CALCULATING MASS FLOW RATES AT SUB-SONIC CONDITIONS THROUGH VENTURIS (FT-4052-H & FT-4053-H) AND AN ORIFICE PLATE (FO-2019-H)

D0 Engineering Note: 3823.000-EN-450

AUGUST 15,1996

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Approved by:

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Table of Contents

1.	Purpose and the equations used throughout	1-3
2.	Table of Thermal Expansion Coefficients -conversion table	4
3.	Method and Procedure for Mass Flow Rate Calculation	5-11
	-Figure of Venturi Flowmeter	6
	-Figure of Orifice Plate Flowmeter	7
4.	Sample performance data provided by FLOW-DYNE	12-16
	-Drawing FDE-3582 ,Venturi Flowmeter	17
5.	Comparison of flow rates for the iterative and constant C and Fa methods	18-21
6.	Performance data for the actual venturis and orifice plate used (note the corrections)	22-27
7.	Graphs and equations for viscosity vs temperature, ratio of specific heats vs temperature and density vs temperature for the 14.7psia to 25psia inlet pressure range	28-58
8.	FORTRAN 77 program venturi.f	59-66
9.	TISOFT Special function	67-75
10.	References	76

The purpose of this engineering note is to explain the method involved in calculating the mass flow rates through venturis and orifice plates at sub-sonic conditions. In particular, the mass flow rate calculations are required for two FLOW-DYNE venturi flow meters, serial no. 35821 and no. 35822, and an orifice plate flow meter, serial no. 35823. The two venturis, FT-4052-H and FT-4053-H, are located in the D-Zero VLPC valve box at the refrigerator and the orifice plate, FO-2019-H, is on the high pressure helium supply line in the assembly building.

Equations and Parameters

For further analysis, knowledge of the following equations and their parameters is necessary. The equations were taken from FLOW-DYNE Engineering Inc. and adapted for the specific purpose of this paper. They are valid for the calculation of mass flow rates through ASME flow nozzles, venturis, and orifice plates:

$$m = 0.52502\left(\frac{CYd^2Fa}{\sqrt{1-\beta^4}}\right)\sqrt{\rho_1(p_1 - p_2)} \qquad [1]$$

m =	MASS FLOW RATE	lbm/sec
p_1 =	INLET STATIC PRESSURE	psia
p_2 =	THROAT STATIC PRESSURE	psia
ρ_1 =	FLUID DENSITY AT INLET CONDITIONS	lbm/cu-ft
d =	THROAT DIAMETER	in
β =	d / D = BETA RATIO, RATIO OF THROAT DIAMETER TO INLET DIAMETER	
C =	DISCHARGE COEFFICIENT	eq. 7a or 7b
Fa =	THERMAL CORRECTION FACTOR	eq. 9
Y =	EXPANSION FACTOR	eq. 4
$(p_1 - p_2)$ =	DIFFERENTIAL PRESSURE	eq. 2

If measuring the differential pressure in inches of water (room temperature), then

$$(p_1 - p_2) = h_W \frac{62.3164 lbm / cu - ft}{1728 cu - in / cu - ft} \qquad [2]$$

If the fluid is a dry gas then the inlet density may be computed with the general equation of state for an actual gas.

$$\rho_1 = \frac{p_1}{Z_1 R_g T_1} \qquad [3]$$

where:

p_1 =	INLET STATIC PRESSURE	psia
Z_1 =	COMPRESSIBLITY FACTOR AT INLET CONDITIONS	App
T_1 =	INLET TEMPERATURE	R
R_g =	SPECIFIC GAS CONSTANT	ft-lbf/lbm-R
=	1545.33 / MOLECULAR WEIGHT	
=	386.08 for Helium (m.w. 4.0026)	

The equation for the expansion factor is:

$$Y = \left[r^{2/\gamma} \left(\frac{\gamma}{\gamma - 1} \right) \left(\frac{1 - r^{\frac{\gamma-1}{\gamma}}}{1 - r} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 r^{2/\gamma}} \right) \right]^{1/2} \qquad [4]$$

where:

Y = EXPANSION FACTOR
r = p_2 / p_1 = PRESSURE RATIO
γ = c_p / c_v = RATIO OF SPECIFIC HEATS
β = d / D = BETA RATIO

For ASME square-edge orifice plates:

$$Y_1 = 1 - (0.410 + 0.350\beta^4)\, x/\gamma \qquad [5]$$

where:

Y_1 = EXPANSION FACTOR EVALUATED FROM PROPERTIES AT INLET CONDITIONS

$$x = (p_1 - p_2) / p_1 \qquad [6]$$

This equation is valid for corner, flange, vena contracta, and D and 1/2D taps. For jet velocities below the velocity of sound

The equations for the Discharge Coefficient (Sub-Sonic Operating Conditions) are:

- Machined Venturi/ASME flow Nozzle with Throat Taps:

  C = ASME Discharge Coefficient

$$C = 0.9975 - 0.00653(10^6 / Rd)^a \qquad [7a]$$

  $a = 1/2$ for $Rd < 10^6$
  $a = 1/5$ for $Rd > 10^6$

- ASME Flow Nozzle with Pipe Wall Taps at 1D and 1/2D:

$$C = 0.99622 + 0.00059D - (6.36 + 0.13D - 0.24\beta^2)Rd^{-0.5} \qquad [7b]$$

where:

$\beta = d / D$ = BETA RATIO
Rd= Throat Reynolds Number

$$Rd = (48/\pi) * (m/(d*\mu)) \qquad [8]$$

m = Mass Flow rate (lbm/sec) (see eq.1)
d = Throat Diameter (inch)
μ = Absolute Viscosity @ T_1 (lbm.ft-sec)

Thermal Correction Factor:

Fa = Thermal Correction Factor

$$Fa = 1 + 2*\alpha_{pe}*(T_F - 68) \qquad [9]$$

where:

α_{pe} = Coefficient of Thermal Expansion (see Table 1 below)

Temperature conversion:

$T_F = T_1$ (°F)

$$T_F = 1.8 * (T_1(K) - 273.15) + 32 \qquad [10]$$

TABLE 1 COEFFICIENTS OF THERMAL EXPANSION

Material		Coefficient of Thermal Expansion α, (in/(in F)
Plain Carbon Steel (SAE 1020)		
	70 - 600 °F	0.0000067
	-300 - 70 °F	0.0000047
Stainless Steels		
304	70 - 600 °F	0.0000095
	-300 - 70 °F	0.0000074
316	70 - 600 °F	0.0000096
	-300 - 70 °F	0.0000071
Hastelloy C		0.0000063
Inconel X, annealed		0.0000067
Yellow Brass (ASTM B152,B124,B133)		0.0000105
K-Monel		0.0000074
Titanium 70 - 212 °F		0.0000047
Tentalum 70 - 212 °F		0.0000036

(note: values selected from R.W. Miller, Flow Measurement Engineering Handbook, 2nd edition 1989, TABLE B.4)

USEFUL CONVERSIONS

To convert from _____ to _____ multiply the first by_____

kg/m^3	lb/cu-ft	$\frac{1}{16.018}$
micro Pa-s	lbm-ft/s	$\frac{10^{-6}}{(4.1338E-4)}\frac{}{(3600)}$
lbm/s	grams/s	453.592

Method & Procedure for Mass Flow Rate Calculation

VENTURIS

Having reviewed the above equations we may now proceed with the analysis. The mass flow rate through the venturi is calculated by determining the inlet fluid state (temperature and pressure for a single phase fluid) and the measured differential pressure between the inlet and throat. The mass flow rate is mainly dependent on the operating temperature, because as the temperature changes, the density of the fluid and the discharge coefficient (C) also change. Temperature also has an affect on the value of the viscosity as well as on the specific heat ratio. Since the mass flow rate is a function of the density and the discharge coefficient, it becomes a function of the temperature and a provision for the temperature variable must be made. Given the measured pressure and temperature of the fluid one must, via a computer program (using Cricket Graph for the Macintosh is suggested), curve fit to obtain correct values of ρ(density), μ(viscosity), c_p/c_v (specific heat ratio) to use in the mass flow equations. The data points necessary must be obtained from a thermodynamic properties table for helium for each pressure increment in the expected operating range. (Note: Example curves and equations have been attached to this engineering note for inlet static pressures from 14.7 psia to 25 psia. There are two graphs for each variable, one for temperatures of less than 15 K while the other is for temperatures of 15 to 300 K). In the case of the D-zero venturis (see dwg. FDE 3582 on page 17), the operating temperature range is usually 4 to 15 Kelvin, while the pressure range is approximately 14.7 psia to 25 psia. The actual pressure readings from PT-4084-H and PT-4086-H are measured in gauge pressure,0 psig to 7.5 psig;

therefore, a conversion from gauge to absolute pressure is necessary. This can most easily be achieved using equation [11] below, where the atmospheric pressure is assumed to be about 14.5 psia based on Fermilab's elevation above sea level.

$$P_{abs} = P_{gauge} + P_{atm} \qquad [11]$$

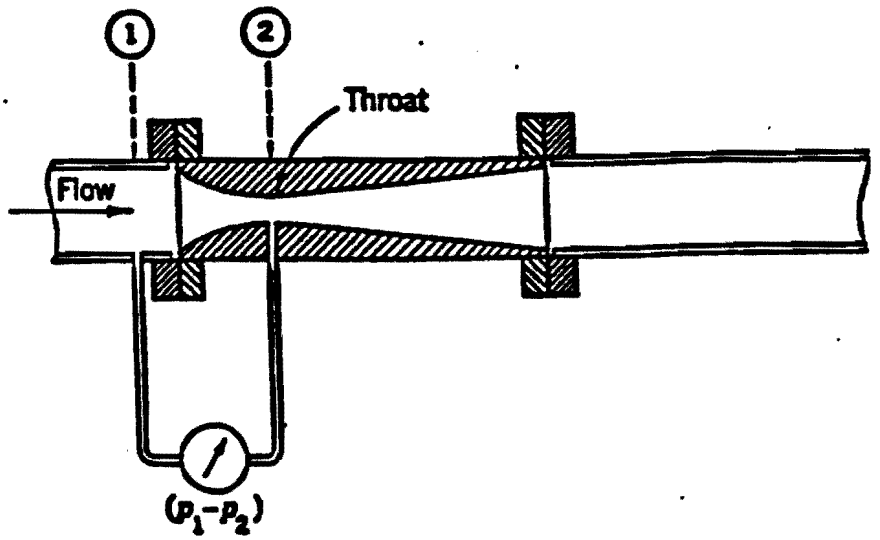

Figure 1. Venturi Flowmeter

ORIFICE PLATES

On the other hand, the temperature varies slightly for the orifice plate(see Figure 2) and it is assumed to be constant at 294 K or room temperature. The pressure range of the orifice plate is measured by the D0BPXHP pressure transmitter whose range is 14.7 to 514.7 psia (normal operating conditions have been observed to be 170 to 310 psia). Since the pressure transmitter for the orifice plate also measures in gauge pressure, equation [11] will have to be used once again. Unlike the venturi, the orifice plate flow meter will not require extensive equations for density, viscosity and the specific heat ratio. Since the conditions at 294 K are nearly ideal we can use equation [3] to determine the density.

Also, since the values for the viscosity and the specific heat ratio vary slightly at this higher temperature, their values can be assumed to be 1.6646 and 1.342E-5 lb/ft-s, for the specific heat ratio and viscosity, respectively.

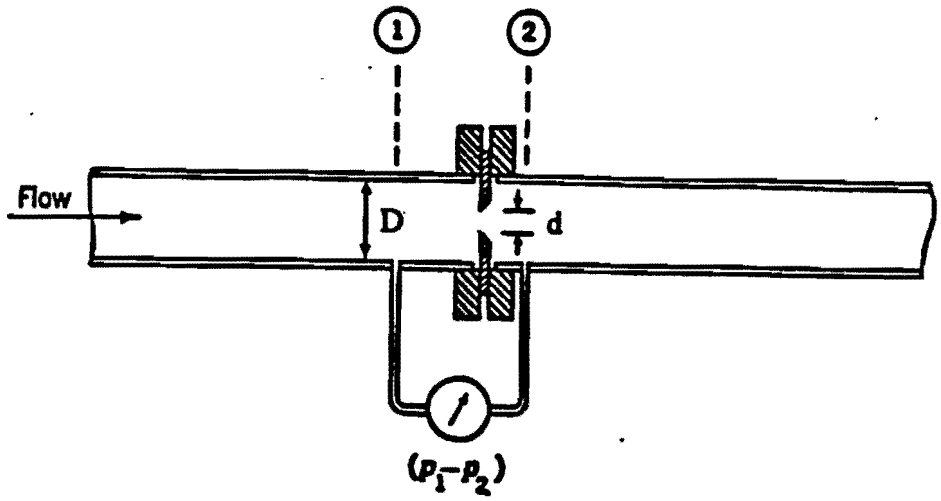

Figure 2. Orifice Plate Flowmeter

PROCEDURE

After having obtained the necessary data above, the first step is to calculate the expansion factor (Y) using equation [4] for a venturi and equation [5] for an orifice plate. The necessary values include: the beta ratio (β), inlet static pressure (p_1), throat static pressure (p_2), and the ratio of specific heats (r). If the inlet static pressure is between two of the pressure increments in the curve fitted equations, then it may be necessary to interpolate between these two pressures to obtain the ratio of specific heats (r). Similarly, interpolation such as the one described above will most likely be necessary when calculating the density and the viscosity in later equations.

The next step involves calculating the thermal correction factor (Fa). In order to do this we must determine the coefficient of thermal expansion based upon the material type used for the venturis and the orifice plate from Table 1. It may be necessary to convert the inlet temperature into degree Fahrenheit using equation [10] in order to calculate the thermal correction factor.

After obtaining the necessary values above, we can calculate the mass flow rate. It is clearly evident that the mass flow rate is a function of the discharge coefficient (C) which in turn is a function of the throat Reynold's number (Rd), while the Reynold's number is itself a function of the mass flow rate. This inter twining of equations means that an iterative process will be necessary. Thus, the first step requires an educated guess of a value for the discharge coefficient (C). This value varies slightly as the mass flow rate changes and is usually around 0.9 for a venturi and 0.6 for an orifice plate. This guess is then entered into the mass flow rate equation and an answer is obtained. The mass flow rate is then entered into equation [8] to obtain the throat Reynold's number (Rd). Finally, the throat Reynold's number is placed into the corresponding discharge coefficient equation (7a or 7b), and this answer is then compared to the guess with which this iteration began. If the two values match closely then no further calculation for mass flow rate is necessary. On the other hand, if the values are not within 2 or 3 percent difference then the iterative process will have to be repeated with the first guess being replaced by the new value for the discharge coefficient.

As we can see, the process of calculating the mass flow rate is a rather complicated and time consuming event. Because these equations are to be inputted into the Programmable Logic Controller (PLC), it is imperative that the number of

calculations performed be as minimal as possible in order to conserve time and memory. Due to this overwhelming memory concern, an attempt to cut processor time has been made. The first step involves an assumption that the discharge coefficient (C) is a constant value. This assumption was made based on the observation that the value of (C) did not change significantly as the mass flow rate varied. In fact, it remained nearly constant at 0.986 for the venturi and 0.604 for the orifice plate. These values were obtained by taking some average value of (C) for the two extreme differential pressures in the performance data provided by FLOW-DYNE. Another assumption made was that the thermal correction factor (Fa) also did not change much for our range of temperatures. Therefore, the thermal correction factor (Fa) was also assumed to be constant. The values chosen are 0.992 for the venturi and 1.00002 for the orifice plate. The venturi thermal correction factor was obtained by taking the average value for the 4 K to 15 K temperature range while the value for the orifice plate was calculated at 294 K. In order to verify that the mass flow rate does not deviate significantly from the iterated data, comparison calculations have been made. The percent difference between the mass flow rate for the iterated and constant Fa & C values was never more than 0.7 percent. A comparison with the FLOW-DYNE performance data gave percent differences of at most 4 percent.

These results have further strengthened the notion that Fa and C may be considered constant for our 4 K to 15 K temperature range for the venturi and the 294 K point for the orifice plate. The final equations that will be used are as follow:

(note: These equations assume constant C & Fa)

* For a venturi with C = 0.986 and Fa = 0.992

$$m = \left(0.514564\left(\frac{Yd^2}{\sqrt{1-\beta^4}}\right)\sqrt{\rho_1(p_1 - p_2)}\right)453.592 \qquad [g/s]$$

* For an orifice plate with C = 0.604 and Fa = 1.00002

$$m = \left(0.317169\left(\frac{Yd^2}{\sqrt{1-\beta^4}}\right)\sqrt{\rho_1(p_1 - p_2)}\right)453.592 \qquad [g/s]$$

It should be noted that the above assumptions may not be valid for larger ranges or higher temperatures. Therefore, it is necessary to perform comparison calculations similar to the ones mentioned above in order to be within bounds of experimental error. In order to aid in these calculations, a program using FORTRAN 77 has been written. It is called 'venturi.f' and is attached to the back of this engineering note. The main features of this program include the display of the important variables as well as a comparative display of the mass flow rate for each method of calculation. A percent difference is also provided to help the user determine which method is best suited for his needs. In order to make the program more flexible, only the variable inputs (temperature, pressures, inlet and throat diameters, etc.) are requested during the run. The constant values for Fa and C mentioned above have already been entered into the main program. This allows the user to refrain form having to edit and compile the program before every run.

The final equations and constants are now ready to be entered into a special function format for input into the PLC. The TISOFT program will be used to write this

special function and then it will be loaded into the PLC. A sample copy of the actual special function has also been attached to this engineering note. The ultimate goal of the special function is to provide a connection between the PLC and a user interface. This interface is the Fermilab DMACS server which displays graphical output of monitored operations such as the mass flow rates through the venturis and the orifice plate.

(1) Sample Performance Data for a Venturi and an Orifice plate used to verify the mass flow rate equations.

(2) Comparison data for mass flow rate calculation using the iterative and constant C & Fa methods

• CRITICAL FLOW VENTURIS
• VENTURI TUBES
• FLOW NOZZLES
• ORIFICE PLATES AND FLANGES
• METER RUNS
• TEST STANDS AND SYSTEMS

PRIMARY FLOWMETERS SINCE 1969

FLOW-DYNE *Engineering, Inc.*
MAIL – P.O. Box 161655 • Fort Worth, Texas 76161-1655
PLANT – 4108 Garland Drive • Fort Worth, Texas 76117
TEL. 817-281-6448 FAX: 817-581-0936

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FACSIMILE COVER SHEET

PAGE 1

TO: FERMILAB

DATE: 25 JULY 95

TIME:

ATTN: STEVE SAKLA

PAGES: 4

ZONE:

REF: VENTURI FLOWMETER AND ORIFICE PLATES

FAX: 708-840-8481

TEL: 708-840-5640

FROM: TYSON SCHMIDT

ZONE: ENGINEERING

REF: Q0695-23B

STEVE,

ENCLOSED IS A COPY OF THE NEW QUOTE FOR THE VENTURI FLOWMETERS AND ORIFICE PLATE WITH FLANGES. I DID NOT TAKE THE TIME TO DO THE INTERPOLATIONS REQUIRED TO GET THE ACTUAL Properties for SIZING THE THROATS AND BORES. BUT I DID RUN SOME PERFORMANCE DATA AT 14.7 PSIA AND 17.4 PSIA FOR THE VENTURI. THE ERROR WAS ABOUT 1%.

JUST LOOKING AT THE DENSITY CHANGE FOR THE ORIFICE PLATES FROM 1.4MPa & 280K AND 2.2 MPa & 280K THERE WILL BE A HUGE ERROR, THEREFORE THE EQUATIONS WILL BE NEEDED. CALL ME IF YOU HAVE ANY QUESTIONS OR CONCERNS: 817-281-6448

SINCERELY,
FLOW-DYNE ENGINEERING, INC.

Tyson Schmidt

TYSON SCHMIDT
ENGINEERING

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QUOTATION

DATE: 25 JULY 95
QUOTATION NO: Q069523B
COMPANY: FERMILAB

QTY	ITEM	DESCRIPTION	UNIT COST	AMOUNT
2	01	VENTURI FLOWMETER MATERIAL: 304-SS END CONN: SOCKET WELD LINE: 5/8" OD x 0.049 WALL	825.00	1650.00
1	02	ORIFICE PLATE ASSEMBLY ORIFICE PLATE MAT.: 304-SS FLANGE: RAISED FACED SLIP ON; 304-SS LINE: 2" SCH 10 PIPE	650.00	650.00
1	04	ORIFICE PLATE ASSEMBLY ORIFICE PLATE MAT.: 304-SS FLANGE: RAISED FACED SLIP ON; 304-SS LINE: 3/4" SCH 10 PIPE	525.00	525.00
			TOTAL	2,825.00

NOTES:
DELIVERY: 4-6 WEEKS.
ALL ITEMS FOB FORT WORTH, TEXAS.
SHIPMENT VIA BEST WAY.
TERMS 1% 10 NET 30 DAYS.
QUOTATION GOOD FOR 90 DAYS.

