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NTWO - A NITROGEN PROPERTIES PACKAGE

by K. J. Pew, R. C. Hendricks, and R. J. Simoneau
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Cryogenic Engineering Conference sponsored by the
National Academy of Science/National Research Council
Boulder, Colorado, June 17-19, 1970

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Cleveland, Ohio

E-5067

ABSTRACT

A family of FORTRAN IV subroutines was developed to calculate the thermodynamic and transport properties of molecular nitrogen from the triple point to 300° K at pressures ranging from 0.1 to 200 atmospheres. The master subroutine NTWO calculates the remaining state variable when given any two of pressure, density, and temperature as input. In addition, any or all of the thermodynamic and transport properties - enthalpy, entropy, specific heats (Cp, Cv), sonic velocity, viscosity, thermal conductivity, surface tension - can be obtained by the state variable call or by a separate call. A call to NTWO with pressure and enthalpy will also generate all the other properties.

The NTWO package was developed to be used in conjunction with heat transfer and fluid flow calculations. Because of this intent, the package was written as a family of independent subroutines with a separate subroutine for each specific property or set of related properties. Thus a user with limited needs can work with only those subroutines required for his program.

NTWO - A NITROGEN PROPERTIES PACKAGE

Cryogenic nitrogen is inert, inexpensive, and generally available in large quantities at many research centers. It is used for cooling equipment, heating or cooling other fluids, as a modeling fluid, and in many cases as the primary test fluid in heat transfer and fluid dynamics research. Many of the authors who have submitted research papers to the Cryogenic Engineering Conference have used cryogenic nitrogen as their working fluid.

TM X-52814

NTWO is a FORTRAN IV family of subroutines which was developed on a 7094-7044 DCS machine to determine the thermodynamic and transport properties of nitrogen and be used in conjunction with other research programs. The NTWO property package is subdivided into subroutines and functions for computing the individual properties. The individual subroutines may be used independently of subroutine NTWO if the user's requirements are of a more restricted nature (say, memory or time limited). Appendix A is a descriptive breakdown of all the functions and subroutines used by the master subroutine NTWO, which is listed in appendix B.

The basis for the program is the work of Strobridge (ref. 1). Strobridge curve fit the available nitrogen data with a modified Benedict-Webb-Rubin (BWR) (ref. 2) equation of state. This work represented a major advance in establishing an equation of state for cryogens. The excellent hydrogen data of Roder and Goodwin (ref. 3) were fit using a form similar to that of reference 1. In the early days of work with cryogenic hydrogen such an equation represented a milestone to those working in research and development.

The NTWO property package differs from that of Strobridge (ref. 1) in that it was developed to be used in fluid flow and heat transfer calculations. As such, there are independent calls for the three state variables pressure, density, or temperature (see OPERATIONS SHEET). In addition, temperature and all the other properties can be obtained as a function of pressure and enthalpy, which is of considerable value in forced convection studies.

While enthalpy and entropy are available in reference 1, the specific heats (Cp, Cv), sonic velocity, viscosity, thermal conductivity, and surface tension were not computed. One of the major reasons that the specific heats were not given is the significant deviations in $\partial^2 P/\partial T^2$ at near critical temperatures which generally lead to very large values of Cv, see figure 1. After much effort in this area, we finally decided to use numerical techniques to determine $\Delta U/\Delta T = Cv$ and $\Delta H/\Delta T = Cp$. The viscosity and thermal conductivity computational method were adapted from Svehla (ref. 4) for the gaseous regime and from Thodos

(refs. 5 and 6) for the near-critical regime. The surface tension calculation was adapted from reference 7.

Sample property calculations are found in figures 2 to 13. The plots of Cp and Cv exhibit some irregularities in the near-critical regime. Smoothing techniques could be applied, however, for most applications these are unwarranted because the values returned are within acceptable tolerance. The properties P, ρ, T, H, S are in good agreement with those tabulated by Strobridge (ref. 1). The values of k, μ, and σ are limited by the state of the art. For example, the spikes in thermal conductivity that are known to exist in the critical region cannot presently be computed. See reference 8 for discussion of this.

At the time of writing, two papers (refs. 9 and 10) were brought to the attention of the authors. Pierce (ref. 9) prepared a FORTRAN IV program for nitrogen and helium for the pressure range of 1 to 2500 psia (0.068 to 170 atm), temperatures of 120° to 4500° R (66.5° to 2500° K) for nitrogen and 35° to 4500° R (19.4° to 2500° K), for helium. A superficial examination indicates that the essential differences are, the flexibility and versatility of NTWO is much greater, and in reference 9 the calculation of specific heats uses $\partial^2 P/\partial T^2$ throughout and the surface tension is not calculated. The tables presented in reference 9 have not been checked as of this time. Reference 10 represents a theoretical work with tabulated results for temperatures above 300° K. As 300° K nitrogen is considered noncryogenic, the results should not alter the results presented herein or those of reference 1.

OPERATIONS SHEET

The nitrogen PVT surface has been subdivided into three regimes: two-phase or saturation (KR=1); liquid (KR=2); and gas and/or fluid (KR=3), see the sketch on table I. In the two phase regime, KR=1, only the saturated liquid and saturated vapor properties are returned through COMMON/N2/. In order to avoid the choice of which properties should be used to compute quality, its calculation is left to the user.

Specification of KS

The values of KS represent what basic thermodynamic input has been supplied to NTWO and what basic thermodynamic information is desired as output (see appendix B).

KS=1 implies that temperature and pressure are specified and density is required. NTWO computes density

$$\rho = f(T, P)$$

KS=2 implies that temperature and density are specified and NTWO is requested to compute pressure

$$P = f(T, \rho)$$

KS=3 implies that pressure and density are specified and NTWO is requested to compute the temperature

$$T = f(P, \rho)$$

KS=4 is a particularly useful call for heat transfer and fluid dynamic calculations. Given the enthalpy and the pressure, NTWO returns temperature and density

$$T = f(P, H)$$

$$\rho = f(P, H)$$

Specification of KP

To obtain thermodynamic properties other than P, T, or ρ, and transport properties, various values are assigned to KP (see appendix B). However, a value must still be assigned to KS, to inform NTWO of what state variables are known.

KP=1 in combination with a value of KS informs NTWO that enthalpy must be determined.

KP=2, with KS specified, requests NTWO to compute entropy.

KP=4, specify KS, requests NTWO to compute specific heat at constant volume and constant pressure, the ratio of specific heats, and the sonic velocity.

KP=8, specify KS, NTWO returns a value for dynamic viscosity.

KP=16, specify KS, NTWO returns a value for thermal conductivity.

KP=32, specify KS, NTWO returns a value for surface tension.

To obtain any combination of the above properties, simply add the KP values. Thus if all the properties are required, specify KP=63. If everything except surface tension is required, set KP=31. If enthalpy, entropy, and viscosity are required, specify KP=11, etc.

KU Specification

KU=2 is a units specification which gives units as listed in table I. KU=1 will return those units of table I, except density will be returned as gram-moles/liter. KU=1 represents the working units of the program (see units of ref. 1). Additional room is available to specify other conversion factors; consult the authors on this matter.

The subroutine NTWO uses the call vector and COMMON to communicate with the subroutines within the NTWO package and the users program. The call vector and the COMMON are explained on the operations sheet, table I. A sample problem is provided in table I to illustrate the calling procedure. Table II is provided to illustrate assembly of the programs for machine operation.

Experience has taught us to check KR when working near the saturation loci and in the near critical region. Our calculations sometimes put us in the two-phase regime when we do not want to be; NTWO, however, thinks we are asking for saturation values and sets KR=1. Since specifying KR=1 is a code instructing NTWO to calculate saturation values directly without determining the regime, saturation values could be returned for all subsequent calls. Hence, the user must reset KR≠1 for nonsaturation values.

The NTWO properties package is currently available through the authors and will become available through the NASA-software program.

