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**A COMPUTER PROGRAM FOR DETERMINING
THE THERMODYNAMIC PROPERTIES OF FREON
REFRIGERANTS**

By
David H. Riemer
Harold R. Jacobs
Robert F. Boehm

MASTER

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University of Utah
Department of Mechanical Engineering
Salt Lake City, Utah

**U. S. DEPARTMENT OF ENERGY
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A UNIVERSITY OF UTAH
DIRECT CONTACT GEOTHERMAL POWER
PROJECT REPORT

A Computer Program
for Determining the Thermodynamic
Properties of Freon Refrigerants

David H. Riemer
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NOMENCLATURE

a	constant in heat capacity of vapor equation
b	
c	
d	
f	
A ₂	constant in Downing-Martin equation
A ₃	
A ₄	
A ₅	
A ₆	
B ₂	
B ₃	
B ₄	
B ₅	
B ₆	
C ₁	
C ₂	
C ₃	
C ₄	
C ₅	
C ₆	
h	enthalpy (Btu/lbm)
K	constant in Downing-Martin equation
P	pressure (psia)
R	universal gas constant
S	enthalpy (Btu/lbm°R)
T	temperature (°R)
V	specific volume (ft ³ /lbm)
α	constant in Downing-Martin equation
Ø	conversion factor
β	constant in Downing-Martin equation

ABSTRACT

This program was written to be used as a subroutine. The program determines the thermodynamics of Freon refrigerants. The following refrigerants can be analyzed F-11, F-12, F-13, F-14, F-21, F-22, F-23, F-113, and F-114. The subroutine can evaluate a thermodynamic state for these refrigerants given any of the following pairs of state quantities: pressure and quality, pressure and entropy, pressure and enthalpy, temperature and quality, temperature and specific volume and temperature and pressure. These six pairs of knowns allow the user to analyze any thermodynamic cycle utilizing a refrigerant as the working fluid. The Downing form of the Martin equation of state was used. This report contains a brief description, flow chart and listing of all subroutines required.

INTRODUCTION

This subroutine computes the thermodynamic properties of Freon refrigerants. The subroutine was developed to allow for a wide range of applications such that it may be used to determine the properties of Freon refrigerants in a refrigeration cycle or, as the authors developed it, for use in evaluating binary fluid cycles. This routine can be treated as a "black box" by the user with a limited background in programming or the program may be modified to meet the users requirements. This manual was written to assist the user in which ever manner he intends to use this subroutine.

DEVELOPMENT OF PROPERTIES

The basic equation used is the Downing form of the Martin equation of state which have the form:

$$\begin{aligned}
 P = & \frac{RT}{V-B} + \frac{A_2 + B_2T + C_2e^{(-KT/Tc)}}{(V-B)^2} + \frac{A_3 + B_3T + C_3e^{(-KT/Tc)}}{(V-B)^3} \\
 & + \frac{A_4 + B_4T + C_4e^{(-KT/Tc)}}{(V-B)^4} + \frac{A_5 + B_5T + C_5e^{(-KT/Tc)}}{(V-B)^5} + \frac{A_6 + B_6T + C_6e^{(-KT/Tc)}}{e^{\alpha V}(1 + C_1e^{\alpha V})} \\
 h = & aT + bT^2/2 + cT^3/3 + dT^4/4 - f/T + \rho PV + \rho \left(\frac{A_2}{(V-B)} + \frac{A_3}{2(V-B)^2} + \frac{A_4}{3(V-B)^3} \right. \\
 & + \frac{A_5}{4(V-B)^4} + \frac{A_6}{\alpha} \left(\frac{1}{e^{\alpha V}} - C_1 \ln \left(\frac{C_1 e^{\alpha V} + 1}{C_1 e^{\alpha V}} \right) \right) \Bigg) \\
 & + \rho e^{-KT/Tc} (1 + KT/Tc) \left(\frac{C_2}{V-B} + \frac{C_3}{2(V-B)^3} + \frac{C_4}{3(V-B)^3} + \frac{C_5}{4(V-B)^4} \right. \\
 & + \frac{C_6}{\alpha e^{\alpha V}} - \frac{C_6 C_1}{\alpha} \ln \left(\frac{C_1 e^{\alpha V} + 1}{C_1 e^{\alpha V}} \right) \Bigg) + \Delta h(\text{latent at } -40^\circ\text{F}) - h(\text{saturated} \\
 & \text{vapor at } -40^\circ\text{F})
 \end{aligned}$$

$$\begin{aligned}
S = & a \ln T + BT + CT^2/2 + DT^3/3 - f/2T^2 + \phi R \ln(V-\beta) + \phi \left(\frac{B_2}{V-\beta} + \frac{B_3}{2(V-\beta)^2} \right. \\
& + \frac{B_4}{3(V-\beta)^3} + \frac{B_5}{4(V-\beta)^4} + \frac{B_6}{\alpha} \left(\frac{1}{e^{\alpha v}} - C_1 \ln \left(\frac{C_1 e^{\alpha v} + 1}{C_1 e^{\alpha v}} \right) \right) \\
& + \frac{\phi e^{-KT/TC}}{TC} \left(\frac{C_2}{V-\beta} + \frac{C_3}{2(V-\beta)^2} + \frac{C_4}{3(V-\beta)^3} + \frac{C_5}{4(V-\beta)^4} + \frac{C_6}{\alpha e^{\alpha v}} \right. \\
& \left. \left. - \frac{C_6 C_1}{\alpha} \ln \left(\frac{C_1 e^{\alpha v} + 1}{C_1 e^{\alpha v}} \right) \right) + \Delta h(\text{latent at } -40^\circ\text{F}) / -40 - S(\text{saturated} \right. \\
& \left. \text{vapor at } -40^\circ\text{F})
\end{aligned}$$

The above equations only predict properties in the vapor region. In order to determine saturated liquid properties the Clapeyron equation is used to compute saturated liquid enthalpy and entropy. Saturated liquid specific volume is computed as a function of temperature. Compressed liquid states are approximated by saturated liquid states at the same temperature.

For evaluating an ideal cycle the following processes are employed, constant entropy(turbine, pump and compressor), constant enthalpy (expansion valve), constant pressure(heat exchanger). In order to determine properties for these processes, properties must be determined with one of the following pairs known (Recall that a thermodynamic state requires that two state quantities be known and for saturation states temperature and pressure are dependent): temperature and pressure, temperature and quality, pressure and quality, pressure and enthalpy and pressure and entropy. Since pressure is a function of specific volume and temperature, when pressure and temperature are known a search technique must be used to find the specific volume. Once the specific is found the remaining properties may be calculated. The saturation pressure is known as a function of temperature, thus allowing saturation conditions of known pressure or temperature to be solved

as the case of pressure and temperature already described. Once the saturation properties have been determined the effect of a given quality can be determined. The cases of pressure and entropy or enthalpy as knowns require a two variable search since all three of these quantities and functions of specific volume and temperature. This search is only used in the superheated vapor region or the compressed liquid approximated region because for saturation states only a quality need be computed. For all searches in FREON the Newton Raphson iteration technique was used. This method was selected for its generally rapid convergence.

PROGRAM DEVELOPMENT

Subroutine FREON was written in FORTRAN V for the UNIVAC 1108 series computer but should be easily adapted to any similar FORTRAN computer. The subroutine allows the user to use the program at two levels, first as a "black box" (the main text describes the use and general development of the program), second the program may be modified to best suit the users needs. (The remaining text contains a more complete description of each subroutine.) Subroutines were used throughout to allow for easy modification and as a means of tracing any possible problems. This report contains variable description tables, flow charts, equations and brief descriptions of all subroutines.

USE OF FREON

In order to use FREON the user must supply to the subroutine the following information:

1. The process for which properties are to be determined (CYCLE).

The allowable values of CYCLE are the following pairs of knowns:

TP - temperature and pressure

TX - temperature and quality

TV - temperature and specific volume

PH - pressure and enthalpy

PS - pressure and entropy

PX - pressure and quality

These are the only allowable values of CYCLE and the order is important, i.e., PT or SP, etc., are illegal and will generate an error termination of FREON.

2. The value of the first known specified by the value of CYCLE (FGIVEN).
3. The value of the second known specified by the value of CYCLE (SGIVEN).
4. Freon refrigerant type (FTYPE). FTYPE is formed by placing an F in front of the refrigerant number. The following values are acceptable: F11, F12, F13, F14, F21, F22, F23, F113 and F114.
5. Print selector - if NPRT = 0 then do not print out results, otherwise print out results

FREON will return the following information:

1. Quality - applies to saturation states (if greater than 1 then superheated vapor and if less than 1 then compressed liquid.)
2. enthalpy (Btu/lbm)
3. entropy (Btu/lbm[°]R)
4. specific volume (ft³/lbm)
5. temperature (°F)
6. pressure (psia)
7. saturated liquid enthalpy (Btu/lbm)

8. saturated liquid entropy (Btu/lbm°R)
9. saturated liquid specific volume (ft³/lbm)
10. saturated vapor enthalpy (Btu/lbm)
11. saturated vapor entropy (Btu/lbm)
12. saturated vapor specific volume (ft³/lbm)

A typical call on FREON would look like:

```
CALL FREON ('TP', TEMP, PRESS, 'F113', H, S, V, T, P, HV, SU, VV,
HL, SL, VL, QUAL, NPRT)
```

This call on FREON evaluates properties for FREON-113 given temperature (TEMP) and pressure (PRESS). Subroutine FREON was written so as to be independent of the calling program except for the passage of the above parameters, therefore no external variables need be placed in common.