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Date 07-25-1995 Time 11:40:24

PRIMARY ELEMENTS

**** Performance Data ****

Based Upon;

Primary Element Type	Subsonic Venturi	
Flowing Gas	HELIUM	
Molecular Weight	4.0026	
Inlet Density	8.256258	kg/m^3
Compressibilty Factor	0.9088	
Specific Heat Ratio	1.8800	
Absolute Viscosity	1.6860E-03	cp
Inlet Static Pressure	101.3250	kPa(a)
Inlet Temperature	6.5000	K
Throat Diameter	0.2108	in
Inlet Diameter	0.527	in
Beta Ratio	0.4000	
Coef. of Thermal Expansion	7.40E-06	in/in*F
Thermal Expansion Factor	0.9924	
Discharge Coefficient	Theoretical	

DP/P: Diff. Press./Inlet Press. (PSID/PSIA)
P: Inlet Static Pressure (PSIA)
T: Inlet Temperature (RANKINE)
W: Flowrate (IN UNITS AS SPECIFIED)
Rd: Throat Reynolds No.
Cd: Discharge Coefficient
Y: Gas Expansion Factor

DP (in H2O)	DP/P	W√T/P (lbm/s)	W (lbm/s)	Rd	Cd	Y
60.000	.14724	5.351E-03	2.299E-02	1,470,814	0.9915	0.9361
50.000	.12270	4.942E-03	2.123E-02	1,358,455	0.9914	0.9472
40.000	.09816	4.471E-03	1.921E-02	1,228,878	0.9912	0.9581
30.000	.07362	3.915E-03	1.682E-02	1,075,966	0.9911	0.9689
20.000	.04908	3.229E-03	1.387E-02	887,641	0.9906	0.9794
10.000	.02454	2.305E-03	9.902E-03	633,490	0.9893	0.9898
5.000	.01227	1.636E-03	7.027E-03	449,567	0.9878	0.9949
3.000	.00736	1.268E-03	5.447E-03	348,479	0.9864	0.9970
1.000	.00245	7.309E-04	3.140E-03	200,888	0.9829	0.9990

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Date 07-25-1995 Time 12:20:10

PRIMARY ELEMENTS

**** Performance Data ****

Based Upon;

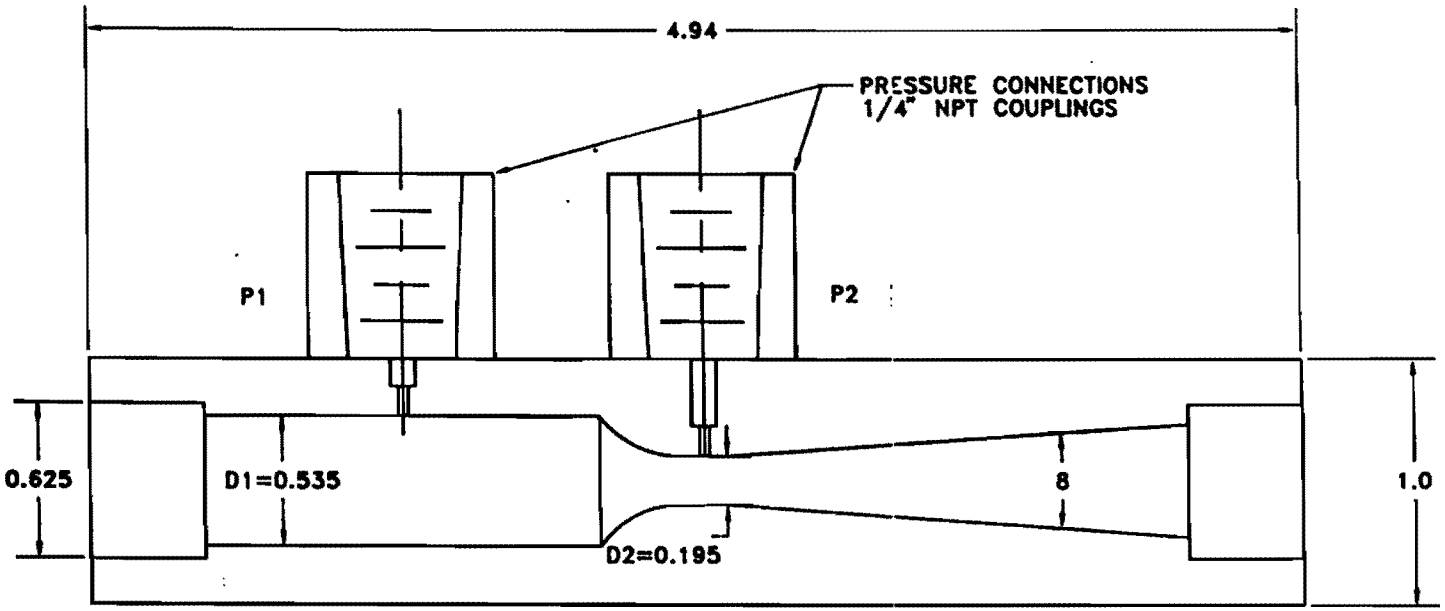
Primary Element Type	Subsonic Venturi	
Flowing Gas	HELIUM	
Molecular Weight	4.0026	
Inlet Density	9.974410	kg/m^3
Compressibilty Factor	0.8909	
Specific Heat Ratio	1.9320	
Absolute Viscosity	1.7100E-03	cp
Inlet Static Pressure	120.0000	kPa(a)
Inlet Temperature	6.5000	K
Throat Diameter	0.2108	in
Inlet Diameter	0.527	in
Beta Ratio	0.4000	
Coef. of Thermal Expansion	7.40E-06	in/in*F
Thermal Expansion Factor	0.9924	
Discharge Coefficient	Theoretical	

DP/P: Diff. Press./Inlet Press. (PSID/PSIA)
P: Inlet Static Pressure (PSIA)
T: Inlet Temperature (RANKINE)
W: Flowrate (IN UNITS AS SPECIFIED)
Rd: Throat Reynolds No.
Cd: Discharge Coefficient
Y: Gas Expansion Factor

DP (in H2O)	DP/P	W√T/P (lbm/s)	W (lbm/s)	Rd	Cd	Y
60.000	.12433	5.029E-03	2.559E-02	1,614,158	0.9916	0.9479
50.000	.10361	4.634E-03	2.358E-02	1,487,361	0.9915	0.9569
40.000	.08288	4.183E-03	2.128E-02	1,342,493	0.9913	0.9658
30.000	.06216	3.655E-03	1.860E-02	1,172,954	0.9912	0.9745
20.000	.04144	3.009E-03	1.531E-02	965,868	0.9909	0.9831
10.000	.02072	2.144E-03	1.091E-02	688,021	0.9896	0.9916
5.000	.01036	1.520E-03	7.734E-03	487,838	0.9882	0.9958
3.000	.00622	1.178E-03	5.993E-03	378,026	0.9869	0.9975
1.000	.00207	6.788E-04	3.454E-03	217,872	0.9835	0.9992

DESIGN PT. 1

1.21×10^{-2} 1 3/5 = 5.5



NOTE: SERVICE FOR HELIUM GAS AT 16.7 PSIA AND 6.7 K TO FLOW 0.0198 LBM/SEC @ A DIFFERENTIAL PRESSURE OF 50.6 INWC.

QTY	PART NO.	DESCRIPTION	MATERIAL	SEE NOTE	ITEM NO.
2	V100195-SSW		304-SS		

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED: TOLERANCES
2 PLACE DECIMAL +/- .010
3 PLACE DECIMAL +/- .005
FRACTION +/- 1/64
ANGULAR +/- -30'
REMOVE BURRS AND BREAK ALL CORNERS .005 MAXIMUM.
ALL DIMENSIONS ARE IN INCHES
DO NOT SCALE

DWN.BY TS DATE 25 SEPT 95
CHECKED
ENGRG.

FLOW-DYNE *Engineering, Inc.*
P.O. BOX 161655 FORT WORTH TEXAS 76161
TEL: 817 281-6448 FAX: 817 581-0936

TITLE
VENTURI FLOWMETER INSTALLATION FOR 5/8" O.D. x 0.049" WALL TBG. SOCKET WELD TYPE END CONN.

SIZE B
DWG. NO. FDE 3582
SCALE NONE
SHEET OF

NOTICE
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For the Venturi Flow meter:

```
TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=     1.00000
-----------------------------------------------------------------------
        DP          W[lbm/s]    Rd           Cd        Y
-----------------------------------------------------------------------
(1)    1.00000    3.14616E-03              0.986000   0.998997

(2)    1.00000    3.13757E-03    200778.   0.982927   0.998997
-----------------------------------------------------------------------
% DIFFERENCE=      0.274%
NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant
 ==============================================================
(P1-P2)=    3.60627E-02  r=   0.997546  BETA=   0.400000
 ==============================================================
VISCOSITY     =    1.13266E-06 lb/ft-s
DENSITY       =   0.514635 lb/cu-ft
GAMMA(y)      =    1.87647

Mass flow rate in grams/s :
           1.42707  (1)
           1.42318  (2)
```

****

```
TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=     3.00000
-----------------------------------------------------------------------
        DP          W[lbm/s]    Rd           Cd        Y
-----------------------------------------------------------------------
(1)    3.00000    5.43811E-03              0.986000   0.996944

(2)    3.00000    5.44010E-03    348121.  0.   0.996944
-----------------------------------------------------------------------
% DIFFERENCE=      0.037%
NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant

 ==============================================================
(P1-P2)=   0.108188  r=   0.992638  BETA=   0.400000
 ==============================================================
VISCOSITY     =    1.13266E-06 lb/ft-s
DENSITY       =   0.514635 lb/cu-ft
GAMMA(y)      =    1.87647

Mass flow rate in grams/s :
           2.46668  (1)
           2.46759  (2)
```

```
*************************************************************************

TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=     5.00000
 ---------------------------------------------------------------------
        DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)    5.00000    7.00620E-03              0.986000   0.994905

 (2)    5.00000    7.00877E-03    448503.  0.   0.994905
 ---------------------------------------------------------------------
 % DIFFERENCE=      0.037%
 NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=   0.180314  r=   0.987730  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
           3.17796  (1)
           3.17912  (2)

*************************************************************************

TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=    10.00000
 ---------------------------------------------------------------------
        DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)   10.00000    9.85713E-03              0.986000   0.989770

 (2)   10.00000    9.89354E-03    633104.   0.989293   0.989770
 ---------------------------------------------------------------------
 % DIFFERENCE=      0.368%
 NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=   0.360627  r=   0.975461  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
           4.47112  (1)
           4.48763  (2)
```

```
*************************************************************************

TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=     20.0000
 ---------------------------------------------------------------------
         DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)    20.0000    1.37937E-02               0.986000   0.979376

 (2)    20.0000    1.38624E-02    887080.    0.990567   0.979376
 ---------------------------------------------------------------------
 % DIFFERENCE=      0.496%
 NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=   0.721255  r=   0.950922  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
            6.25671  (1)
            6.28789  (2)

*************************************************************************

TEMP=     6.50000K  STAT.PRES.=     14.6960    DIFF.PRES.=     30.0000
 ---------------------------------------------------------------------
         DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)    30.0000    1.67115E-02               0.986000   0.968811

 (2)    30.0000    1.68034E-02    1.07528E+06   0.991064   0.968811
 ---------------------------------------------------------------------
 % DIFFERENCE=      0.547%
 NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=    1.08188  r=   0.926383  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
            7.58021  (1)
            7.62188  (2)
```

```
*************************************************************************

TEMP=      6.50000K  STAT.PRES.=      14.6960    DIFF.PRES.=      40.0000
 ---------------------------------------------------------------------
          DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)     40.0000    1.90828E-02                0.986000   0.958070

 (2)     40.0000    1.91910E-02    1.22807E+06   0.991233   0.958070
 ---------------------------------------------------------------------
 % DIFFERENCE=       0.564%
 NOTE: (2) ITIRATED VALUES          (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=     1.44251  r=   0.901843  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
            8.65583  (1)
            8.70490  (2)

*************************************************************************
*

TEMP=      6.50000K  STAT.PRES.=      14.6960    DIFF.PRES.=      50.0000
 ---------------------------------------------------------------------
          DP          W[lbm/s]    Rd            Cd        Y
 ---------------------------------------------------------------------
 (1)     50.0000    2.10919E-02                0.986000   0.947142

 (2)     50.0000    2.12141E-02    1.35753E+06   0.991357   0.947142
 ---------------------------------------------------------------------
 % DIFFERENCE=       0.576%
 NOTE: (2) ITIRATED VALUES          (1) Cd and Fa are constant

 ==================================================================
 (P1-P2)=     1.80314  r=   0.877304  BETA=   0.400000
 ==================================================================
 VISCOSITY     =    1.13266E-06 lb/ft-s
 DENSITY       =   0.514635 lb/cu-ft
 GAMMA(y)      =    1.87647

 Mass flow rate in grams/s :
            9.56713  (1)
            9.62257  (2)
```

Performance data for the FT-4052-H & FT-4053-H venturis and the FO-2019-H orifice plate

(note: The venturi data is incorrect. Corrections have been made next to the FLOW-DYNE values)

• VENTURI TUBES
• FLOW NOZZLES
• ORIFICE PLATES AND FLANGES
• METER RUNS
• TEST STANDS AND SYSTEMS

PRIMARY FLOWMETERS
SINCE 1969

FLOW-DYNE Engineering, Inc.
MAIL – P.O. Box 161655 • Fort Worth, Texas 76161-1655
PLANT – 4108 Garland Drive • Fort Worth, Texas 76117
TEL. 817-281-6448 FAX: 817-581-0936

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• Manufacturing
• Calibration
• Software

25 September 1995

Fermilab
Receiving Dept.
Batavia, Ill. 60510

Attention: D. Rogus
Purchasing Contact

Subject: Fermilab P.O. U11770

Ladies/Gentlemen:

Please keep this booklet. It contains:

TECHNICAL DATA
FOR
VENTURI FLOWMETER
&
ORIFICE PLATE
FLOW-DYNE ENGINEERING
P/N: V100195-SSW; S/N: 35821, 35822
P/N: OPP020947-S; S/N: 35823

Enclosed are:

1. Venturi and Orifice Plate Theoretical Performance Curves and Data
2. Venturi Installation Drawing
3. Orifice Plates and Flanges Bulletin OP401

Thank you for this opportunity to be of service.
Sincerely,

Tyson Schmidt

Tyson Schmidt
Engineering

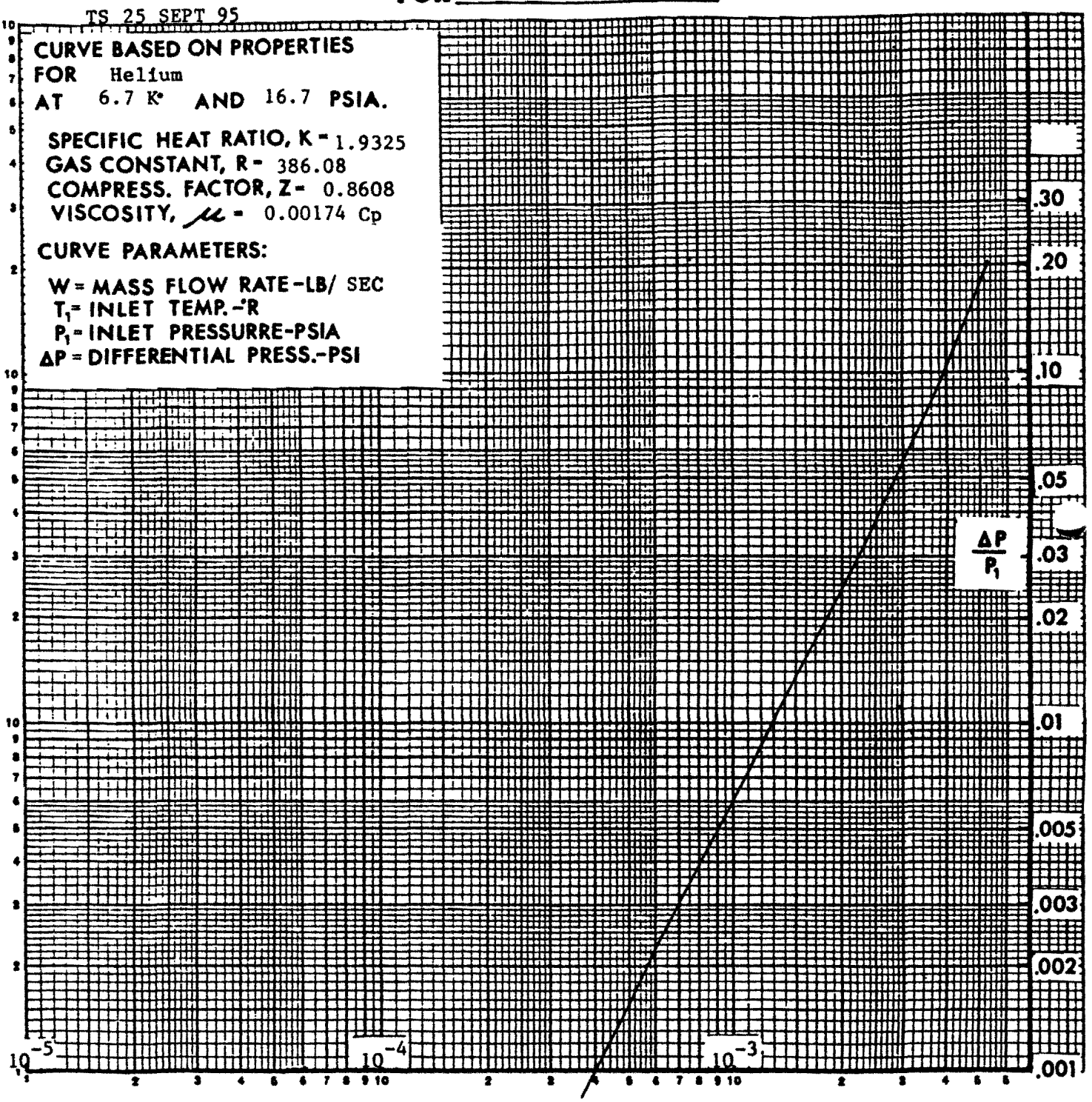
FLOWMETERS—Liquid—Gaseous—Cryogenic
P. O. BOX 9034
FORT WORTH, TEXAS 76107
(817) 732-2859

P/N: V100145-SSW
S/N: 35821; 35822
THROAT DIA: 0.195"
LINE SIZE: 5/8" OD x 0.049" wall
LENGTH: 4.94"

VENTURI PERFORMANCE CURVE

FOR Helium

TS 25 SEPT 95



• CRITICAL FLOW VENTURIS
• VENTURI TUBES
• FLOW NOZZLES
• ORIFICE PLATES AND FLANGES
• METER RUNS
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PLANT – 4108 Garland Drive • Fort Worth, Texas 76117
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• Calibration
• Software

0-50" H_2O FT 4052 H WX 3098
0-50" H_2O FT 4053 H WX 3099

Date 09-22-1995 Time 15:22:14

PRIMARY ELEMENTS

**** Performance Data ****

Based Upon;

			Corrections
Primary Element Type	Subsonic Venturi		
Flowing Gas	Helium		
Molecular Weight	4.0026		
Inlet Density	0.599860	lbm/ft^3	0.573135 lbm/ft^3
Compressibilty Factor	0.8608		0.90314
Specific Heat Ratio	1.9325		1.90055
Absolute Viscosity	1.7397E-03	cp	1.73664 e-03 cp

Inlet Static Pressure	16.6960	psia
Inlet Temperature	6.7000	K
Throat Diameter	0.1950	in
Inlet Diameter	0.536	in
Beta Ratio	0.3638	
Coef. of Thermal Expansion	7.40E-06	in/in*F
Thermal Expansion Factor	0.9924	
Discharge Coefficient	Theoretical	

DP/P: Diff. Press./Inlet Press. (PSID/PSIA)
P: Inlet Static Pressure (PSIA)
T: Inlet Temperature (RANKINE)
W: Flowrate (IN UNITS AS SPECIFIED)

Rd: Throat Reynolds No.
Cd: Discharge Coefficie
Y: Gas Expansion Facto

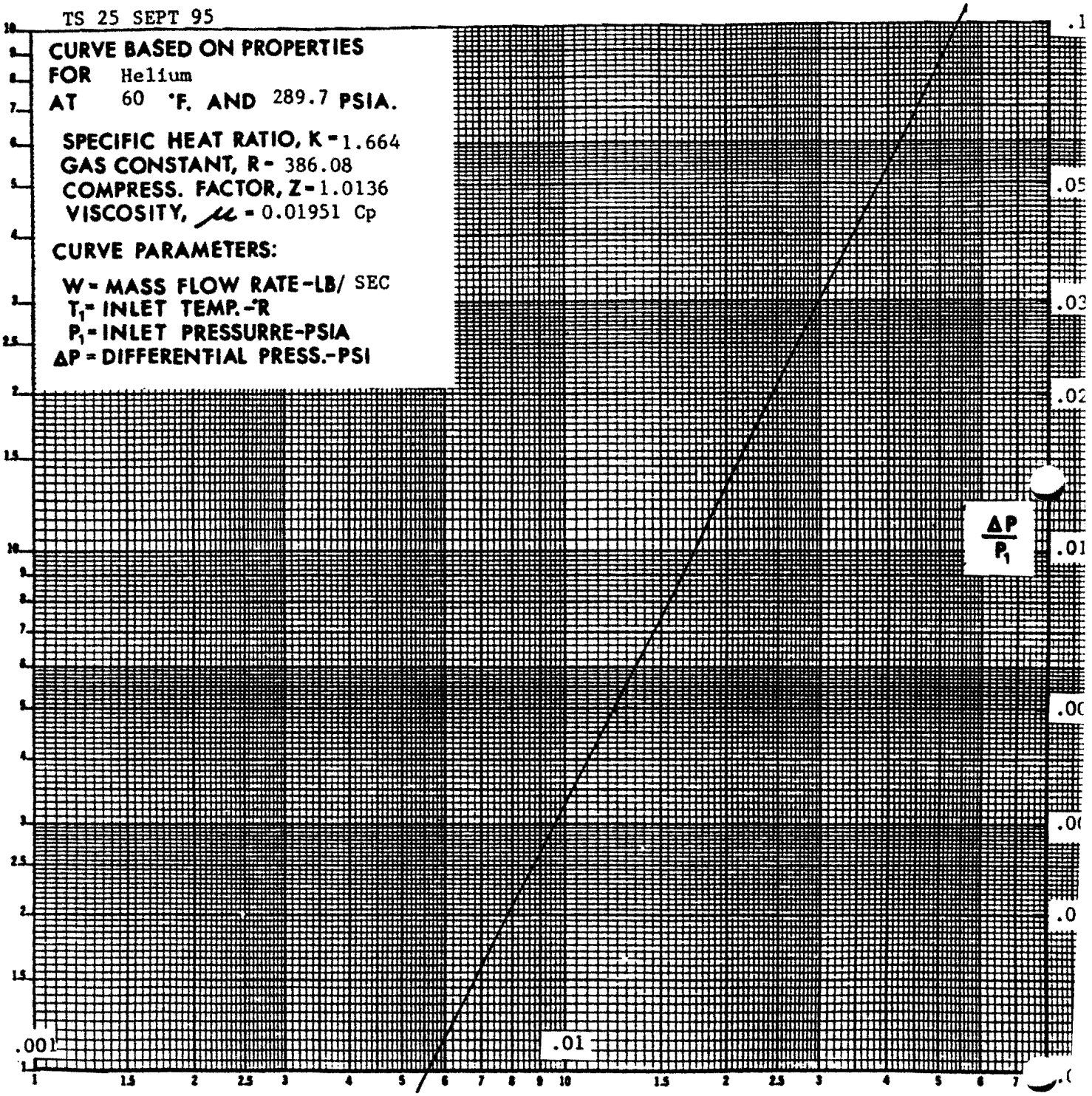
DP (in H2O)	DP/P	W√T/P (lbm/s)	W (lbm/s)	Rd	Cd	Y
92.594	.20000	5.337E-03	2.566E-02	1,719,636	0.9916	0.9146
69.445	.15000	4.735E-03	2.276E-02	1,525,752	0.9915	0.9372
46.297	.10000	3.955E-03	1.901E-02	1,274,327	0.9913	0.9589
23.148	.05000	2.856E-03	1.373E-02	920,196	0.9907	0.9798
13.889	.03000	2.228E-03	1.071E-02	718,067	0.9898	0.9880
4.630	.01000	1.294E-03	6.221E-03	416,939	0.9874	0.9960
2.315	.00500	9.150E-04	4.399E-03	294,839	0.9855	0.9980
1.389	.00300	7.081E-04	3.404E-03	228,183	0.9838	0.9988
0.463	.00100	4.074E-04	1.958E-03	131,263	0.9795	0.9996

FLOW-DYNE *Engineering, Inc.*
FLOWMETERS—Liquid—Gaseous—Cryogenic
P. O. BOX 9034
FORT WORTH, TEXAS 76107
(817) 732-2859

ORIFICE P/N: OPP020947-S
S/N: 35823
THROAT DIA: 0.947"
LINE SIZE: 2" SCH 10S PIPE
LENGTH:

ORIFICE PERFORMANCE CURVE
FOR HELIUM

TS 25 SEPT 95



• CRITICAL FLOW VENTURIS
• VENTURI TUBES
• FLOW NOZZLES
• ORIFICE PLATES AND FLANGES
• METER RUNS
• TEST STANDS AND SYSTEMS

PRIMARY FLOWMETERS
SINCE 1959

WX 3073 0-5 PSIL

FLOW-DYNE *Engineering, Inc.*
MAIL – P.O. Box 161655 • Fort Worth, Texas 76161-1655
PLANT – 4108 Garland Drive • Fort Worth, Texas 76117
TEL. 817-281-6448 FAX: 817-581-0936

• Consulting
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• Development
• Manufacturing
• Calibration
• Software

453.6 g/lb

Date 09-22-1995 Time 15:31:09

PRIMARY ELEMENTS

**** Performance Data ****

Based Upon;

