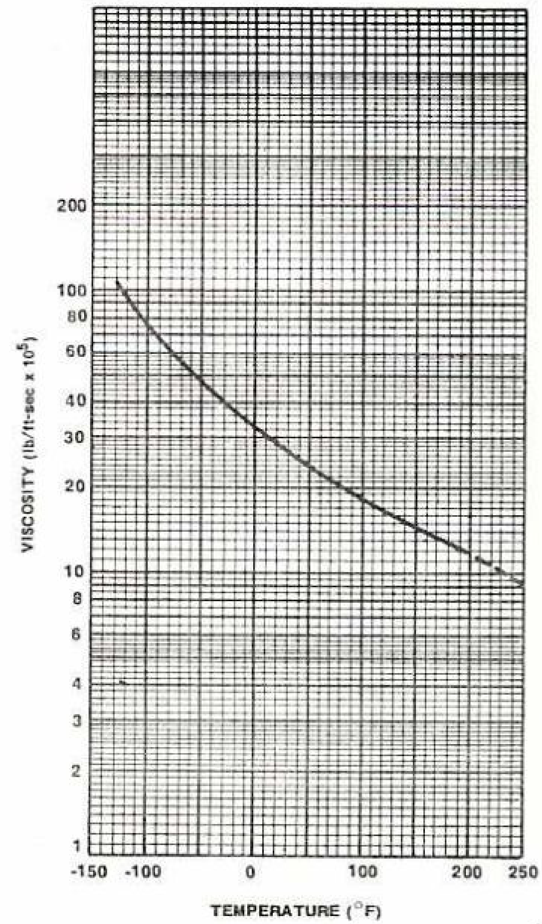
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT o









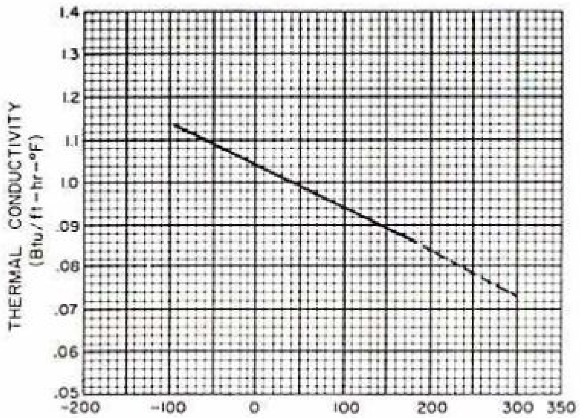


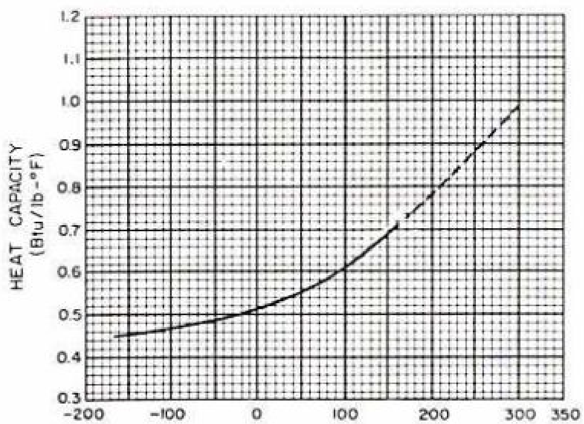
PHYSICAL PROPERTIES OF CHLORINE PENTAFLUORIDE: ClF_5

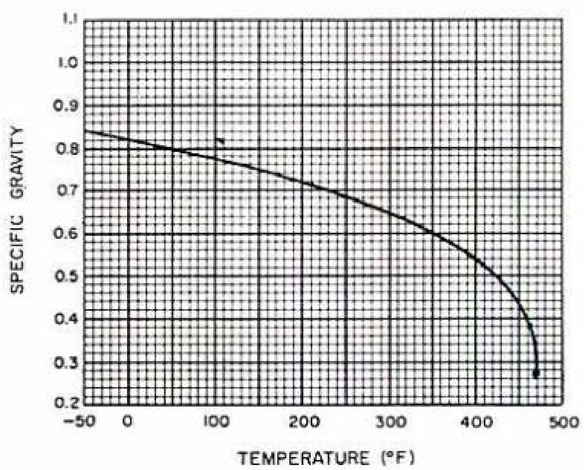
MOLECULAR WEIGHT	130.445
FREEZING TEMPERATURE (°F)	-153.4 ± 7.2
NORMAL BOILING POINT (°F)	7.3
CRITICAL TEMPERATURE (°F)	289.4 ± 0.9
CRITICAL PRESSURE (psia)	771
HEAT OF FORMATION (cal/mole liq @ 298.16°K)	-60,500
HEAT OF VAPORIZATION (Btu/lb @ NBP)	76.04

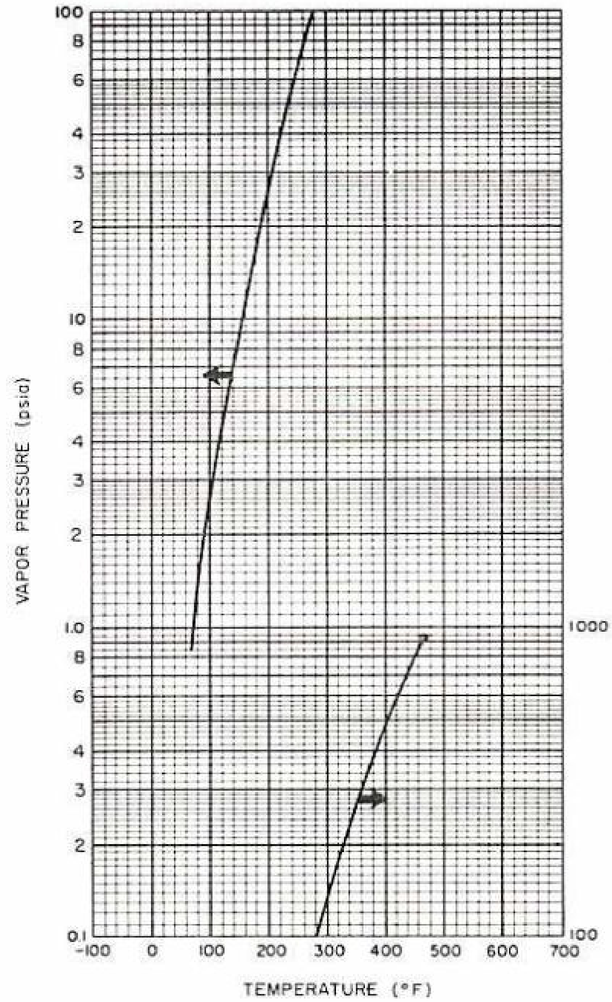
REFERENCE DATA ———
EXTRAPOLATED DATA - - - -
CRITICAL POINT ⊙

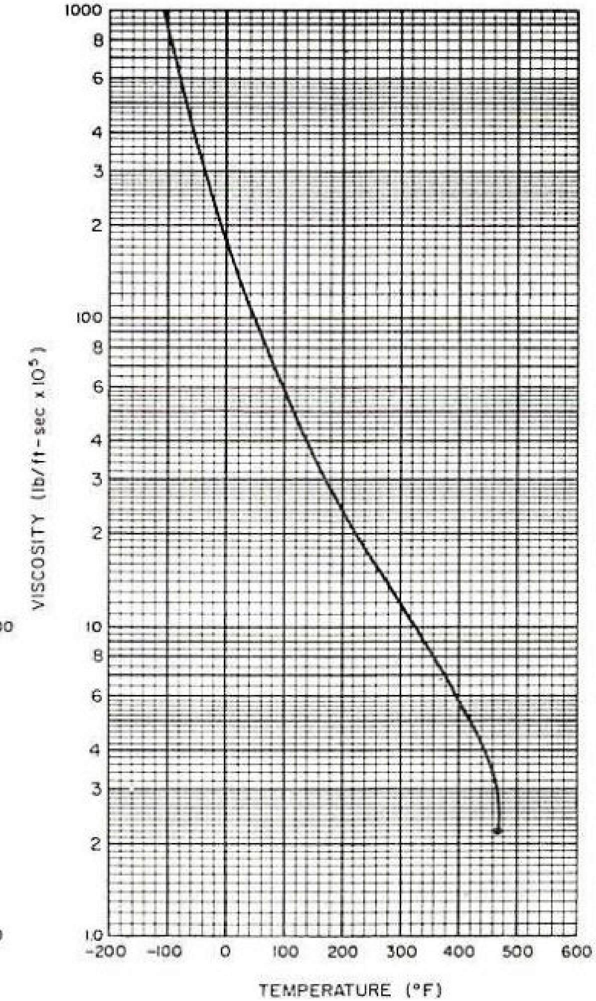
REVISED NOV 1974











PHYSICAL PROPERTIES OF ETHYL ALCOHOL – C_2H_5OH

MOLECULAR WEIGHT	46.068
FREEZING TEMPERATURE (°F)	−174
NORMAL BOILING POINT (°F)	172.89
CRITICAL TEMPERATURE (°F)	469.4
CRITICAL PRESSURE (psia)	925
HEAT OF FORMATION (cal / mole liq @ 298.16°K)	−66,363
HEAT OF VAPORIZATION (Btu / lb)	362