SYMBOL LIST

	Fortran symbol*	
c	C	sonic velocity, cm/sec
	CL	sonic velocity, saturated liquid, cm/sec
	CVP	sonic velocity, saturated gas, cm/sec
Cp	CP	specific heat at constant pressure, J/(g)(K)
	CPL	saturated liquid specific heat, Cp, J/(g)(K)
	CPV	saturated vapor specific heat, Cp, J/(g)(K)
Cv	CV	specific heat at constant volume, J/(g)(K)
	CVL	saturated liquid specific heat, Cv, J/(g)(K)
	CVV	saturated vapor specific heat, Cv, J/(g)(K)
H	H	enthalpy, J/g
	HV	enthalpy, saturated vapor, J/g
	HL	enthalpy, saturated liquid, J/g
k	K	thermal conductivity, W/(cm)(K)
	KL	thermal conductivity, saturated liquid, W/(cm)(K)
	KV	thermal conductivity, saturated vapor, W/(cm)(K)
	KP	thermodynamic and transport properties specification
	KR	thermodynamic region specification
	KS	state relation specification
	KU	units specification
P	P	pressure, atm
S	S	entropy, J/(g)(K)

*Symbols used in the individual subroutines are identified in the work statement of that subroutine (see appendix A).

	SV	entropy, saturated vapor, J/(g)(K)
	SL	entropy, saturated liquid, J/(g)(K)
T	T	temperature, K
γ	GAMMA	ratio of specific heats, Cp/Cv
	GAMMAL	ratio of specific heats, saturated liquid
	GAMMAV	ratio of specific heats, saturated vapor
σ	CSGMA	surface tension, dyne/cm
μ	CMU	dynamic viscosity, g/(cm)(sec)
ρ	D	density, g/cm^3
	DV	density, saturated vapor, g/cm^3
	DL	density, saturated liquid, g/cm^3

APPENDIX A

FUNCTIONS AND SUBROUTINES CONTAINED IN SUBROUTINE NTWO

If the user wishes to disassemble NTWO into its family of subroutines, reference 11 should be consulted.

BLOCK DATA

1. Equation of State Coefficients
2. Saturated Vapor Laws Coefficients
3. Specific Heat at Zero Pressure Coefficients
4. Conversion constants for use with other units

SUBROUTINE

DCHECK(KU, D)

This subroutine converts the density D to gram-moles/liter and checkes to see if D is out of range. The units are specified by KU.

If D is out of range, the program

(a) tags the word if Tagged Arithmetic is used

(b) writes an out of range note and continues

PCHECK(KU, KR, P)

Converts the pressure P to atmospheres and checks for out of range. If KR=1, P is checked for out of saturation range. Units are specified by KU.

Out of range cause P to be tagged (if tagged arithmetic is used) or effects an out of range write out.

TCHECK(KU, KR, T)

Converts the temperature T to degrees Kelvin and checks for out of range. If KR=1, T is checked for out of saturation range.

FUNCTION SOLVE(XI, F, DF)

Newton-Raphson iteration given an initial estimate XI, the function F, and its derivative DF. If the convergence has not been attained in 100 iterations, the result is tagged (or a note is outputed).

SUBROUTINE ROOT(X0, X2, FOFX, FUNC, X1)

Solve for X1, such that FUNC(X1)=FOFX, where X1 lies between X0 and X2. This is a modified half-interval search technique and permits only one root between X0 and X2. If a root has not been found in 100 iterations, the result is tagged (or a note is outputed).

SUBROUTINE ROOTX - same as SUBROUTINE ROOT - must be included to avoid recursion

SUBROUTINE SPLINA(X, Y, NX, T, NT, YINT, KFD, KERROR)

A spline curve fit routine used for interpolation

SUBROUTINE DENS(KU, T, P, D, DL, DV, KR)

Compute the density D, given the temperature T and pressure P. The units are specified by KU. If KR is either specified as 1 or returned as 1, the saturated liquid and vapor densities, DL and DV, respectively, are computed as a function of T only.

SUBROUTINE PRESS(KU, T, D, P, KR)

Compute the pressure P, given temperature T and density D. Units are specified by KU. If KR is either specified as 1 or returned as 1, P will be the saturation pressure computed as a function of T only.

SUBROUTINE TEMP(KU, P, D, T, KR)

Compute the temperature T, given pressure P and density D. Units are specified by KU. If KR is either specified as 1 or returned as 1, T will be the saturation value computed as a function of P only.

FUNCTION DSF(DS)

Function used to solve for density DS given temperature and pressure

DSF = P equation of state - P given

FUNCTION DDSF(DS)

Derivative of the above function and used to solve for density DS given temperature and pressure

$$DDSF = \frac{\partial(DSF)}{\partial \rho}$$

SUBROUTINE PSSS(PSS)

Compute the saturation pressure PSS given temperature

FUNCTION TSS(PS)

Function used to compute saturation temperature given the pressure PS

FUNCTION TSSF(TSS)

Function used to solve for saturation temperature TSS given pressure PS

$$TSSF = \text{Vapor Pressure Equation} - \log_{10}(PS)$$

FUNCTION DTSSF(TSS)

Derivative of the function used to solve for saturation temperature TSS given the pressure PS

$$DTSSF = \frac{\partial(TSSF)}{\partial T}$$

FUNCTION TSF(TS)

Function used to solve for the temperature TS given pressure PS and density

$$TSF = \text{Equation of State} - PS$$

FUNCTION DTSF(TS)

Derivative of the function used to solve for temperature TS given pressure PS and density

$$DTSF = \frac{\partial(TSF)}{\partial T}$$

SUBROUTINE TEMPH(KU, P, H, T, D, DL, DV, KR)

For a given pressure P and enthalpy H, this routine will return values of temperature T and density D. If KR is either set equal to 1 or return as 1, saturated liquid and vapor densities DL and DV, respectively, will be returned.

FUNCTION TSHF(TS)

A function used in conjunction with TEMPH. This routine calls DENS with the given P and trial values of T to obtain values of density D. The enthalpy routine ENTH is then called and a value of H is computed.

SUBROUTINE ENTH(KU, KR, T, P, D, H, HL, HV)

Compute enthalpy H given the temperature T, pressure P, and density D. The units are specified by KU. The region is specified by KR. If KR is specified as 1, then the saturated liquid and vapor enthalpies HL and HV, respectively, are computed as a function of T only.

SUBROUTINE HSLV(PS)

Compute the saturated liquid and vapor enthalpies given pressure PS and temperature

HV from HSS, and HL=HV-T*HSSLV

FUNCTION HSS(PS, DS)

Compute the enthalpy in the region No. 3 or saturated vapor enthalpy given pressure PS, density DS, and temperature

$$H = H^0 + \int_{T_0}^{T} Cp_0 \, dT + (Z - 1)RT + \int_0^{\rho} \left[\frac{P}{\rho^2} - \frac{T}{\rho^2} \left(\frac{\partial P}{\partial T} \right)_{\rho} \right]_T d\rho$$

FUNCTION HINTF(TS)

Function used to compute the integral in the enthalpy computation based on temperature TS

$$\int_{T_0}^{T} Cp_0 \, dT$$

FUNCTION HDINT(DS, DSL)

Compute the integral used in the enthalpy computation from density DSL to density DS.

$$\Delta H = \int_{DSL}^{DS} \left[\frac{P}{\rho^2} - \frac{T}{\rho^2} \left(\frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho$$

FUNCTION HDINTF(DS)

Function used in the computation of enthalpy

$$\frac{P}{\rho^2} - \frac{T}{\rho^2} \left(\frac{\partial P}{\partial T} \right)_\rho$$

FUNCTION HSSLVF(PS)

Function used to compute saturated liquid enthalpy from saturated vapor enthalpy or saturated liquid entropy from saturated vapor entropy given pressure PS and temperature

$$HSSLV = \frac{\partial P}{\partial T} \Delta V$$

SUBROUTINE ENT(KU, KR, T, P, D, S, SL, SV)

Compute entropy S given temperature T, pressure P, and density D. Units are specified by KU. The region is specified by KR. If KR is specified as 1, the saturated liquid and vapor entropies SL and SV, respectively, are computed as a function of T only.