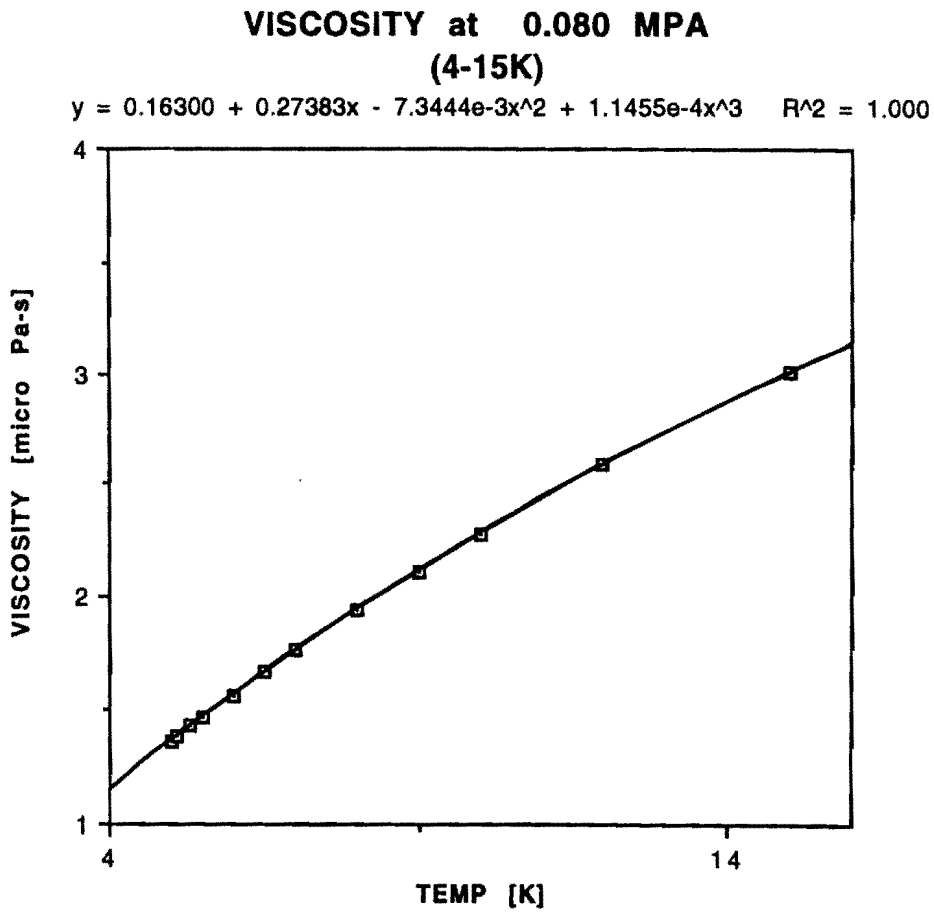
Primary Element Type	Orifice Plate w/ Flange Taps	
Flowing Gas	Helium	
Molecular Weight	4.0026	
Inlet Density	0.205136	lbm/ft^3
Compressibilty Factor	1.0136	
Specific Heat Ratio	1.6640	
Absolute Viscosity	1.9510E-02	cp
Inlet Static Pressure	289.7000	psia = 1997.4 kPa
Inlet Temperature	60.0000	F = 15.556 C = 288.7 K
Throat Diameter	0.9470	in
Inlet Diameter	2.157	in
Beta Ratio	0.4390	
Coef. of Thermal Expansion	9.50E-06	in/in*F
Thermal Expansion Factor	0.9998	
Discharge Coefficient	Theoretical	

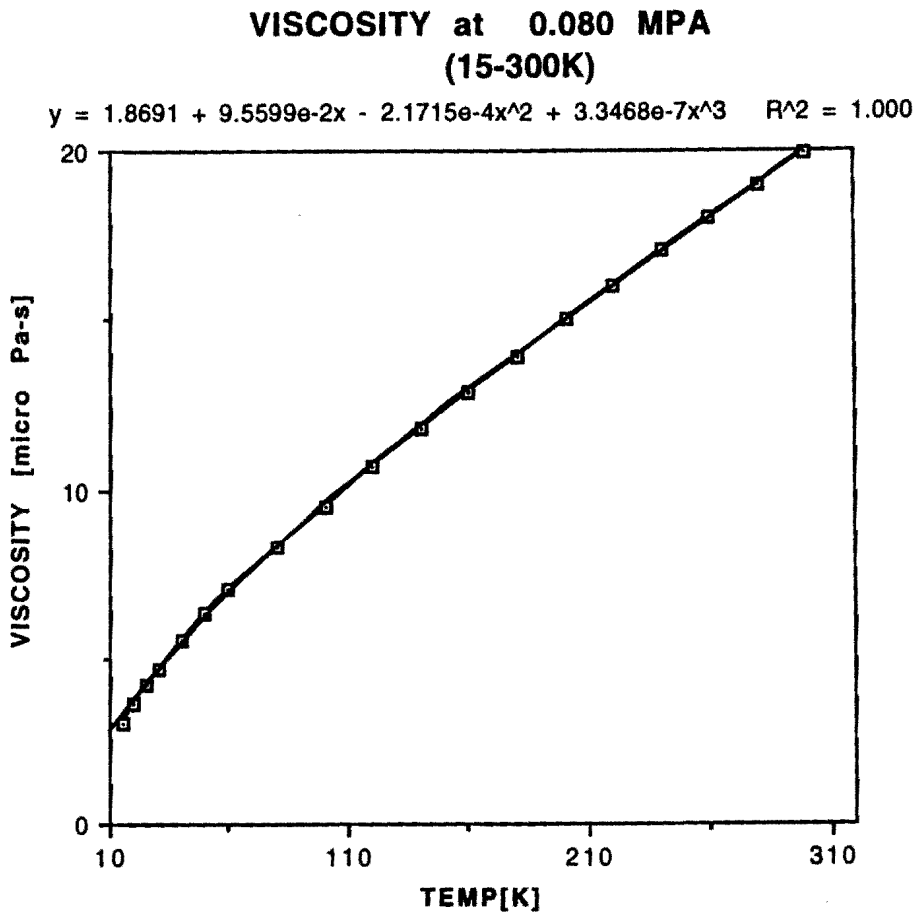
DP/P: Diff. Press./Inlet Press. (PSID/PSIA)
P: Inlet Static Pressure (PSIA)
T: Inlet Temperature (RANKINE)
W: Flowrate (IN UNITS AS SPECIFIED)
Rd: Throat Reynolds No.
Cd: Discharge Coefficie
Y: Gas Expansion Facto

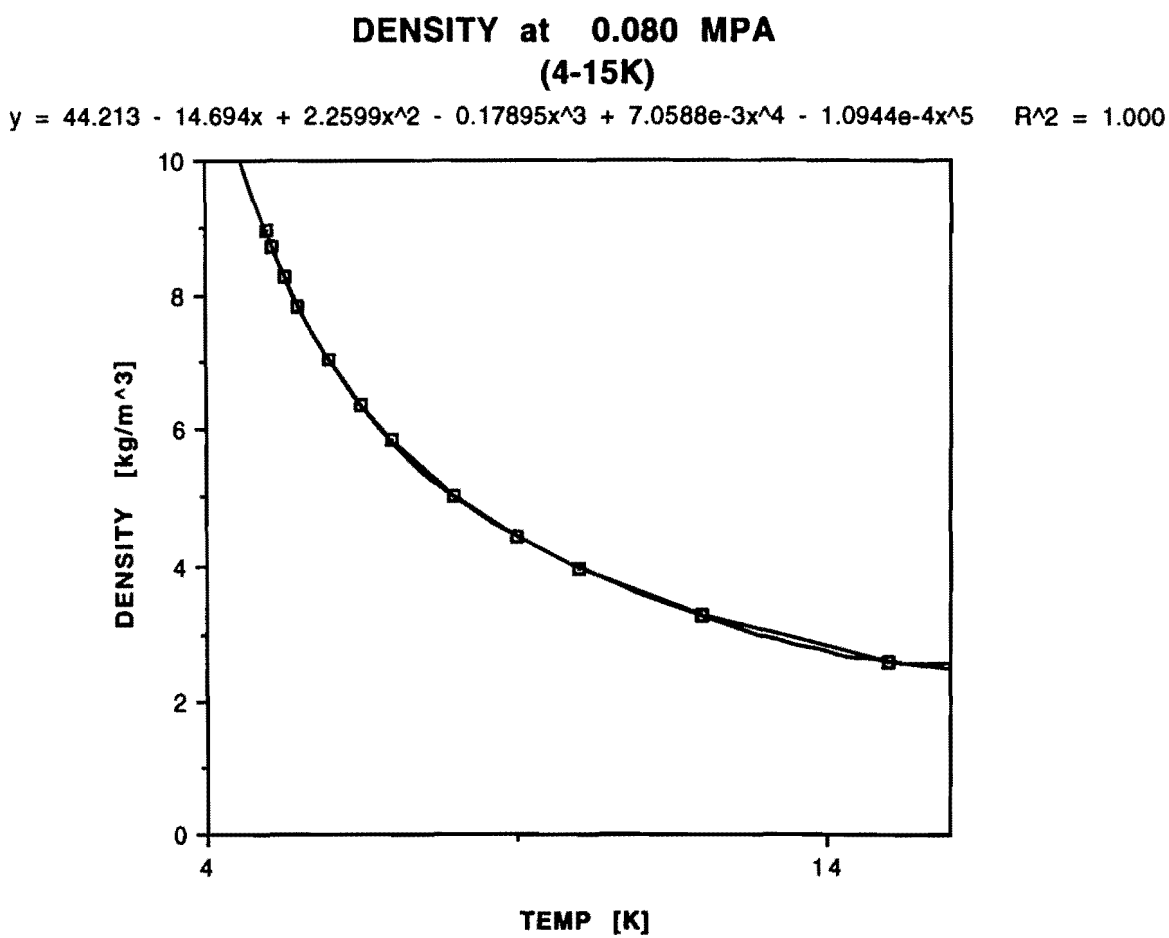
DP (in H2O)	DP/P	W√T/P (lbm/s)	W (lbm/s)	Rd	Cd	Y
803.316	.10000	5.401E-02	6.864E-01	844,657	0.6021	0.9746
401.658	.05000	3.870E-02	4.918E-01	605,275	0.6024	0.9873
240.995	.03000	3.014E-02	3.831E-01	471,420	0.6026	0.9924
80.332	.01000	1.751E-02	2.225E-01	273,844	0.6032	0.9975
40.166	.00500	1.241E-02	1.577E-01	194,056	0.6037	0.9987
24.099	.00300	9.624E-03	1.223E-01	150,514	0.6042	0.9992
8.033	.00100	5.573E-03	7.082E-02	87,151	0.6056	0.9997
5.623	.00070	4.667E-03	5.931E-02	72,994	0.6063	0.9998
4.017	.00050	3.949E-03	5.019E-02	61,761	0.6069	0.9999

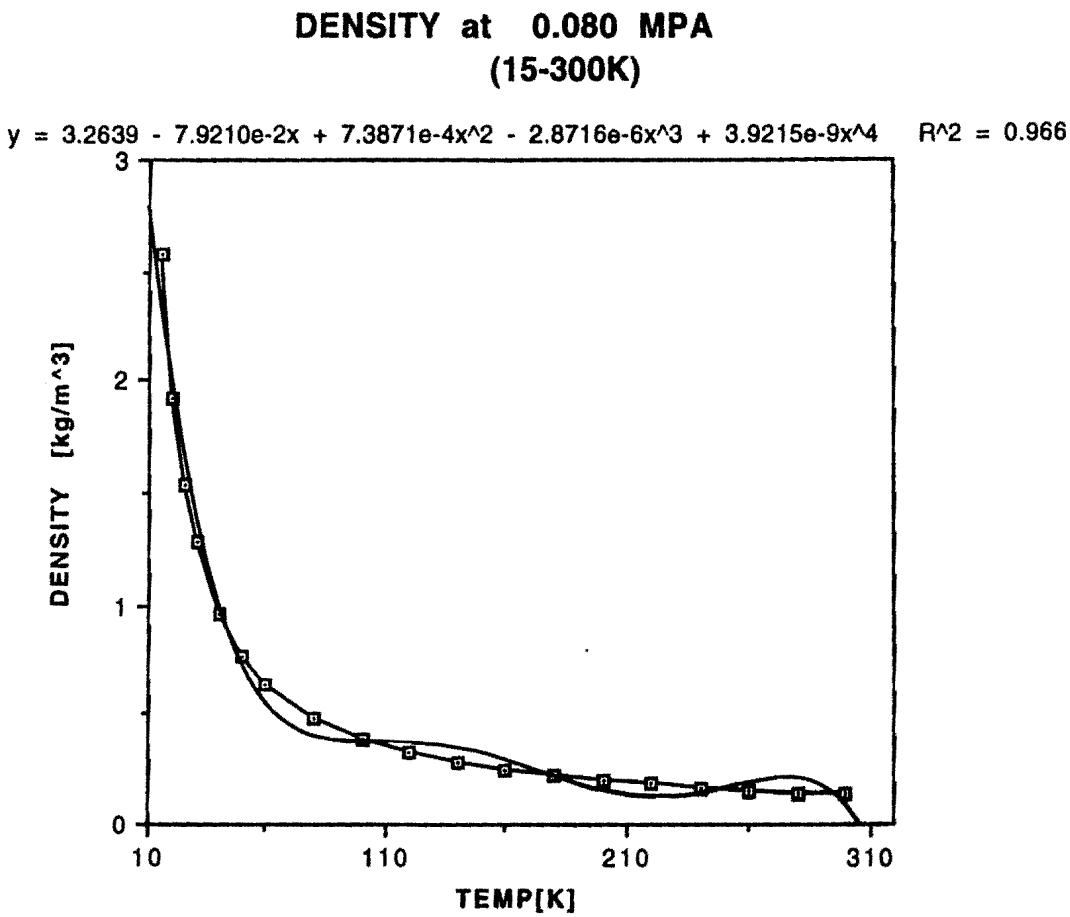
Viscosity vs Temperature, ratio of specific heats vs Temperature, Density vs Temperature equations for the specified pressure range of 14.7 psia to 25 psia

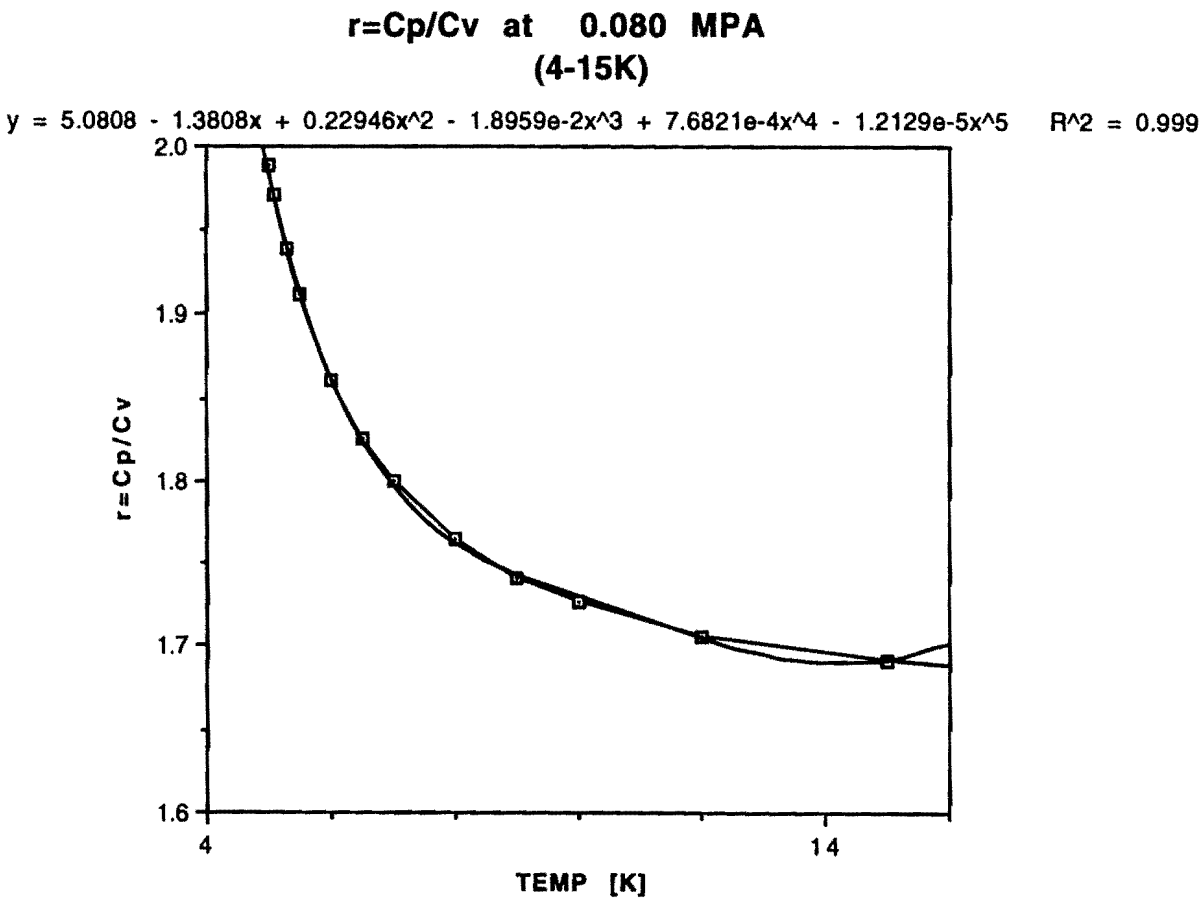
venturi.f FORTRAN 77 program along with the TISOFT special function


VISCOSITY at 0.080 MPA
(4-15K)
y = 0.16300 + 0.27383x - 7.3444e-3x^2 + 1.1455e-4x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
4
3
2
1
4
14
TEMP [K]


VISCOSITY at 0.080 MPA
(15-300K)
y = 1.8691 + 9.5599e-2x - 2.1715e-4x^2 + 3.3468e-7x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
20
10
0
10
110
210
310
TEMP[K]

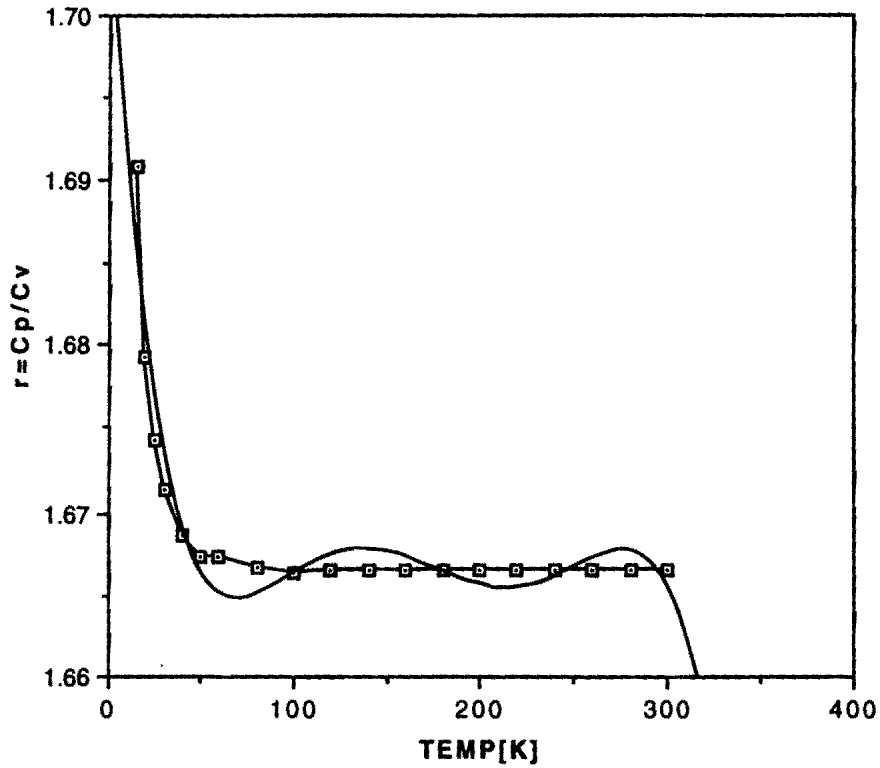

DENSITY at 0.080 MPA
(4-15K)
y = 44.213 - 14.694x + 2.2599x^2 - 0.17895x^3 + 7.0588e-3x^4 - 1.0944e-4x^5 R^2 = 1.000
DENSITY [kg/m^3]
10
8
6
4
2
0
4
14
TEMP [K]

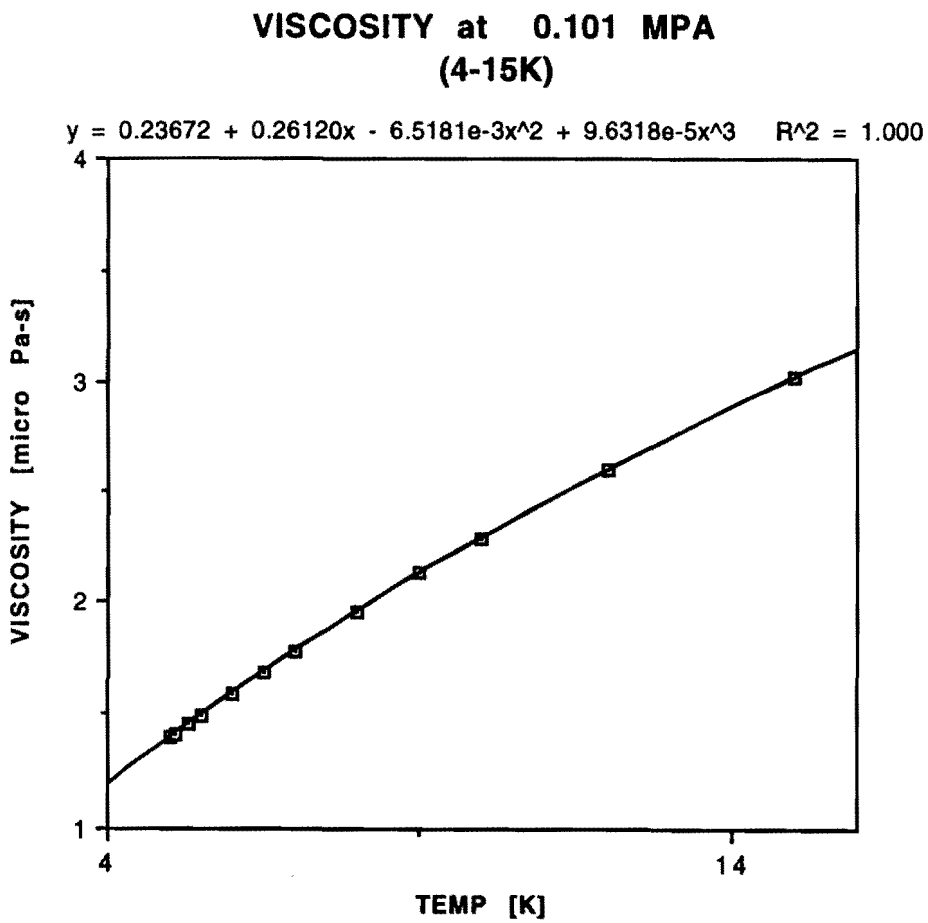

DENSITY at 0.080 MPA
(15-300K)
y = 3.2639 - 7.9210e-2x + 7.3871e-4x^2 - 2.8716e-6x^3 + 3.9215e-9x^4
R^2 = 0.966
DENSITY [kg/m^3]
3
2
1
0
10
110
210
310
TEMP[K]