Q Array

VAPOR PRESSURE COEFFICIENTS

Q(1,1) A	Q(2,1) B	Q(3,1) C	Q(4,1) D
-------------	-------------	-------------	-------------

Q(1,2) E	Q(2,2) F	Q(3,2) G	Q(4,2) H
-------------	-------------	-------------	-------------

EQUATION OF STATE COEFFICIENTS

Q(1,3) L	Q(2,3) R	Q(3,3) β	Q(4,3) T _c (°F)
-------------	-------------	-------------------	-------------------------------

LIQUID DENSITY

Q(1,4) A _L	Q(2,4) A ₂	Q(3,4) B ₂	Q(4,4) C ₂
--------------------------	--------------------------	--------------------------	--------------------------

Q(1,5) B _L	Q(2,5) A ₃	Q(3,5) B ₃	Q(4,5) C ₃
--------------------------	--------------------------	--------------------------	--------------------------

Q(1,6) C _L	Q(2,6) A ₄	Q(3,6) B ₄	Q(4,6) C ₄
--------------------------	--------------------------	--------------------------	--------------------------

Q(1,7) D _L	Q(2,7) A ₅	Q(3,7) B ₅	Q(4,7) C ₅
--------------------------	--------------------------	--------------------------	--------------------------

Q(1,8) E _L	Q(2,8) A ₆	Q(3,8) B ₆	Q(4,8) C ₆
--------------------------	--------------------------	--------------------------	--------------------------

HEAT EQUATION COEFFICIENTS

Q(1,9) a	Q(2,9) b	Q(3,9) c	Q(4,9) d
-------------	-------------	-------------	-------------

Q(1,10) f	Q(2,10) X	Q(3,10) Y	Q(4,10) S _{CRIT}
--------------	--------------	--------------	------------------------------

Q(1,11) ABST	Q(2,11) H _{CRIT}	Q(3,11) NTYPE	Q(4,11) V _{CRIT}
-----------------	------------------------------	------------------	------------------------------

Q(1,12) C ₁	Q(2,12) k	Q(3,12) α	Q(4,12) P _{CRIT}
---------------------------	--------------	---------------------	------------------------------

Figure 1.

FREON DESCRIPTION

FREON is the main routine for determining the thermodynamic properties of the Freon refrigerants. The routine selects the correct set of coefficients for the fluid to be evaluated. These coefficients are stored in the array Q which has the form as shown in Figure 1. FREON then must determine if the two state quantities given are legitimate values, i.e. for temperature and quality the temperature must be less than or equal to the critical temperature and the quality must lie between zero and one. Once the quantities are found to be legitimate FREON must determine the region to which the point corresponds, i.e. compressed liquid, saturated liquid-vapor equilibrium or superheated vapor. Given the region FREON then calls the proper subroutines to compute the remaining thermodynamic properties.

VARIABLE SYMBOL TABLE

FREON

VARIABLE

DESCRIPTION

BTOLER

Lower tolerance on convergence and saturation tests

CYCLE

Type of calculation to be made, CYCLE has the following possible pairs of knowns:

1. temperature and pressure = TP
2. temperature and quality = TX
3. temperature and specific volume = TV
4. pressure and quality = PX
5. pressure and enthalpy = PH
6. pressure and entropy = PS

DELTH	h_{fg} - calculated from Clapeyron Equation
DERROR	tolerance used in checks for zero
DHDT	$\frac{\partial h(V,T)}{\partial T}$
DHDV	$\frac{\partial h(V,T)}{\partial V}$
DPSDT	$\frac{dp_{SAT}(T)}{dT}$
DPSDT2	$\frac{d^2 p_{SAT}(T)}{dT^2}$
DSDT	$\frac{\partial S(V,T)}{\partial T}$
DSDV	$\frac{\partial S(V,T)}{\partial V}$
DVLDT	$\frac{dV_L(T)}{dT}$
F11	2-dimensional array containing the coefficients for F11
F12	2-dimensional array containing the coefficients for F12
F13	2-dimensional array containing the coefficients for F13
F14	2-dimensional array containing the coefficients for F14
F21	2-dimensional array containing the coefficients for F21
F22	2-dimensional array containing the coefficients for F22
F23	2-dimensional array containing the coefficients for F23
F113	2-dimensional array containing the coefficients for F113

F114	2-dimensional array containing the coefficients for F114
FGIVEN	First known passed to FREON, i.e. temperature for values of CYCLE of TP, TX, TV and pressure for values of CYCLE of PS, PH AND PX
FTYPE	Freon type
H	enthalpy (Btu/lbm)
HCRIT	critical enthalpy (Btu/lbm)
HL	saturated liquid enthalpy (Btu/lbm)
HV	saturated vapor enthalpy (Btu/lbm)
I	index
J	index
LIMIT	maximum number of iterations allowed in any one search
M2	unit number for printer
NPRT	print selector NPRT = 1 print and results NPRT ≠ 1 do not print results
NTYPE	saturated liquid specific volume equation selector
PCAL	calculated pressure (psia)
PCRIT	critical pressure (psia)
PSAT	saturation pressure (psia)
PSIA	Pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated
QUAL	quality

RJ	conversion factor = 0.185053
S	entropy (Btu/lbm [°] R)
SCRIT	critical entropy (Btu/lbm [°] R)
SGIVEN	second known passed to FREON
SL	saturated liquid entropy (Btu/lbm [°] R)
SV	saturated vapor entropy (Btu/lbm [°] R)
T	temperature (°R)
TF	temperature (°F)
TCRIT	critical temperature (°F)
TTOLER	upper tolerance on convergence and saturation tests
V	specific volume (ft ³ /lbm)
VL	saturated liquid specific volume (ft ³ /lbm)
VV	saturated vapor specific volume (ft ³ /lbm)

```

1      C *****
2      C *
3      C *
4      C *
5      C * THIS SUBROUTINE CALCULATES THE THERMODYNAMIC PROPERTIES OF *
6      C * FREONS BY USING THE MARTIN-HOU EQUATION OF STATE. THE TYPES OF *
7      C * STATES WHICH CAN BE EVALUATED ARE, GIVEN THE FOLLOWING PAIRS OF *
8      C * KNOWN: *
9      C * 1) TEMPERATURE-PRESSURE *
10     C * 2) TEMPERATURE-QUALITY *
11     C * 3) PRESSURE-ENTROPY *
12     C * 4) PRESSURE-ENTHALPY *
13     C * 5) PRESSURE-QUALITY *
14     C * 6) TEMPERATURE-SPECIFIC VOLUME *
15     C * COMPRESSED LIQUID STATES ARE APPROXIMATED BY SATURATED *
16     C * LIQUID STATES. THIS PROGRAM WAS WRITTEN BY DAVID H. RIEMER *
17     C *
18     C *****
19     C SUBROUTINE FREON(CYCLE,F6IVEN,S6IVEN,FTYPE,H,S,V,T,PSIA,
20     C 1 HV,SV,VV,HL,SL,VL,QUAL,NPRT)
21     C PARAMETER M2=6
22     C DIMENSION F113(4,12),F114(4,12),F11(4,12),F12(4,12),F13(4,12),
23     C 1F14(4,12),F21(4,12),F22(4,12),F23(4,12)
24     C COMMON/FREON1/Q(4,12),TTOLER,BTOLER,LIMIT,DError,NTYPE
25     C DATA LIMIT,DError,TTOLER,BTOLER/50,1.0E-10,1.005,0.995/
26     C DATA ((F113(I,J),I=1,4),J=1,12)/33.0655,-4330.98,-9.2635,
27     C 1 0.0020539,0.0,0.0,0.0,0.0,0.0,0.0,0.05728,0.0,417.4,122.872,
28     C 2 -4.035,0.002618,0.0,-0.0128,-0.0214,5.0E-05,0.0,-6.36E-05,0.0,
29     C 3 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.07963,1.159E-04,0.0,
30     C 4 0.0,0.0,25.198,-0.40552,0.1699,459.6,109.49,3.0,0.02781,0.0,
31     C 5 0.0,0.0,498.9/
32     C DATA((F114(I,J),I=1,4),J=1,12)/27.071306,-5113.7021,-6.3086761,
33     C 1 6.913003E-04,0.7814211002,768.35,0.0,0.0,0.0,0.062780807,
34     C 2 5.914907E-03,294.35,36.32,-2.3856704,1.0801207E-03,-6.5643648,