SUBROUTINE SSLV(PS)

Compute the saturated liquid and vapor entropies given pressure PS and temperature

SV from SSS, and SL=SV-HSSLV

FUNCTION SSS(PS, DS)

Compute the entropy in region 3 or the saturated vapor entropy given the pressure PS, the density DS, and temperature.

$$S = S^0 + \int_{T_0}^{T} Cp_0 \, d(\ln T) - R \ln(RT\rho) + \int_0^{\rho} \left[\frac{R}{\rho} - \frac{1}{\rho^2}\left(\frac{\partial P}{\partial T}\right)_T \right] d\rho$$

FUNCTION STINTF(TS)

Function used to compute entropy based on the temperature TS

$$\int_{T_0}^{TS} Cp_0 \, d(\ln T)$$

FUNCTION SDINT(DS, DSL)

Compute the integral in entropy from the density DSL to the density DS

$$\Delta S = \int_{DSL}^{DS} \left[-\frac{1}{\rho^2}\left(\frac{\partial P}{\partial T}\right)_\rho \right]_T d\rho$$

FUNCTION SDINTF(DS)

The integrand of the function used to compute entropy

$$-\frac{1}{\rho^2}\left(\frac{\partial P}{\partial T}\right)_\rho$$

SUBROUTINE SPCHTV(KU, KR, T, P, D, CV, CVL, CVV)

Compute the specific heat at constant volume CV given temperature T, pressure P, and density D. The units are specified by KU and the region by KR. If KR is specified as 1, the saturated liquid and vapor specific heats, CVL and CVV, respectively, are computed.

$$CV = \frac{\Delta U}{\Delta T} = \frac{\Delta[H - (P/\rho)]}{\Delta T}$$

SUBROUTINE CVPS(KVP, KR, CVS)

Compute the specific heat given temperature pressure and density. The region is specified by KR. This routine is used to determine the incremental changes in internal energy U, and enthalpy H for computation of specific heats at constant volume and pressure, respectively.

SUBROUTINE SPCHTP(KU, KR, T, P, CP, CPL, CPV)

Compute the specific heat at constant pressure CP, given temperature T, and pressure P. Units are given by KU and the region is specified by KR. If KR=1, the saturated liquid and vapor specific heats, CPL and CPV, respectively, are computed.

SUBROUTINE SONIC(KU, KR, T, D, GAMMA, C)

Compute sonic velocity C given temperature T, density D, and the specific heat ratio GAMMA=CP/CV. Units are specified by KU and the region by KR.

SUBROUTINE VISC(KU, KR, T, D, MU)

Compute the viscosity MU, given temperature T and density D. Units are specified by KU and the region by KR.

SUBROUTINE THERM(KU, KR, T, D, K)

Compute the thermal conductivity K, given temperature T and density D. The units are specified by KU and the region by KR.

SUBROUTINE SURFT(KU, KR, T, SIGMA)

Compute the surface tension SIGMA, given the temperature T.

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APPENDIX B

NTWO LISTING

The following listing of the master program NTWO displays the major logic envolving KS and KP.

```
      SUBROUTINE NTWO(KS,KP,T,P,D,H,KR)
C
C        COMPUTE THE STATE RELATIONS AND THERMODYNAMIC AND
C        TRANSPORT PROPERTIES OF MOLECULAR NITROGEN GIVEN TEMPERATURE T,
C        PRESSURE P, DENSITY D, OR ENTHALPY H.  STATE RELATIONS ARE
C        SPECIFIED BY KS.  THERMODYNAMIC AND TRANSPORT PROPERTIES
C        ARE SPECIFIED BY KP.  IF KR IS RETURNED AS SPECIFIED AS 1,
C        PROPERTIES ARE COMPUTED AT SATURATION.
C
      DIMENSION KPC1(32), KPC2(32), KPC3(32),KPC4(32)
      COMMON /N2/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
     1L, GAMMAV,C,CL,CVP,MU,MUL,MUV ,K,KL,KV ,SIGMA
      REAL MU,MUL,MUV,K,KL,KV
      DATA KPC1 /2,3,6,7,10,11,14,15,18,19,22,23,26,27,30,31,34,35,38,
     139,42,43,46,47,50,51,54,55,58,59,62,63/
      DATA KPC2 /4,5,6,7,12,13,14,15,20,21,22,23,28,29,30,31,36,37,38,
     139,44,45,46,47,52,53,54,55,60,61,62,63/
      DATA KPC3 /8,9,10,11,12,13,14,15,24,25,26,27,28,29,30,31,40,41,42,
     143,44,45,46,55,56,57,58,59,60,61,62,63/
      DATA KPC4 /16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,
     148,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63/
      GO TO (10,20,30,40),KS
C
C        COMPUTE DENSITY
C
   10 CALL DENS(KU,T,P,D,DL,DV,KR)                                      4
      GO TO 50
C
C        COMPUTE PRESSURE
C
   20 CALL PRESS(KU,T,D,P,KR)                                           7
      GO TO 50
C
C        COMPUTE TEMPERATURE
C
   30 CALL TEMP(KU,P,D,T,KR)                                            10
      GO TO 50
C
C        COMPUTE TEMPERATURE AND DENSITY GIVEN PRESSURE AND ENTHALPY
C
   40 CALL TEMPPH(KU,P,H,T,D,DL,DV,KR)                                  13
   50 IF (MOD(KP,2)) 60,70,80
C
C        COMPUTE ENTHALPY
C
   60 CALL ENTH(KU,KR,T,P,D,H,HL,HV)                                    17
      DO 80 I=1,32
      IF (KP-KPC1(I)) 80,100,80
   80 CONTINUE
      GO TO 110
C
C        COMPUTE ENTROPY
C
  100 CALL ENT(KU,KR,T,P,D,S,SL,SV)                                     24
  110 DO 120 I=1,32
      IF(KP-KPC2(I)) 120,130,120
  120 CONTINUE
      GO TO 140
C
C        COMPUTE SPECIFIC HEATS
C
  130 CALL SPCHTV(KU,KR,T,P,D,CV,CVL,CVV)                               30
      CALL SPCHTP(KU,KR,T,P,CP,CPL,CPV)                                 30
      IF (KR.NE.1) GO TO 200
      GAMMAL=CPL/CVL
      GAMMAV=CPV/CVV
      CALL DENS(KU,T,P,D,DL,DV,1)                                       43
      CALL SONIC(KU,KR,T,DL,GAMMAL,CL)                                  45
      CALL SONIC(KU,KR,T,DV,GAMMAV,CVP)                                 47
      GO TO 140
  200 GAMMA=CP/CV
      DEBUG CP,CV,GAMMA
      CALL SONIC(KU,KR,T,D,GAMMA,C)                                     50
  140 DO 150 I=1,32
      IF (KP-KPC3(I)) 150,160,150
  150 CONTINUE
      GO TO 170
C
C        COMPUTE VISCOSITY
C
  160 IF (KR.NE.1) GO TO 210
      CALL DENS(KU,T,P,D,DL,DV,1)                                       44
      CALL VISC(KU,KR,T,D,MUL)                                          46
      CALL VISC(KU,KR,T,DV,MUV)                                         48
      GO TO 170
  210 CALL VISC(KU,KR,T,D,MU)                                           71
  170 DO 250 I=1,32
      IF(KP-KPC4(I)) 250,180,250
  250 CONTINUE
      GO TO 190
C
C        COMPUTE THERMAL CONDUCTIVITY
C
  180 IF (KR.NE.1) GO TO 220
      CALL DENS(KU,T,P,D,DL,DV,1)                                       85
      CALL THCOND(KU,KR,T,DL,KL)                                        87
      CALL THCOND(KU,KR,T,DV,KV)                                        89
      GO TO 190
  220 CALL THCOND(KU,KR,T,D,K)                                          92
  190 IF(KP-21) 200,240,240
C
C        COMPUTE SURFACE TENSION
C
  240 CALL SURF (KU,KR,T,SIGMA)                                         96
  200 RETURN
      END
```

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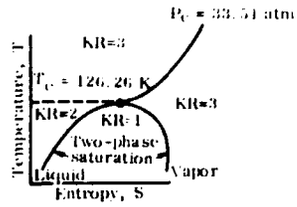
TABLE 1 — OPERATIONS SHEET FOR SUBROUTINE NTWO

SUBROUTINE NTWO (KS, KP, T, P, D, H, KR)