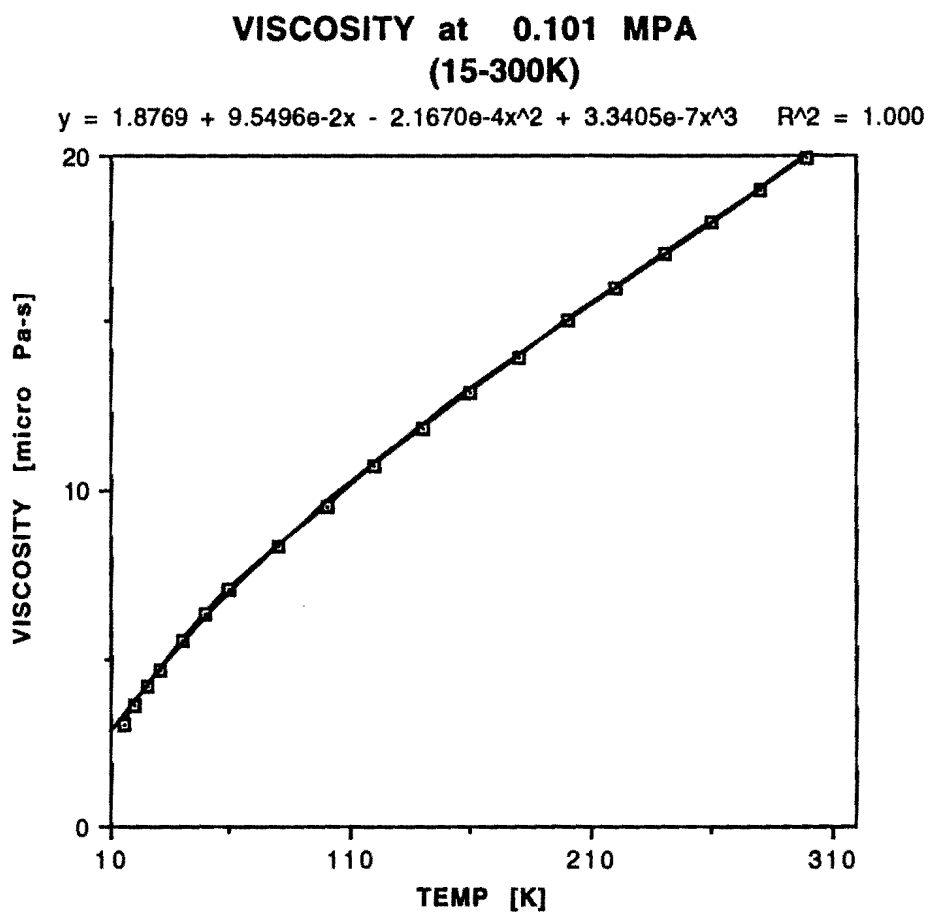

r=Cp/Cv at 0.080 MPA
(4-15K)
y = 5.0808 - 1.3808x + 0.22946x^2 - 1.8959e-2x^3 + 7.6821e-4x^4 - 1.2129e-5x^5 R^2 = 0.999
2.0
1.9
1.8
1.7
1.6
r=Cp/Cv
4
14
TEMP [K]

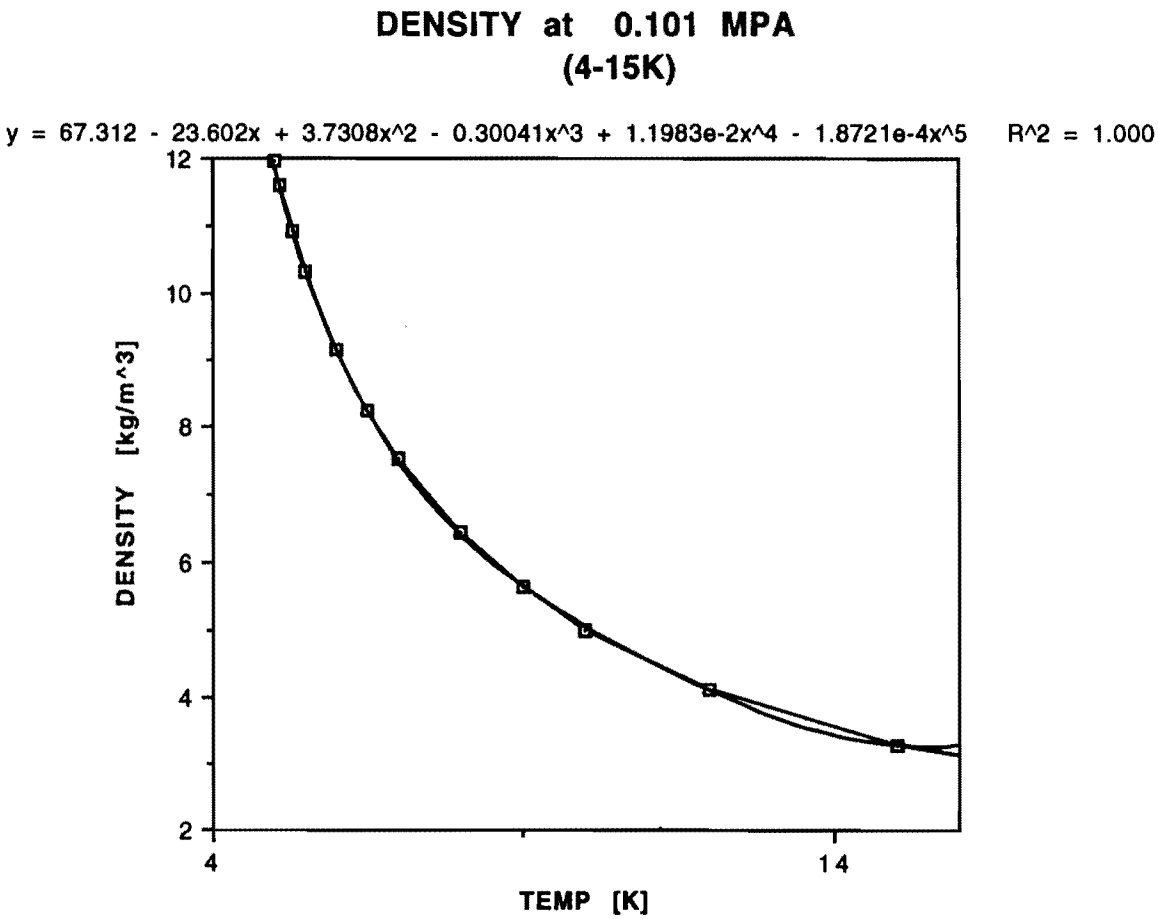
r=Cp/Cv at 0.080 MPA
(15-300K)

y = 1.7067 - 1.7225e-3x + 2.5694e-5x^2 - 1.7154e-7x^3 + 5.2499e-10x^4 - 5.9979e-13x^5 R^2 = 0.914



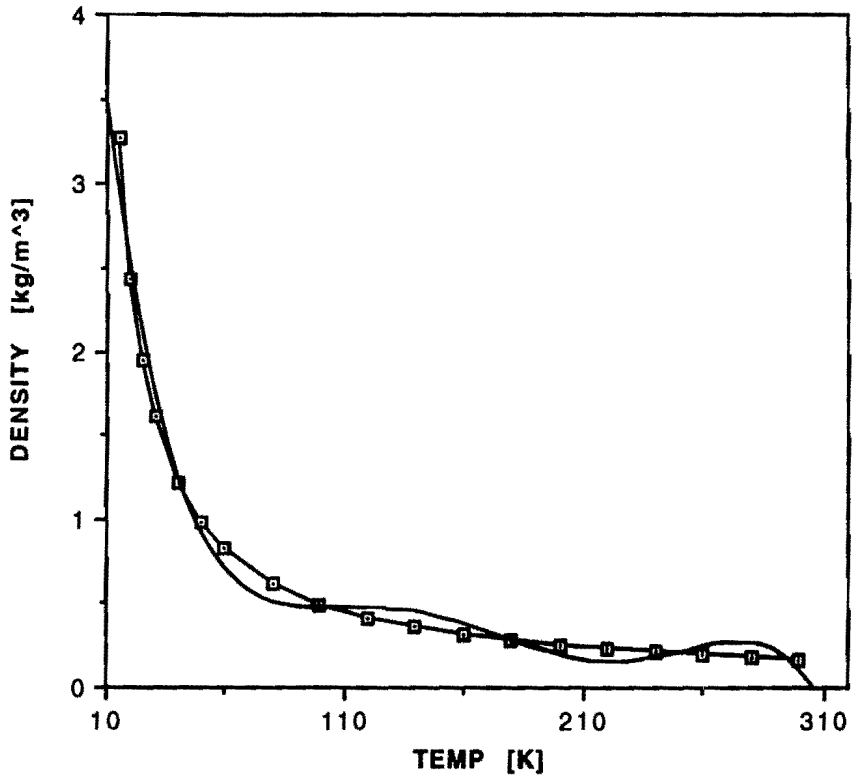

VISCOSITY at 0.101 MPA
(4-15K)
y = 0.23672 + 0.26120x - 6.5181e-3x^2 + 9.6318e-5x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
4
3
2
1
4
14
TEMP [K]


VISCOSITY at 0.101 MPA
(15-300K)
y = 1.8769 + 9.5496e-2x - 2.1670e-4x^2 + 3.3405e-7x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
20
10
0
10
110
210
310
TEMP [K]


DENSITY at 0.101 MPA
(4-15K)
y = 67.312 - 23.602x + 3.7308x^2 - 0.30041x^3 + 1.1983e-2x^4 - 1.8721e-4x^5 R^2 = 1.000
DENSITY [kg/m^3]
12
10
8
6
4
2
4
14
TEMP [K]

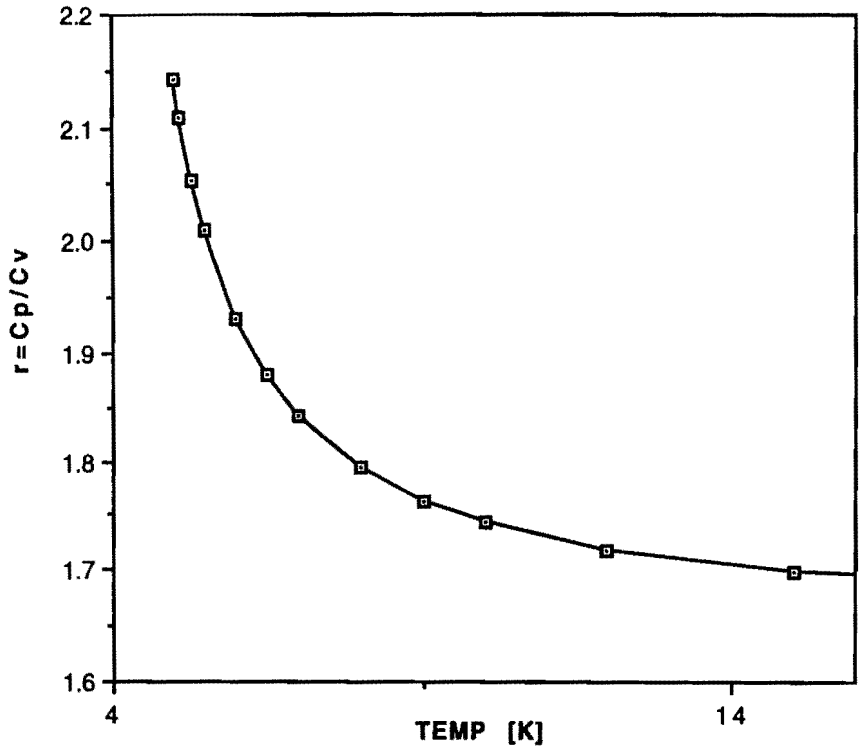
DENSITY at 0.101 MPA
(15-300K)

y = 4.9175 - 0.15662x + 2.1052e-3x^2 - 1.3378e-5x^3 + 3.9820e-8x^4 - 4.4702e-11x^5 R^2 = 0.985



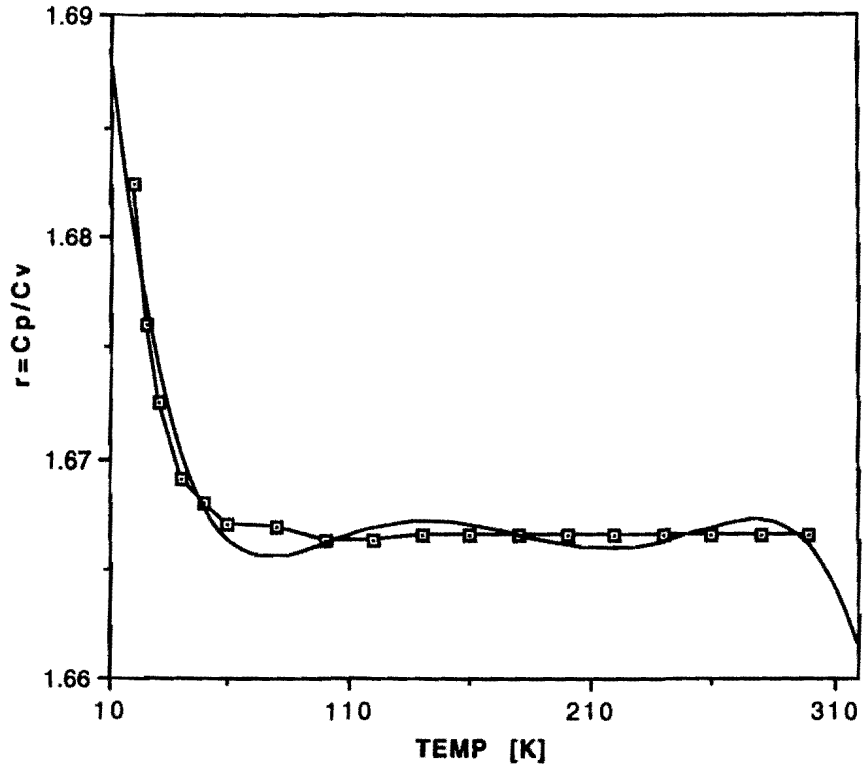
r=Cp/Cv at 0.101 MPA
(4-15K)

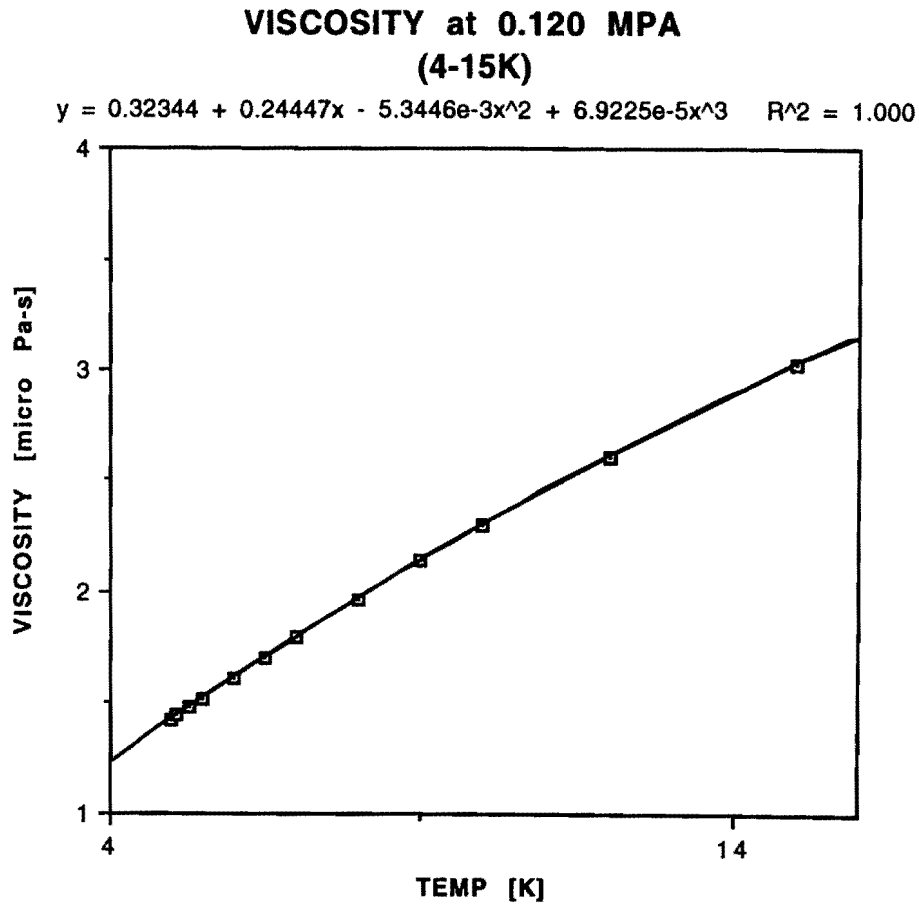
y = 7.6119 - 2.4907x + 0.42273x^2 - 3.5410e-2x^3 + 1.4483e-3x^4 - 2.3016e-5x^5 R^2 = 0.999

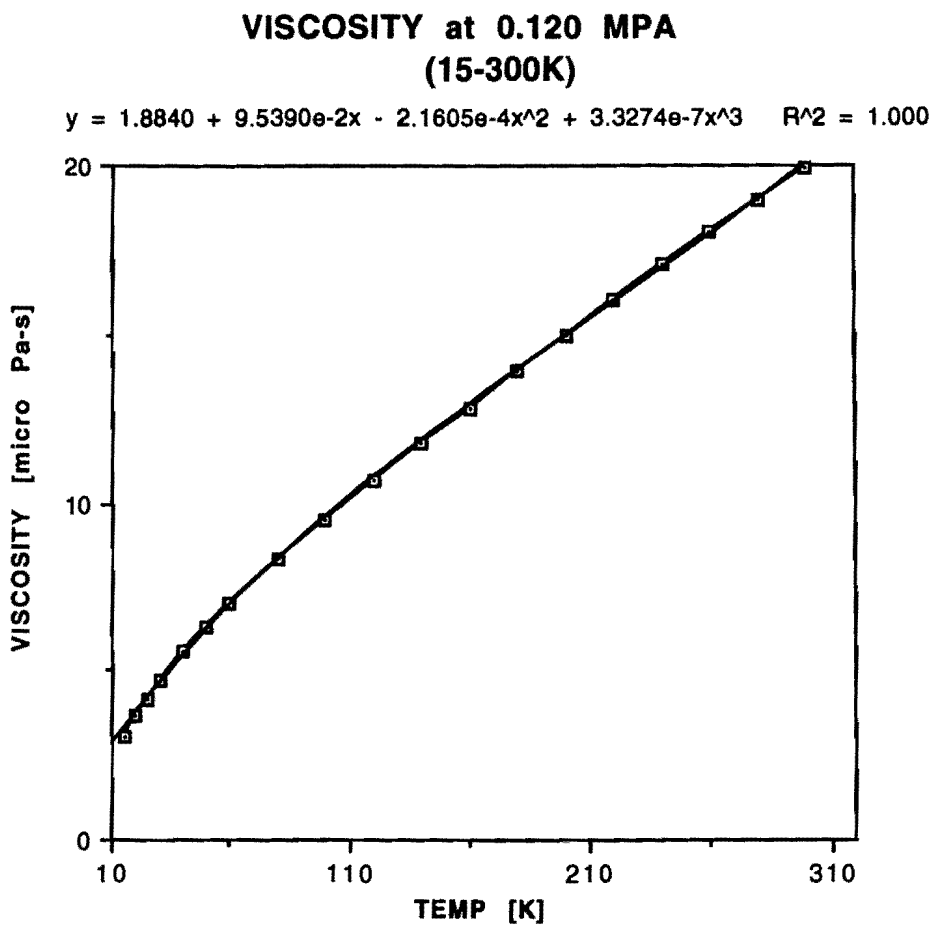


r=Cp/Cv at 0.101 MPA
(15-300K)

y = 1.6997 - 1.3001e-3x + 1.8231e-5x^2 - 1.1661e-7x^3 + 3.4610e-10x^4 - 3.8650e-13x^5 R^2 = 0.949

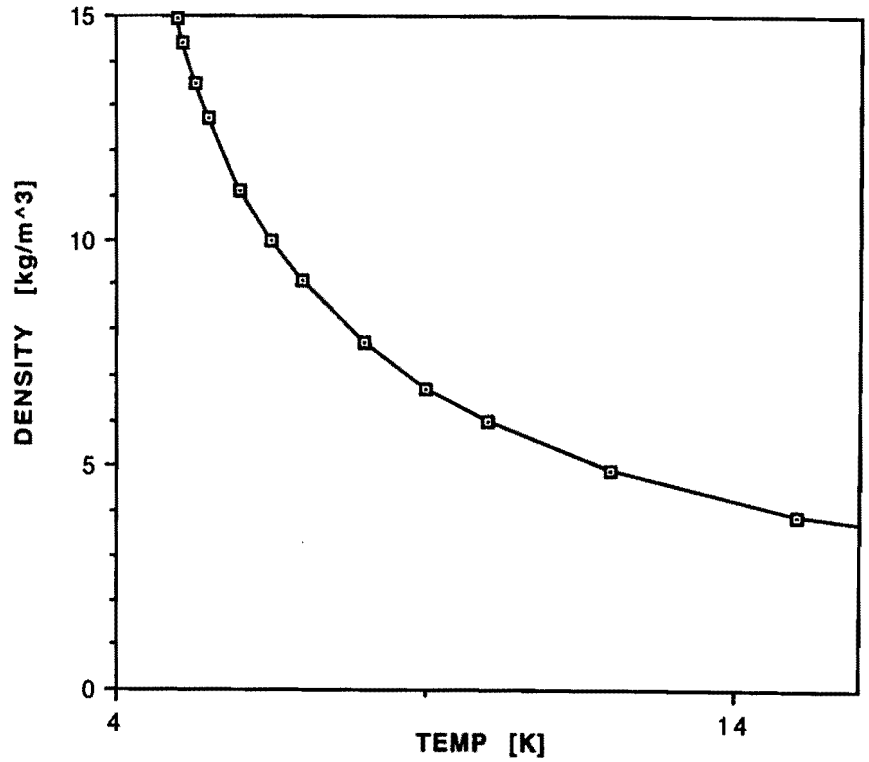



VISCOSITY at 0.120 MPA
(4-15K)
y = 0.32344 + 0.24447x - 5.3446e-3x^2 + 6.9225e-5x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
4
3
2
1
4
14
TEMP [K]


VISCOSITY at 0.120 MPA
(15-300K)
y = 1.8840 + 9.5390e-2x - 2.1605e-4x^2 + 3.3274e-7x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
20
10
0
10
110
210
310
TEMP [K]

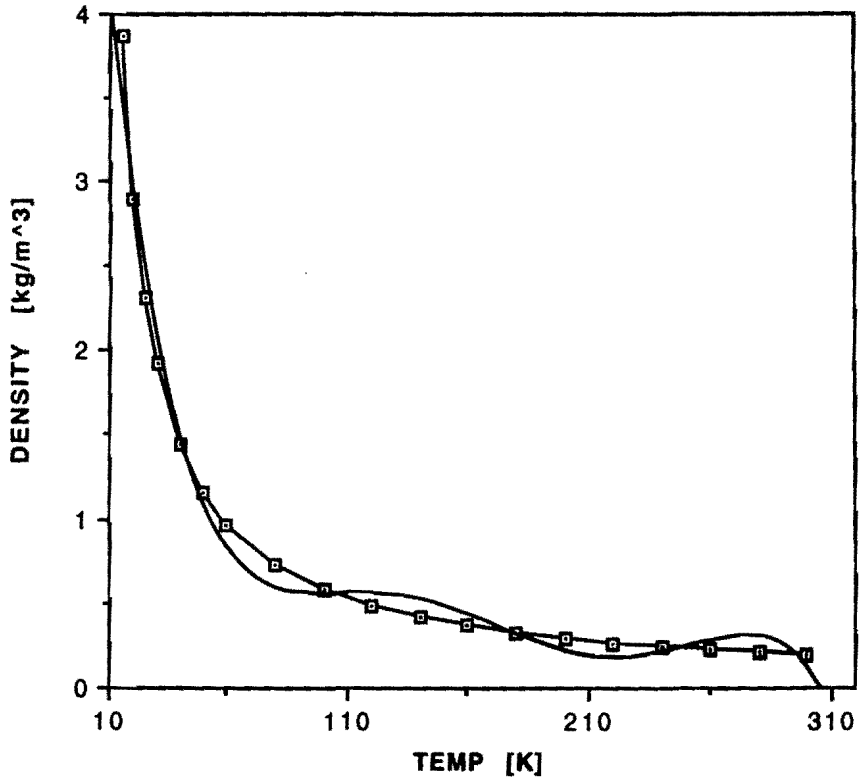
DENSITY at 0.120 MPA
(4-15K)