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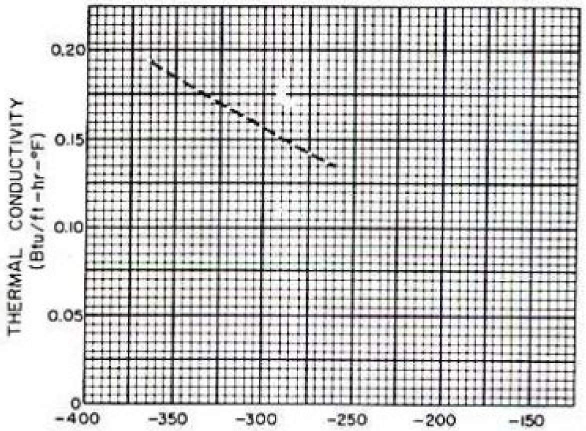
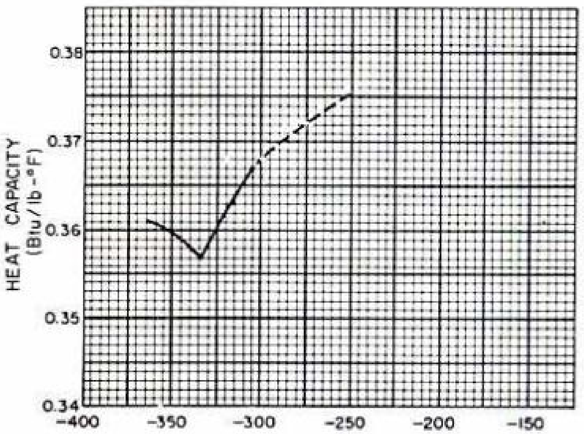
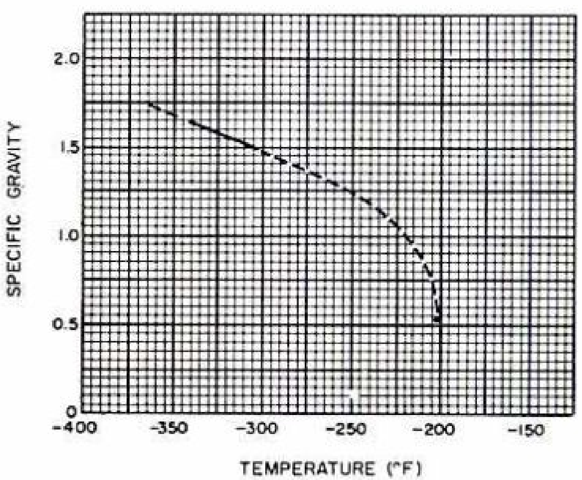
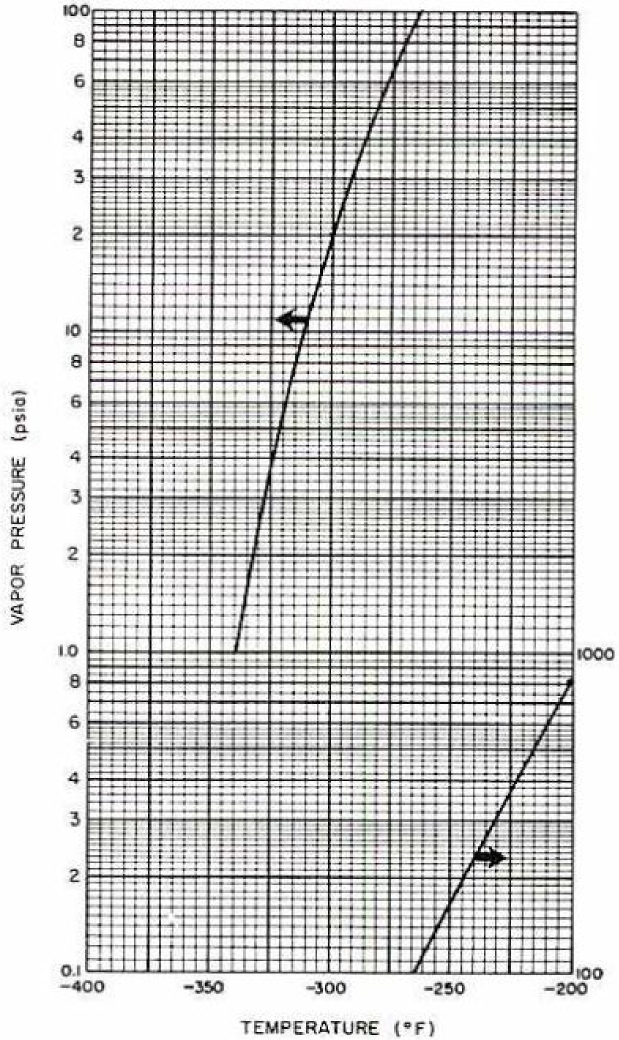
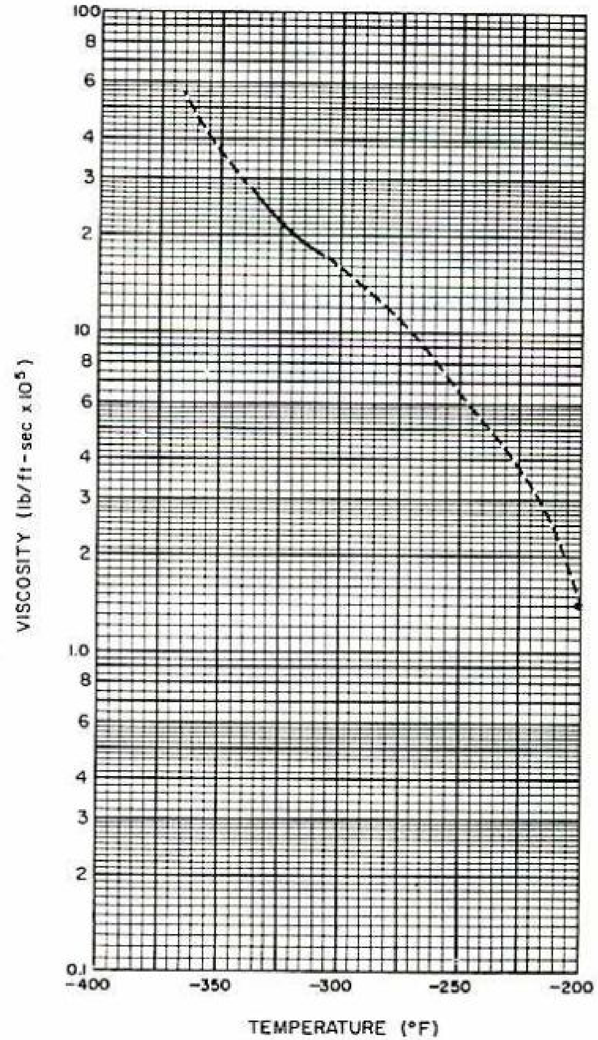
CRITICAL POINT o











PHYSICAL PROPERTIES OF **FLUORINE – F_2**

MOLECULAR WEIGHT	38.000
FREEZING TEMPERATURE (°F)	-365
NORMAL BOILING POINT (°F)	-307
CRITICAL TEMPERATURE (°F)	-201
CRITICAL PRESSURE (psia)	808.5
HEAT OF FORMATION, (cal / mole liq @ nbp)	-3056
HEAT OF VAPORIZATION (Btu / lb)	71.5

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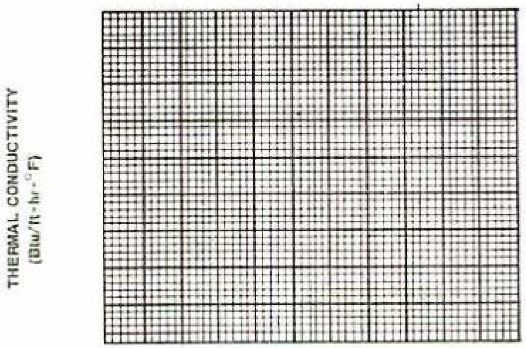