- KR — Region
  - KR 0 Unknown, check KR returned
  - KR 1 Saturation
  - KR 2 Liquid
  - KR 3 Gas and or fluid
- H — Enthalpy, J/g
- D — Density, g/cm^3
- P — Pressure, atm
- T — Temperature, K
- KP — Thermodynamic and Transport properties*
  - KP 0 — Only P, ρ, T returned
  - KP 1 — H — Enthalpy, J/g, (H), (HL), (HV)
  - KP 2 — S — Entropy, J/(g)(K), (S), (SL), (SV)
  - KP 4 — Cv — Specific heat at constant volume, J/(g)(K), (CV), (CVL), (CVV)
    - Cp — Specific heat at constant pressure, J/(g)(K), (CP), (CPL), (CPV)
    - γ — Ratio of specific heats, Cp/Cv, (GAMMA), (GAMMAL), (GAMMAV)
    - c — Sonic velocity, cm/sec, (C), (CL), (CVP)
  - KP 8 — μ — Dynamic viscosity, g/(cm)(sec), (MU), (MUL), (MUV)
  - KP 16 — k — Thermal conductivity, W/(cm)(K), (K), (KL), (KV)
  - KP 32 — σ — Surface tension, dyne/cm, (SIGMA)
- KS — Input specification of independent properties
  - KS 1 — ρ = f(T, P); given T, P find ρ
  - KS 2 — P = f(T, ρ); given T, ρ find P
  - KS 3 — T = f(P, ρ); given P, ρ find T
  - KS 4 — T, ρ = f(P, H); given P, H find T, ρ



COMMON N2 KU, DL, DV, HL, HV, S, SL, SV, CV, CVL, CVV, CP, CPL, CPV, GAMMA, GAMMAL, GAMMAV, C, CL, CVP, MU, MUL, MUV, K, KL, KV, SIGMA

When working near the saturation locus, check KR≠1 each time to be assured of nonsaturation calculations.

At the beginning of the user's program,

set KU=1 or 2 and
CALL TAGSCN (tagged arithmetic)

If TAGSCN is not available on the machine, contact the authors for a modified package.

SAMPLE PROBLEM

CALL NTWO(2, 31, 80., P, 1.254, H, KR)

The program has been asked to find the pressure P, corresponding to a density of 1.254 g/cm^3 and a temperature of 80 K. Furthermore, the program will return values for H, S, Cv, Cp, γ, C, μ, and k. The values of H and P are returned through the call vector and the remaining values are returned through the COMMON statement.

*For example: KP 1+2=3 will return enthalpy and entropy; KP=1+8+16=25 will return enthalpy, viscosity, and thermal conductivity; KP=1+2+4+8+16=31 returns everything except σ; KP=2 will return entropy.

TABLE II. - PROGRAM ASSEMBLY

1. Set up the return of thermodynamic and transport properties

   COMMON/N2/KU, DL, DV, HL, HV, S, SL,SV, CV, CVL, CVV, CP, CPL, CPV, GAMMA, GAMMAL, GAMMAV, C, CL, CVP, MU, MUL, MUV, K, KL, KV, SIGMA

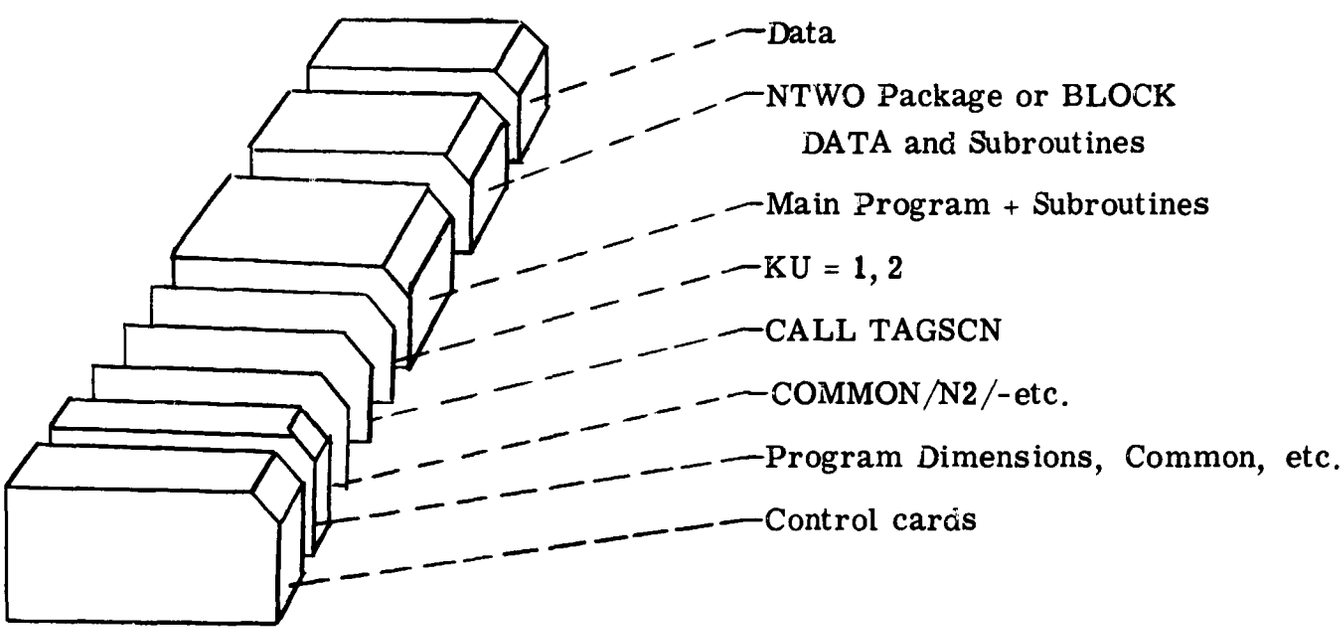
2. Set up tagged arithmetic (if not available, see notes in the subroutine FORTRAN listing).

   CALL TAGSCN

3. Establish the units you are working in KU = (specify 1, 2,).

4. Add your Program here.

5. Add NTWO Package, or BLOCK DATA and required subroutines.



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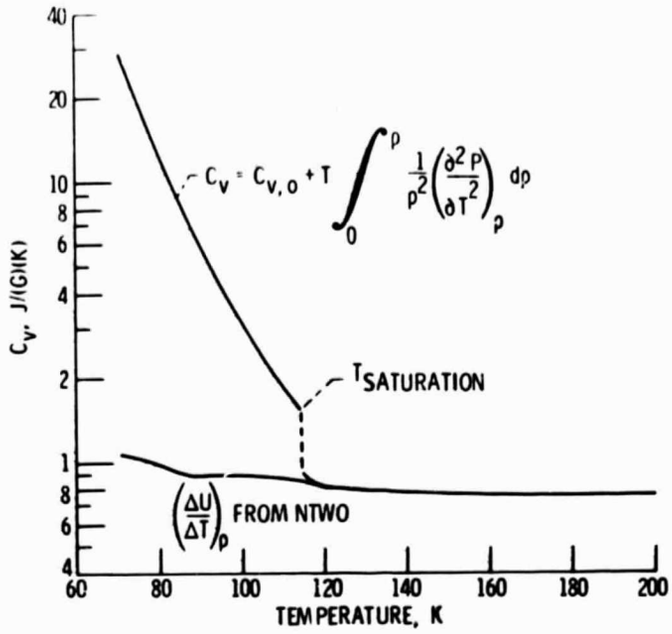

Figure 1. - Behavior of the specific heat at constant volume, Cv, calculated using $\partial^2 P/\partial T^2$ relative to computed C_v computed from NTWO using $(\Delta U/\Delta T)_\rho$. Pressure = 15 atm.