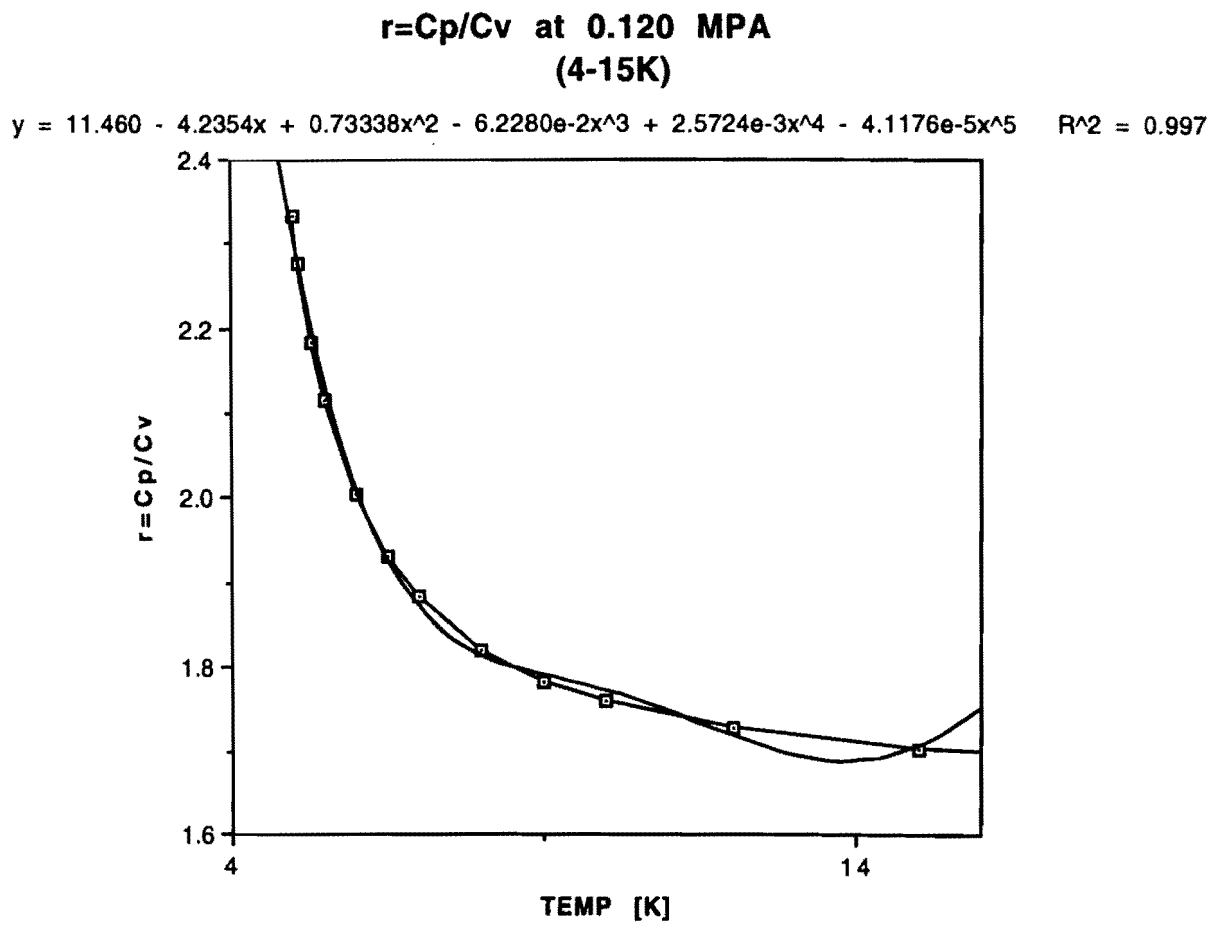
y = 95.668 - 35.116x + 5.6810x^2 - 0.46408x^3 + 1.8693e-2x^4 - 2.9409e-4x^5 R^2 = 1.000



DENSITY at 0.120 MPA
(15-300K)

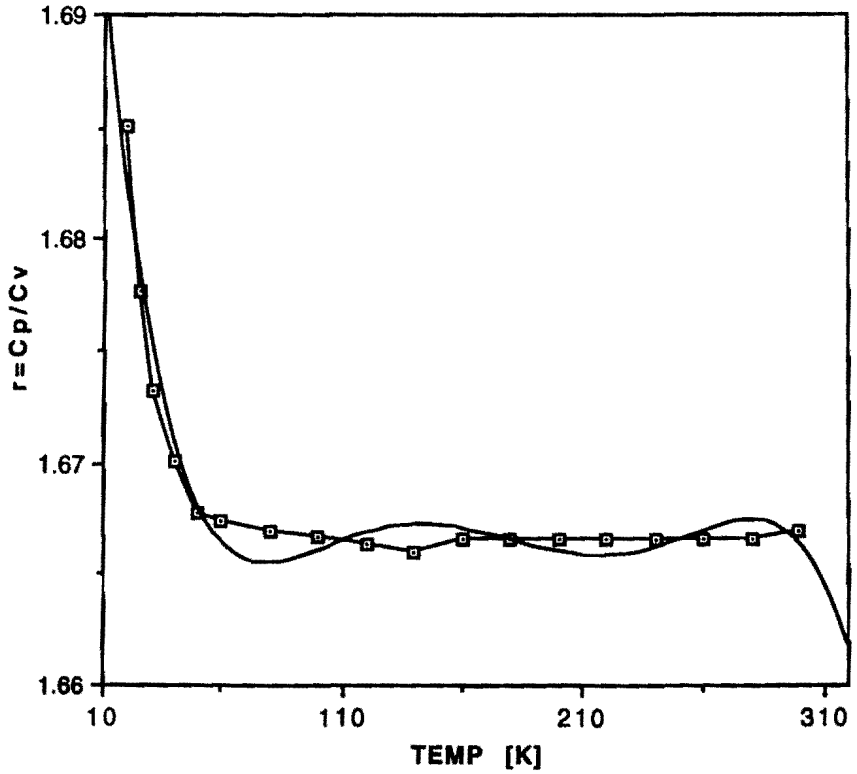
y = 5.8293 - 0.18579x + 2.4983e-3x^2 - 1.5880e-5x^3 + 4.7274e-8x^4 - 5.3075e-11x^5 R^2 = 0.985

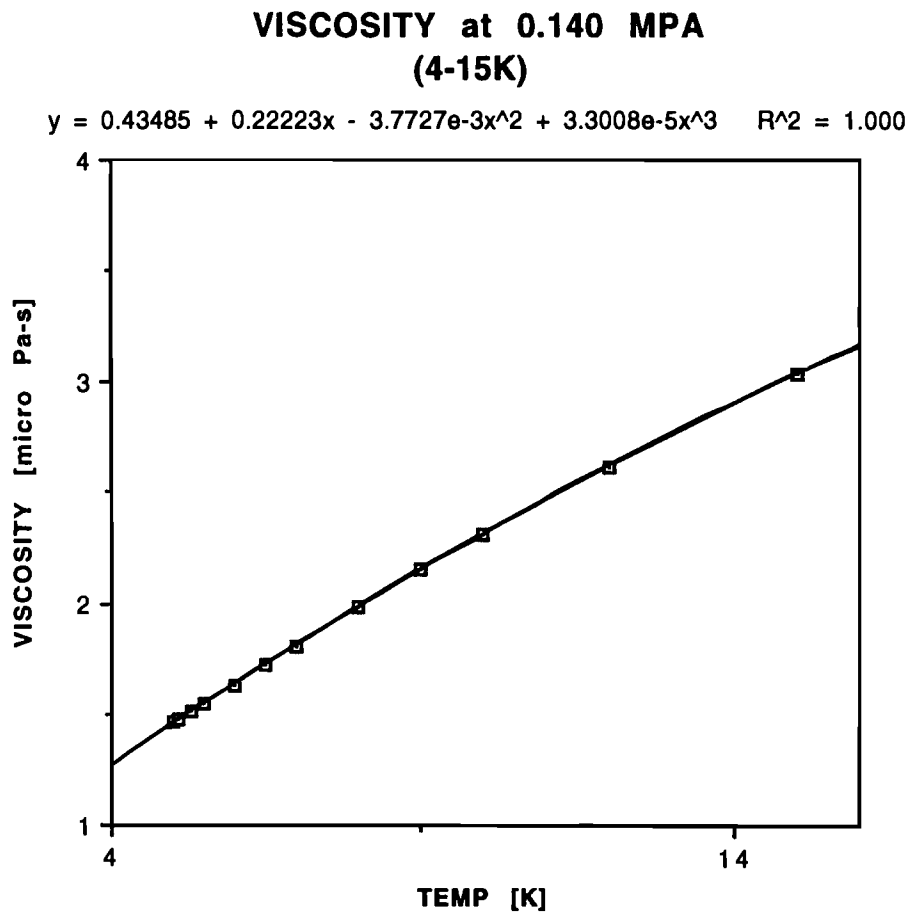


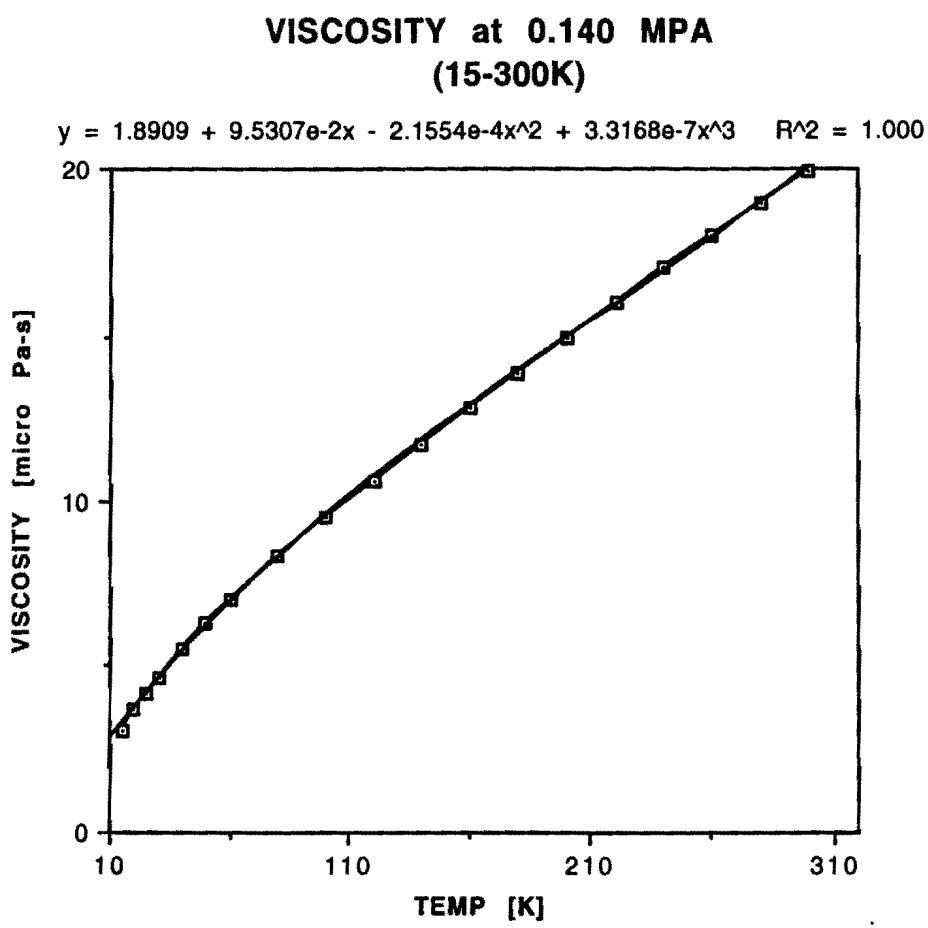

r=Cp/Cv at 0.120 MPA
(4-15K)
y = 11.460 - 4.2354x + 0.73338x^2 - 6.2280e-2x^3 + 2.5724e-3x^4 - 4.1176e-5x^5 R^2 = 0.997
2.4
2.2
2.0
1.8
1.6
r=Cp/Cv
4
14
TEMP [K]

r=Cp/Cv at 0.120 MPA
(15-300K)

y = 1.7049 - 1.4931e-3x + 2.0826e-5x^2 - 1.3264e-7x^3 + 3.9207e-10x^4 - 4.3593e-13x^5 R^2 = 0.945

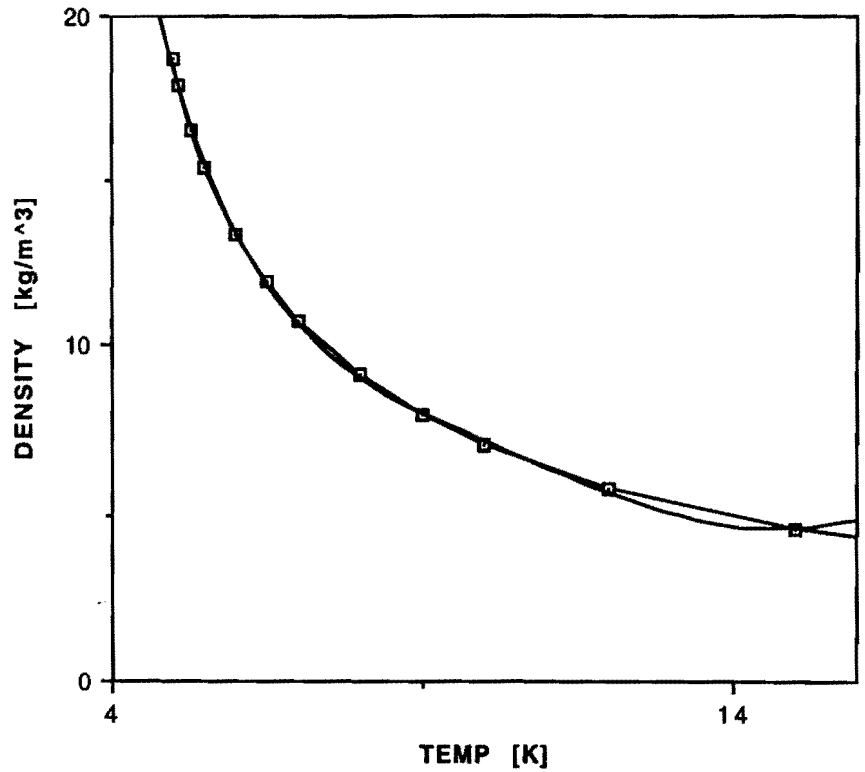



VISCOSITY at 0.140 MPA
(4-15K)
y = 0.43485 + 0.22223x - 3.7727e-3x^2 + 3.3008e-5x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
4
3
2
1
4
14
TEMP [K]


VISCOSITY at 0.140 MPA
(15-300K)
y = 1.8909 + 9.5307e-2x - 2.1554e-4x^2 + 3.3168e-7x^3 R^2 = 1.000
20
10
0
VISCOSITY [micro Pa-s]
10
110
210
310
TEMP [K]

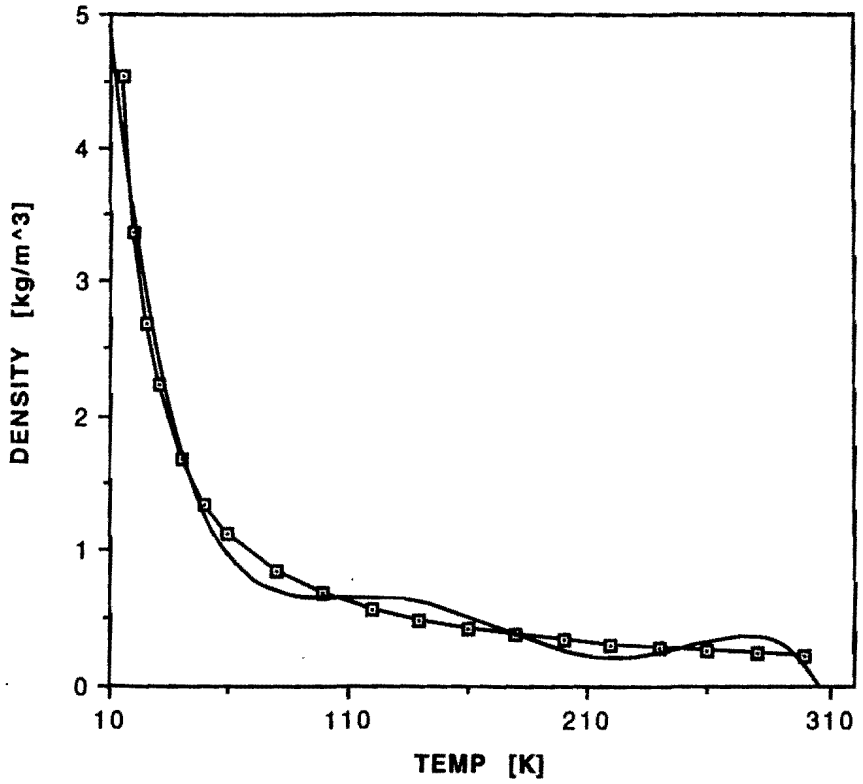
DENSITY at 0.140 MPA
(4-15K)

y = 139.73 - 53.822x + 8.9216x^2 - 0.73994x^3 + 3.0114e-2x^4 - 4.7727e-4x^5 R^2 = 0.999



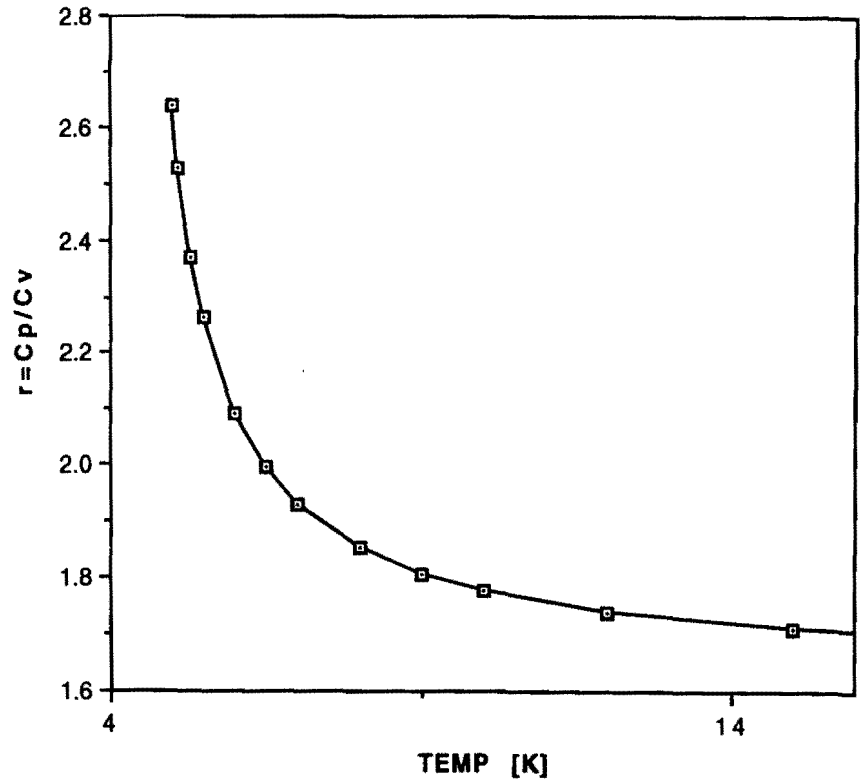
DENSITY at 0.140 MPA
(15-300K)

y = 6.8105 - 0.21728x + 2.9236e-3x^2 - 1.8590e-5x^3 + 5.5353e-8x^4 - 6.2156e-11x^5 R^2 = 0.985



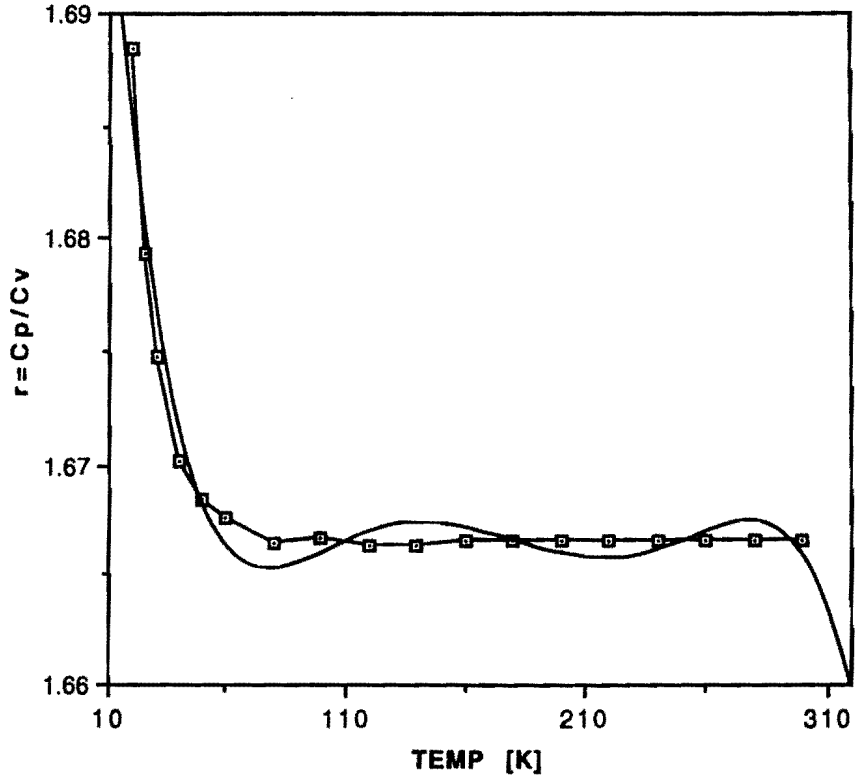
r=Cp/Cv at 0.140 MPA
(4-15K)

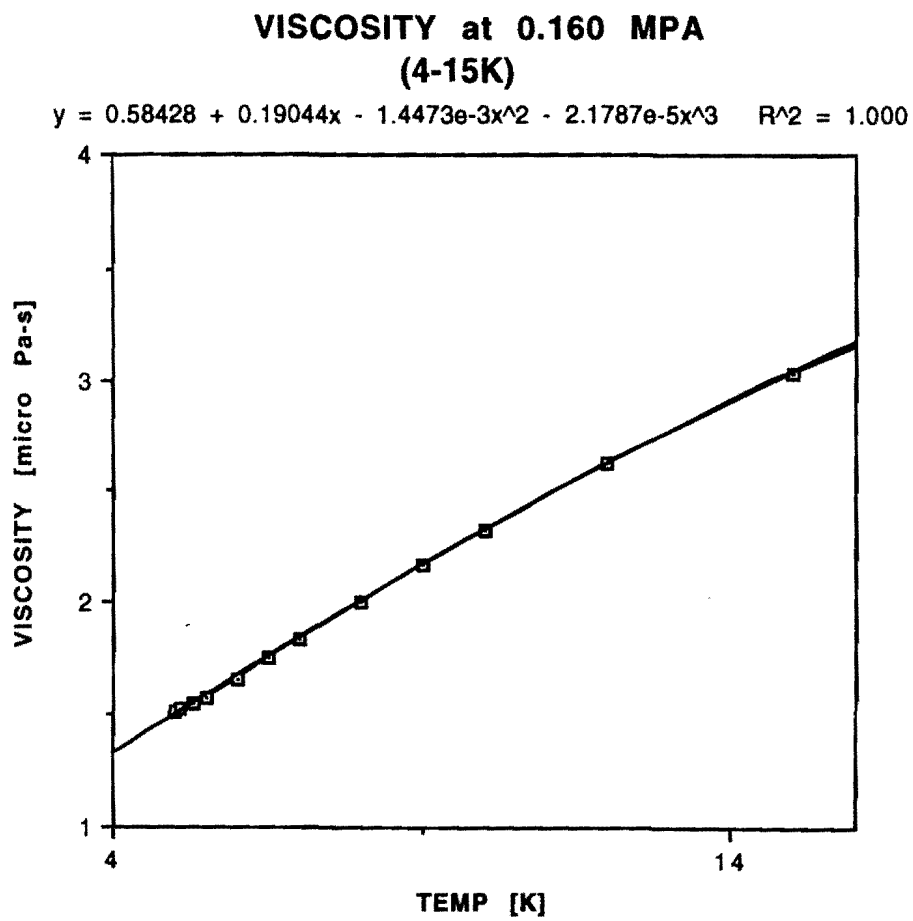
y = 18.984 - 7.7297x + 1.3651x^2 - 0.11751x^3 + 4.9005e-3x^4 - 7.8999e-5x^5 R^2 = 0.994



r=Cp/Cv at 0.140 MPA
(15-300K)