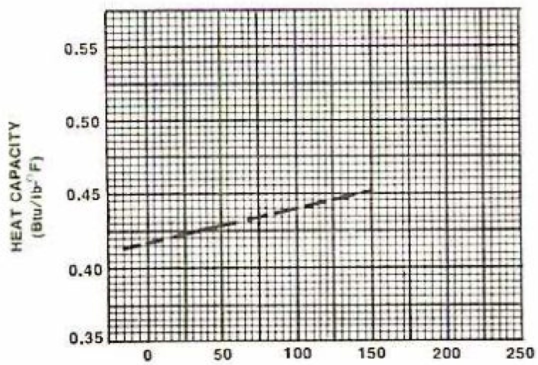

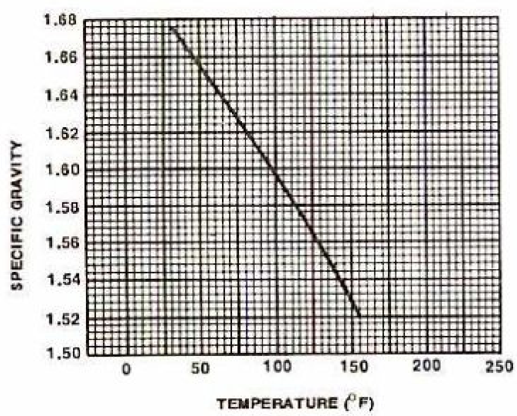

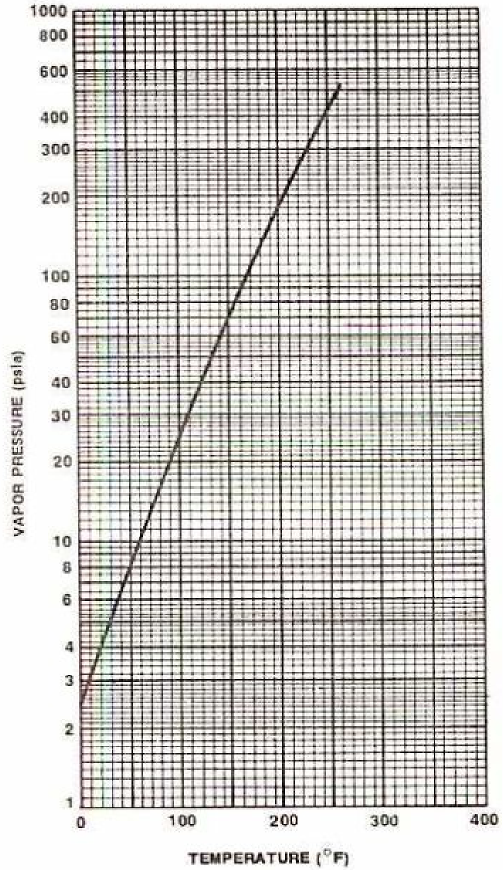

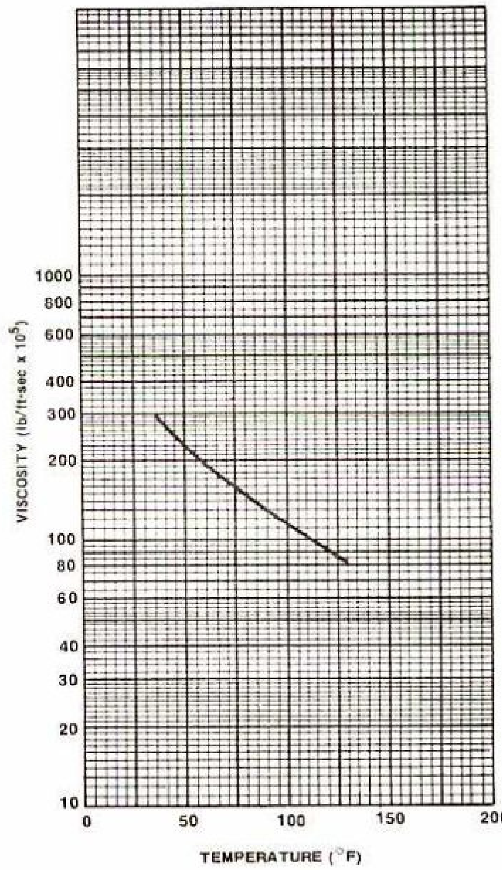

PHYSICAL PROPERTIES OF MAXIMUM DENSITY INHIBITED FUMING NITRIC ACID:
54.8% HNO_3 – 44.0% N_2O_4 – 0.5% H_2O – 0.7% HF, b.w.

EMPIRICAL FORMULA (100 g basis)	$H_{0.9602}$ $N_{1.8261}$ $O_{4.5495}$ $F_{0.0350}$
FREEZING TEMPERATURE (°F)	-35
NORMAL BOILING POINT (°F)	76.5
CRITICAL TEMPERATURE (°F)	512
CRITICAL PRESSURE (psia)	1428
HEAT OF FORMATION (cal/100 g liq. @ 298.16°K)	-43,400
HEAT OF VAPORIZATION (Btu/lb @ NBP)	270

REFERENCE DATA ———
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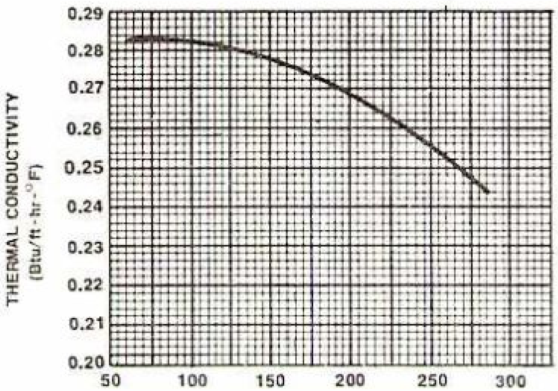

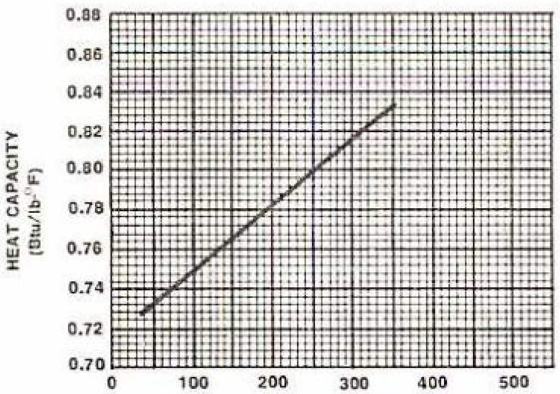

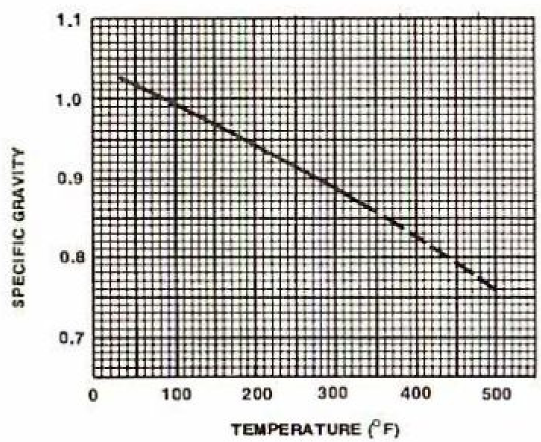

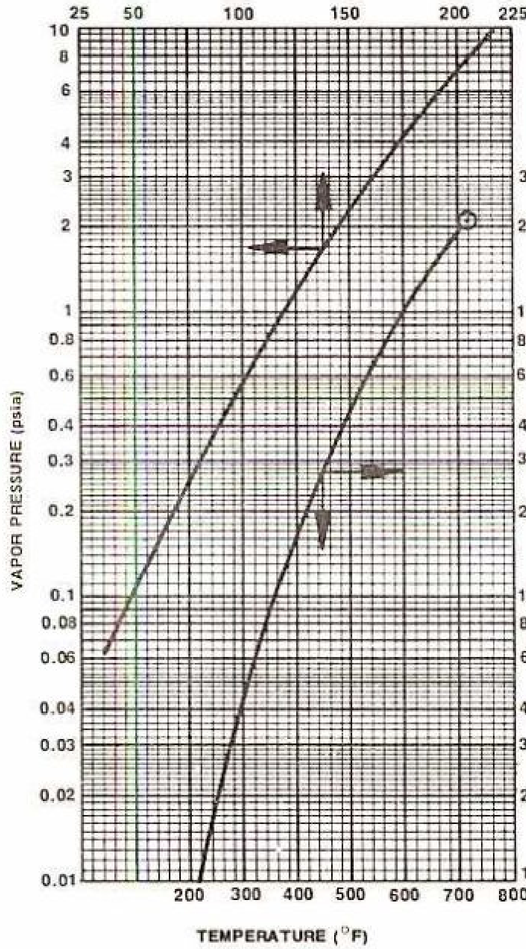

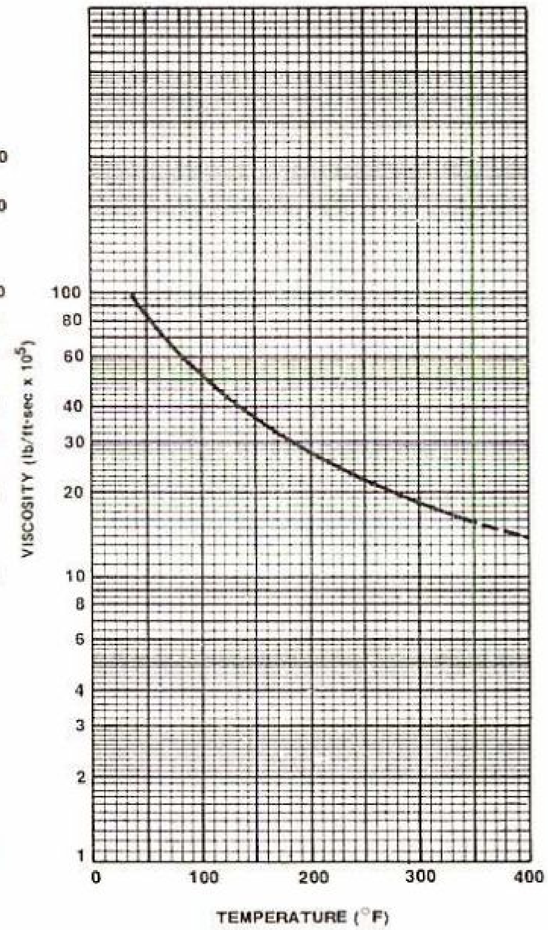

PHYSICAL PROPERTIES OF HYDRAZINE: N_2H_4

REFERENCE DATA ——
EXTRAPOLATED DATA - - - -
CRITICAL POINT ⊙

MOLECULAR WEIGHT	32,0453
FREEZING TEMPERATURE (°F)	34.75
NORMAL BOILING POINT (°F)	237.6
CRITICAL TEMPERATURE (°F)	716
CRITICAL PRESSURE (psia)	2131
HEAT OF FORMATION (cal/mole liq. @ 298.16°K)	12,054
HEAT OF VAPORIZATION (Btu/lb @ 298.16°K)	583