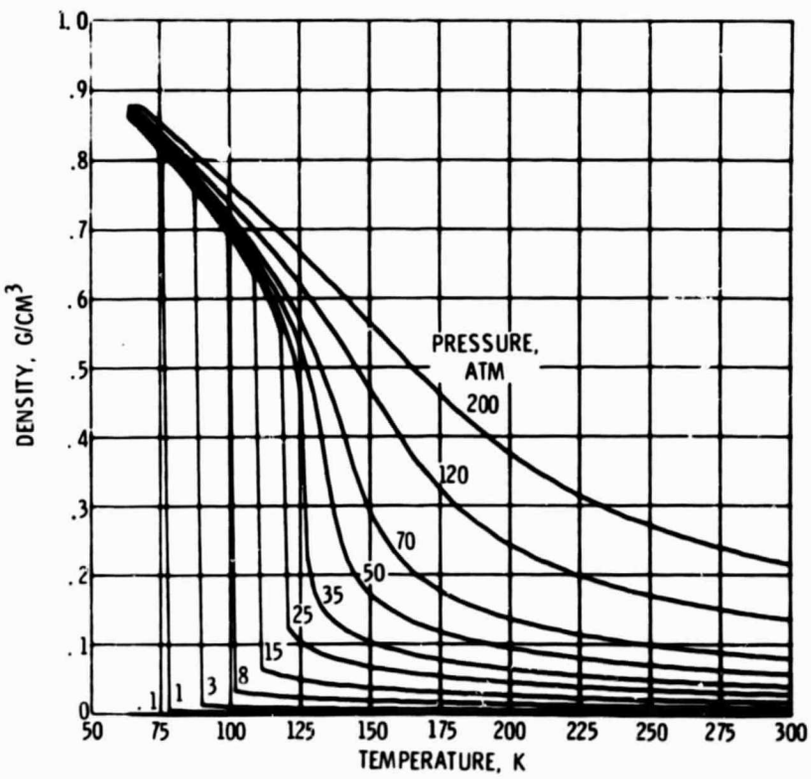

Figure 2. - Density as a function of temperature for various isobars.

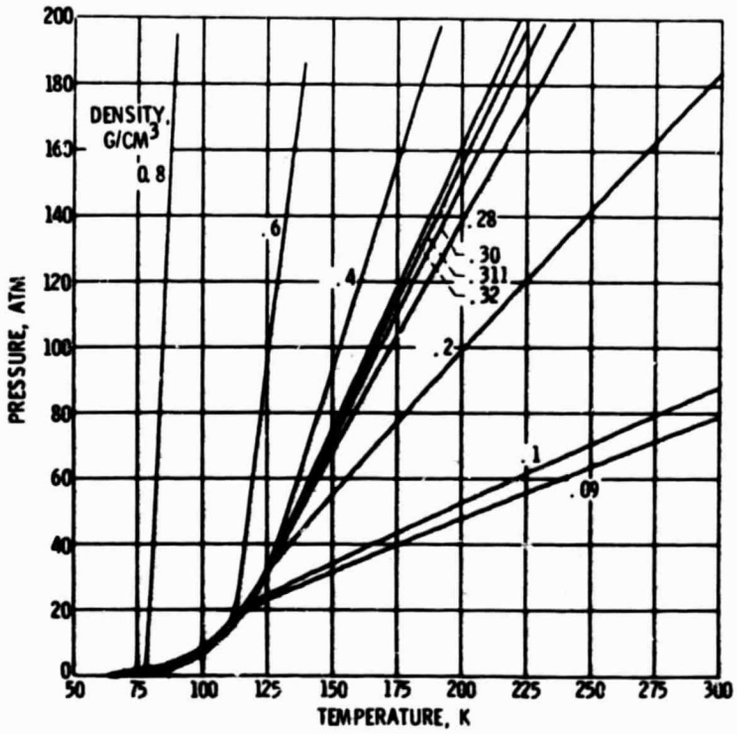

Figure 3. - Pressure as a function of temperature for various isobars.

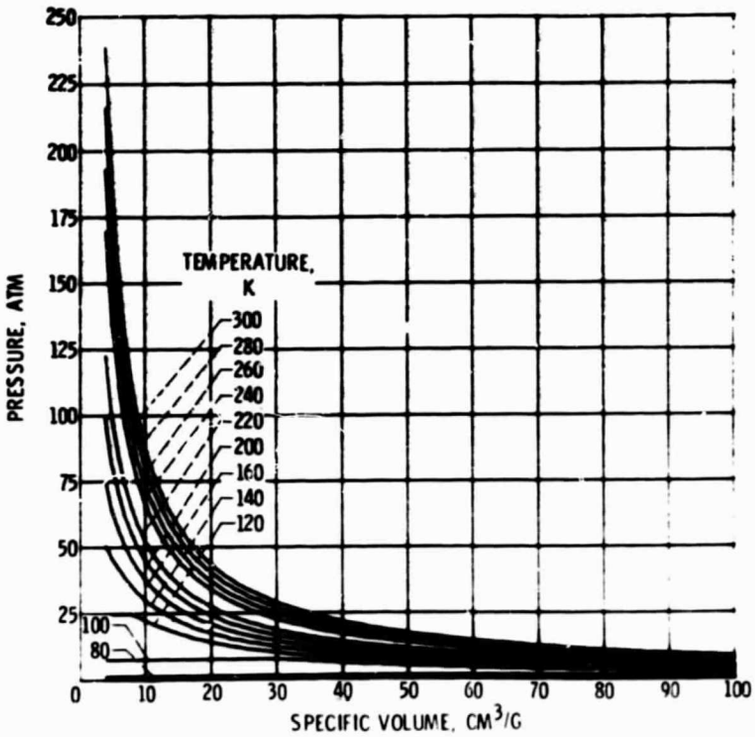

Figure 4. - Pressure as a function of specific volume for various isotherms.

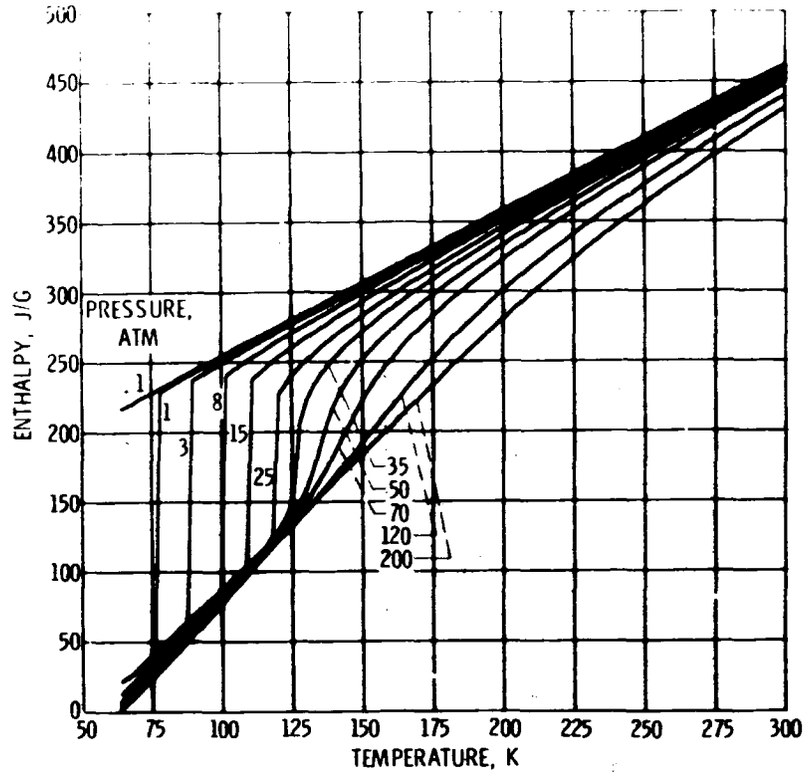

Figure 5. - Enthalpy as a function of temperature for various isobars.