```

35 3 0.021776,0.034055087,-5.3336494E-06,0.16366057,0.63649,
36 4 -3.857481E-04,0.0,0.0,0.7186,1.6017659E-06,6.2632341E-10,
37 5 -1.0165314E-05,1.97E-06,0.0,0.0,0.0,0.0175,3.49E-04,-1.67E-07,
38 6 0.0,0.0,25.33968211,-0.1151371756,0.15842,459.6,95.4,2.0,
39 7 0.027533,0.0,3.0,6.0,473.187/
40 DATA((F11(I,J),I=1,4),J=1,12)/42.14702865,-4344.343807,
41 1-12.84596753,0.004038372507,0.0313605356,862.07,0.0,0.0,0.0,
42 20.078117,0.00190,388.47,34.57,-3.126759,1.318523E-03,-35.769990,
43 357.63811,-0.025341,4.8751212E-05,1.220367,43.63220,1.687277E-03,
44 4-1.805062E-06,0.0,-42.82556,-2.358930E-05,2.448303E-08,
45 5-1.478379E-04,36.70603,1.057504E08,-9.472103E04,0.0,0.023815,
46 62.798823E-04,-2.123734E-07,5.999018E-11,-336.807030,50.5418,
47 7-0.0918395,0.17219,459.6,112.080,1.0,0.028927,0.0,4.50,580.00,
48 8639.50/
49 DATA((F12(I,J),I=1,4),J=1,12)/39.88381727,-3436.632228,
50 1-12.47152228,0.004730442442,0.0,0.0,0.0,0.0,0.0,0.088734,
51 20.00065093886,235.70,34.84,-3.409727134,0.00159434848,-56.7627671,
52 30.02696,0.06023944634,-1.879618431E-05,1.311399084,0.834921,
53 4-0.000548737007,0.0,0.0,6.02683,0.0,3.468834E-09,-2.54390678E-05,
54 5-0.655549E-05,0.0,0.0,0.0,0.0080945,0.000332662,-2.413896E-07,
55 66.72363E-11,0.0,-39.55655122,-0.0165379361,0.1359,459.6,78.86,2.0,
56 70.02870,0.0,5.475,0.0,596.9/
57 DATA((F13(I,J),I=1,4),J=1,12)/25.96797498,-2709.538217,
58 1-7.172343913,0.00254515398,0.2803010913,546.00,0.0,0.0,0.0,
59 20.102720,0.0048,84.00,36.06996128,-3.083417,2.341695E-03,
60 3-18.212643,0.01566,6.058854,-5.671268E-05,0.571958,1.110,
61 4-1.026061E-03,1.338679E-06,0.0,6.665,5.290649E-06,-7.395111E-9,
62 5-3.874233E-05,3.245E-05,7.378601E07,-7.435565E04,0.0,0.01602,
63 62.823E-04,-1.159E-07,0.0,0.0,20.911,-0.05676,0.08898,459.6,
64 745.271,2.0,0.0277239,0.0,4.00,625.00,561.30/
65 DATA((F14(I,J),I=1,4),J=1,12)/20.71545389,-2467.505285,
66 1-4.69017025,0.00064798076,0.770707795,424.0,0.0,0.0,0.0,0.1219336,
67 20.0015,-50.1,39.06,-2.162959,2.135114E-03,-18.941131,69.56848907,
68 34.404057E-03,1.282818E-05,0.539776,4.58661139,1.921072E-04,
69 4-3.918263E-07,0.0,36.17166615,-4.481049E-06,9.062318E-09,

```

70 5-4.856676E-05,-8.05898583,5.838823E07,-9.263923E04,0.0,
71 63.00559202E-02,2.37043352E-04,-2.85660077E-08,-2.95338800E-11,0.0,
72 786.102162,0.36172526,0.5284,459.0,100.636,1.0,0.02560163,0.0,4.00,
73 8661.199997,543.16/
74 DATA((F21(I,J),I=1,4),J=1,12)/42.7908,-4261.34,-13.0295,0.0039851,
75 10.0,0.0,0.0,0.0,0.0,0.0,0.10427,0.0,812.9,116.37962,-7.316,0.00464210,
76 20.0,-0.03106808,-0.20382376,0.0003593,0.0,-0.0000501,0.0,0.0,0.0,
77 30.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0427,0.000140,0.0,0.0,0.0,0.0,
78 40.0,0.1906,459.6,123.45,3.0,0.030675,0.0,0.0,0.0,0.0,750.0/
79 DATA((F22(I,J),I=1,4),J=1,12)/29.35754453,-3845.193152,
80 1-7.86103122,0.002190939044,0.445746703,606.1,0.0,0.0,0.0,0.124098,
81 20.002,204.81,32.76,-4.353547,0.002407252,-44.066868,54.6344093,
82 3-0.017464,7.62789E-05,1.483763,36.74892,0.002310142,-3.605723E-06,
83 40.0,-22.2925657,-3.724044E-05,5.355465E-08,-1.845051E-04,
84 520.47328662,1.363387E08,-1.672612E05,0.0,0.02812836,2.255406E-04,
85 6-6.509607E-08,0.0,257.341,62.4009,-0.0453335,0.16016,459.69,
86 791.329,1.0,0.030525,0.0,4.2,548.2,721.906/
87 DATA((F23(I,J),I=1,4),J=1,12)/328.90853,-7952.70913,-144.5142304,
88 10.2421150182,0.0,0.0,0.0,-2.128066524E-04,9.43495542E-08,0.153270,
89 20.00125,78.73,32.7759,-4.679499,3.472778E-03,-159.775232,63.37784,
90 3-0.012475,7.733388E-05,5.941212,-25.30533,2.068042E-03,
91 4-3.684238E-06,0.0,144.16182,-3.868546E-05,6.455643E-08,
92 5-7.394214E-04,-106.13280,7.502357E07,-1.114202E05,0.0,0.07628087,
93 6-7.561805E-06,3.9065696E-07,-2.454905E-10,0.0,0.0,0.0,0.1198,
94 7459.6,60.77,1.0,0.030510,0.0,5.50,520.00,701.42/
95 KJ=0.185053
96 n=0.0
97 S=0.0
98 V=0.0
99 T=0.0
100 PSIA=0.0
101 HV=0.0
102 SV=0.0
103 VV=0.0
104 HL=0.0

```

```
105      SL=0.0
106      VL=0.0
107      QUAL=0.0
108      IF(FTYPE.EQ.'F113') GO TO 10
109      IF(FTYPE.EQ.'F114') GO TO 20
110      IF(FTYPE.EQ.'F11')GO TO 30
111      IF(FTYPE.EQ.'F12')GO TO 40
112      IF(FTYPE.EQ.'F13')GO TO 50
113      IF(FTYPE.EQ.'F14')GO TO 60
114      IF(FTYPE.EQ.'F21')GO TO 70
115      IF(FTYPE.EQ.'F22')GO TO 80
116      IF(FTYPE.EQ.'F23')GO TO 90
117      WRITE(M2,9Q60) FTYPE
118      RETURN
119      10 DO 15 I=1,4
120          DO 15 J=1,12
121              Q(I,J)=F113(I,J)
122      15 CONTINUE
123          GO TO 350
124      20 DO 25 I=1,4
125          DO 25 J=1,12
126              Q(I,J)=F114(I,J)
127      25 CONTINUE
128          GO TO 350
129      30 DO 35 I=1,4
130          DO 35 J=1,12
131              Q(I,J)=F11(I,J)
132      35 CONTINUE
133          GO TO 350
134      40 DO 45 I=1,4
135          DO 45 J=1,12
136              Q(I,J)=F12(I,J)
137      45 CONTINUE
138          GO TO 350
139      50 DO 55 I=1,4
```

```

140      DO 55 J=1,12
141      Q(I,J)=F13(I,J)
142      55 CONTINUE
143      GO TO 350
144      60 DO 65 I=1,4
145      DO 65 J=1,12
146      Q(I,J)=F14(I,J)
147      65 CONTINUE
148      GO TO 350
149      70 DO 75 I=1,4
150      DO 75 J=1,12
151      Q(I,J)=F21(I,J)
152      75 CONTINUE
153      GO TO 350
154      80 DO 85 I=1,4
155      DO 85 J=1,12
156      Q(I,J)=F22(I,J)
157      85 CONTINUE
158      GO TO 350
159      90 DO 95 I=1,4
160      DO 95 J=1,12
161      Q(I,J)=F23(I,J)
162      95 CONTINUE
163      350 NTYPE=Q(3,11)
164      HCRIT=Q(2,11)
165      SCRIT=Q(4,10)
166      PCRIT=Q(4,12)
167      TCRIT=Q(4,3)
168      IF(CYCLE.EQ.'TP') GO TO 400
169      IF(CYCLE.EQ.'TX') GO TO 600
170      IF(CYCLE.EQ.'PX') GO TO 700
171      IF(CYCLE.EQ.'PS') GO TO 900
172      IF(CYCLE.EQ.'PH') GO TO 1000
173      IF(CYCLE.EQ.'TV') GO TO 1100
174      WRITE(M2,9000)

```

```

175      RETURN
176      400 TF=FGIVEN
177      PSIA=SGIVEN
178      T=TF+Q(1,11)
179      IF(TF.LT.Q(4,3)) GO TO 430
180      V=1.0/Q(1,4)
181      GO TO 480
182      430 CALL VPEGM(PSAT,1,1)
183      IF(PSIA/PSAT.GT.TTOLER.OR.PSIA/PSAT.LT.BTOLER) GO TO 470
184      WRITE(M2,9010)
185      RETURN
186      470 IF(PSIA/PSAT.GT.TTOLER) GO TO 500
187      480 QUAL=2.0
188      CALL VOLUME(T,PSIA,V)
189      CALL ENTHAL(PSIA,T,V,H,DHDT,DHDV)
190      CALL ENTROP(T,V,S,DSDT,DSDV)
191      CALL PRINTF(T,PSIA,QUAL,V,H,S,0.0,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
192      RETURN
193      500 CALL VOLUME(T,PSAT,V)
194      CALL DRVPT(DPSDT,PSAT,T,DPSDT2)
195      CALL ENTHAL(PSAT,T,V,H,DHDT,DHDV)
196      CALL ENTROP(T,V,S,DSDT,DSDV)
197      CALL FLQDEN(VL,T,DVLDT)
198      DELTH=RJ*DPSDT*(V-VL)*T
199      H=H-DELTH
200      S=S-DELTH/T
201      QUAL=-2.0
202      CALL PRINTF(T,PSIA,QUAL,VL,H,S,0.0,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
203      V=VL
204      RETURN
205      600 TF=FGIVEN
206      QUAL=SGIVEN
207      IF(QUAL.LE.1.0.AND.QUAL.GE.0.0) GO TO 610
208      WRITE(M2,9070) QUAL
209      RETURN

```

```

245      910 CALL VPEQW(PSIA,T,2)
246      CALL VOLUME(T,PSIA,v)
247      VV=V
248      CALL SATN(PSIA,T,VV,HV,SV,HL,SL,VL)
249      IF(S/SV.GT.TTOLER) GO TO 940
250      IF(S/SL.LT.BTOLER) GO TO 960
251      QUAL=(S-SL)/(SV-SL)
252      H=(1.0-QUAL)*HL+QUAL*HV
253      V=(1.0-QUAL)*VL+QUAL*VV
254      CALL PRINTF(T,PSIA,QUAL,V,H,S,VV,HV,SV,VL,HL,SL,FTYPE,NPRT)
255      RETURN
256      940 CALL SFIND(T,PSIA,V,S)
257      CALL ENTHAL(PSIA,T,V,H,DHDT,DHDTV)
258      QUAL=2.0
259      CALL PRINTF(T,PSIA,QUAL,V,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
260      RETURN
261      960 P=PSIA
262      CALL COMPS(P,T,V,S,VL)
263      CALL ENTHAL(P,T,V,H,DHDT,DHDTV)
264      CALL DRVPT(DPSDT,P,T,DPSDT2)
265      DELTH=RJ*LPSDT*(V-VL)*T
266      H=H-DELTH
267      QUAL=-2.0
268      CALL PRINTF(T,PSIA,QUAL,VL,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
269      V=VL
270      RETURN
271      1000 PSIA=FGIVEN
272      H=SGIVEN
273      IF(PSIA.LT.Q(4,12)) GO TO 1020
274      IF(H.GT.HCRIT) GO TO 1010
275      WRITE(M2,9050)
276      RETURN
277      1010 T=Q(1,11)+Q(4,3)+10.0
278      V=1.0/Q(4,11)
279      GO TO 1040