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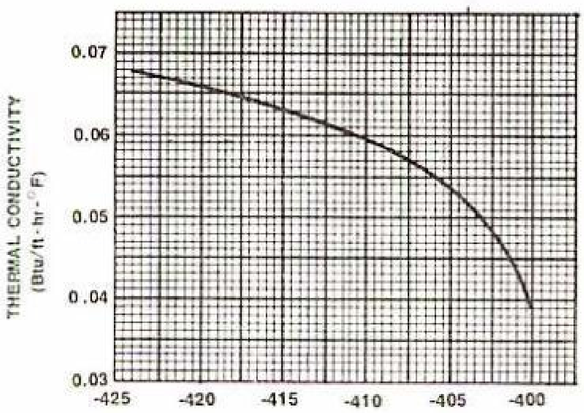
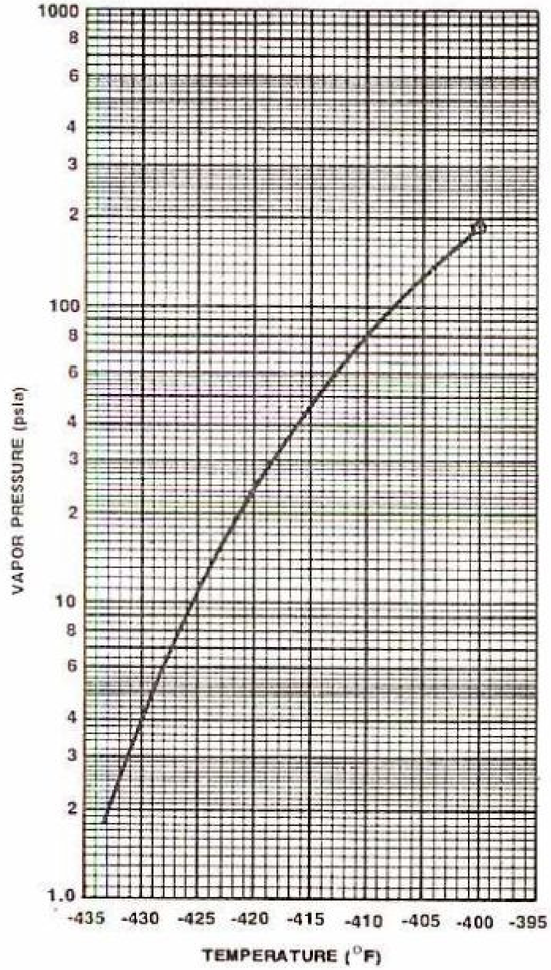
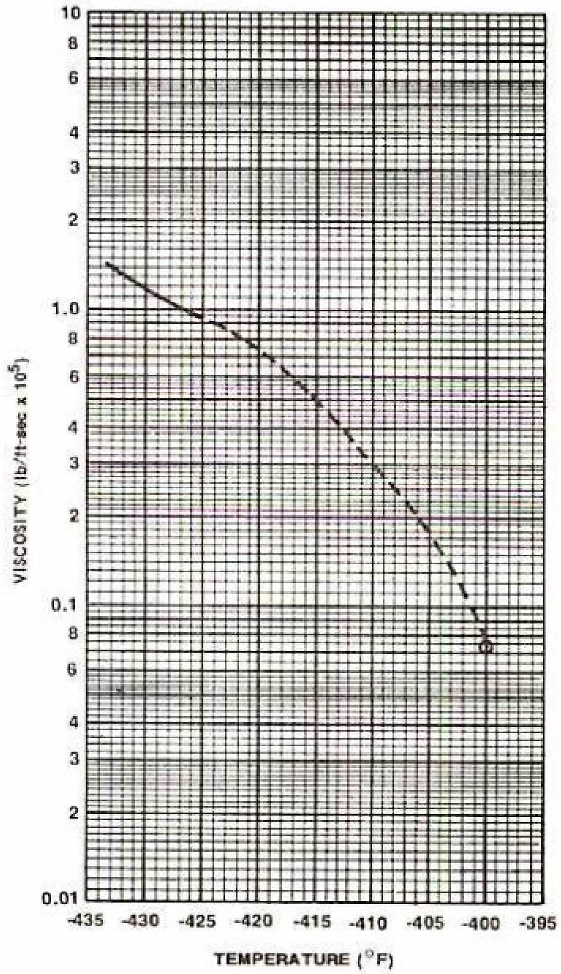
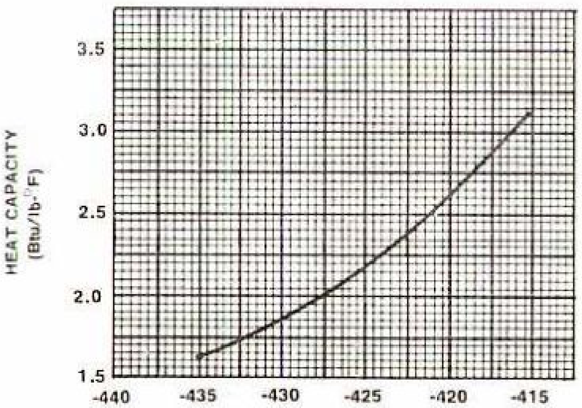
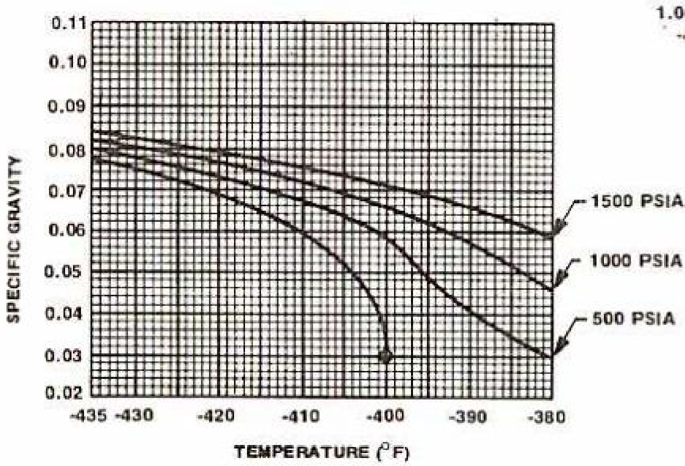






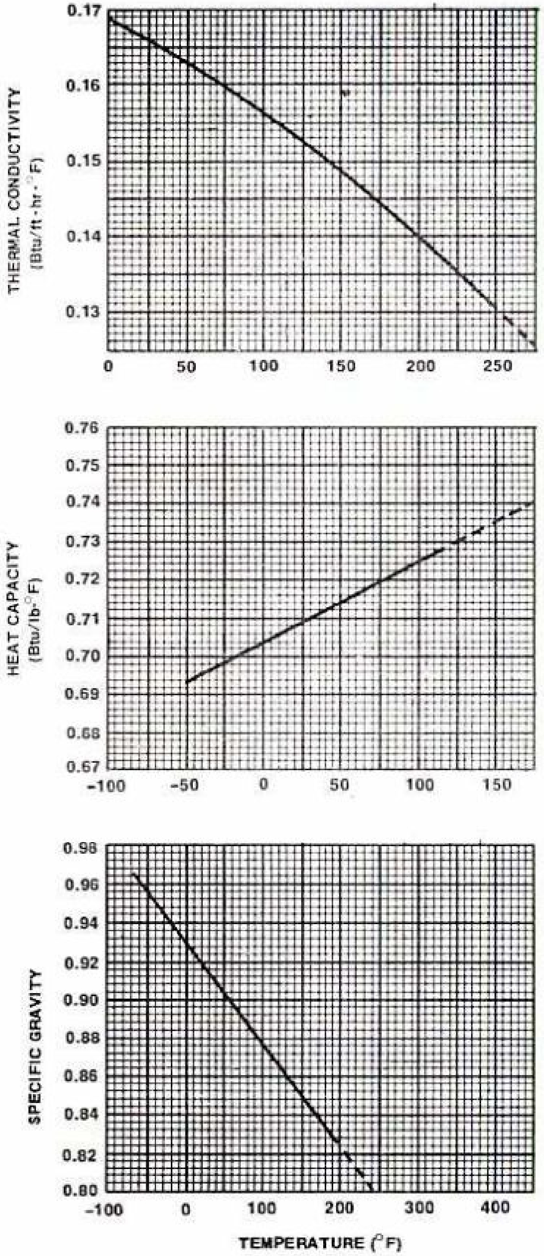


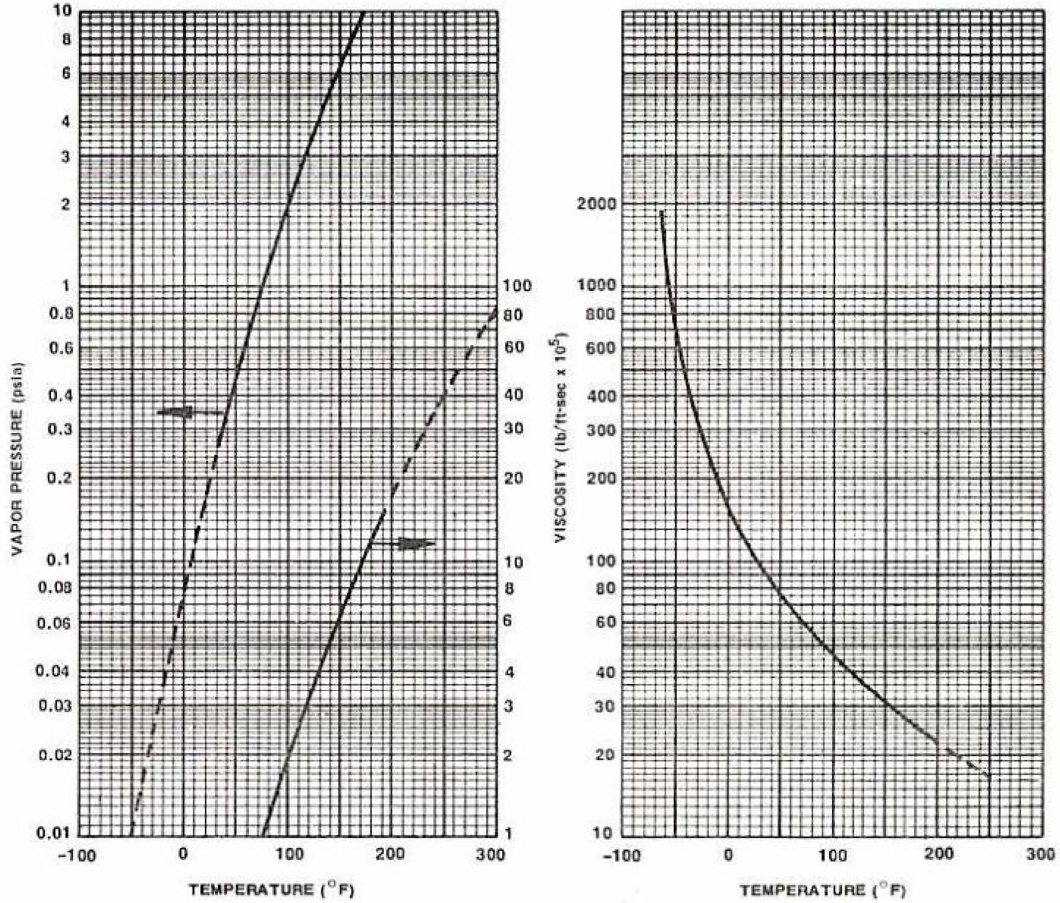


PHYSICAL PROPERTIES OF LIQUID HYDROGEN – H_2

MOLECULAR WEIGHT	2.016
FREEZING TEMPERATURE (°F)	-434.8
NORMAL BOILING POINT (°F)	-423.3
CRITICAL TEMPERATURE (°F)	-399.9
CRITICAL PRESSURE (psia)	188
HEAT OF FORMATION (cal/mole liq nbp)	-1895
HEAT OF VAPORIZATION (Btu/lb)	195.3

REFERENCE DATA ———
EXTRAPOLATED DATA – – – –
CRITICAL POINT ⊙





PHYSICAL PROPERTIES OF MHF-3: 86% MMH - 14% N_2H_4, b.w.