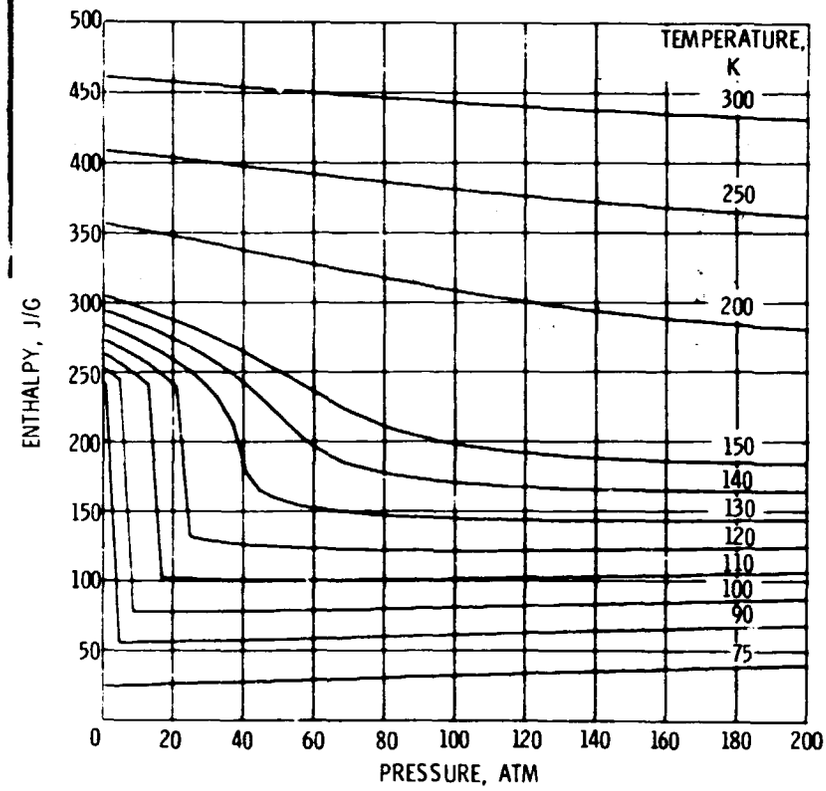

Figure 6. - Enthalpy as a function of pressure for various isotherms.

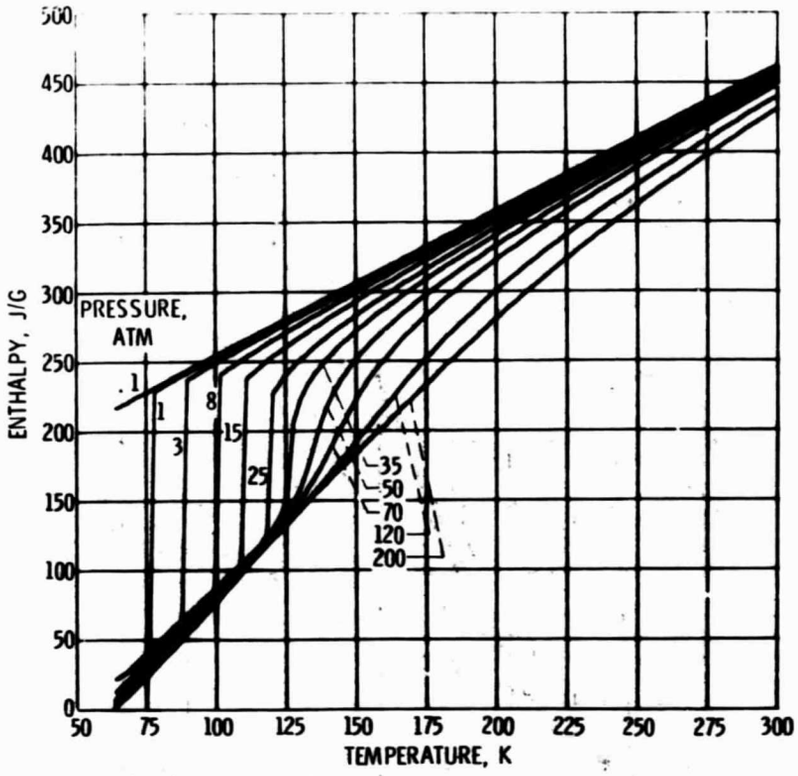

Figure 5. - Enthalpy as a function of temperature for various isobars.

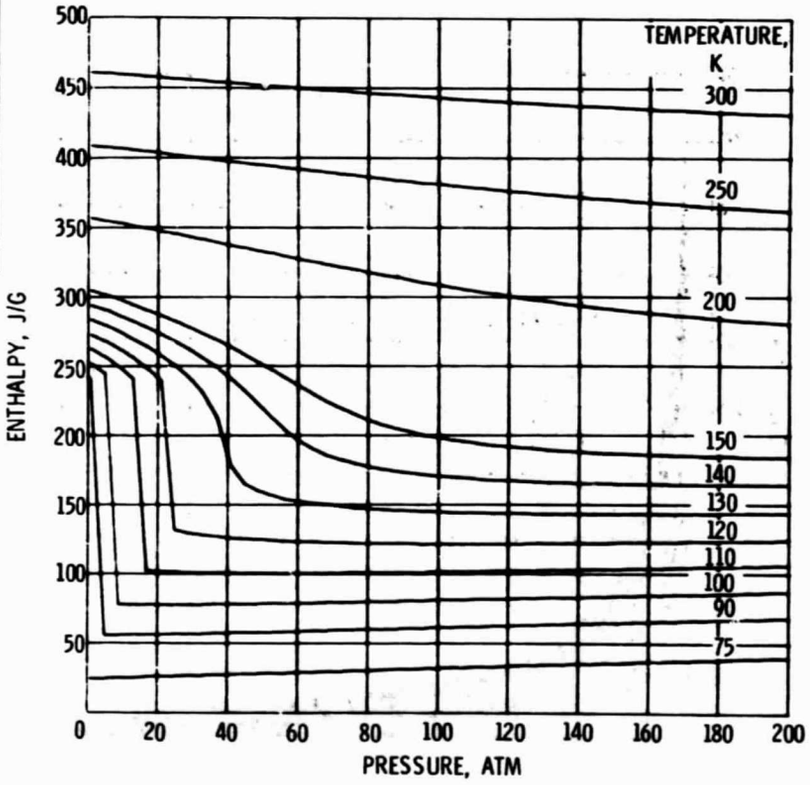

Figure 6. - Enthalpy as a function of pressure for various isotherms.

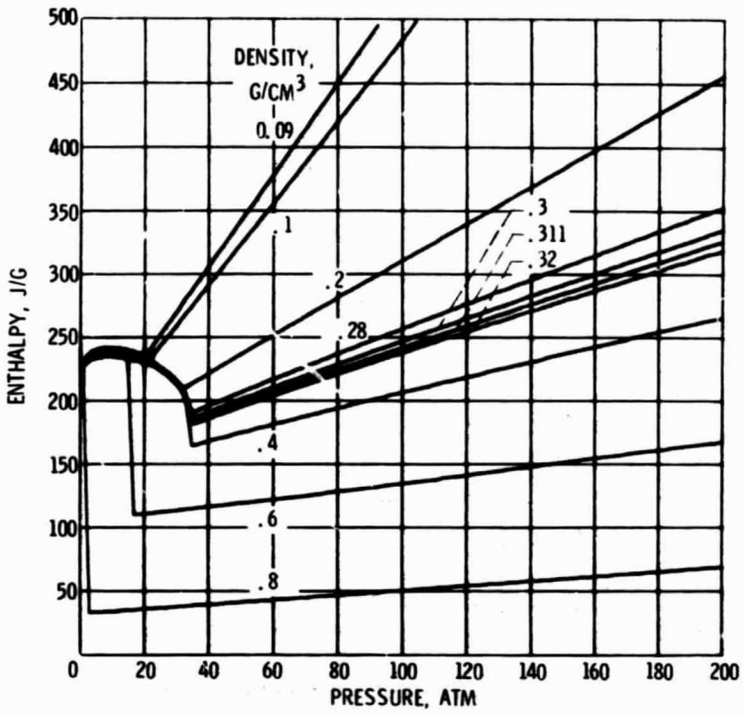

Figure 7. - Enthalpy as a function of pressure for various isobars.