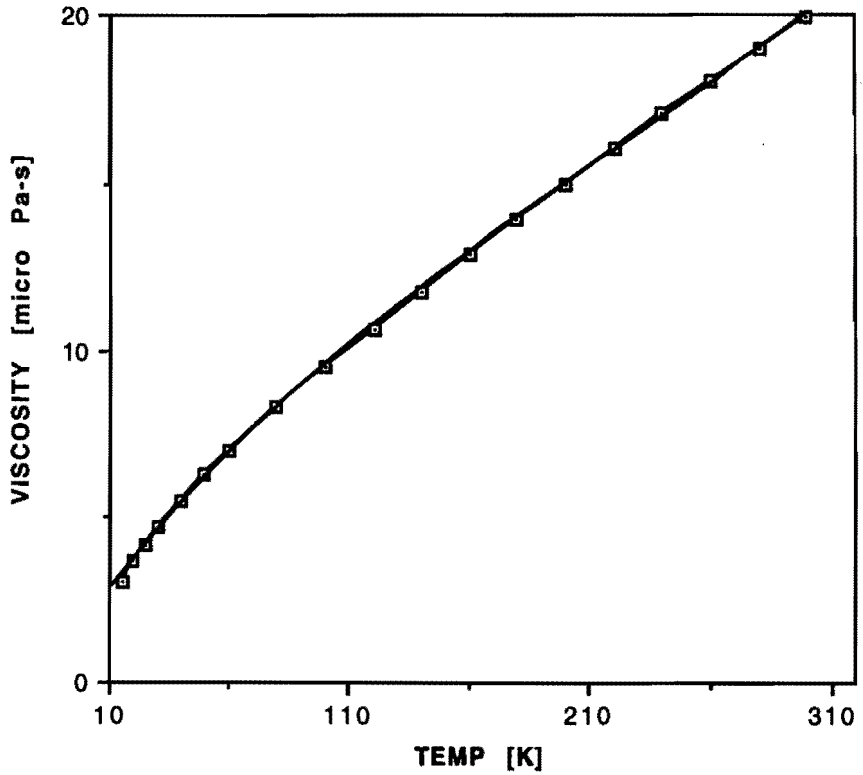
y = 1.7120 - 1.7790e-3x + 2.4903e-5x^2 - 1.5910e-7x^3 + 4.7184e-10x^4 - 5.2665e-13x^5 R^2 = 0.951

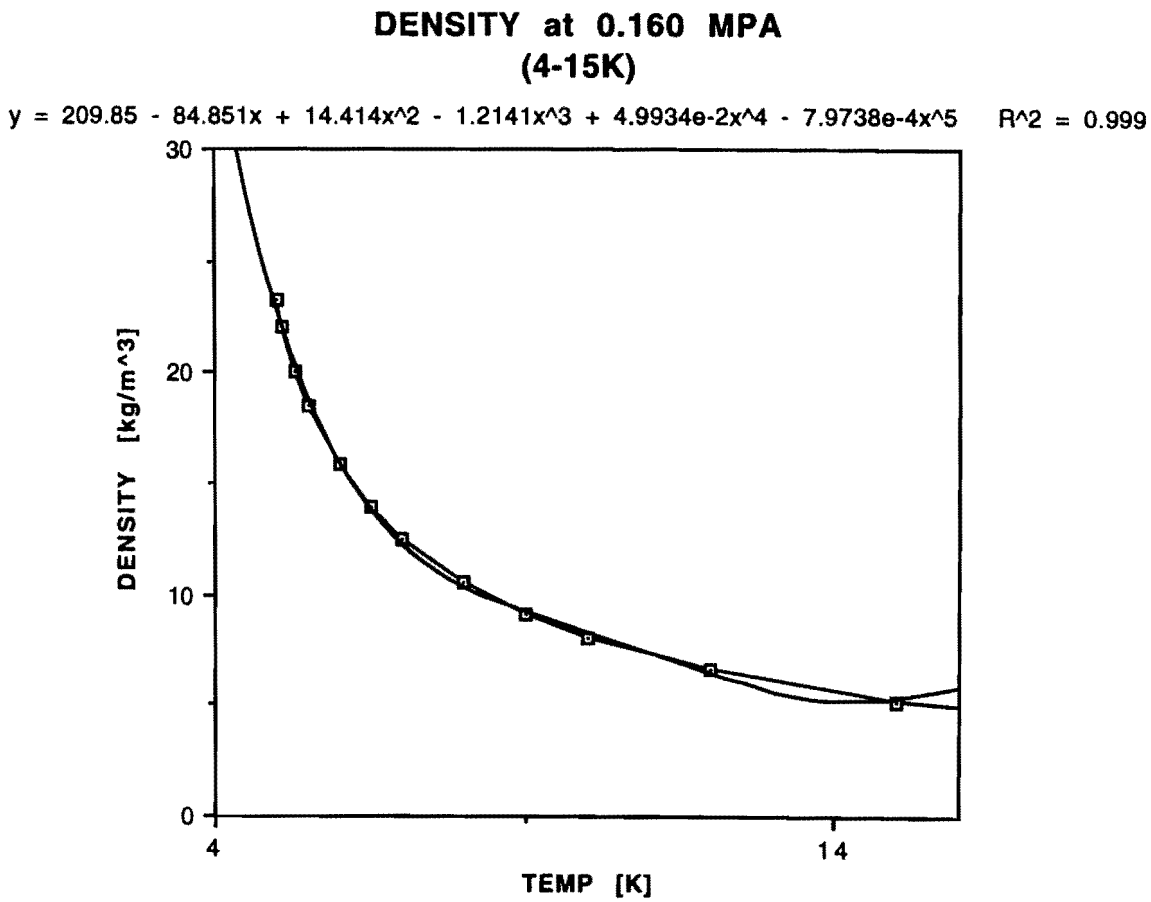



VISCOSITY at 0.160 MPA
(4-15K)
y = 0.58428 + 0.19044x - 1.4473e-3x^2 - 2.1787e-5x^3 R^2 = 1.000
VISCOSITY [micro Pa-s]
4
3
2
1
4
14
TEMP [K]

VISCOSITY at 0.160 MPA
(15-300K)

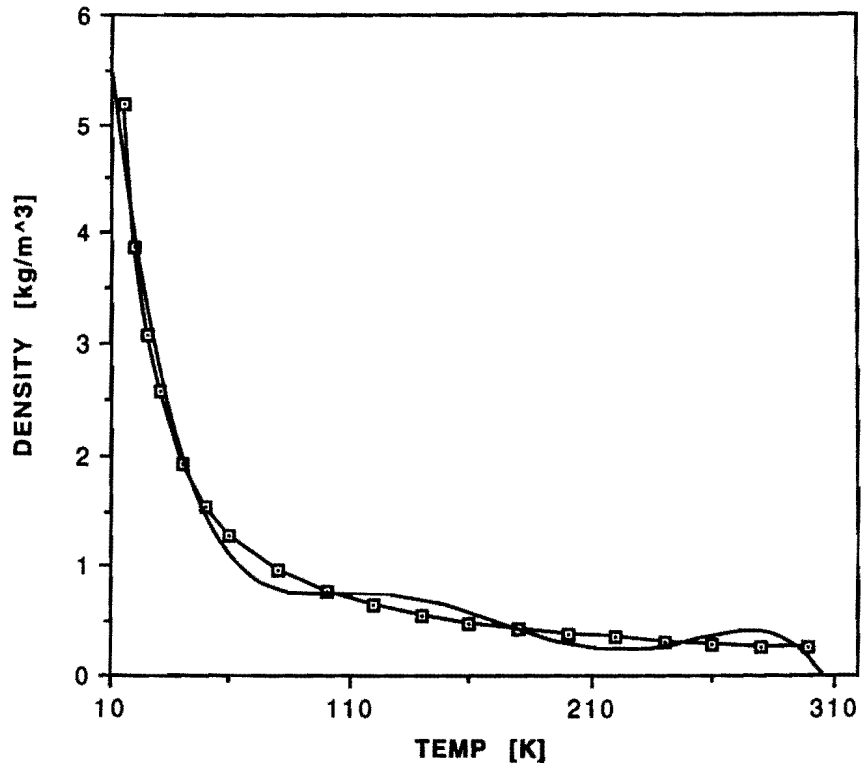
y = 1.8969 + 9.5275e-2x - 2.1539e-4x^2 + 3.3128e-7x^3 R^2 = 1.000

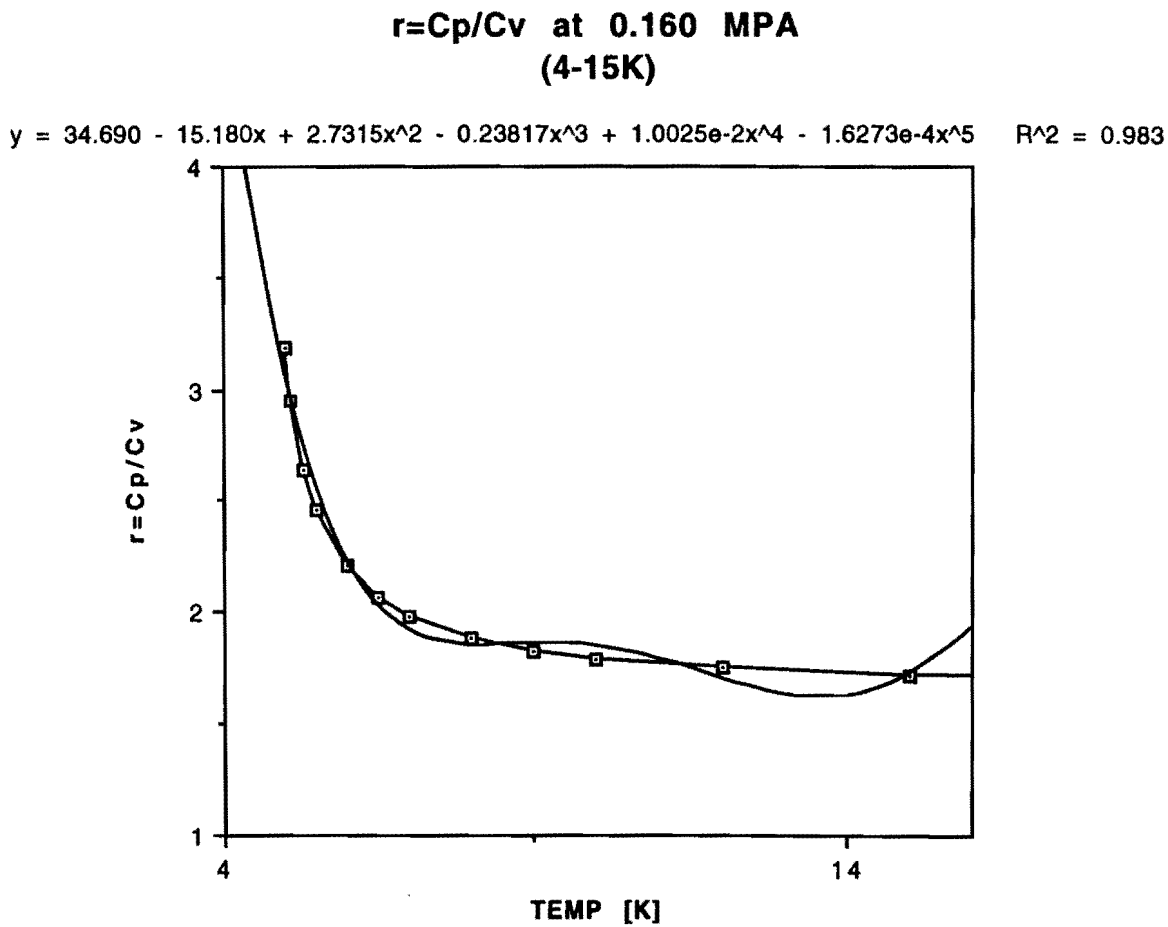



DENSITY at 0.160 MPA
(4-15K)
y = 209.85 - 84.851x + 14.414x^2 - 1.2141x^3 + 4.9934e-2x^4 - 7.9738e-4x^5
R^2 = 0.999
30
20
10
0
DENSITY [kg/m^3]
4
14
TEMP [K]

DENSITY at 0.160 MPA
(15-300K)

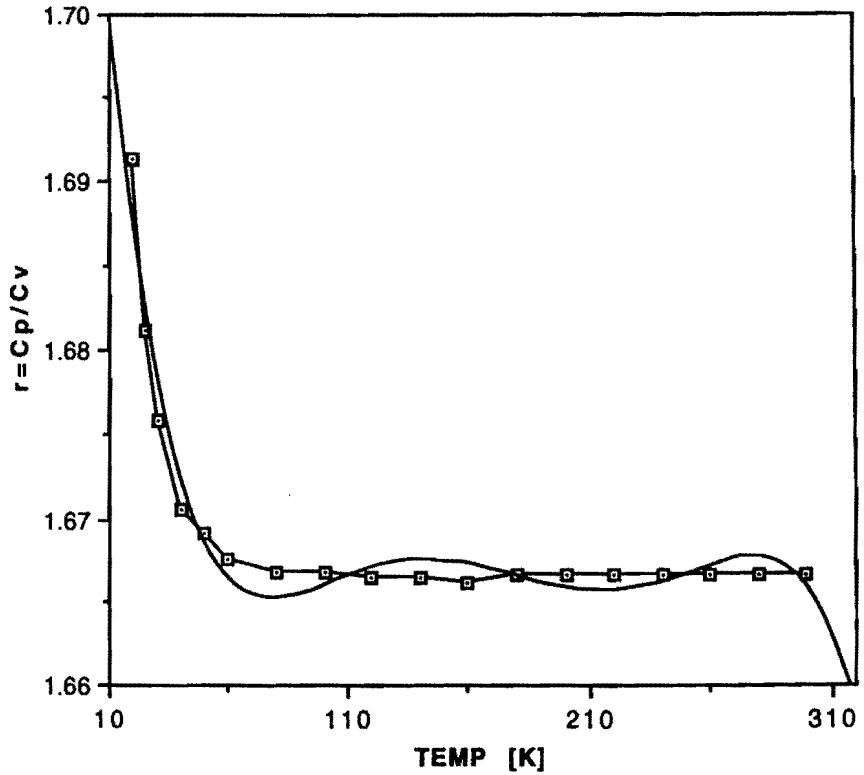
y = 7.7918 - 0.24880x + 3.3492e-3x^2 - 2.1301e-5x^3 + 6.3439e-8x^4 - 7.1244e-11x^5 R^2 = 0.985




r=Cp/Cv at 0.160 MPA
(4-15K)
y = 34.690 - 15.180x + 2.7315x^2 - 0.23817x^3 + 1.0025e-2x^4 - 1.6273e-4x^5 R^2 = 0.983
r=Cp/Cv
4
3
2
1
4
14
TEMP [K]

r=Cp/Cv at 0.160 MPA
(15-300K)