MOLECULAR WEIGHT	43.4120
FREEZING TEMPERATURE (°F)	- 65
NORMAL BOILING POINT (°F)	193.4
CRITICAL TEMPERATURE (°F)	617
CRITICAL PRESSURE (psia)	1373
HEAT OF FORMATION (cal/mole liq @ 298.16°K)	12,907
HEAT OF VAPORIZATION (Btu/lb @ NBP)	370

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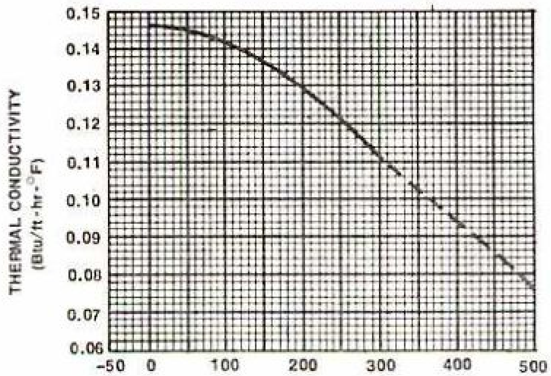

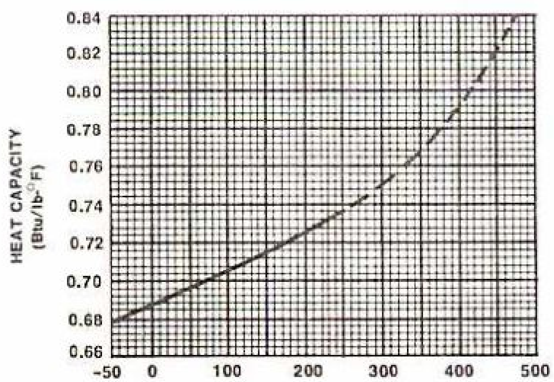

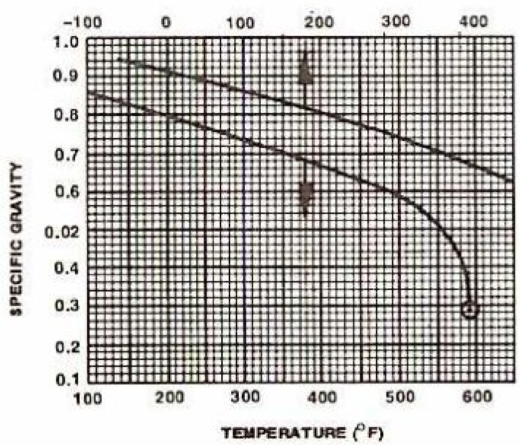

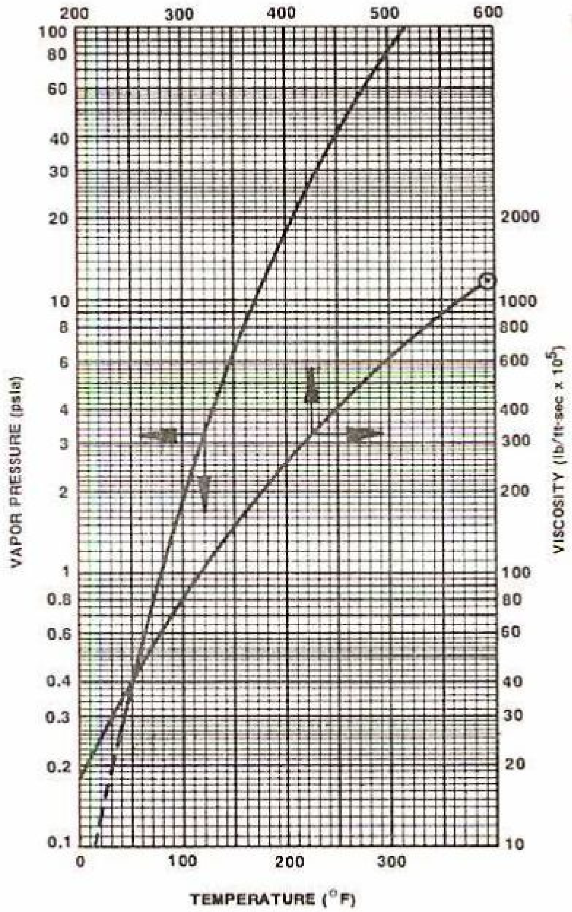

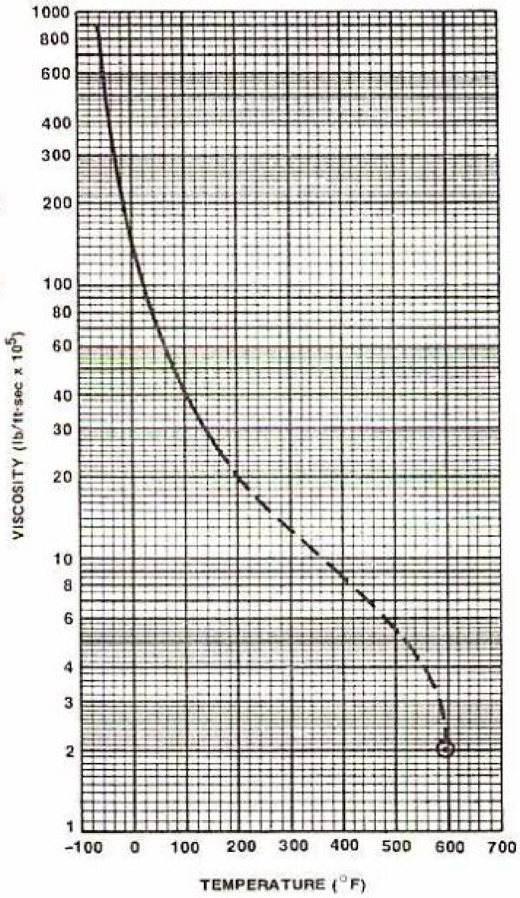

PHYSICAL PROPERTIES OF MONOMETHYL HYDRAZINE: $CH_3N_2H_3$

MOLECULAR WEIGHT	46.0724
FREEZING TEMPERATURE (°F)	-62.3
NORMAL BOILING POINT (°F)	189.8
CRITICAL TEMPERATURE (°F)	594
CRITICAL PRESSURE (psia)	1195
HEAT OF FORMATION (cal/mole liq. @ 298.16°K)	13,106
HEAT OF VAPORIZATION (Btu/lb @ 298.16 °K)	377

REFERENCE DATA	———
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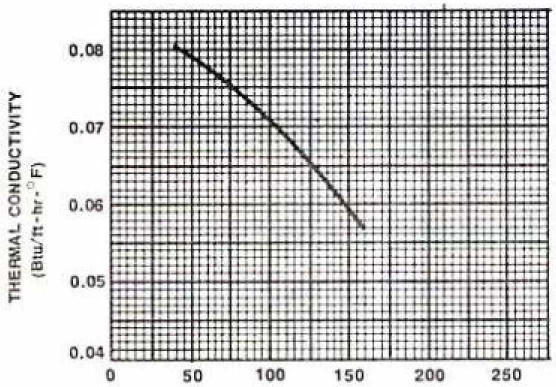
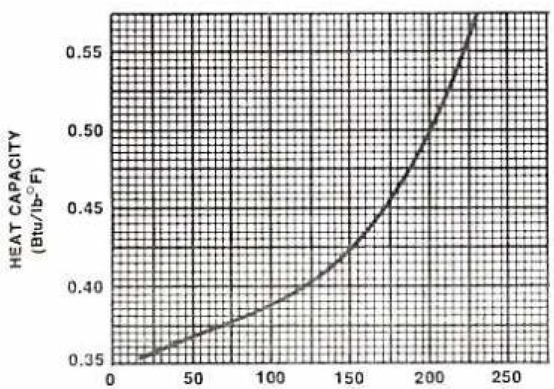
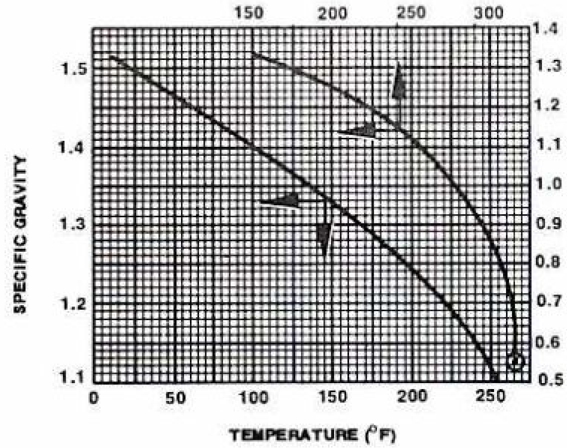
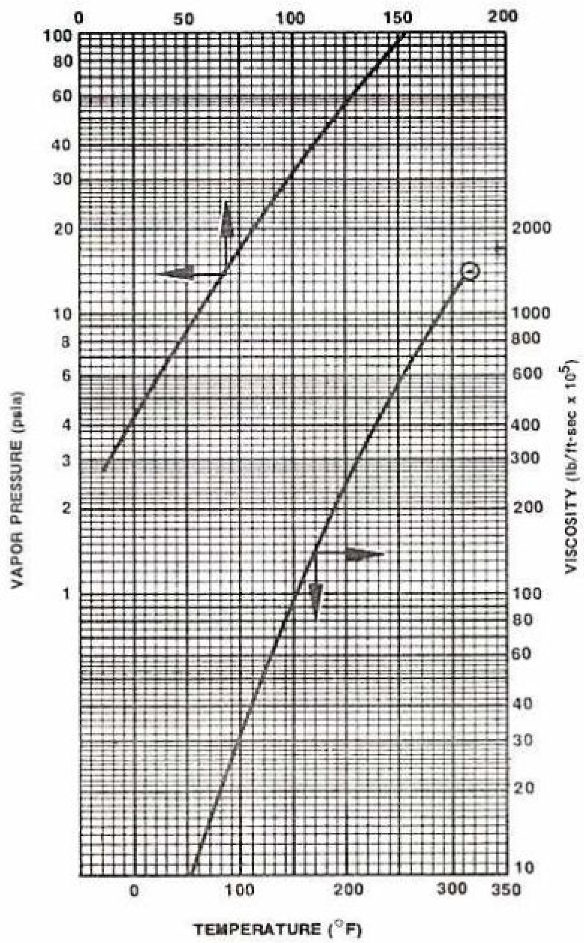
CRITICAL POINT	⊙