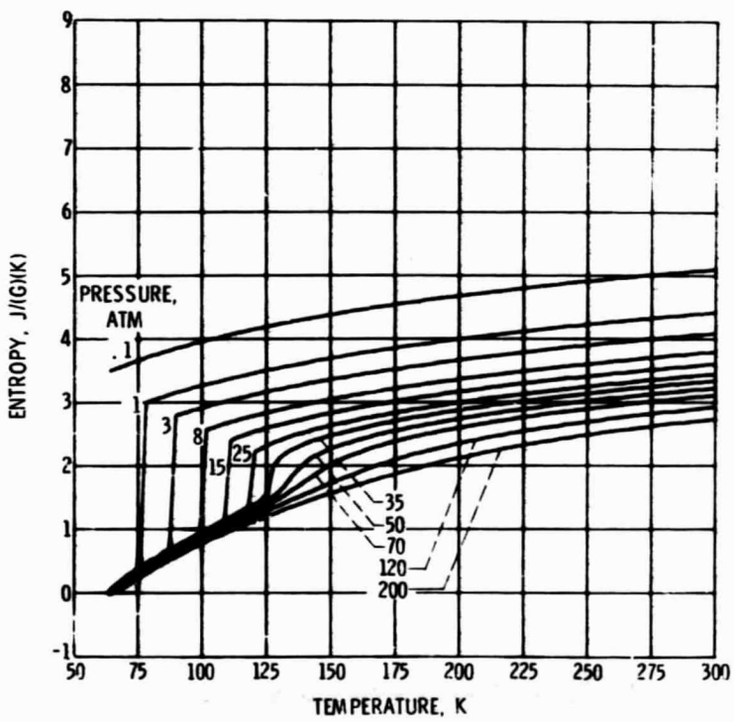

Figure 8. - Entropy as a function of temperature for various isobars.

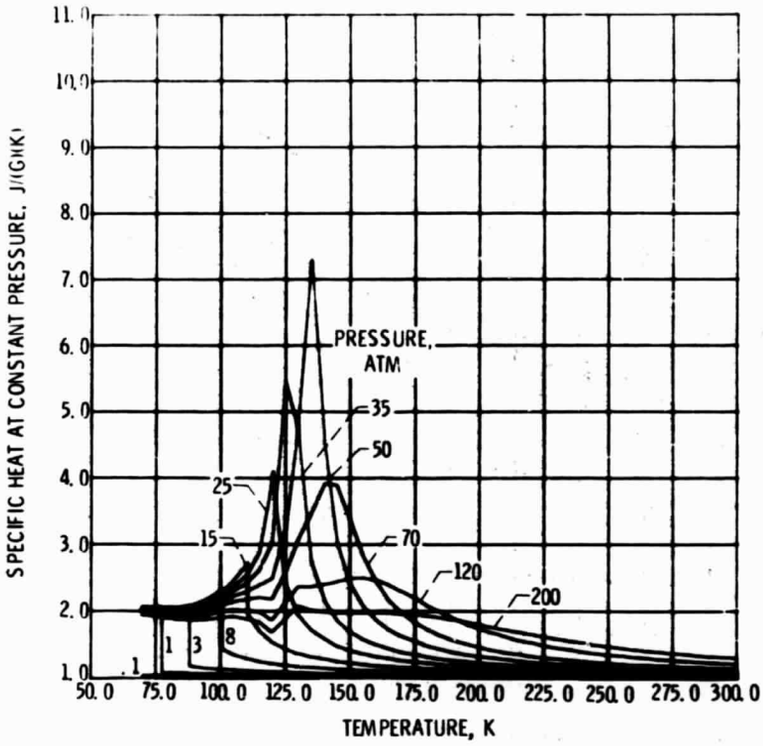

Figure 9(a). - Specific heat at constant pressure as a function of temperature for various isobars.

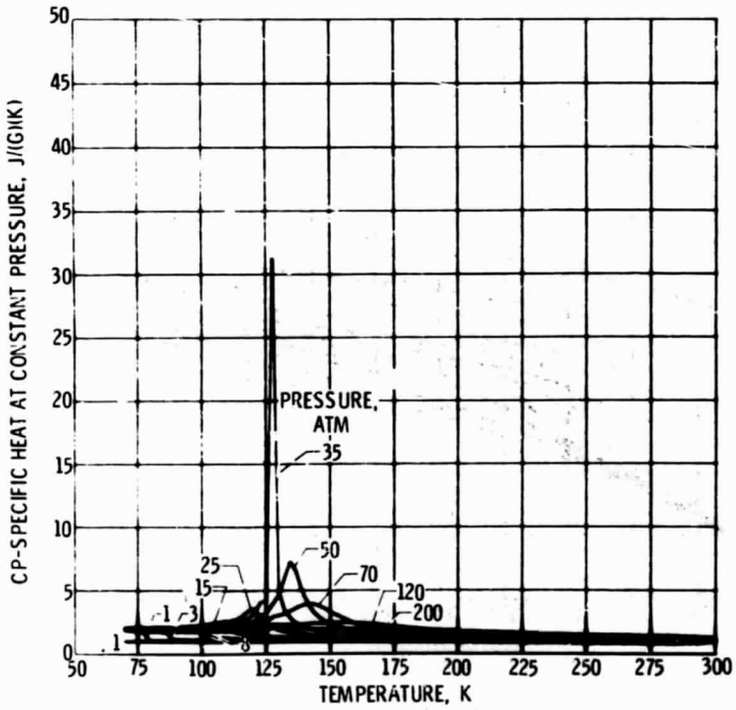

Figure 9(b). - Specific heat at constant pressure as a function of temperature for various isobars.

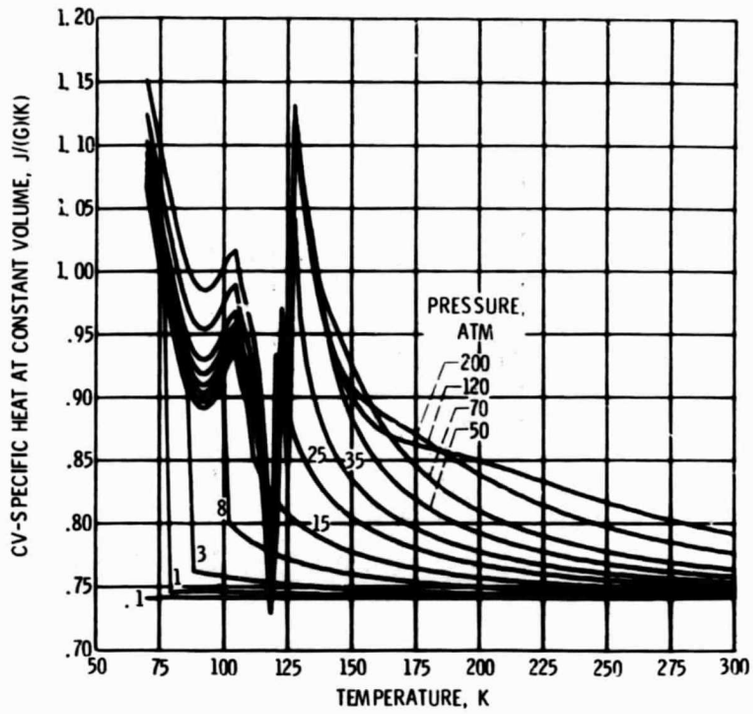

Figure 10. - Specific heat at constant volume as a function of temperature for various isobars.

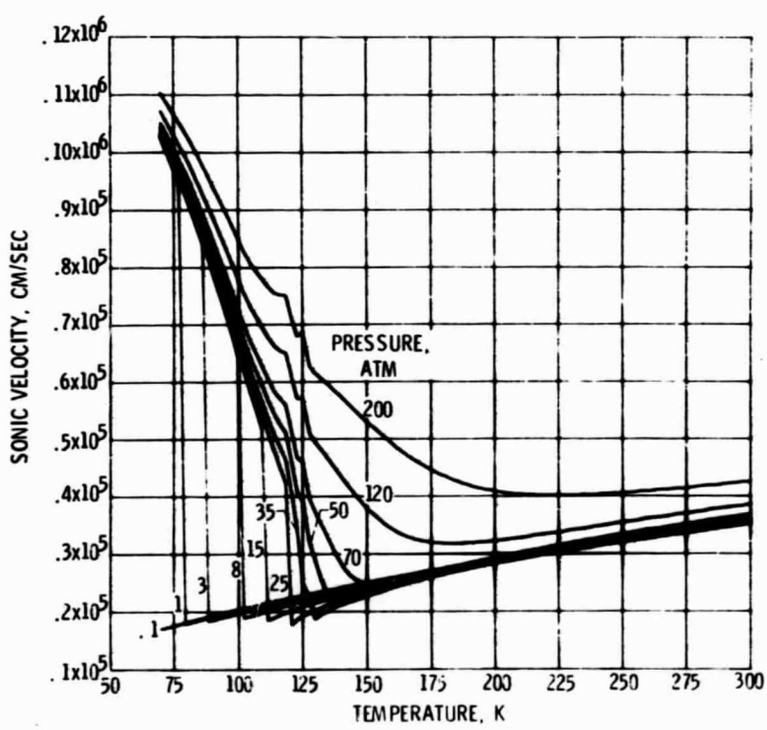

Figure 11. - Sonic velocity as a function of temperature for various isobars.