```

```

210      610 T=TF+Q(1,11)
211          IF(TF.LE.Q(4,3)) GO TO 630
212          WRITE(M2,9020)ICRIT
213          RETURN
214      630 CALL VPEQM(PSIA,1,1)
215          GO TO 800
216      700 PSIA=FGIVEN
217          QUAL=SGIVEN
218          IF(QUAL.LE.1.0.AND.QUAL.GE.0.0) GO TO 710
219          WRITE(M2,9070) QUAL
220          RETURN
221      710 IF(PSIA.LE.Q(4,12)) GO TO 730
222          WRITE(M2,9030) PCRIT
223          RETURN
224      730 CALL VPEQM(PSIA,1,2)
225          TF=T-Q(1,11)
226      800 IF(TF-Q(4,3)) 830,810,810
227      810 V=1.0/Q(4,11)
228          GO TO 840
229      830 CALL VOLUME(T,PSIA,VV)
230      840 CALL SATN(PSIA,T,VV,HV,SV,HL,SL,VL)
231          H=(1.0-QUAL)*HL+QUAL*HV
232          S=(1.0-QUAL)*SL+QUAL*SV
233          V=(1.0-QUAL)*VL+QUAL*VV
234          CALL PRINTF(T,PSIA,QUAL,V,H,S,VV,HV,SV,VL,HL,SL,FTYPE,NPRT)
235          RETURN
236      900 PSIA=FGIVEN
237          S=SGIVEN
238          IF(PSIA.LT.Q(4,12)) GO TO 910
239          IF(S.LE.SCRIT) GO TO 905
240          T=Q(4,3)+Q(1,11)
241          V=1.0/Q(4,11)
242          GO TO 940
243      905 WRITE(M2,9040)
244          RETURN

```



```

280      1020 CALL VPEQM(PSIA,1,2)
281      CALL VOLUME(T,PSIA,V)
282      VV=V
283      CALL SATN(PSIA,T,VV,HV,SV,HL,SL,VL)
284      IF(H/HV.GT.TTOLER) GO TO 1040
285      IF(H/HL.LT.BTOLER) GO TO 1060
286      QUAL=(H-HL)/(HV-HL)
287      S=(1.0-QUAL)*SL+QUAL*SV
288      V=(1.0-QUAL)*VL+QUAL*VV
289      CALL PRINTF( T,PSIA,QUAL,V,H,S,VV,HV,SV,VL,HL,SL,FTYPE,NPRT)
290      RETURN
291      1040 CALL HFIND(T,PSIA,V,H)
292      CALL ENTROP(T,V,S,DSUT,DSUV)
293      QUAL=2.0
294      CALL FRINTF(T,PSIA,QUAL,V,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
295      RETURN
296      1060 P=PSIA
297      CALL COMPH(P,T,V,H,VL)
298      CALL ENTROP(T,V,S,DSUT,DSUV)
299      CALL URVPT(UPSUT,P,T,DPSUT2)
300      DELTH=RJ*UPSUT*(V-VL)
301      S=S-DELTH
302      QUAL=-2.0
303      CALL PRINTF(T,PSIA,QUAL,VL,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
304      V=VL
305      RETURN
306      1100 TF=FGIVEN
307      T=TF+G(1,11)
308      V=SGIVEN
309      IF(T.GE.TCRIT) GO TO 1140
310      CALL VPEQM(PSAT,T,1)
311      CALL FLQDEN(VL,T,DVLDT)
312      CALL VOLUME(T,PSAT,VV)
313      IF(V/VL.LT.BTOLER) GO TO 1160
314      IF(V/VV.GT.TTOLER) GO TO 1140

```

```

015      CALL SATN(PSAT,T,VV,HV,SV,HL,SL,VL)
016      QUAL=(V-VL)/(VV-VL)
017      H=(1.0-QUAL)*HL+QUAL*HV
018      S=(1.0-QUAL)*SL+QUAL*SV
019      CALL PRINTF(T,PSAT,QUAL,V,H,S,VV,HV,SV,VL,HL,SL,FTYPE,NPRT)
020      PSIA=PSAT
021      RETURN
1140     CALL EOS(PCAL,T,V,D2PT,D2DV,D2PDT2)
022     CALL ENTHAL(PCAL,T,V,H,DHDT,DH2V)
023     CALL ENTROP(T,V,S,DSDT,DSDV)
024     QUAL=2.0
025     CALL PRINTF(T,PCAL,QUAL,V,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
026     PSIA=PCAL
027     RETURN
1160     CALL VPEQM(PSIA,T,1)
028     CALL VOLUME(T,PSIA,V)
029     CALL DRVPT(DPSDT,PSIA,T,DPSDT2)
030     CALL ENTHAL(PSIA,T,V,H,DHDT,DH2V)
031     CALL ENTROP(T,VV,S,DSDT,DSDV)
032     QUAL=-2.0
033     DELTH=RJ*DPSDT*(VV-v)
034     S=S-DELTH
035     H=H-DELTH*T
036     CALL PRINTF(T,PSIA,QUAL,V,H,S,0.0,0.0,0.0,0.0,0.0,0.0,FTYPE,NPRT)
037     RETURN
9000     FORMAT(1H,4X,'***ERROR*** CYCLE = ',A3,' CYCLE MUST EQUAL TP, TX,
038     1 PX, PS, PH',//,5X,'FREON TERMINATED')
9010     FORMAT(1H,4X,'***ERROR*** TEMPERATURE AND PRESSURE ARE NOT INDEPE
039     1NDENT UNDER THE SATURATION DOME',//,5X,'FREON TERMINATED')
9020     FORMAT(1H,4X,'***ERROR*** A SATURATION STATE DOES NOT EXIST FOR T
040     1EMPERATURES ABOVE THE CRITICAL TEMPERATURE',F10.3,'DEG.F',//,5X,
041     2 'FREON TERMINATED')
9030     FORMAT(1H,4X,'***ERROR*** A SATURATION STATE DOES NOT EXIST FOR P
042     1RESSURES ABOVE THE CRITICAL PRESSURE',F10.3,'PSIA',//,5X,'FREON TE
043     2RMINATED')

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```

350 9040 FORMAT(1H,4X,'THE MARTIN-HOU EQUATION OF STATE IS NOT VALID IN TH
351 115 REGION,2.E. P>PC AND S<SC',//,5X,'FREON TERMINATED')
352 9050 FORMAT(1H,4X,'THE MARTIN HOU EQUATION OF STATE IS NOT VALID IN TH
353 115 REGION,2.E. P>PC AND H<HC',//,5X,'FREON TERMINATED')
354 9060 FORMAT(1H,4X,'***ERROR*** THE FLUID ',A4,' CAN NOT BE EVALUATED U
355 15ING THE SUBROUTINE FREON',//,5X,'FREON TERMINATED')
356 9070 FORMAT(1H,4X,'***ERROR*** A QUALITY OF ',F6.3,' IS NOT ALLOWED',
357 1//, 5X,'FREON TERMINATED')
358 END

```

COMPH DESCRIPTION

COMPH searches for the temperature and specific volume in the compressed liquid region given pressure and enthalpy. The compressed liquid region is approximated by saturated liquid at the same temperature. A two variable Newton-Raphson iteration technique is used in the search.

EQUATIONS

$$F_p = P(V,T) - P_{SAT}(T)$$

$$F_h = h(V,T) - \text{CONVR} \frac{dP_{SAT}}{dT} (V - V_L) * T - h_{KNOWN}$$

$$\frac{\partial F_p}{\partial T} = \frac{\partial P(V,T)}{\partial T} - \frac{dP_{SAT}}{dT}$$

$$\frac{\partial F_h}{\partial T} = \frac{\partial h(V,T)}{\partial T} - \text{CONVR} \left(\frac{d^2 P_{SAT}}{dT^2} (V - V_L) * T + \frac{dP_{SAT}}{dT} (V - V_L) - \left(\frac{dP_{SAT}}{dT} \right) \left(\frac{dV_L}{dT} \right) * T \right)$$

$$\frac{\partial F_h}{\partial V} = \frac{\partial h(V,T)}{\partial V} - \text{CONVR} * \frac{dP_{SAT}}{dT} * T$$

$$\text{Jacobian} = \left(\frac{\partial P(V,T)}{\partial V} \right) \left(\frac{\partial F_h}{\partial T} \right) - \left(\frac{\partial F_p}{\partial T} \right) \left(\frac{\partial F_h}{\partial V} \right)$$

$$V_{i+1} = V_i - \left[\frac{F_p * \frac{\partial F_h}{\partial T} - F_h * \frac{\partial F_p}{\partial T}}{\text{Jacobian}} \right]_i$$

$$T_{i+1} = T_i - \left[\frac{F_h * \frac{\partial P}{\partial V} - F_p * \frac{\partial F_h}{\partial V}}{\text{Jacobian}} \right]_i$$

VARIABLE SYMBOL TABLE

BTOLER

lower tolerance on convergence and saturation tests

DFHDT

$$\frac{\partial h(V,T)}{\partial T} - \text{RJ} * \frac{d^2 P_{SAT}}{dT^2} (V - V_L) * T - \frac{dP_{SAT}}{dT} * \frac{dV_L}{dT} * T + \frac{dP_{SAT}}{dT} (V - V_L)$$