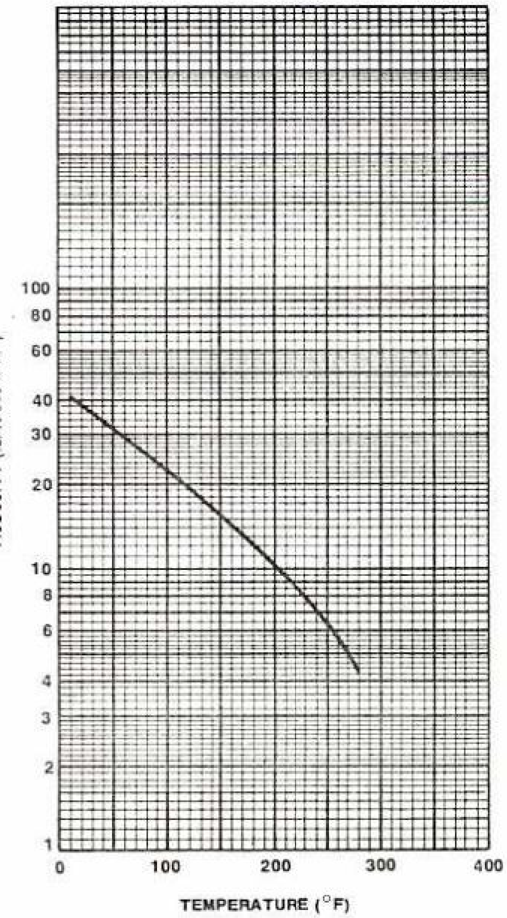
REVISED NOV. 1974









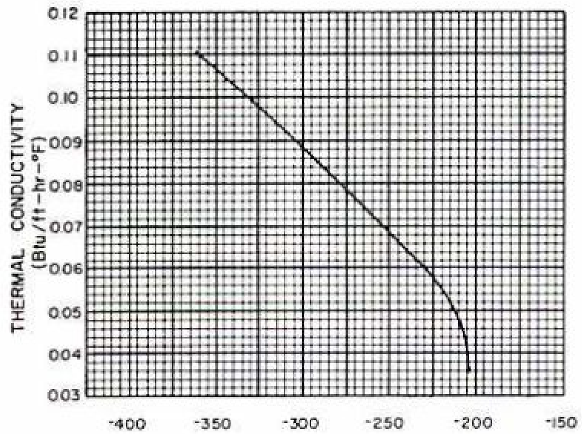


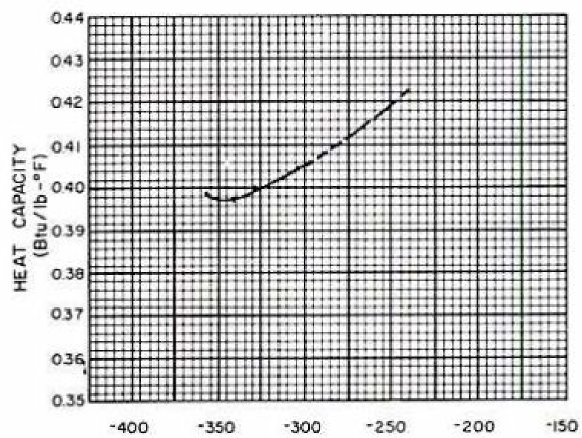
PHYSICAL PROPERTIES OF NITROGEN TETROXIDE: N_2O_4

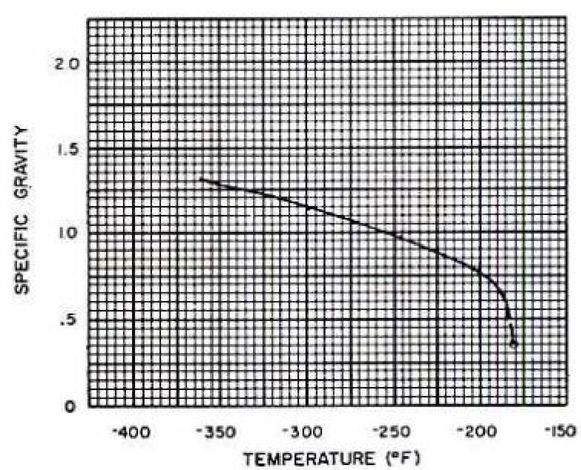
MOLECULAR WEIGHT	92.011
FREEZING TEMPERATURE (°F)	11.75
NORMAL BOILING POINT (°F)	70.4
CRITICAL TEMPERATURE (°F)	316.8
CRITICAL PRESSURE (psia)	1441.3
HEAT OF FORMATION (cal/mole liq @ 298.16°K)	-4.676
HEAT OF VAPORIZATION (Btu/lb @ NBP)	178.2