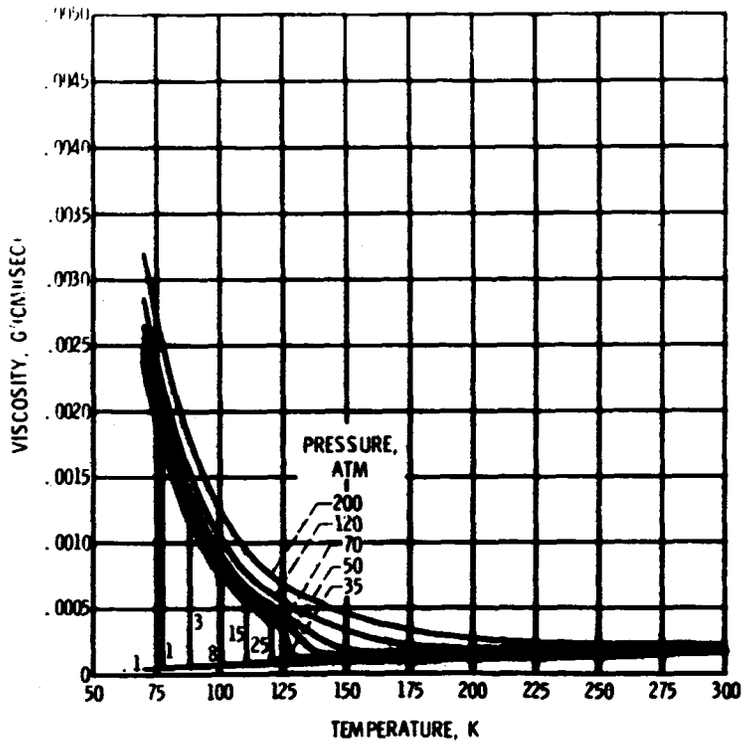

Figure 12. - Dynamic viscosity as a function of temperature for various isobars.

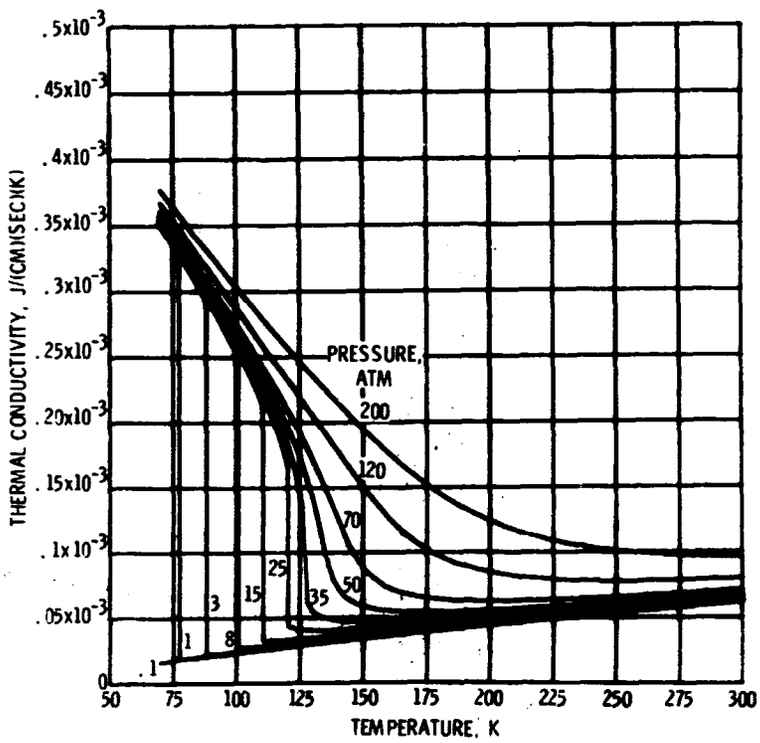

Figure 13. - Thermal conductivity as a function of temperature for various isobars.

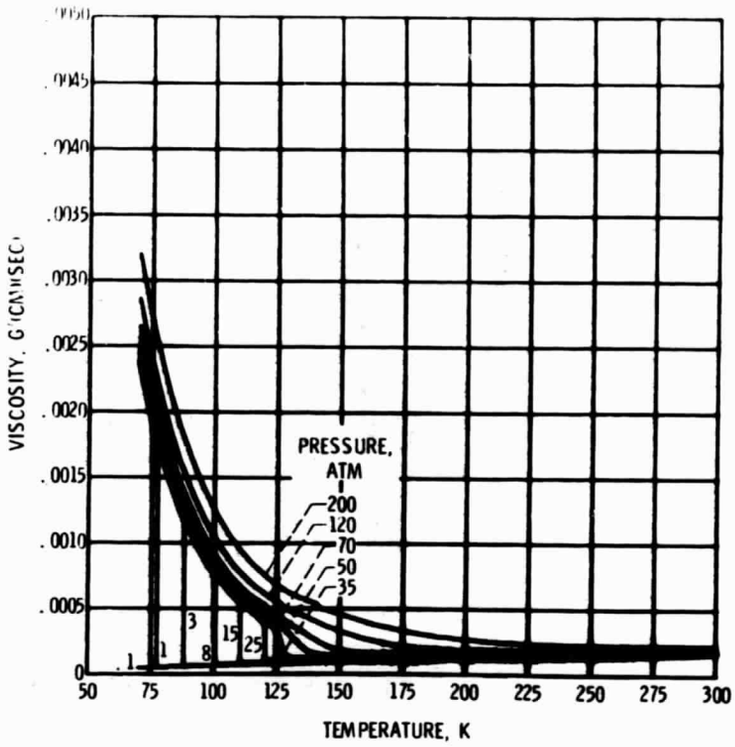

Figure 12. - Dynamic viscosity as a function of temperature for various isobars.

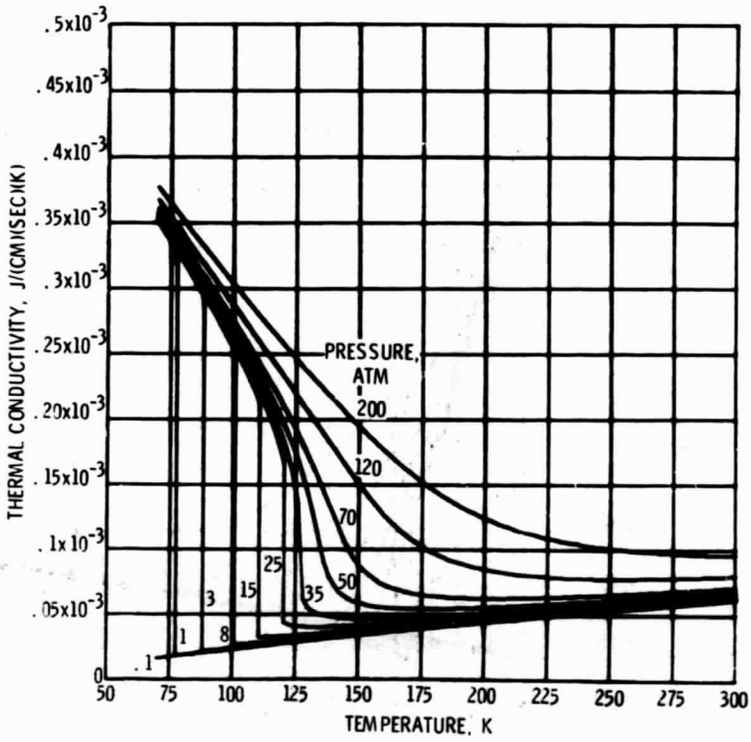

Figure 13. - Thermal conductivity as a function of temperature for various isobars.