DFHDV

$$\frac{\partial h(V,T)}{\partial V} - \text{RJ} * \frac{dP_{SAT}}{dT} * T$$

DFPDT

$$\frac{\partial P(V,T)}{\partial T} - \frac{dP_{SAT}}{dT}$$

DHDT	$\frac{\partial h(V,T)}{\partial T}$
DHDV	$\frac{\partial h(V,T)}{\partial V}$
DP2DT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVDT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
DPSDT	$\frac{dP_{SAT}}{dT}$
DPSDT2	$\frac{d^2 P_{SAT}}{dT^2}$
DVLDT	$\frac{dV_L}{dT}$
FH	$h \text{ calculated} - RJ * \frac{dP_{SAT}}{dT} * (V - V_L) * T - h_{KNOWN}$
FP	$P \text{ calculated} - P_{KNOWN}$
H	known enthalpy (Btu/lbm)
HCAL	calculated vapor enthalpy (Btu/lbm)
I	index number
LIMIT	maximum of iterations allowed in any one search
M2	unit number for printer
P	known pressure (psia)
PCAL	calculated pressure (psia)
PSAT	saturated pressure (psia)
RJ	conversion factor = 0.185053
T	temperature (°R)
TLAST	last temperature calculated, to be used in next iteration

TTOLER	upper tolerance in convergence and saturation tests
V	specific volume (ft^3/lbm)
VL	saturated liquid specific volume (ft^3/lbm)
VLAST	last specific volume calculated, to be used in next iteration
XJACOB	Jacobian of pressure and enthalpy

```

1      C      *****
2      C      *
3      C      *               C O M P H               *
4      C      *
5      C      *   THIS SUBROUTINE FINDS THE TEMPERATURE AND DENSITY GIVEN   *
6      C      * PRESSURE AND ENTHALPY FOR COMPRESSED LIQUID STATES.         *
7      C      *
8      C      *****
9      C      SUBROUTINE COMPH(P,T,V,H,VL)
10     C      PARAMETER MZ=6
11     C      COMMON/FREUN1/G(4,12),TTOLER,BTOLER,LIMIT,DEERROR,NTYPE
12     C      RJ=0.185053
13     C      VLAST=V
14     C      TLAST=T
15     C      CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,DP2DT2)
16     C      CALL VPEQM(PSAT,T,1)
17     C      CALL ENTHAL(PCAL,T,V,HCAL,DHDT,DHDV)
18     C      CALL DRVPT(UPSDT,PSAT,T,UPSDT2)
19     C      CALL FLQDEN(VL,T,DVLDT)
20     C      DO 1000 I=1,LIMIT
21     C      FP=PCAL-PSAT
22     C      DFPDT=DPDT-DPSDT
23     C      FH=HCAL-RJ*DPSDT*(V-VL)*T-H
24     C      DFHDT=DHDT-RJ*(UPSDT2*(V-VL)*T-DPSDT*DVLDT*T+DPSDT*(V-VL))
25     C      DFHDV=DHDV-RJ*UPSDT*T
26     C      XJACOB=UPDV*DFHDT-DFPDT*DFHDV
27     C      V=VLAST-(FP*DFHDT-FH*DFPDT)/XJACOB
28     C      T=TLAST-(FH*UPDV-FP*DFHDV)/XJACOB
29     C      IF(T.LE.0.0) T=TLAST/10.0
30     C      IF(V.LE.0.0) V=VLAST/10.0
31     C      CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,DP2DT2)
32     C      CALL VPEQM(PSAT,T,1)
33     C      CALL ENTHAL(PCAL,T,V,HCAL,DHDT,DHDV)
34     C      CALL DRVPT(UPSDT,PSAT,T,UPSDT2)

```

```

35      CALL FLODEN(VL,T,OVLEST)
36      HL=HCAL-KC*DPSDT*(V-VL)*T
37      IF(PCAL/PSAT.LT.ITOLER.AND.PCAL/PSAT.GT.BTOLER.AND.HL/H.LT.
38      1  ITOLER.AND.HL/H.GT.BTOLER) GO TO 1050
39      IF(ABS(T-TLAST).LT.1.0E-04.AND.ABS(V-VLAST).LT.1.0E-07) GO TO 1050
40      VLAST=V
41      TLAST=T
42      1000 CONTINUE
43      WRITE(M2,9000) LIMIT
44      1050 P=PCAL
45      RETURN
46      9000 FORMAT(' ',10X,'***COMPH FAILED TO CONVERGE IN ',I5,' ITERATIONS')
47      END

```

COMPS DESCRIPTION

COMPS searches for the temperature and specific volume in the compressed liquid region given pressure and entropy. The compressed liquid region is approximated by saturated liquid at the same temperature. A two variable Newton-Raphson iteration technique is used in the search.

EQUATIONS

$$F_p = P(V,T) - P_{SAT}(T)$$

$$F_S = S(V,T) - \text{CONVR} \frac{dP_{SAT}}{dT} (V - V_L) * T - S_{KNOWN}$$

$$\frac{\partial F_p}{\partial T} = \frac{\partial S(V,T)}{\partial T} - \frac{dP_{SAT}}{dT}$$

$$\frac{\partial F_S}{\partial T} = \frac{\partial S(V,T)}{\partial T} - \text{CONVR} \frac{d^2 P_{SAT}}{dT^2} (V - V_L) + \text{CONVR} \left(\frac{dP_{SAT}}{dT} \right) \left(\frac{dV_L}{dT} \right)$$

$$\frac{\partial F_S}{\partial V} = \frac{\partial S(V,T)}{\partial V} - \text{CONVR} \frac{dP_{SAT}}{dT}$$

$$\text{Jacobian} = \left(\frac{\partial P(V,T)}{\partial V} \right) \left(\frac{\partial F_S}{\partial T} \right) - \left(\frac{\partial P(V,T)}{\partial T} \right) \left(\frac{\partial F_S}{\partial V} \right)$$

$$V_{i+1} = V_i - \left[\frac{F_p \left(\frac{\partial F_T}{\partial T} \right) - F_S \left(\frac{\partial F_p}{\partial T} \right)}{\text{Jacobian}} \right]_i$$

$$T_{i+1} = T_i - \left[\frac{F_S \left(\frac{\partial F_p}{\partial V} \right) - F_p \left(\frac{\partial F_S}{\partial V} \right)}{\text{Jacobian}} \right]_i$$

VARIABLE SYMBOL TABLE

BTOLER

(.1E-5) lower tolerance on convergence and

DFPDT

(1.0) saturation tests
 $\frac{d(P(V,T) - P_{SAT}(T))}{dT}$

DFSdT

(1.0E-5) lower tolerance on convergence and
 $\frac{\partial S(V,T)}{\partial T} - \text{RJ} * \frac{dP_{SAT}(T)}{dT} * (V - V_L)$
 $+ \text{RJ} * \frac{dP_{SAT}(T)}{dT} * \frac{dV_L}{dT}$

DPSDV	$\frac{\partial S(V,T)}{\partial V} - RJ* \frac{dP_{SAT}(T)}{dT}$
DP2DT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVRT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
DPSDT	$\frac{dP_{SAT}(T)}{dT}$
DPSDT2	$\frac{d^2 P_{SAT}(T)}{dT^2}$
DSDT	$\frac{\partial S(V,T)}{\partial T}$
DSDV	$\frac{\partial S(V,T)}{\partial V}$
DVLDT	$\frac{dV_L(T)}{dT}$
FP	P calculated - P _{GIVEN}
FS	S calculated - S _{GIVEN}
I	index
LIMIT	maximum number of iterations allowed in any one search
M2	unit number for printer
P	known pressure (psia)
PCAL	pressure calculated (psia)
PSAT	saturation pressure (psia)
RJ	conversion factor = 0.185053
S	known entropy (Btu/lbm°R)
SCAL	calculated entropy (Btu/lbm°R)

T	temperature ($^{\circ}\text{R}$)
TLAST	last temperature calculated, to be used in next iteration
TTOLER	upper tolerance on convergence and saturation tests
V	specific volume (ft^3/lbm)
VL	saturation liquid specific volume (ft^3/lbm)
VLAST	last specific volume calculated, to be used in next iteration
XJACOB	Jacobian of pressure and entropy

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *
6      C      *
7      C      *
8      C      *
9      C      *
10     C      *
11     C      *
12     C      *
13     C      *
14     C      *
15     C      *
16     C      *
17     C      *
18     C      *
19     C      *
20     C      *
21     C      *
22     C      *
23     C      *
24     C      *
25     C      *
26     C      *
27     C      *
28     C      *
29     C      *
30     C      *
31     C      *
32     C      *
33     C      *
34     C      *

```

C O M P S

THIS SUBROUTINE FINDS THE TEMPERATURE AND DENSITY GIVEN
 *PRESSURE AND ENTROPY FOR COMPRESSED LIQUID STATES.

SUBROUTINE COMPS(P,T,V,S,VL)
 PARAMETER M2=0
 COMMON/FREON1/0(4,12),TTOLER,BTOLER,LIMIT,DERROR,NTYPE
 RJ=0.185053
 VLAST=V
 TLAST=T
 CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,D2PDT2)
 CALL VPEQM(PSAT,T,1)
 CALL ENTROP(T,V,SCAL,DSDT,DSDV)
 CALL DRVPT(DPSDT,PSAT,T,DPSDT2)
 CALL FLQDEN(VL,T,DVLDLT)
 DO 1000 I=1,LIMIT
 FP=PCAL-PSAT
 DFPDT=DPDT-DPSDT
 FS=SCAL-RJ*DPSDT*(V-VL)-S
 DFPDT=USDT-RJ*DPSDT2*(V-VL)+RJ*DPSDT*DVLDLT
 DFPDV=DSUV-RJ*DPSDT
 XJACOB=DPDV*DFSDT-DFPDT*DFSDV
 V=VLAST-(FP*DFSDT-FS*DFPDT)/XJACOB
 T=TLAST-(FS*DPDV-FP*DFSDV)/XJACOB
 IF(T.LE.0.0) T=TLAST/10.0
 IF(V.LE.0.0) V=VLAST/10.0
 CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,D2PDT2)
 CALL VPEQM(PSAT,T,1)
 CALL ENTROP(T,V,SCAL,DSDT,DSDV)
 CALL DRVPT(DPSDT,PSAT,T,DPSDT2)