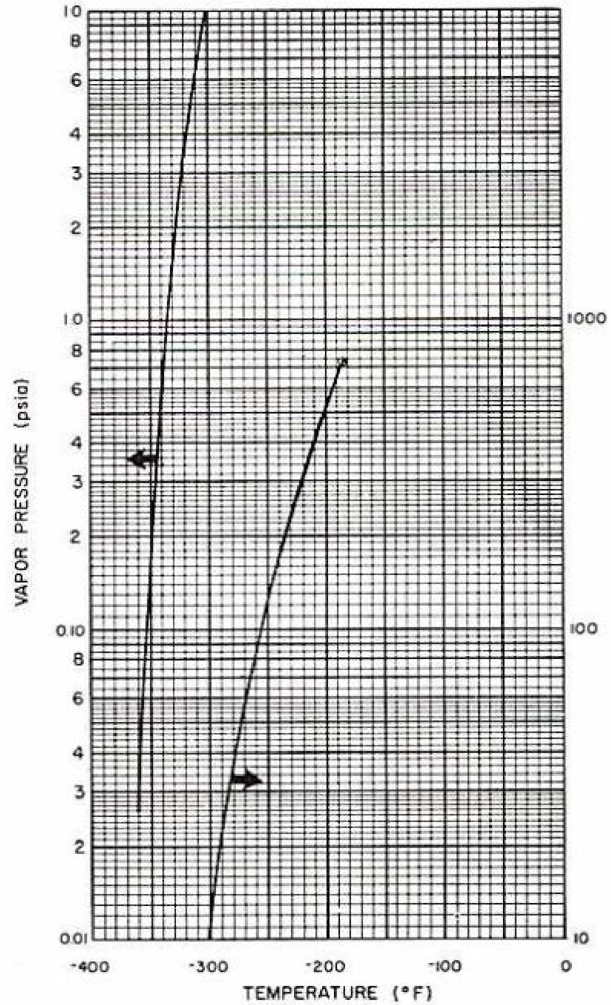
REFERENCE DATA ———
CRITICAL POINT ⊙

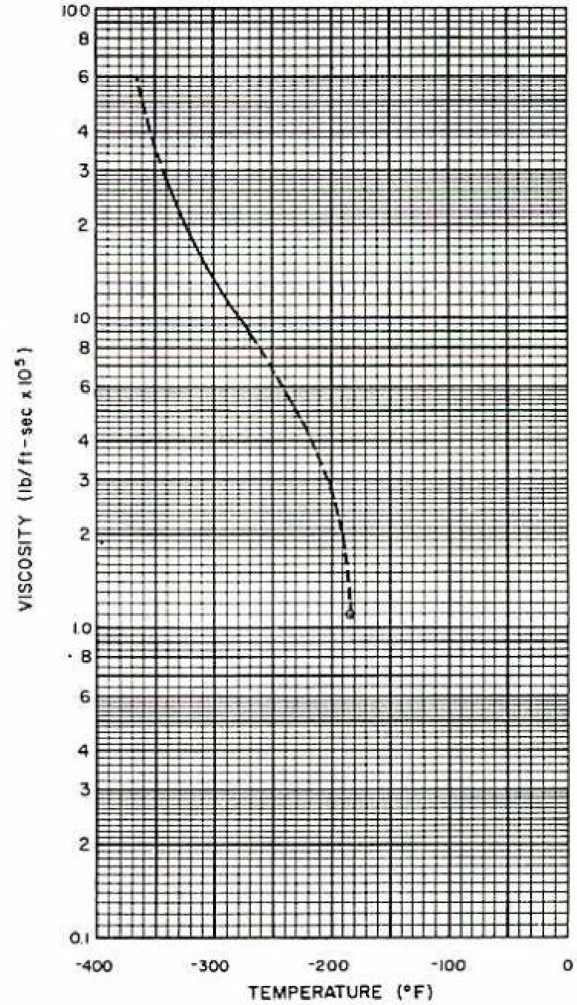
REVISED NOV 1974







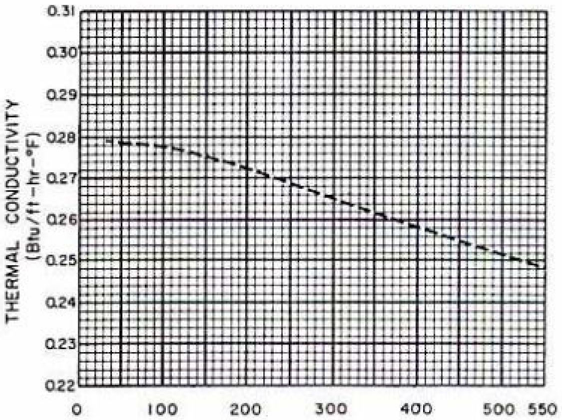


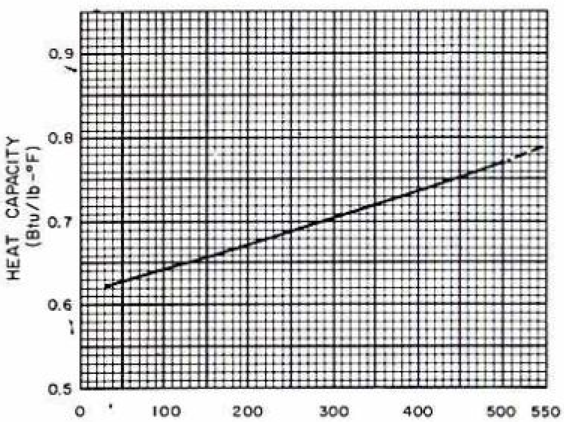


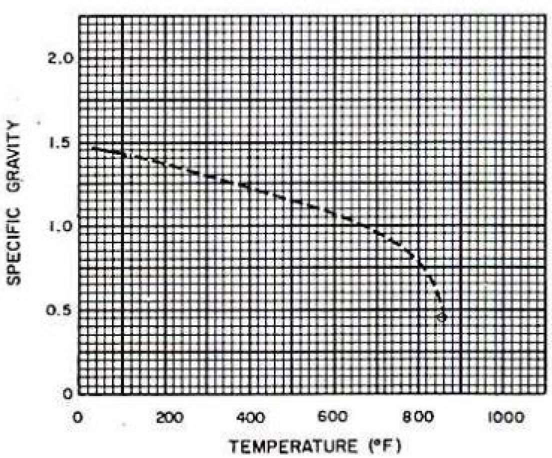
PHYSICAL PROPERTIES OF OXYGEN - O_2

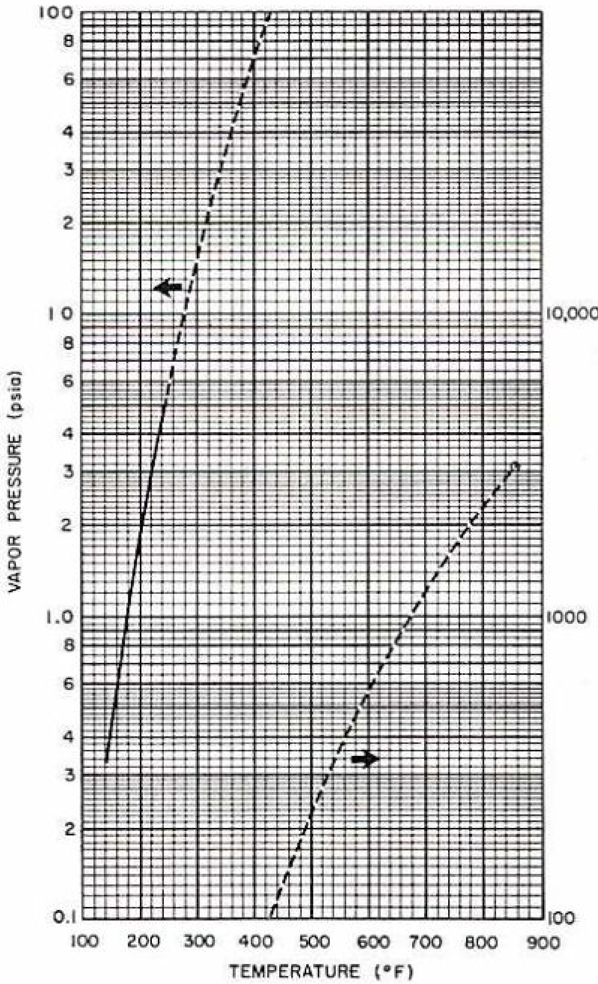
MOLECULAR WEIGHT	32.000
FREEZING TEMPERATURE (°F)	-362
NORMAL BOILING POINT (°F)	-297
CRITICAL TEMPERATURE (°F)	-182.0
CRITICAL PRESSURE (psia)	730.6
HEAT OF FORMATION (cal / mole liq@nbp)	-2896
HEAT OF VAPORIZATION (Btu / lb)	91.62

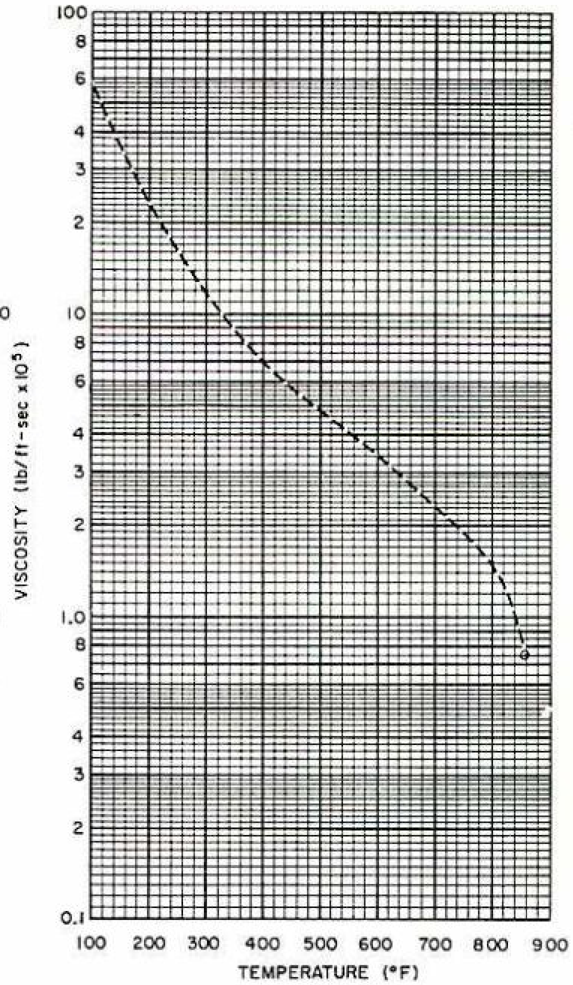
REFERENCE DATA ———
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT o







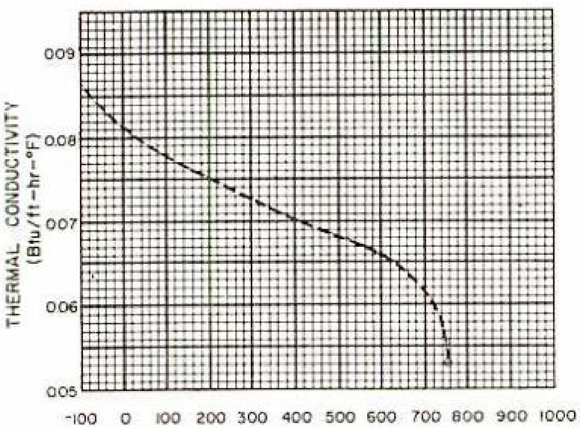


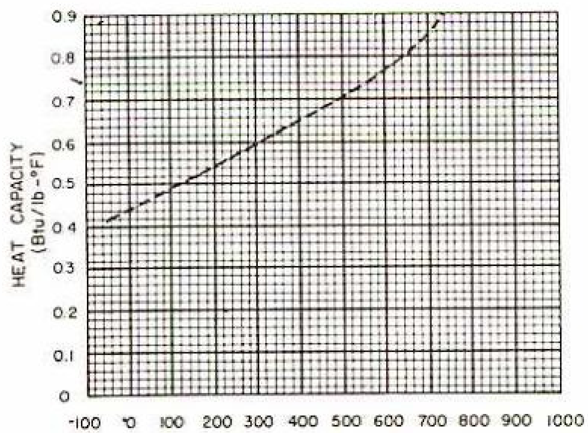


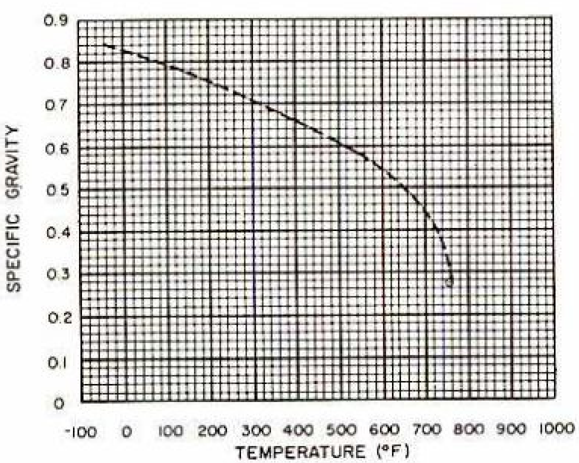
PHYSICAL PROPERTIES OF HYDROGEN PEROXIDE - H_2O_2(100%)