y = 1.7180 - 2.0099e-3x + 2.8173e-5x^2 - 1.8050e-7x^3 + 5.3706e-10x^4 - 6.0136e-13x^5 R^2 = 0.949



```
      program venturi

C-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|C
C     The Program 'venturi.f' has been written by                        C
C    Zaczek Mariusz from the Mechanical Research Division at             C
C    D-Zero, FERMILAB. For any questions contact Mariusz Zaczek          C
C    at X-8453 in FERMILAB or at  zaczek@students.uiuc.edu               C
C           written on July 22,1996                                      C
C           REVISED on AUGUST 14,1996                                    C
C-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|C


C*****************************************************************C
C   The purpose of this program is to help in the calculation     C
C of mass flow across a venturi or orifice plate flow meter. The C
C mass flow equations required have been obtained from the        C
C FLOW-DYNE company which has also made these flow meters.  The   C
C equations for the density,viscosity, and specific heat ratio    C
C have been curve fit (using Cricket Graph for the Mac) based on C
C data points obtained from thermodynamic tables for Helium.      C
C*****************************************************************C
      implicit none
      real WXTEMP,WX3100,WX3098,DELTAP,r,THRDIA,INDIA,BETA
      REAL DISCOE,X,GAMMA1,GAMMA2,GAMMA,DENSI1,DENSI2
      real DENSI,VISCO1,VISCO2,VISCO,TEMPF,FA,CONST,CONST2,MDOT
      real a,RD,C,PERCNT,CNEW,EXPANF,error1,Mold,Fold,consta,TEMPR
      integer choice

C*** Ask user for the inputs: type of flow meter,inlet temp. and
C**  pressure, Differential pressure,throat and inlet diameters.
      write(6,*)'ENTER CHOICE (1)VENTURI (2)ORIFICE PLATE'
      read(5,*) choice
      write(6,*)'ENTER INLET TEMP=T1(K)'
      read(5,*) WXTEMP
      write(6,*)'ENTER INLET STATIC PRESSURE=P1(psia)'
      read(5,*) WX3100
      write(6,*)'ENTER DIFF.PRESSURE=hw(inches H20)'
      read(5,*) WX3098
      write(6,*) 'ENTER THROAT DIAMETER(inches)'
      read(5,*) THRDIA
      write(6,*) 'ENTER INLET DIAMETER(inches)'
      read(5,*) INDIA
      write(6,*)
      write(6,*)

      TEMPF=(1.8*(WXTEMP-273.15)) + 32.0
      TEMPR=TEMPF+459.67
```

```
C*** Display output table
      if (choice.eq.1) then
      write(6,*)'For the Venturi Flow meter:'
      else
      write(6,*)'For the Orifice plate flow meter:'
      endif
      write(6,*)'TEMP= ',WXTEMP,'K  STAT.PRES.= ',WX3100,
     &'    DIFF.PRES.= ',WX3098
      write(6,*)'-----------------------------------------------
     &--------------------'

C*** Convert pressure (P1-P2) and calculate the pressure ratio (r)
      DELTAP=WX3098*(62.3164/1728)
      r=(WX3100-DELTAP)/WX3100
C*** Calculate the Beta ratio
      BETA=THRDIA/INDIA
      if (choice.eq.1) then
      DISCOE=0.986
      else if (choice.eq.2) then
      DISCOE=.604
      end if

C*** Based on the choice of venturi or orifice plate flow
C**  meter, calculate the density,viscosity, and ratio of
C*   specific heats.

C*** The equations provided here have been obtained through
C**  curve-fitting of data points for various pressures
C*   of Helium contained in thermodynamic property tables.


          if (choice.eq.1) then
            if (WXTEMP .le. 15) then
              if (WX3100 .ge. 11.603 .and. WX3100 .lt.14.696) then
        X=(WX3100-11.603)/(14.696-11.603)

        DENSI1=44.213-(14.694*WXTEMP)+(2.2599*WXTEMP**2.0)-(0.17895*
     &WXTEMP**3.0)+(7.0588E-3*WXTEMP**4.0)-(1.0944E-4*WXTEMP**5.0)
        DENSI2=67.312-(23.602*WXTEMP)+(3.7308*WXTEMP**2.0)-(0.30041*
     &WXTEMP**3.0)+(1.1983E-2*WXTEMP**4.0)-(1.8721E-4*WXTEMP**5.0)

        GAMMA1=5.0808-(1.3808*WXTEMP)+(0.22946*WXTEMP**2.0)-
     &(1.8959E-2*WXTEMP**3.0)+(7.6821E-4*WXTEMP**4.0)-(1.2129E-5*
     &WXTEMP**5.0)
        GAMMA2=7.6119-(2.4907*WXTEMP)+(0.42273*WXTEMP**2.0)-
     &(3.5410E-2*WXTEMP**3.0)+(1.4483E-3*WXTEMP**4.0)-(2.3016E-5*
     &WXTEMP**5.0)

        VISCO1=0.16300+(0.27383*WXTEMP)-(7.3444E-3*WXTEMP**2.0)+
     &(1.1455E-4*WXTEMP**3.0)
        VISCO2=0.23672+(0.26120*WXTEMP)-(6.5181E-3*WXTEMP**2.0)+
     &(9.6318E-5*WXTEMP**3.0)
```

```
 else if (WX3100 .ge. 14.696 .and. WX3100 .lt.17.405) then
 X=(WX3100-14.696)/(17.405-14.696)

    DENSI1=67.312-(23.602*WXTEMP)+(3.7308*WXTEMP**2.0)-(0.30041*
&WXTEMP**3.0)+(1.1983E-2*WXTEMP**4.0)-(1.8721E-4*WXTEMP**5.0)
    DENSI2=95.668-(35.116*WXTEMP)+(5.6810*WXTEMP**2.0)-
&(0.46408*WXTEMP**3.0)+(1.8693E-2*WXTEMP**4.0)-(2.9409E-4*WXTEMP
&**5.0)

    GAMMA1=7.6119-(2.4907*WXTEMP)+(0.42273*WXTEMP**2.0)-
&(3.5410E-2*WXTEMP**3.0)+(1.4483E-3*WXTEMP**4.0)-(2.3016E-5*
&WXTEMP**5.0)
    GAMMA2=11.46-(4.2354*WXTEMP)+(0.73338*WXTEMP**2.0)-(6.228E-2
&*WXTEMP**3.0)+(2.5724E-3*WXTEMP**4.0)-(4.1176E-5*WXTEMP**5.0)

    VISCO1=0.23672+(0.26120*WXTEMP)-(6.5181E-3*WXTEMP**2.0)+
&(9.6318E-5*WXTEMP**3.0)
    VISCO2=0.32344+(0.24447*WXTEMP)-(5.3446E-3*WXTEMP**2.0)+
&(6.9225E-5*WXTEMP**3.0)

 else if (WX3100 .ge. 17.405 .and. WX3100 .lt.20.305) then
 X=(WX3100-17.405)/(20.305-17.405)

    DENSI1=95.668-(35.116*WXTEMP)+(5.6810*WXTEMP**2.0)-
&(0.46408*WXTEMP**3.0)+(1.8693E-2*WXTEMP**4.0)-(2.9409E-4*WXTEMP
&**5.0)
    DENSI2=139.73-(53.822*WXTEMP)+(8.9216*WXTEMP**2.0)-
&(0.73994*WXTEMP**3.0)+(3.0114E-2*WXTEMP**4.0)-(4.7727E-4*WXTEMP
&**5.0)

    GAMMA1=11.46-(4.2354*WXTEMP)+(0.73338*WXTEMP**2.0)-(6.228E-2
&*WXTEMP**3.0)+(2.5724E-3*WXTEMP**4.0)-(4.1176E-5*WXTEMP**5.0)
    GAMMA2=18.984-(7.7297*WXTEMP)+(1.3651*WXTEMP**2.0)-(0.11751
&*WXTEMP**3.0)+(4.9005E-3*WXTEMP**4.0)-(7.8999E-5*WXTEMP**5.0)

    VISCO1=0.32344+(0.24447*WXTEMP)-(5.3446E-3*WXTEMP**2.0)+
&(6.9225E-5*WXTEMP**3.0)
    VISCO2=0.43485+(0.22223*WXTEMP)-(3.7727E-3*WXTEMP**2.0)+
&(3.3008E-5*WXTEMP**3.0)

 else if (WX3100 .ge. 20.305 .and. WX3100 .lt.23.206) then
   X=(WX3100-20.305)/(23.206-20.305)

    DENSI1=139.73-(53.822*WXTEMP)+(8.9216*WXTEMP**2.0)-
&(0.73994*WXTEMP**3.0)+(3.0114E-2*WXTEMP**4.0)-(4.7727E-4*WXTEMP
&**5.0)
    DENSI2=209.85-(84.851*WXTEMP)+(14.414*WXTEMP**2.0)-
&(1.2141*WXTEMP**3.0)+(4.9934E-2*WXTEMP**4.0)-(7.9738E-4*WXTEMP
&**5.0)

    GAMMA1=18.984-(7.7297*WXTEMP)+(1.3651*WXTEMP**2.0)-(0.11751
&*WXTEMP**3.0)+(4.9005E-3*WXTEMP**4.0)-(7.8999E-5*WXTEMP**5.0)
    GAMMA2=34.690-(15.180*WXTEMP)+(2.7315*WXTEMP**2.0)-(0.23817
&*WXTEMP**3.0)+(1.0025E-2*WXTEMP**4.0)-(1.6273E-4*WXTEMP**5.0)
```

```
      VISCO1=0.43485+(0.22223*WXTEMP)-(3.7727E-3*WXTEMP**2.0)+
     &(3.3008E-5*WXTEMP**3.0)
      VISCO2=0.58428+(0.19044*WXTEMP)-(1.4473E-3*WXTEMP**2.0)-
     &(2.1787E-5*WXTEMP**3.0)
       end if


C*********   15-300 K range

       else  if ((WXTEMP .gt.15).and.(WXTEMP.le.300)) then
       if (WX3100 .ge. 11.603 .and. WX3100 .lt.14.696) then
            X=(WX3100-11.603)/(14.696-11.603)

      DENSI1=3.2639-(7.9210E-2*WXTEMP)+(7.3871E-4*WXTEMP**2.0)-
     &(2.8716E-6*WXTEMP**3.0)+(3.9215E-9*WXTEMP**4.0)
      DENSI2=4.9175-(0.15662*WXTEMP)+(2.1052E-3*WXTEMP**2.0)-
     &(1.3378E-5*WXTEMP**3.0)+(3.982E-8*WXTEMP**4.0)-(4.4702E-11*
     &WXTEMP**5.0)

      GAMMA1=1.7067-(1.7225E-3*WXTEMP)+(2.5694E-5*WXTEMP**2.0)-
     &(1.7154E-7*WXTEMP**3.0)+(5.2499E-10*WXTEMP**4.0)-(5.9979E-13*
     &WXTEMP**5.0)
      GAMMA2=1.6997-(1.3001E-3*WXTEMP)+(1.8231E-5*WXTEMP**2.0)-
     &(1.1661E-7*WXTEMP**3.0)+(3.4610E-10*WXTEMP**4.0)-(3.865E-13*
     &WXTEMP**5.0)

            VISCO1=1.8691+(9.5599E-2*WXTEMP)-(2.1715E-4*WXTEMP**2.0)+
     &(3.3468E-7*WXTEMP**3.0)
            VISCO2=1.8769+(9.5496E-2*WXTEMP)-(2.1670E-4*WXTEMP**2.0)+
     &(3.3405E-7*WXTEMP**3.0)

       else if (WX3100 .ge. 14.696 .and. WX3100 .lt.17.405) then
          X=(WX3100-14.696)/(17.405-14.696)

            DENSI1=4.9175-(0.15662*WXTEMP)+(2.1052E-3*WXTEMP**2.0)-
     &(1.3378E-5*WXTEMP**3.0)+(3.982E-8*WXTEMP**4.0)-(4.4702E-11*
     &WXTEMP**5.0)
            DENSI2=5.8293-(0.18579*WXTEMP)+(2.4983E-3*WXTEMP**2.0)-
     &(1.5880E-5*WXTEMP**3.0)+(4.7274E-8*WXTEMP**4.0)-(5.3075E-11*
     &WXTEMP**5.0)

            GAMMA1=1.6997-(1.3001E-3*WXTEMP)+(1.8231E-5*WXTEMP**2.0)-
     &(1.1661E-7*WXTEMP**3.0)+(3.4610E-10*WXTEMP**4.0)-(3.865E-13*
     &WXTEMP**5.0)
      GAMMA2=1.7049-(1.4931E-3*WXTEMP)+(2.0826E-5*WXTEMP**2.0)-
     &(1.3264E-7*WXTEMP**3.0)+(3.9207E-10*WXTEMP**4.0)-(4.3593E-13*
     &WXTEMP**5.0)

      VISCO1=1.8769+(9.5496E-2*WXTEMP)-(2.1670E-4*WXTEMP**2.0)+
     &(3.3405E-7*WXTEMP**3.0)
            VISCO2=1.8840+(9.539E-2*WXTEMP)-(2.1605E-4*WXTEMP**2.0)+
     &(3.3274E-7*WXTEMP**3.0)
```

```
      else if (WX3100 .ge. 17.405 .and. WX3100 .lt.20.305) then
      X=(WX3100-17.405)/(20.305-17.405)

       DENSI1=5.8293-(0.18579*WXTEMP)+(2.4983E-3*WXTEMP**2.0)-
     &(1.5880E-5*WXTEMP**3.0)+(4.7274E-8*WXTEMP**4.0)-(5.3075E-11*
     &WXTEMP**5.0)
       DENSI2=6.8105-(0.21728*WXTEMP)+(2.9236E-3*WXTEMP**2.0)-
     &(1.859E-5*WXTEMP**3.0)+(5.5353E-8*WXTEMP**4.0)-(6.2156E-11*
     &WXTEMP**5.0)

       GAMMA1=1.7049-(1.4931E-3*WXTEMP)+(2.0826E-5*WXTEMP**2.0)-
     &(1.3264E-7*WXTEMP**3.0)+(3.9207E-10*WXTEMP**4.0)-(4.3593E-13*
     &WXTEMP**5.0)
       GAMMA2=1.7120-(1.779E-3*WXTEMP)+(2.4903E-5*WXTEMP**2.0)-
     &(1.591E-7*WXTEMP**3.0)+(4.7184E-10*WXTEMP**4.0)-(5.2665E-13*
     &WXTEMP**5.0)

       VISCO1=1.8840+(9.539E-2*WXTEMP)-(2.1605E-4*WXTEMP**2.0)+
     &(3.3274E-7*WXTEMP**3.0)
       VISCO2=1.8909+(9.5307E-2*WXTEMP)-(2.1554E-4*WXTEMP**2.0)+
     &(3.3168E-7*WXTEMP**3.0)

      else if (WX3100 .ge. 20.305 .and. WX3100 .lt.23.206) then
       X=(WX3100-20.305)/(23.206-20.305)

       DENSI1=6.8105-(0.21728*WXTEMP)+(2.9236E-3*WXTEMP**2.0)-
     &(1.859E-5*WXTEMP**3.0)+(5.5353E-8*WXTEMP**4.0)-(6.2156E-11*
     &WXTEMP**5.0)
       DENSI2=7.7918-(0.2488*WXTEMP)+(3.3492E-3*WXTEMP**2.0)-
     &(2.1301E-5*WXTEMP**3.0)+(6.3439E-8*WXTEMP**4.0)-(7.1244E-11*
     &WXTEMP**5.0)

       GAMMA1=1.7120-(1.779E-3*WXTEMP)+(2.4903E-5*WXTEMP**2.0)-
     &(1.591E-7*WXTEMP**3.0)+(4.7184E-10*WXTEMP**4.0)-(5.2665E-13*
     &WXTEMP**5.0)
       GAMMA2=1.718-(2.0099E-3*WXTEMP)+(2.8173E-5*WXTEMP**2.0)-
     &(1.8050E-7*WXTEMP**3.0)+(5.3706E-10*WXTEMP**4.0)-(6.0136E-13*
     &WXTEMP**5.0)

       VISCO1=1.8909+(9.5307E-2*WXTEMP)-(2.1554E-4*WXTEMP**2.0)+
     &(3.3168E-7*WXTEMP**3.0)
       VISCO2=1.8969+(9.5275E-2*WXTEMP)-(2.1539E-4*WXTEMP**2.0)+
     &(3.3128E-7*WXTEMP**3.0)
      end if
      end if
C**********
      DENSI=(X*(DENSI2-DENSI1) + DENSI1)/16.018
      GAMMA=X*(GAMMA2-GAMMA1) + GAMMA1
      VISCO=(X*(VISCO2-VISCO1) + VISCO1)*(6.71967E-7)
C**********
```

```
      else if (choice.eq.2) then
      DENSI=(0.3729797*WX3100/TEMPR)
      GAMMA=1.6646
      VISCO=1.342E-5
      end if

C*** Based on choice of flow meter, calculate the expansion
C*** factor and thermal correction factor.
      if (choice.eq.1) then
      EXPANF=((r**(2.0/GAMMA))*(GAMMA/(GAMMA-1.0))*((1.0-r**
     &((GAMMA-1.0)/GAMMA))/(1.0-r))*((1.0-BETA**4.0)/(1.0-
     &(BETA**4.0)*(r**(2.0/GAMMA)))))**0.5
      if (TEMPF.ge.-500 .and. TEMPF.lt.70.0) then
            FA=1.0+2.0*0.0000074*(TEMPF-68)
      else if (TEMPF.ge.70.0 .and. TEMPF.lt.600.0) then
            FA=1.0+2.0*0.0000095*(TEMPF-68)
      end if
       else if(choice.eq.2) then
        EXPANF=(1.0-((0.410+0.350*BETA**4.0)*(DELTAP/WX3100)))
        FA=0.997
      end if
C*** Simplify mass flow equation.
      CONST=((0.52502)*FA*(THRDIA**2.0)*EXPANF)*((DENSI*DELTAP)
     &**0.5)/((1.0-BETA**4.0)**0.5)

C*** Based on choice of flow meter and holding Fa constant, chose an
C**  Fa.
      if (choice.eq.1)then
      Fold=.992
      else if (choice.eq.2) then
      Fold=1.00002
      end if

C*** Simplify the mass flow equation for the constant Fa and Cd
C**  solution.
      consta=((0.52502)*Fold*(THRDIA**2.0)*EXPANF)*((DENSI*DELTAP)
     &**0.5)/((1.0-BETA**4.0)**0.5)
C*** Simplify the Throat Reynolds equation.
      CONST2=(48/3.14159)/(THRDIA*VISCO)
C*** Begin first step in itiration process by calculating the
C**  Mass flows, and Reynold's numbers.
      MDOT=DISCOE*CONST
      Mold=DISCOE*consta
      RD=CONST2*MDOT
      if (RD.lt.10**6.0) then
            a=0.5
      else if (RD.gt.10**6.0) then
            a=0.2
      end if

      if (choice.eq.1) then
      C=0.9975-0.00653*(((10**6.0)/RD)**a)
      PERCNT=(ABS(C-DISCOE))/DISCOE
      else if (choice.eq.2) then
```

```
      C=.604
      end if
C*** Display output.
       write(6,*)'        DP          W[lbm/s]    Rd          Cd
     &        Y'
        write(6,*)'-----------------------------------------------------
--
     &---------------'
        write(6,*)'(1)', WX3098,Mold,'            ',DISCOE,EXPANF
      write(6,*)
C*** Determine if precent difference is greater than allowed.
      if (choice.eq.1) then
      do while(PERCNT.gt..0025)
      MDOT=C*CONST
      RD=CONST2*MDOT
      if (RD.lt.10**6.0) then
                a=0.5
        else if (RD.gt.10**6.0) then
                a=0.2
        endif
      CNEW=0.9975-0.00653*(((10**6.0)/RD)**a)
      PERCNT=(abs(CNEW-C))/C

      end do
      else if(choice.eq.2) then
      CNEW=C
      end if
C*** Display more results.
      write(6,*)'(2)', WX3098,MDOT,RD,CNEW,EXPANF
      write(6,*)'-----------------------------------------------
     &---------------------'
      error1=(abs(MDOT-Mold)/MDOT)*100.0
      write(6,'(1X,A,F9.3,A)')'% DIFFERENCE=  ',error1,'%'
      write(6,*)'NOTE: (2) ITIRATED VALUES        (1) Cd and Fa are
     &constant'
      write(6,*)
      write(6,*)'===============================================
     &==================='
      write(6,*)'(P1-P2)=',DELTAP,'  r=',r,'  BETA=',BETA
      write(6,*)'=====================================================
     &==========='
      write(6,*)'VISCOSITY    =',VISCO,' lb/ft-s'
      write(6,*)'DENSITY      =',DENSI,' lb/cu-ft'
      write(6,*)'GAMMA(y)     =',GAMMA
      write(6,*)
      WRITE(6,*)'Mass flow rate in grams/s :'
      write(6,*)'       ',Mold*453.592,  '  (1)'
      write(6,*)'       ',Mdot*453.592,  '  (2)'
      end
```

```
C****   NOTE ON UNITS
C***        Currently the mass flow rate is displayed in [lbm/sec], but
C           it may be necessary to convert it into kg/s or g/s. This
C           conversion can be achieved in the following manner:
C           pound-mass/sec [lbm/s]-->kilogram/s[kg/s] multiply by
C                                                          4.53592e-1
C                                 -->gram/s[g/s]      multiply by
C                                                          453.592
C
C           Some conversions are already in the program. They include
C           converting density [kg/m^3] to [lb/cu-ft] by dividing
C           density by 16.018
C           Also converting viscosity from [micro Pa-s] to [lbm-ft/s] by
C           multiplying the viscosity by 6.71967e-7
```

```
TITLE: FT-4052H                                                SF PROGRAM  400
                   CONTINUE ON ERROR (Y,N): NO
                ERROR STATUS ADDR (Y,C,WY,V):
                      PROGRAM TYPE (N,P,C,R): CYCLIC
                          CYCLE TIME (SEC): 3.0
ffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff
00001 *       MASS FLOW RATE THROUGH A VENTURI FLOW METER
              (THE PURPOSE OF THIS SPECIAL FUNCTION IS TO CALCULATE
               THE MASS FLOW RATE [GRAMS/SEC] THROUGH A VENTURI FLOW
               METER FT-4052-H, LOCATED IN THE VLPC VALVE BOX AT THE
               D0 REFRIGERATOR)
00002 *       ----VARIABLE ASSIGNMENTS-----
              WX3100   = UNSCALED BINARY INPUT OF INLET STATIC PRESSURE
              V300.    = SCALED,REAL INPUT OF INLET STATIC PRESSURE (PSIA)
              WX3098   = UNSCALED BINARY INPUT OF DIFFERENTIAL PRESSURE
              V302.    = SCALED,REAL INPUT OF DIFFERENTIAL PRESSURE ("H20)
              V222.    = SCALED,REAL TEMPERATURE(K) OBTAINED FROM SPECIAL
                         FUNCTION #104 FOR A CERNOX RTD #03537
              V304.    = BETA RATIO(INCH), RATIO OF THROAT TO INLET DIAMETERS
              V306.    = THROAT DIAMETER (INCH)
              V308.    = DISCHARGE COEFFICIENT (C) [ASSUMED CONSTANT]
              V310.    = THERMAL CORRECTION FACTOR (FA) [ASSUMED CONSTANT]
              V312.    = PERCENTAGE THAT INPUTTED PRESSURE IS ABOVE LOW
                         PRESSURE IN THE PRESSURE RANGE WHEN DETERMINING
                         THE DENSITY AND RATIO OF SPECIFIC HEATS
00003 *       V314.    = LOW END OF RATIO OF SPECIFIC HEATS FOR THE PRESSURE
                         RANGE AT THE INLET TEMPERATURE V222.
              V316.    = HIGH END OF RATIO OF SPECIFIC HEATS FOR THE PRESSURE
                         RANGE AT THE INLET TEMPERATURE V222.
              V318.    = FINAL,ITERATED VALUE FOR RATIO OF SPECIFIC HEATS AT
                         THE INLET TEMPERATURE V222.
              V320.    = LOW END OF DENSITY FOR THE PRESSURE RANGE AT THE
                         INLET TEMPERATURE V222.
              V322.    = HIGH END OF DENSITY FOR THE PRESSURE RANGE AT THE
                         INLET TEMPERATURE V222.
              V324.    = FINAL,ITERATED DENSITY [LBM/CU-FT] AT THE
                         INLET TEMPERATURE V222.
00004 *       V328.    = PRESSURE (P2)
              V330.    = SIMPLIFIED EXPRESSION
              V332.    = SIMPLIFIED EXPRESSION
              V334.    = SIMPLIFIED EXPRESSION
              V336.    = SIMPLIFIED EXPRESSION
              V338.    = SIMPLIFIED EXPRESSION
              V326.    = VALUE OF EXPANSION FACTOR
              V340.    = CALCULATED, REAL, SCALED VALUE FOR THE MASS FLOW
                         RATE IN [GRAMS/SEC]
              V83      = UNSCALED,INTEGER VALUE OF MASS FLOW RATE [0-32000]
00005 SCALE    BINARY INPUT..: WX3100         SCALED RESULT.: V300.
               LOW LIMIT.....: 0.0            HIGH LIMIT....: 7.5
               20% OFFSET....: YES            BIPOLAR.......: NO
00006 SCALE    BINARY INPUT..: WX3098         SCALED RESULT.: V302.
               LOW LIMIT.....: 0.0            HIGH LIMIT....: 50.0
               20% OFFSET....: YES            BIPOLAR.......: NO
00007 MATH    V300. := V300. + 14.5
00008 MATH    V304. := 0.3638
00009 MATH    V306. := 0.195
00010 MATH    V308. := 0.986
00011 MATH    V310. := 0.992
00012 MATH    V328. := V300. - V302. * 62.3164 / 1728
00013 IF      V222. <= 15.0 AND V222. > 0.0
```

```
00014 IF      V300. >= 11.6 AND V300. < 14.696
00015 MATH    V312. := ( V300. - 11.6 ) / ( 14.696 - 11.6 )
00016 MATH    V314. := 5.0808 - 1.3808 * V222. + 0.22946 * V222. ** 2.0 -
              0.01896 * V222. ** 3.0 + 7.6821E-4 * V222. ** 4.0 - 1.2129E-5 *
              V222. ** 5.0
00017 MATH    V316. := 7.6119 - 2.4907 * V222. + 0.42273 * V222. ** 2.0 -
              0.03541 * V222. ** 3.0 + 1.4483E-3 * V222. ** 4.0 - 2.3016E-5 *
              V222. ** 5.0
00018 MATH    V320. := 44.213 - 14.694 * V222. + 2.2599 * V222. ** 2.0 -
              0.17895 * V222. ** 3.0 + 7.0588E-3 * V222. ** 4.0 - 1.0944E-4 *
              V222. ** 5.0
00019 MATH    V322. := 67.312 - 23.602 * V222. + 3.7308 * V222. ** 2.0 -
              0.30041 * V222. ** 3.0 + 0.01198 * V222. ** 4.0 - 1.8721E-4 *
              V222. ** 5.0
00020 ELSE
00021 IF      V300. >= 14.696 AND V300. < 17.405
00022 MATH    V312. := ( V300. - 14.696 ) / ( 17.405 - 14.696 )
00023 MATH    V314. := 7.6119 - 2.4907 * V222. + 0.42273 * V222. ** 2.0 -
              0.03541 * V222. ** 3.0 + 1.4483E-3 * V222. ** 4.0
00024 MATH    V316. := 11.46 - 4.2354 * V222. + 0.73338 * V222. ** 2.0 -
              0.06228 * V222. ** 3.0 + 2.5724E-3 * V222. ** 4.0 - 4.1176E-5 *
              V222. ** 5.0
00025 MATH    V320. := 67.312 - 23.602 * V222. + 3.7308 * V222. ** 2.0 -
              0.30041 * V222. ** 3.0 + 0.01198 * V222. ** 4.0 - 1.8721E-4 *
              V222. ** 5.0
00026 MATH    V322. := 95.668 - 35.116 * V222. + 5.681 * V222. ** 2.0 - 0.46408
              * V222. ** 3.0 + 0.01869 * V222. ** 4.0 - 2.9409E-4 * V222. **
              5.0
00027 ELSE
00028 IF      V300. >= 17.405 AND V300. < 20.305
00029 MATH    V312. := ( V300. - 17.45 ) / ( 20.305 - 17.405 )
00030 MATH    V314. := 11.46 - 4.2354 * V222. + 0.73338 * V222. ** 2.0 -
              0.06228 * V222. ** 3.0 + 2.5724E-3 * V222. ** 4.0 - 4.1176E-5 *
              V222. ** 5.0
00031 MATH    V316. := 18.984 - 7.7297 * V222. + 1.3651 * V222. ** 2.0 -
              0.11751 * V222. ** 3.0 + 4.9005E-3 * V222. ** 4.0 - 7.8999E-5 *
              V222. ** 5.0
00032 MATH    V320. := 95.668 - 35.116 * V222. + 5.681 * V222. ** 2.0 - 0.46408
              * V222. ** 3.0 + 0.01869 * V222. ** 4.0 - 2.9409E-4 * V222. **
              5.0