```

36 CALL FLQDEN(VL,T,DV,DT)
37 SL=SCAL-KO*(V-VL)*DISDT
38 IF(PCAL/PSAT.LT.ITOLER.AND.PCAL/PSAT.GT.ETOLER.AND.SL/S.LT.
39 1 ITOLER.AND.SL/S.GT.BTOLER) GO TO 1050
40 IF(ABS(T-TLAST).LT.1.0E-04.AND.ABS(V-VLAST).LT.1.0E-07) GO TO 1050
41 VLAST=V
42 TLAST=T
43 1000 CONTINUE
44 WRITE(M2,9000) LIMIT
45 1050 P=PCAL
46 RETURN
47 9000 FORMAT(' ',10X,'***COMPS FAILED TO CONVERGE IN ',I5,' ITERATIONS')
END

```

DRVPT DESCRIPTION

DRVPT calculates the first and second derivative of the saturation pressure with respect to temperature.

EQUATIONS

$$\frac{dP_{SAT}}{dT} = P_{SAT} \left(-\frac{(B+E*F \text{ LOG}_{10}(F-T))\ln(10)}{T^2} + \frac{C-E}{T} + D\ln(10) \right)$$
$$\frac{d^2P_{SAT}}{dT^2} = P_{SAT} \left(\frac{2((B+EF \text{ LOG}_{10}(F-T))\ln(10))}{T^3} + \frac{1}{T^2(F-T)} + \frac{C-E}{T^2} \right)$$

VARIABLE SYMBOL TABLE

DPDT	$\frac{dP_{SAT}}{dT}$
D2PDT2	$\frac{d^2P_{SAT}}{dT^2}$
FT	F-T
P	saturation pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated
T	temperature (°R)
T2	T^2
T3	T^3
XX	$\ln(10)$

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *   THIS SUBROUTINE CALCULATES THE DERIVATIVE OF THE SATURATION
6      C      *PRESSURE WITH RESPECT TO TEMPERATURE
7      C      *
8      C      *****
9      C      SUBROUTINE DRVPT(DPDT,P,I,D2PDT2)
10     COMMON/FREON1/Q(4,12),TTOLER,BTOLER,LIMIT,DError,NTYPE
11     T2 = I*T
12     T3=T2*T
13     FT=Q(2,2)-T
14     IF (F1.LT.0.01) FT = 1.0
15     XX = ALOG(10.0)
16     DPDT = P*((-XX*(Q(2,1) + Q(1,2) *Q(2,2) *ALOG10(FT)))/T2+(Q(3,1)-Q
17     (1,2)) /T+Q(4,1)*XX)
18     D2PDT2=P*(2.0*XX*(Q(2,1)+Q(1,2)*Q(2,2)*ALOG10(FT))/T3+
19     1 XX/T2*(0.43429448/FT)+(Q(3,1)-Q(1,2))/T2)
20     RETURN
21     END

```

ENTHAL DESCRIPTION

ENTHAL calculates the enthalpy and its derivatives with respect to temperature and specific volume for vapor states using the Downings-Martin equation of state.

EQUATIONS

$$\begin{aligned}
 h = & A*T + b*T^2/2 + c*T^3/3 + d*T^4/4 - F/T + \text{CONVR}*P*V + \text{CONVR} \left(\frac{A_2}{(V-\beta)} \right. \\
 & + \frac{A_3}{2(V-\beta)^2} + \frac{A_4}{3(V-\beta)^3} + \frac{A_5}{4(V-\beta)^4} + \frac{A_6}{\alpha} \left(\frac{1}{\exp(\alpha*V)} - C_1 \ln \left(\frac{C_1 \exp(\alpha*V)+1}{C_1 \exp(\alpha*V)} \right) \right) \\
 & + \text{CONVR} \exp(-K*T/TC) \left(\frac{C_2}{V-\beta} + \frac{C_3}{2(V-\beta)^2} + \frac{C_4}{3(V-\beta)^3} \right. \\
 & + \frac{C_5}{4(V-\beta)^4} + \frac{C_6}{\alpha \exp(\alpha*V)} - \frac{C_6*C_1}{\alpha} \ln \left(\frac{C_1 \exp(\alpha*V)+1}{C_1 \exp(\alpha*V)} \right) \\
 & \left. + \Delta h(\text{latent at } -40^\circ\text{F}) - h(\text{saturated vapor at } -40^\circ\text{F}) \right)
 \end{aligned}$$

$$\begin{aligned}
 \frac{\partial h(V,T)}{\partial T} = & a + b*T + c*T^2 + d*T^3 + f/T^2 + \text{CONVR}*V* \frac{\partial P(V,T)}{\partial T} \\
 & - \frac{\text{CONVR}*K^2*T}{T_C^2} \exp(-K*T/TC) \left(\frac{C_2}{V-\beta} + \frac{C_3}{2(V-\beta)^2} + \frac{C_4}{3(V-\beta)^3} + \frac{C_5}{4(V-\beta)^4} \right. \\
 & \left. + \frac{C_6}{\alpha \exp(\alpha*V)} - \frac{C_6*C_1}{\alpha} \ln \left(\frac{C_1 \exp(\alpha*V)+1}{C_1 \exp(\alpha*V)} \right) \right)
 \end{aligned}$$

$$\begin{aligned}
 \frac{\partial h(V,T)}{\partial V} = & \text{CONVR}*P + \text{CONVR}*V* \frac{\partial P(V,T)}{\partial V} + \text{CONVR} \left(\frac{-A_2}{(V-\beta)^2} - \frac{A_3}{(V-\beta)^3} - \frac{A_4}{(V-\beta)^4} \right. \\
 & - \frac{A_5}{(V-\beta)^5} + A_6 \left(\frac{-1}{\exp(\alpha*V)} + \frac{C_1}{C_1 \exp(\alpha*V)+1} \right) + \text{CONVR} \exp(-K*T/TC) \\
 & \left(-\frac{C_2}{(V-\beta)^2} - \frac{C_3}{(V-\beta)^3} - \frac{C_4}{(V-\beta)^4} - \frac{C_5}{(V-\beta)^5} - \frac{C_6}{\exp(\alpha*V)} + \frac{C_6*C_L}{C_1 \exp(\alpha*V)+1} \right)
 \end{aligned}$$

VARIABLE SYMBOL TABLE

C

conversion factor = 0.185053

DERROR

tolerance used in checks for zero

DHDT

$\frac{\partial h(V,T)}{\partial T}$

DHDV

$$\frac{\partial h(V,T)}{\partial V}$$

DPDT

$$\frac{\partial P(V,T)}{\partial T}$$

DPDV

$$\frac{\partial P(V,T)}{\partial V}$$

D2PDT2

$$\frac{\partial^2 P(V,T)}{\partial T^2}$$

DPDVDT

$$\frac{\partial^2 P(V,T)}{\partial V \partial T}$$

EKA

$$\exp(\alpha * V)$$

EKIT

$$\exp(-K * T / TC)$$

H

enthalpy (Btu/lbm)

H1

$$a * T + b * T^2 / 2 + c * T^3 / 3 + d * T^4 / 4 - f / T + \text{CONVR} * P * V$$

H2

$$\text{CONVR} \left(\frac{A_2}{V - \beta} + \frac{A_3}{2(V - \beta)^2} + \frac{A_4}{3(V - \beta)^3} + \frac{A_5}{4(V - \beta)^4} + \text{RX} \right)$$

H3

$$\text{CONVR} \left(\frac{C_2}{V - \beta} + \frac{C_3}{2(V - \beta)^2} + \frac{C_4}{3(V - \beta)^3} + \frac{C_5}{4(V - \beta)^4} + \text{RZ} \right) (1 + K * T / TC) (\exp(-K * T / TC))$$

P

pressure (psia)

PART

$$C_1 \ln \left(\frac{C_1 \exp(\alpha * V) + 1}{C_1 \exp(\alpha * V)} \right)$$

PART1

$$a + b * T + c * T^2 + d * T^3 + f / T^2 + \text{CONVR} * \frac{\partial P(V,T)}{\partial T} * V$$

PART2

$$- \left(\frac{C_2}{V - \beta} + \frac{C_3}{2(V - \beta)^2} + \frac{C_4}{3(V - \beta)^3} + \frac{C_5}{4(V - \beta)^4} + \text{RZ} \right) \left(\frac{\text{CONVR} * K^2 * \exp(-K * T / TC)}{T_C^2} \right)$$

Q

2-dimensional array which contains the coefficients for the fluid to be evaluated