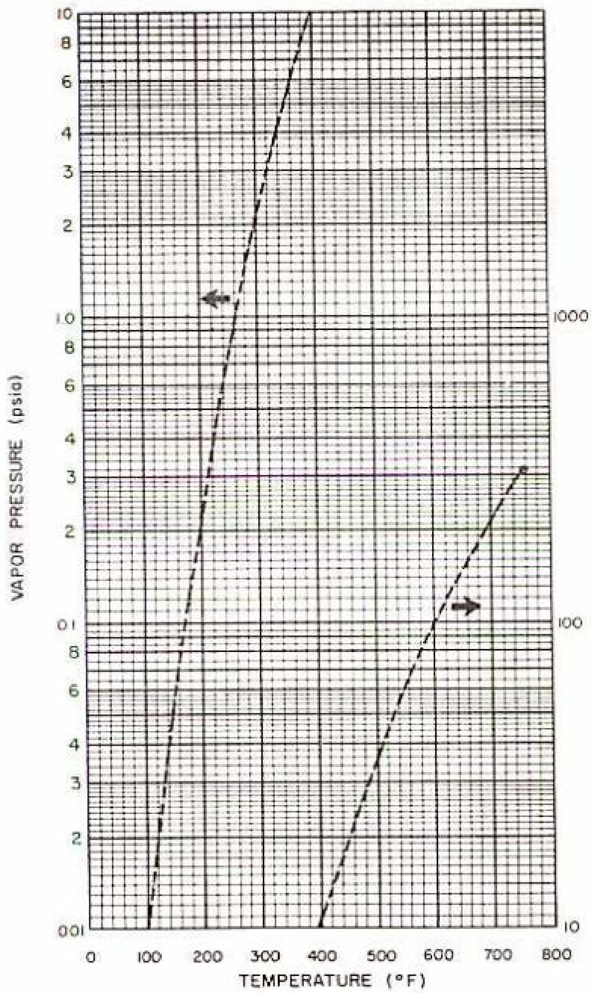
MOLECULAR WEIGHT	34.016
FREEZING TEMPERATURE (°F)	31.2
NORMAL BOILING POINT (°F)	302.4
CRITICAL TEMPERATURE (°F)	855
CRITICAL PRESSURE (psia)	3146
HEAT OF FORMATION (cal / mole liq @ 298.16°K)	- 44,750
HEAT OF VAPORIZATION (Btu / lb)	596

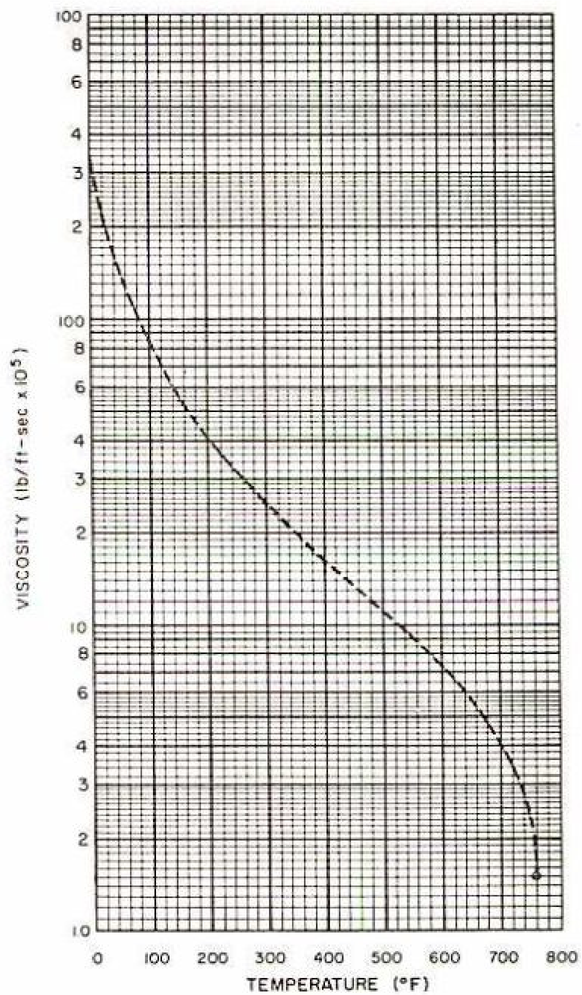
REFERENCE DATA ———
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT ○







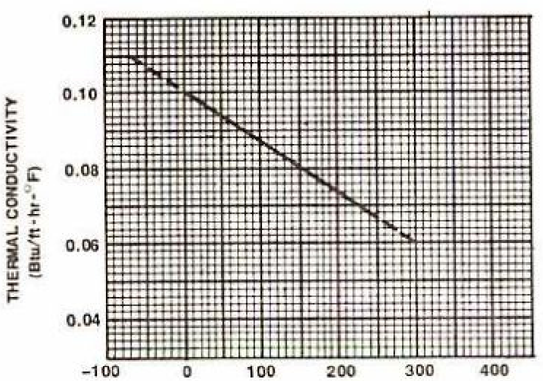


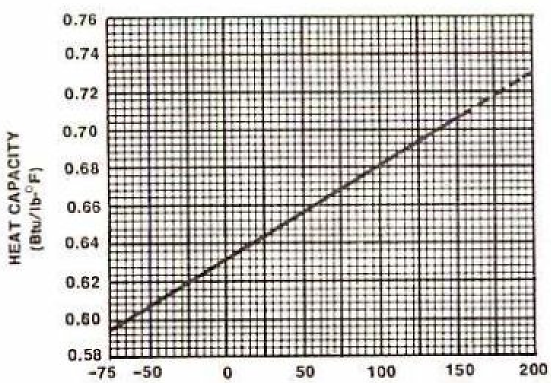


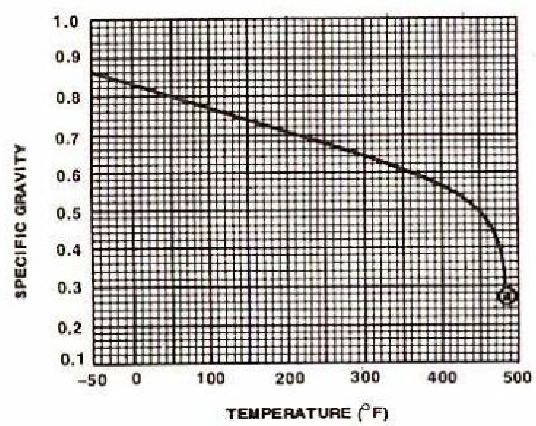
PHYSICAL PROPERTIES OF RP-1 (H/C = 2.0)

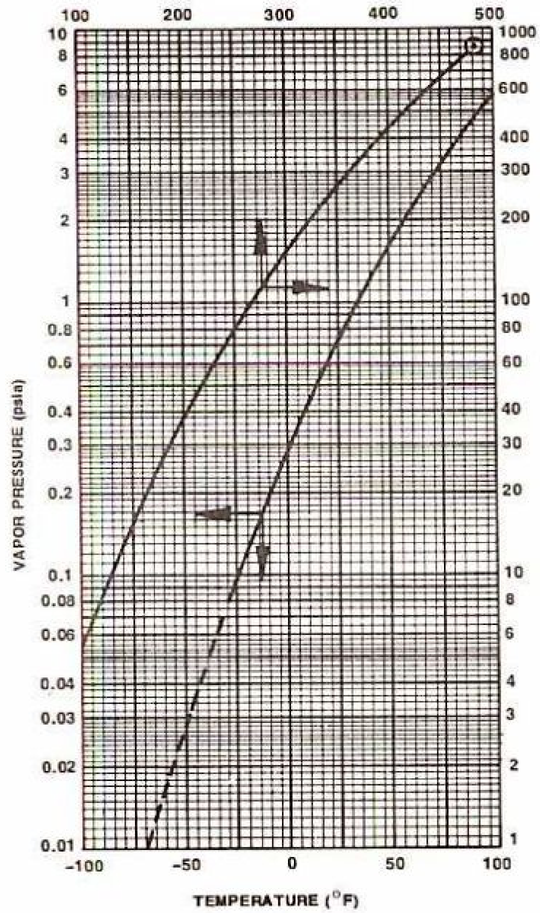
MOLECULAR WEIGHT	172
FREEZING TEMPERATURE (°F)	-50 to -100
NORMAL BOILING POINT (°F)	422
CRITICAL TEMPERATURE (°F)	758
CRITICAL PRESSURE (psia)	315
HEAT OF FORMATION (cal / mole liq 298.16°K)	-6222 (per CH_2 unit)
HEAT OF VAPORIZATION (Btu / lb)	125

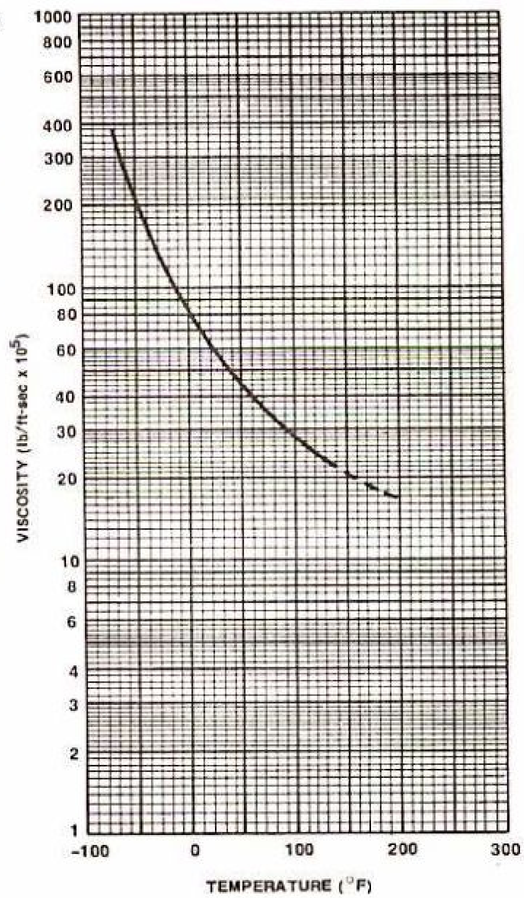
REFERENCE DATA ———
EXTRAPOLATED DATA - - - -
CRITICAL POINT o











PHYSICAL PROPERTIES OF UDMH: $(CH_3)_2 N_2H_2$

MOLECULAR WEIGHT	60.09946
FREEZING TEMPERATURE (°F)	-70.94
NORMAL BOILING POINT (°F)	144.18
CRITICAL TEMPERATURE (°F)	482
CRITICAL PRESSURE (psia)	867
HEAT OF FORMATION (cal/mole liq. @ 298.16°K)	12,339
HEAT OF VAPORIZATION (Btu/lb @ 298.16°K)	250.55

REFERENCE DATA ————
EXTRAPOLATED DATA – – – –
CRITICAL POINT ⊙

REVISED NOV. 1974