00033 MATH    V322. := 139.73 - 53.822 * V222. + 8.9216 * V222. ** 2.0 -
              0.73994 * V222. ** 3.0 + 0.03011 * V222. ** 4.0 - 4.7727E-4 *
              V222. ** 5.0
00034 ELSE
00035 IF      V300. >= 20.305 AND V300. < 23.206
00036 MATH    V312. := ( V300. - 20.305 ) / ( 23.206 - 20.305 )
00037 MATH    V314. := 18.984 - 7.7297 * V222. + 1.3651 * V222. ** 2.0 -
              0.11751 * V222. ** 3.0 + 4.9005E-3 * V222. ** 4.0 - 7.8999E-5 *
              V222. ** 5.0
00038 MATH    V316. := 34.69 - 15.18 * V222. + 2.7315 * V222. ** 2.0 - 0.23817
              * V222. ** 3.0 + 0.01003 * V222. ** 4.0 - 1.6273E-4 * V222. **
              5.0
00039 MATH    V320. := 139.73 - 53.822 * V222. + 8.9216 * V222. ** 2.0 -
              0.73994 * V222. ** 3.0 + 0.03011 * V222. ** 4.0 - 4.7727E-4 *
              V222. ** 5.0
00040 MATH    V322. := 209.85 - 84.851 * V222. + 14.414 * V222. ** 2.0 - 1.2141
              * V222. ** 3.0 + 0.04993 * V222. ** 4.0 - 7.9738E-4 * V222. **
              5.0
00041 ENDIF
00042 ENDIF
```

```
00043 ENDIF
00044 ENDIF
00045 ELSE
00046 IF      V222. <= 350.0 AND V222. > 15.0
00047 IF      V300. >= 11.6 AND V300. < 14.696
00048 MATH    V312. := ( V300. - 11.6 ) / ( 14.696 - 11.6 )
00049 MATH    V314. := 1.7067 - 1.7225E-3 * V222. + 2.5694E-5 * V222. ** 2.0 -
              1.7154E-7 * V222. ** 3.0 + 5.2499E-10 * V222. ** 4.0 - 5.9979E-13
              * V222. ** 5.0
00050 MATH    V316. := 1.6997 - 1.3001E-3 * V222. + 1.8231E-5 * V222. ** 2.0 -
              1.1661E-7 * V222. ** 3.0 + 3.461E-10 * V222. ** 4.0 - 3.865E-13 *
              V222. ** 5.0
00051 MATH    V320. := 3.2639 - 0.07921 * V222. + 7.3871E-4 * V222. ** 2.0 -
              2.8716E-6 * V222. ** 3.0 + 3.9215E-9 * V222. ** 4.0
00052 MATH    V322. := 4.9175 - 0.15662 * V222. + 2.1052E-3 * V222. ** 2.0 -
              1.3378E-5 * V222. ** 3.0 + 3.982E-8 * V222. ** 4.0 - 4.4702E-11 *
              V222. ** 5.0
00053 ELSE
00054 IF      V300. >= 14.696 AND V300. < 17.405
00055 MATH    V312. := ( V300. - 14.696 ) / ( 17.405 - 14.696 )
00056 MATH    V314. := 1.6997 - 1.3001E-3 * V222. + 1.8231E-5 * V222. ** 2.0 -
              1.1661E-7 * V222. ** 3.0 + 3.461E-10 * V222. ** 4.0 - 3.865E-13 *
              V222. ** 5.0
00057 MATH    V316. := 1.7049 - 1.4931E-3 * V222. + 2.0826E-5 * V222. ** 2.0 -
              1.3264E-7 * V222. ** 3.0 + 3.9207E-10 * V222. ** 4.0 - 4.3593E-13
              * V222. ** 5.0
00058 MATH    V320. := 4.9175 - 0.15662 * V222. + 2.1052E-3 * V222. ** 2.0 -
              1.3378E-5 * V222. ** 3.0 + 3.982E-8 * V222. ** 4.0 - 4.4702E-11 *
              V222. ** 5.0
00059 MATH    V322. := 5.8293 - 0.18579 * V222. + 2.4983E-3 * V222. ** 2.0 -
              1.588E-5 * V222. ** 3.0 + 4.7274E-8 * V222. ** 4.0 - 5.3075E-11 *
              V222. ** 5.0
00060 ELSE
00061 IF      V300. >= 17.405 AND V300. < 20.305
00062 MATH    V312. := ( V300. - 17.405 ) / ( 20.305 - 17.405 )
00063 MATH    V314. := 1.7049 - 1.4931E-3 * V222. + 2.0826E-5 * V222. ** 2.0 -
              1.3264E-7 * V222. ** 3.0 + 3.9207E-10 * V222. ** 4.0 - 4.3593E-13
              * V222. ** 5.0
00064 MATH    V316. := 1.712 - 1.779E-3 * V222. + 2.4903E-5 * V222. ** 2.0 -
              1.591E-7 * V222. ** 3.0 + 4.7184E-10 * V222. ** 4.0 - 5.2665E-13
              * V222. ** 5.0
00065 MATH    V320. := 5.8293 - 0.18579 * V222. + 2.4983 * V222. ** 2.0 -
              1.588E-5 * V222. ** 3.0 + 4.7274E-8 * V222. ** 4.0 - 5.3075E-11 *
              V222. ** 5.0
00066 MATH    V322. := 6.8105 - 0.21728 * V222. + 2.9236E-3 * V222. ** 2.0 -
              1.859E-5 * V222. ** 3.0 + 5.5353E-8 * V222. ** 4.0 - 6.2156E-11 *
              V222. ** 5.0
00067 ELSE
00068 IF      V300. >= 20.305 AND V300 < 23.206
00069 MATH    V312. := ( V300. - 20.305 ) / ( 23.206 - 20.305 )
00070 MATH    V314. := 1.712 - 1.779E-3 * V222. + 2.4903E-5 * V222. ** 2.0 -
              1.591E-7 * V222. ** 3.0 + 4.7184E-10 * V222. ** 4.0 - 5.2665E-13
              * V222. ** 5.0
00071 MATH    V316. := 1.718 - 2.0099E-3 * V222. + 2.8173E-5 * V222. ** 2.0 -
              1.805E-7 * V222. ** 3.0 + 5.3706E-10 * V222. ** 4.0 - 6.0136E-13
              * V222. ** 5.0
00072 MATH    V320. := 6.8105 - 0.21728 * V222. + 2.9236E-3 * V222. ** 2.0 -
              1.859E-5 * V222. ** 3.0 + 5.5353E-8 * V222. ** 4.0 - 6.2156E-11 *
              V222. ** 5.0
00073 MATH    V322. := 7.7918 - 0.2488 * V222. + 3.3492E-3 * V222. ** 2.0 -
```

```
            2.1301E-5 * V222. ** 3.0 + 6.3439E-8 * V222. ** 4.0 - 7.1244E-11
            * V222. ** 5.0
00074 ENDIF
00075 ENDIF
00076 ENDIF
00077 ENDIF
00078 ENDIF
00079 ENDIF
00080 MATH    V318. := V312. * ( V316. - V314. ) + V314.
00081 MATH    V324. := ( V312. * ( V322. - V320. ) + V320. ) / 16.018
00082 MATH    V330. := V328. / V300.
00083 MATH    V332. := V304. ** 4.0
00084 MATH    V334. := V318. - 1.0
00085 MATH    V336. := 2.0 / V318.
00086 MATH    V338. := 1.0 - V330.
00087 MATH    V326. := ( V330. ** V336. * ( V318. / V334. ) * ( ( 1.0 - V330.
              ** ( V334. / V318. ) ) / V338. ) * ( ( 1.0 - V332. ) / ( 1.0 -
              V332. * V330. ** V336. ) ) ) ** 0.5
00088 MATH    V340. := V308. * V310. * V326. * 0.52502 * V306. ** 2.0 * ( V324.
              * ( V302. * ( 62.3164 / 1728 ) ) ) ** 0.5 / ( 1.0 - V304. ** 4.0
              ) ** 0.5 * 453.592
00089 UNSCALE  SCALED INPUT..: V340.            BINARY RESULT.: V83
               LOW LIMIT.....: 0.0              HIGH LIMIT....: 8.7
               20% OFFSET....: NO               BIPOLAR.......: NO
****  END ****
```

```
TITLE: FT-4053H                                          SF PROGRAM  401
                    CONTINUE ON ERROR (Y,N): NO
                 ERROR STATUS ADDR (Y,C,WY,V):
                      PROGRAM TYPE (N,P,C,R): CYCLIC
                          CYCLE TIME (SEC): 3.0
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00001 *         MASS FLOW RATE THROUGH A VENTURI FLOW METER
                (THE PURPOSE OF THIS SPECIAL FUNCTION IS TO CALCULATE
                 THE MASS FLOW RATE [GRAMS/SEC] THROUGH A VENTURI FLOW
                 METER FT-4053-H, LOCATED IN THE VLPC VALVE BOX AT THE
                 D0 REFRIGERATOR)
00002 *         ----VARIABLE ASSIGNMENTS-----
                WX3101    = UNSCALED BINARY INPUT OF INLET STATIC PRESSURE
                V342.     = SCALED,REAL INPUT OF INLET STATIC PRESSURE (PSIA)
                WX3099    = UNSCALED BINARY INPUT OF DIFFERENTIAL PRESSURE
                V344.     = SCALED,REAL INPUT OF DIFFERENTIAL PRESSURE ("H20)
                V227.     = SCALED,REAL TEMPERATURE(K) OBTAINED FROM SPECIAL
                            FUNCTION #105 FOR A CERNOX RTD #03539
                V346.     = BETA RATIO(INCH), RATIO OF THROAT TO INLET DIAMETERS
                V348.     = THROAT DIAMETER (INCH)
                V350.     = DISCHARGE COEFFICIENT (C) [ASSUMED CONSTANT]
                V352.     = THERMAL CORRECTION FACTOR (FA) [ASSUMED CONSTANT]
                V354.     = PERCENTAGE THAT INPUTTED PRESSURE IS ABOVE LOW
                            PRESSURE IN THE PRESSURE RANGE WHEN DETERMINING
                            THE DENSITY AND RATIO OF SPECIFIC HEATS
00003 *         V356.     = LOW END OF RATIO OF SPECIFIC HEATS FOR THE PRESSURE
                            RANGE AT THE INLET TEMPERATURE V222.
                V358.     = HIGH END OF RATIO OF SPECIFIC HEATS FOR THE PRESSURE
                            RANGE AT THE INLET TEMPERATURE V222.
                V360.     = FINAL,ITERATED VALUE FOR RATIO OF SPECIFIC HEATS AT
                            THE INLET TEMPERATURE V222.
                V362.     = LOW END OF DENSITY FOR THE PRESSURE RANGE AT THE
                            INLET TEMPERATURE V222.
                V364.     = HIGH END OF DENSITY FOR THE PRESSURE RANGE AT THE
                            INLET TEMPERATURE V222.
                V366.     = FINAL,ITERATED DENSITY [LBM/CU-FT] AT THE
                            INLET TEMPERATURE V222.
00004 *         V368.     = PRESSURE (P2)
                V370.     = SIMPLIFIED EXPRESSION
                V372.     = SIMPLIFIED EXPRESSION
                V374.     = SIMPLIFIED EXPRESSION
                V376.     = SIMPLIFIED EXPRESSION
                V378.     = SIMPLIFIED EXPRESSION
                V380.     = VALUE OF EXPANSION FACTOR
                V382.     = CALCULATED, REAL, SCALED VALUE FOR THE MASS FLOW
                            RATE IN [GRAMS/SEC]
                V84       = UNSCALED,INTEGER VALUE OF MASS FLOW RATE [0-32000]
00005 SCALE      BINARY INPUT..: WX3101          SCALED RESULT.: V342.
                 LOW LIMIT.....: 0.0             HIGH LIMIT....: 7.5
                 20% OFFSET....: YES             BIPOLAR.......: NO
00006 SCALE      BINARY INPUT..: WX3099          SCALED RESULT.: V344.
                 LOW LIMIT.....: 0.0             HIGH LIMIT....: 50.0
                 20% OFFSET....: YES             BIPOLAR.......: NO
00007 MATH      V342. := V342. + 14.5
00008 MATH      V346. := 0.3638
00009 MATH      V348. := 0.195
00010 MATH      V350. := 0.986
00011 MATH      V352. := 0.992
00012 MATH      V368. := V342. - V344. * 62.3164 / 1728
00013 IF        V227. <= 15.0 AND V227. > 0.0
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00014 IF      V342. >= 11.6 AND V342. < 14.696
00015 MATH    V354. := ( V342. - 11.6 ) / ( 14.696 - 11.6 )
00016 MATH    V356. := 5.0808 - 1.3808 * V227. + 0.22946 * V227. ** 2.0 -
              0.01896 * V227. ** 3.0 + 7.6821E-4 * V227. ** 4.0 - 1.2129E-5 *
              V227. ** 5.0
00017 MATH    V358. := 7.6119 - 2.4907 * V227. + 0.42273 * V227. ** 2.0 -
              0.03541 * V227. ** 3.0 + 1.4483E-3 * V227. ** 4.0 - 2.3016E-5 *
              V227. ** 5.0
00018 MATH    V362. := 44.213 - 14.694 * V227. + 2.2599 * V227. ** 2.0 -
              0.17895 * V227. ** 3.0 + 7.0588E-3 * V227. ** 4.0 - 1.0944E-4 *
              V227. ** 5.0
00019 MATH    V364. := 67.312 - 23.602 * V227. + 3.7308 * V227. ** 2.0 -
              0.30041 * V227. ** 3.0 + 0.01198 * V227. ** 4.0 - 1.8721E-4 *
              V227. ** 5.0
00020 ELSE
00021 IF      V342. >= 14.696 AND V342. < 17.405
00022 MATH    V354. := ( V342. - 14.696 ) / ( 17.405 - 14.696 )
00023 MATH    V356. := 7.6119 - 2.4907 * V227. + 0.42273 * V227. ** 2.0 -
              0.03541 * V227. ** 3.0 + 1.4483E-3 * V227. ** 4.0
00024 MATH    V358. := 11.46 - 4.2354 * V227. + 0.73338 * V227. ** 2.0 -
              0.06228 * V227. ** 3.0 + 2.5724E-3 * V227. ** 4.0 - 4.1176E-5 *
              V227. ** 5.0
00025 MATH    V362. := 67.312 - 23.602 * V227. + 3.7308 * V227. ** 2.0 -
              0.30041 * V227. ** 3.0 + 0.01198 * V227. ** 4.0 - 1.8721E-4 *
              V227. ** 5.0
00026 MATH    V364. := 95.668 - 35.116 * V227. + 5.681 * V227. ** 2.0 - 0.46408
              * V227. ** 3.0 + 0.01869 * V227. ** 4.0 - 2.9409E-4 * V227. **
              5.0
00027 ELSE
00028 IF      V342. >= 17.405 AND V342. < 20.305
00029 MATH    V354. := ( V342. - 17.45 ) / ( 20.305 - 17.405 )
00030 MATH    V356. := 11.46 - 4.2354 * V227. + 0.73338 * V227. ** 2.0 -
              0.06228 * V227. ** 3.0 + 2.5724E-3 * V227. ** 4.0 - 4.1176E-5 *
              V227. ** 5.0
00031 MATH    V358. := 18.984 - 7.7297 * V227. + 1.3651 * V227. ** 2.0 -
              0.11751 * V227. ** 3.0 + 4.9005E-3 * V227. ** 4.0 - 7.8999E-5 *
              V227. ** 5.0
00032 MATH    V362. := 95.668 - 35.116 * V227. + 5.681 * V227. ** 2.0 - 0.46408
              * V227. ** 3.0 + 0.01869 * V227. ** 4.0 - 2.9409E-4 * V227. **
              5.0
00033 MATH    V364. := 139.73 - 53.822 * V227. + 8.9216 * V227. ** 2.0 -
              0.73994 * V227. ** 3.0 + 0.03011 * V227. ** 4.0 - 4.7727E-4 *
              V227. ** 5.0
00034 ELSE
00035 IF      V342. >= 20.305 AND V342. < 23.206
00036 MATH    V354. := ( V342. - 20.305 ) / ( 23.206 - 20.305 )
00037 MATH    V356. := 18.984 - 7.7297 * V227. + 1.3651 * V227. ** 2.0 -
              0.11751 * V227. ** 3.0 + 4.9005E-3 * V227. ** 4.0 - 7.8999E-5 *
              V227. ** 5.0
00038 MATH    V358. := 34.69 - 15.18 * V227. + 2.7315 * V227. ** 2.0 - 0.23817
              * V227. ** 3.0 + 0.01003 * V227. ** 4.0 - 1.6273E-4 * V227. **
              5.0
00039 MATH    V362. := 139.73 - 53.822 * V227. + 8.9216 * V227. ** 2.0 -
              0.73994 * V227. ** 3.0 + 0.03011 * V227. ** 4.0 - 4.7727E-4 *
              V227. ** 5.0
00040 MATH    V364. := 209.85 - 84.851 * V227. + 14.414 * V227. ** 2.0 - 1.2141
              * V227. ** 3.0 + 0.04993 * V227. ** 4.0 - 7.9738E-4 * V227. **
              5.0
00041 ENDIF
00042 ENDIF
```

```
00043 ENDIF
00044 ENDIF
00045 ELSE
00046 IF      V227. <= 350.0 AND V227. > 15.0
00047 IF      V342. >= 11.6 AND V342. < 14.696
00048 MATH    V354. := ( V342. - 11.6 ) / ( 14.696 - 11.6 )
00049 MATH    V356. := 1.7067 - 1.7225E-3 * V227. + 2.5694E-5 * V227. ** 2.0 -
              1.7154E-7 * V227. ** 3.0 + 5.2499E-10 * V227. ** 4.0 - 5.9979E-13
              * V227. ** 5.0
00050 MATH    V358. := 1.6997 - 1.3001E-3 * V227. + 1.8231E-5 * V227. ** 2.0 -
              1.1661E-7 * V227. ** 3.0 + 3.461E-10 * V227. ** 4.0 - 3.865E-13 *
              V227. ** 5.0
00051 MATH    V362. := 3.2639 - 0.07921 * V227. + 7.3871E-4 * V227. ** 2.0 -
              2.8716E-6 * V227. ** 3.0 + 3.9215E-9 * V227. ** 4.0
00052 MATH    V364. := 4.9175 - 0.15662 * V227. + 2.1052E-3 * V227. ** 2.0 -
              1.3378E-5 * V227. ** 3.0 + 3.982E-8 * V227. ** 4.0 - 4.4702E-11 *
              V227. ** 5.0
00053 ELSE
00054 IF      V342. >= 14.696 AND V342. < 17.405
00055 MATH    V354. := ( V342. - 14.696 ) / ( 17.405 - 14.696 )
00056 MATH    V356. := 1.6997 - 1.3001E-3 * V227. + 1.8231E-5 * V227. ** 2.0 -
              1.1661E-7 * V227. ** 3.0 + 3.461E-10 * V227. ** 4.0 - 3.865E-13 *
              V227. ** 5.0
00057 MATH    V358. := 1.7049 - 1.4931E-3 * V227. + 2.0826E-5 * V227. ** 2.0 -
              1.3264E-7 * V227. ** 3.0 + 3.9207E-10 * V227. ** 4.0 - 4.3593E-13
              * V227. ** 5.0
00058 MATH    V362. := 4.9175 - 0.15662 * V227. + 2.1052E-3 * V227. ** 2.0 -
              1.3378E-5 * V227. ** 3.0 + 3.982E-8 * V227. ** 4.0 - 4.4702E-11 *
              V227. ** 5.0
00059 MATH    V364. := 5.8293 - 0.18579 * V227. + 2.4983E-3 * V227. ** 2.0 -
              1.588E-5 * V227. ** 3.0 + 4.7274E-8 * V227. ** 4.0 - 5.3075E-11 *
              V227. ** 5.0
00060 ELSE
00061 IF      V342. >= 17.405 AND V342. < 20.305
00062 MATH    V354. := ( V342. - 17.405 ) / ( 20.305 - 17.405 )
00063 MATH    V356. := 1.7049 - 1.4931E-3 * V227. + 2.0826E-5 * V227. ** 2.0 -
              1.3264E-7 * V227. ** 3.0 + 3.9207E-10 * V227. ** 4.0 - 4.3593E-13
              * V227. ** 5.0
00064 MATH    V358. := 1.712 - 1.779E-3 * V227. + 2.4903E-5 * V227. ** 2.0 -
              1.591E-7 * V227. ** 3.0 + 4.7184E-10 * V227. ** 4.0 - 5.2665E-13
              * V227. ** 5.0
00065 MATH    V362. := 5.8293 - 0.18579 * V227. + 2.4983 * V227. ** 2.0 -
              1.588E-5 * V227. ** 3.0 + 4.7274E-8 * V227. ** 4.0 - 5.3075E-11 *
              V227. ** 5.0
00066 MATH    V364. := 6.8105 - 0.21728 * V227. + 2.9236E-3 * V227. ** 2.0 -
              1.859E-5 * V227. ** 3.0 + 5.5353E-8 * V227. ** 4.0 - 6.2156E-11 *
              V227. ** 5.0
00067 ELSE
00068 IF      V342. >= 20.305 AND V342 < 23.206
00069 MATH    V354. := ( V342. - 20.305 ) / ( 23.206 - 20.305 )
00070 MATH    V356. := 1.712 - 1.779E-3 * V227. + 2.4903E-5 * V227. ** 2.0 -
              1.591E-7 * V227. ** 3.0 + 4.7184E-10 * V227. ** 4.0 - 5.2665E-13
              * V227. ** 5.0
00071 MATH    V358. := 1.718 - 2.0099E-3 * V227. + 2.8173E-5 * V227. ** 2.0 -
              1.805E-7 * V227. ** 3.0 + 5.3706E-10 * V227. ** 4.0 - 6.0136E-13
              * V227. ** 5.0
00072 MATH    V362. := 6.8105 - 0.21728 * V227. + 2.9236E-3 * V227. ** 2.0 -
              1.859E-5 * V227. ** 3.0 + 5.5353E-8 * V227. ** 4.0 - 6.2156E-11 *
              V227. ** 5.0
00073 MATH    V364. := 7.7918 - 0.2488 * V227. + 3.3492E-3 * V227. ** 2.0 -
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            2.1301E-5 * V227. ** 3.0 + 6.3439E-8 * V227. ** 4.0 - 7.1244E-11
            * V227. ** 5.0
00074 ENDIF
00075 ENDIF
00076 ENDIF
00077 ENDIF
00078 ENDIF
00079 ENDIF
00080 MATH    V360. := V354. * ( V358. - V356. ) + V356.
00081 MATH    V366. := ( V354. * ( V364. - V362. ) + V362. ) / 16.018
00082 MATH    V370. := V368. / V342.
00083 MATH    V372. := V346. ** 4.0
00084 MATH    V374. := V360. - 1.0
00085 MATH    V376. := 2.0 / V360.
00086 MATH    V378. := 1.0 - V370.
00087 MATH    V380. := ( V370. ** V376. * ( V360. / V374. ) * ( ( 1.0 - V370.
              ** ( V374. / V360. ) ) / V378. ) * ( ( 1.0 - V372. ) / ( 1.0 -
              V372. * V370. ** V376. ) ) ) ** 0.5
00088 MATH    V382. := V350. * V352. * V380. * 0.52502 * V348. ** 2.0 * ( V366.
              * ( V344. * ( 62.3164 / 1728 ) ) ) ** 0.5 / ( 1.0 - V346. ** 4.0
              ) ** 0.5 * 453.592
00089 UNSCALE  SCALED INPUT..: V382.            BINARY RESULT.: V84
               LOW LIMIT.....: 0.0              HIGH LIMIT....: 8.7
               20% OFFSET....: NO               BIPOLAR.......: NO
****  END ****
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TITLE: FO-2019H                                                SF PROGRAM  402
                   CONTINUE ON ERROR (Y,N): NO
              ERROR STATUS ADDR (Y,C,WY,V):
                    PROGRAM TYPE (N,P,C,R): CYCLIC
                          CYCLE TIME (SEC): 3.0
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00001 *       MASS FLOW RATE THROUGH AN ORIFICE FLOW METER
              (THE PURPOSE OF THIS SPECIAL FUNCTION IS TO CALCULATE
               THE MASS FLOW RATE [GRAMS/SEC] THROUGH AN ORIFICE PLATE FLOW
               METER (F0-2019-H) LOCATED ON THE HIGH PRESSURE HELIUM
               SUPPLY LINE IN THE D0 ASSEMBLY BUILDING)
00002 *       ----VARIABLE ASSIGNMENTS-----
              WX3095   = UNSCALED BINARY INPUT OF INLET STATIC PRESSURE
              V390.    = SCALED,REAL INPUT OF INLET STATIC PRESSURE (PSIG)
                         AT 294K
              WX3073   = UNSCALED BINARY INPUT OF DIFFERENTIAL PRESSURE
              V392.    = SCALED,REAL INPUT OF DIFFERENTIAL PRESSURE (INH2O) PSID
              V394.    = BETA RATIO(INCH), RATIO OF THROAT TO INLET DIAMETERS
              V396.    = THROAT DIAMETER (INCH)
              V398.    = DISCHARGE COEFFICIENT (C) [ASSUMED CONSTANT]
              V400.    = THERMAL CORRECTION FACTOR (FA) [ASSUMED CONSTANT]
00003 *       V402.    = TEMP IN DEGREES RANKINE
                       =((1.8*(T(K)-273.15))+32.0)+459.67
              V404.    = FINAL,ITERATED VALUE FOR RATIO OF SPECIFIC HEATS AT
                         THE INLET TEMPERATURE OF 294 K
              V406.    = FINAL,ITERATED DENSITY [LBM/CU-FT] AT THE
                         INLET TEMPERATURE OF 294 K
00004 *       V408.    = PRESSURE (P2)
              V410.    = VALUE OF EXPANSION FACTOR
              V412.    = CALCULATED, REAL, SCALED VALUE FOR THE MASS FLOW
                         RATE IN [GRAMS/SEC]
              V85      = UNSCALED, INTEGER VALUE FOR MASS FLOW RATE [0-3200]
00005 SCALE    BINARY INPUT..: WX3095          SCALED RESULT.: V390.
               LOW LIMIT.....: 0.0             HIGH LIMIT....: 5.0
               20% OFFSET....: YES             BIPOLAR.......: NO
00006 SCALE    BINARY INPUT..: WX3073          SCALED RESULT.: V392.
               LOW LIMIT.....: 0.0             HIGH LIMIT....: 500.0
               20% OFFSET....: YES             BIPOLAR.......: NO
00007 MATH    V390. := V390. + 14.5
00008 MATH    V394. := 0.439
00009 MATH    V396. := 0.947
00010 MATH    V398. := 0.604
00011 MATH    V400. := 1.00018
00012 MATH    V402. := 529.2
00013 MATH    V408. := V390. - V392.
00014 MATH    V404. := 1.6646
00015 MATH    V406. := 0.37298 * V390. / V402.
00016 MATH    V410. := ( 1.0 - ( 0.41 + 0.35 * V394. ** 4.0 ) * ( V392. / V390.
              ) ) / V404.
00017 MATH    V412. := V398. * V400. * V410. * 0.52502 * V396. ** 2.0 * ( V406.
              * V392. ) ** 0.5 / ( 1.0 - V394. ** 4.0 ) ** 0.5 * 453.592
00018 UNSCALE  SCALED INPUT..: V412.           BINARY RESULT.: V85
               LOW LIMIT.....: 0.0             HIGH LIMIT....: 77.99
               20% OFFSET....: NO              BIPOLAR.......: NO
****  END ****
```

REFERENCES:

ASME, Fluid Meters, Their Theory and Application sixth edition, 1971

R.W.Miller. Flow Measurement Engineering Handbook second edition, 1989

FLOW-DYNE Engineering, Inc. contact: Tyson Schmidt (817)281-6448

Thermodynamic Properties Tables for Helium