RX	$A_6(1/\exp(\alpha*V)-PART)/\alpha$
RZ	$(C_6/\exp(\alpha*V)-C_6*PART)/\alpha$
T	temperature (°R)
T2	T^2
T3	T^3
T4	T^4
TC	critical temperature (°R)
TERMA	$A_6(-1/\exp(\alpha*V)+C_1)/(C_1\exp(\alpha*V)+1)$
V	specific volume (ft ³ /lbm)
VMB	$V-\beta$
VMB2	$(V-\beta)^2$
VMB3	$(V-\beta)^3$
VMB4	$(V-\beta)^4$
VMB5	$(V-\beta)^5$

```

H1 = Q(1,9)*T + Q(2,9)*T2/2.0 + Q(3,9)*T3/3.0
      + Q(4,9)*T4/4.0 - Q(1,10)/T + C*P*V
H2 = C*(Q(2,4)/VMB + Q(2,5)/(2.0*VMB2) + Q(2,6)/
      (3.0*VMB3) + Q(2,7)/(4.0*VMB4) + RX)
H3 = C*(Q(4,4)/VMB + Q(4,5)/(2.0*VMB2) + Q(4,7)/
      (4.0*VMB4) + Q(4,6)/(3.0*VMB3) + RZ)*(1.0
      + Q(2,12)*T/(Q(4,3) + Q(1,11)))*EKIT + Q(2,10)
H = H1 + H2 + H3
TC = Q(4,3) + Q(1,11)
PART1 = Q(1,9) + Q(2,9)*T + Q(3,9)*T2 + Q(4,9)*T3
      + Q(1,10)/T2 + C*DPDT*V
PART2 = Q(4,4)/VMB + Q(4,5)/(2.0*VMB2) + Q(4,6)/
      (3.0*VMB3) + Q(4,7)/(4.0*VMB4) + RZ
PART2 = -C*EKIT*Q(2,12)**2*T/TC**2*PART2
DHOT = PART1 + PART2
PART1 = C*DPDV*V + C*P + C*(-Q(2,4)/VMB2 - Q(2,5)/
      VMB3 - Q(2,6)/VMB4 - Q(2,7)/VMB5 + TERMA
PART2 = -Q(4,4)/VMB2 - Q(4,5)/VMB3 - Q(4,6)/VMB4
      - Q(4,7)/VMB5 - TERMB + Q(4,8)*Q(1,12)/
      (Q(1,12)*EKA + 1.0)
PART2 = C*EKIT*(1.0 + Q(1,12)*T/TC)*PART2
DPDV = PART1 + PART2
  
```

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *
6      C      *
7      C      *
8      C      *
9      C      *
10     C      *
11     C      *
12     C      *
13     C      *
14     C      *
15     C      *
16     C      *
17     C      *
18     C      *
19     C      *
20     C      *
21     C      *
22     C      *
23     C      *
24     C      *
25     C      *
26     C      *
27     C      *
28     C      *
29     C      *
30     C      *
31     C      *
32     C      *
33     C      *
34     C      *

```

ENTHAL

THIS SUBROUTINE COMPUTES THE ENTHALPY OF THE VAPOR.

SUBROUTINE ENTHAL(P,T,V,n,DHDT,DHdV)

COMMON/FREON1/Q(4,12),TTOLER,BTOLER,LIMIT,DError,NTYPE

C=0.185053

T2=T*T

T3=T2*T

T4=T3*T

VM1=V-Q(3,3)

VM2=VM1*VM1

VM3=VM2*VM1

VM4=VM3*VM1

VM5=VM4*VM1

EKIT=-Q(2,12)*T/(Q(4,3)+Q(1,11))

EKIT=EXP(EKIT)

EKA=Q(3,12)*V

IF (EKA.GT.30.0) GO TO 105

IF (ABS(EKA).LE.DError) GO TO 105

EKA = EXP(EKA)

IF (ABS(Q(1,12)).LE.DError) GO TO 100

PART = Q(1,12)*ALOG((Q(1,12)*EKA+1.0)/(Q(1,12)*EKA))

GO TO 110

100 PART = 0.0

GO TO 110

105 EKA = 0.0

RX = 0.0

RZ = 0.0

PART = 0.0

TERMA=0.0

```

35      TERMB=0.0
36      GO TO 115
37 110  RX = Q(2,8)/Q(3,12)*(1.0/EKA-PART1)
38      RZ=Q(4,8)/(Q(3,12)*EKA)-(Q(4,8)*PART/Q(3,12))
39      TERMA=Q(2,8)*(-1.0/EKA+Q(1,12)/(Q(1,12)*EKA+1.0))
40      TERMB=Q(4,8)/EKA
41 115  CALL EOS(P,T,V,DPDT,DPDV,DPDVT,D2PDT2)
42      H1=Q(1,9)*T+Q(2,9)*T2/2.0+Q(3,9)*T3/3.0+Q(4,9)*T4/4.0-
43      1  Q(1,10)/T+C*P*V
44      H2=C*(Q(2,4)/VMB+Q(2,5)/(2.0*VMB2)+Q(2,6)/(3.0*VMB3)+Q(2,7
45      1)/(4.0*VMB4)+RX)
46      H3=C*(Q(4,4)/VMB+Q(4,5)/(2.0*VMB2)+Q(4,7)/(4.0*VMB4)+Q(4,6
47      1)/(3.0*VMB3)+RZ)*(1.0+Q(2,12)*T/(Q(4,3)+Q(1,11)))*EKIT+Q(
48      22,10)
49      H = H1 + H2 + H3
50      TC=Q(4,3)+Q(1,11)
51      PART1=Q(1,9)+Q(2,9)*T+Q(3,9)*T2+Q(4,9)*T3+Q(1,10)/T2+C*DPDT*V
52      PART2=Q(4,4)/VMB+Q(4,5)/(2.0*VMB2)+Q(4,6)/(3.0*VMB3)+Q(4,7)/(4.0*
53      1  VMB4)+RZ
54      PART2=-C*EKIT*Q(2,12)**2*T/TC**2*PART2
55      DHDV=PART1+PART2
56      PART1=C*DPDV*V+C*P+C*(-Q(2,4)/VMB2-Q(2,5)/VMB3-Q(2,6)/VMB4-Q(2,7)/
57      1  VMB5+TERMA)
58      PART2=-Q(4,4)/VMB2-Q(4,5)/VMB3-Q(4,6)/VMB4-Q(4,7)/VMB5-TERMB
59      1  +Q(4,8)*Q(1,12)/(Q(1,12)*EKA+1.0)
60      PART2=C*EKIT*(1.0+Q(1,12)*T/TC)*PART2
61      DHDV=PART1+PART2
62      RETURN
63      END

```

ENTROP DESCRIPTION

ENTROP calculates the entropy and its derivatives with respect to temperature and specific volume for the vapor region using the Downling-Martin equation of state.

EQUATIONS

$$S = a \ln T + B \cdot T + C \cdot T^2 / 2 + d \cdot T^3 / 3 - f / 2 \cdot T^2 + \text{CONVR} \cdot R \ln(V - \beta) - \text{CONVR} \left(\frac{B_2}{V - \beta} + \frac{B_3}{2(V - \beta)^2} + \frac{B_4}{3(V - \beta)^3} + \frac{B_5}{4(V - \beta)^4} + \frac{B_6}{\alpha} \left(1 / \exp(\alpha \cdot V) - C_1 \ln \left(\frac{C_1 \exp(\alpha \cdot V) + 1}{C_1 \exp(\alpha \cdot V)} \right) \right) \right)$$

$$\frac{\partial S(V, T)}{\partial V} = \frac{\text{CONVR} \cdot R}{V - \beta} - \text{CONVR} \left(\frac{-B_2}{(V - \beta)^2} - \frac{B_3}{(V - \beta)^3} - \frac{B_4}{(V - \beta)^4} - \frac{B_5}{(V - \beta)^5} + B_6 \left(-1 / \exp(\alpha \cdot V) + \frac{C_1}{C_1 \exp(\alpha \cdot V) + 1} \right) \right)$$

$$\frac{\partial S(V, T)}{\partial T} = a / T + b + C \cdot T + d \cdot T^2 + f / T^3 - \frac{\text{CONVR} \cdot K^2}{T_C^2} \exp(-K \cdot T / T_C) \left(\frac{C_2}{(V - \beta)} + \frac{C_3}{2(V - \beta)^2} + \frac{C_4}{3(V - \beta)^3} + \frac{C_5}{4(V - \beta)^4} + \frac{C_6}{\alpha \exp(\alpha \cdot V)} - \frac{C_6 \cdot C_1}{\alpha} \ln \left(\frac{C_1 \exp(\alpha \cdot V) + 1}{C_1 \exp(\alpha \cdot V)} \right) \right)$$

VARIABLE SYMBOL TABLE

C	conversion factor = 0.185053
DERROR	tolerance used in checks for zero
DSDT	$\frac{\partial S(V, T)}{\partial T}$
DSDV	$\frac{\partial S(V, T)}{\partial V}$
EKA	$\exp(\alpha \cdot V)$
EKIT	$\exp(-K \cdot T / T_C)$
G	$\frac{C_2}{V - \beta} + \frac{C_3}{2(V - \beta)^2} + \frac{C_4}{3(V - \beta)^3} + \frac{C_5}{4(V - \beta)^4} + RZ$
PART	$C_1 \ln \left(\frac{C_1 \exp(\alpha \cdot V) + 1}{C_1 \exp(\alpha \cdot V)} \right)$

PART1

$$\frac{\text{CONVR} \cdot R}{V-B} - \text{CONVR} \left(\frac{-B_2}{(V-B)^2} - \frac{B_3}{(V-B)^3} \right.$$

$$\left. - \frac{B_4}{(V-B)^4} - \frac{B_5}{(V-B)^5} + \text{TERMA} \right)$$

PART2

$$\text{CONVR} \cdot K \exp(-K \cdot T/TC) \left(\frac{-C_2}{(V-B)^2} - \frac{C_3}{(V-B)^3} - \frac{C_4}{(V-B)^4} \right.$$

$$\left. - \frac{C_5}{(V-B)^5} - \text{TERMB} + \frac{C_6 \cdot C_1}{C_1 \exp(\alpha \cdot V) + 1} \right)$$

Q

2-dimensional array containing the coefficients
for the fluid to be evaluated

RX

$$\frac{B_6}{\alpha} \left(\frac{1}{\exp(\alpha \cdot V)} - \text{PART} \right)$$

RZ

$$\frac{C_6}{\alpha \exp(\alpha \cdot V)} - \frac{C_6 \cdot \text{PART}}{\alpha}$$

S

entropy (Btu/lbm°R)

S1

$$a \ln T + b \cdot T + c \cdot T^2/2 + d \cdot T^3/3 - f/2 \cdot T^2$$

S2

$$\text{CONVR} \cdot R \ln(V-B)$$

S3

$$-\text{CONVR} \left(\frac{B_2}{(V-B)} + \frac{B_3}{2(V-B)^2} + \frac{B_4}{3(V-B)^3} \right. \\ \left. + \frac{B_5}{4(V-B)^4} + \text{RX} \right)$$

S4

$$\text{CONVR} \left(\frac{K}{TC} \exp(-K \cdot T/TC) \left(\frac{C_2}{V-B} + \frac{C_3}{2(V-B)^2} \right. \right. \\ \left. \left. + \frac{C_4}{3(V-B)^3} + \frac{C_5}{4(V-B)^4} + \text{RZ} \right) + \frac{\Delta S(\text{latent at } -40^\circ\text{F})}{-40} \right. \\ \left. - S(\text{saturation } -40^\circ\text{F}) \right)$$

T

temperature (°R)

T2

$$T^2$$

T3

$$T^3$$

TC

critical temperature (°R)

TERMA

$$B_6 \left(\frac{-1}{\exp(\alpha \cdot V)} + \frac{C_1}{C_1 \exp(\alpha \cdot V) + 1} \right)$$

TERMB	$C_6/\exp(\alpha*V)$
V	specific volume (ft ³ /lbm)
VM	$(V-\beta)$
VM2	$(V-\beta)^2$
VM3	$(V-\beta)^3$
VM4	$(V-\beta)^4$
VM5	$(V-\beta)^5$
ZZ	$\frac{K^2}{T_C^2} \exp(-K*T/T_C)$

```

1      C      *****
2      C      *
3      C      *           E N T R O P
4      C      *
5      C      *   THIS SUBROUTINE COMPUTES THE ENTROPY OF THE VAPOR.
6      C      *
7      C      *****
8      C      SUBROUTINE ENTROP(T,V,S,USDT,USDV)
9      C      COMMON/FREUNI/Q(4,12),TTOLER,BTOLER,LIMIT,DEKERR,NTYPE
10     C      C=0.165053
11     C      VMB=V-Q(3,3)
12     C      VMB2=VMB*VMB
13     C      VMB3=VMB2*VMB
14     C      VMB4=VMB3*VMB
15     C      VMB5=VMB4*VMB
16     C      EKA=Q(3,12)*V
17     C      IF(ABS(EKA).GT.30.0) GO TO 100
18     C      IF(ABS(EKA).LT.DEKERR) GO TO 100
19     C      IF(ABS(Q(1,12)).LE.DEKERR) GO TO 100
20     C      EKA = EXP(EKA)
21     C      PART = Q(1,12)*ALOG((Q(1,12)*EKA+1.0)/(Q(1,12)*EKA))
22     C      GO TO 105
23     C 100  RX = 0.0
24     C      RZ = 0.0
25     C      EKA = 0.0
26     C      PART = 0.0
27     C      TERMA=0.0
28     C      TERMB=0.0
29     C      GO TO 110
30     C 105  RX = Q(3,8)/Q(3,12)*(1.0/EKA-PART)
31     C      RZ = Q(4,8)/(Q(3,12)*EKA)-(Q(4,8)/Q(3,12)*PART)
32     C      TERMA=Q(3,8)*(-1.0/EKA+Q(1,12)/(Q(1,12)*EKA+1.0))
33     C      TERMB=Q(4,8)/EKA
34     C 110  G=Q(4,4)/VMB+Q(4,5)/(2.0*VMB2)+Q(4,7)/(4.0*VMB4)+Q(4,6)/(

```

```

35      1      3.0*VMB3)+RZ
36      T2 = T*1
37      T3 = T2*1
38      EK1T=-Q(2,12)*1/(Q(4,3)+Q(1,11))
39      IF (ABS(EK1T).GT.30.0) GO TO 115
40      EK1T = EXP(EK1T)
41      GO TO 120
42  115 EK1T = 0.0
43  120 ZZ = Q(2,12)**2.00/(Q(4,3)+Q(1,11))**2.0*EK1T
44      S1=Q(1,9)*ALOG(T)+Q(2,9)+T+Q(3,9)*T2/2.0+Q(4,9)*T3/3.0-Q(1
45      1,10)/(2.0*T2)
46      S2=C*Q(2,3)*ALOG(VMB)
47      S3=-C*(Q(3,4)/VMB+Q(3,5)/(2.0*VMB2)+Q(3,6)/(3.0*VMB3)+Q(3,
48      1 7)/(4.0*VMB4)+RZ)
49      S4=C*(Q(2,12)/(Q(4,3)+Q(1,11))*EK1T)*(Q(4,4)/VMB+Q(4,5)/(2.0*V
50      1 MB2)+Q(4,6)/(3.0*VMB3)+Q(4,7)/(4.0*VMB4)+RZ)+Q(3,10)
51      S=S1+S2+S3+S4
52      USD1=Q(1,9)/1+Q(2,9)+Q(3,9)*T+Q(4,9)*T2+Q(1,10)/T3-C*G*ZZ
53      TC=Q(4,3)+Q(1,11)
54      PART1=C*Q(2,3)/VMB-C*(-Q(3,4)/VMB2-Q(3,5)/VMB3-Q(3,6)/VMB4-Q(3,7)/
55      1 VMB5+TERMA)
56      PART2=C*Q(2,12)*EK1T/TC*(-Q(4,4)/VMB2-Q(4,5)/VMB3-Q(4,6)/VMB4
57      1 -Q(4,7)/VMB5-TERMB+Q(4,8)*Q(1,12)/(Q(1,12)*EKA+1.0))
58      USDV=PART1+PART2
59  130 RETURN
60      END

```

EOS DESCRIPTION

EOS calculates the pressure and its derivatives with respect to temperature and specific volume in the vapor region given temperature and specific volume by using the Downing-Martin equation of state.

EQUATIONS

$$P = \frac{R \cdot T}{V - B} + \frac{A_2 + B_2 \cdot T + C_2 \exp(-K \cdot T / T_C)}{(V - B)^2} + \frac{A_3 + B_3 \cdot T + C_3 \exp(-K \cdot T / T_C)}{(V - B)^3} \\ + \frac{A_4 + B_4 \cdot T + C_4 \exp(-K \cdot T / T_C)}{(V - B)^4} + \frac{A_5 + B_5 \cdot T + C_5 \exp(-K \cdot T / T_C)}{(V - B)^5} + \frac{A_6 + B_6 \cdot T + C_6 \exp(-K \cdot T / T_C)}{\exp(\alpha \cdot V) (1 + C_1 \exp(\alpha \cdot V))}$$

$$\frac{\partial P(V, T)}{\partial V} = \frac{-R \cdot T}{(V - B)^2} - \frac{2(A_2 + B_2 \cdot T + C_2 \exp(-K \cdot T / T_C))}{(V - B)^3} - \frac{3(A_3 + B_3 \cdot T + C_3 \exp(-K \cdot T / T_C))}{(V - B)^4} \\ - \frac{4(A_4 + B_4 \cdot T + C_4 \exp(-K \cdot T / T_C))}{(V - B)^5} - \frac{5(A_5 + B_5 \cdot T + C_5 \exp(-K \cdot T / T_C))}{(V - B)^6} \\ - (A_6 + B_6 \cdot T + C_6 \exp(-K \cdot T / T_C)) \left(\frac{\exp(\alpha \cdot V) + 2 \cdot C_1 \exp(2 \cdot \alpha \cdot V)}{(\exp(\alpha \cdot V) + C_1 \exp(2 \cdot \alpha \cdot V))^2} \right)$$

$$\frac{\partial P(V, T)}{\partial T} = \frac{R}{V - B} + \frac{B_2 - \frac{K C_2 \exp(-K \cdot T / T_C)}{T_C}}{(V - B)^2} + \frac{B_3 - \frac{K C_3 \exp(-K \cdot T / T_C)}{T_C}}{(V - B)^3} \\ + \frac{B_4 - \frac{K C_4 \exp(-K \cdot T / T_C)}{T_C}}{(V - B)^4} + \frac{B_5 - \frac{K C_5 \exp(-K \cdot T / T_C)}{T_C}}{(V - B)^5} + \frac{B_6 - \frac{K C_6 \exp(-K \cdot T / T_C)}{T_C}}{\exp(\alpha \cdot V) (C_1 \exp(\alpha \cdot V) + 1)}$$

$$\frac{\partial^2 P(V, T)}{\partial T^2} = \frac{K^2 \exp(-K \cdot T / T_C)}{T_C^2} \left(\frac{C_2}{(V - B)^2} + \frac{C_3}{(V - B)^3} + \frac{C_4}{(V - B)^4} + \frac{C_5}{(V - B)^5} \right. \\ \left. + \frac{C_6}{\exp(\alpha \cdot V) (C_1 \exp(\alpha \cdot V) + 1)} \right)$$

$$\frac{\partial^2 P(V,T)}{\partial V \partial T} = \frac{-R}{(V-\beta)^2} - \frac{2(B_2 - \frac{KC_2 \exp(-K^*T/TC)}{T_C})}{(V-\beta)^3} - \frac{3(B_3 - \frac{KC_3 \exp(-K^*T/TC)}{T_C})}{(V-\beta)^4}$$

$$- \frac{4(B_4 - \frac{KC_4 \exp(-K^*T/TC)}{T_C})}{(V-\beta)^5} - \frac{5(B_5 - \frac{KC_5 \exp(-K^*T/TC)}{T_C})}{(V-\beta)^6} - (B_6 - \frac{KC_6 \exp(-K^*T/TC)}{T_C})$$

$$\frac{\alpha(1+2*C_1 \exp(\alpha*V))}{(\exp(\alpha*V)(1+C_1 \exp(\alpha*V)))}$$

VARIABLE SYMBOL TABLE

CK2	C_2^*K/TC
CK3	C_3^*K/TC
CK4	C_4^*K/TC
CK5	C_5^*K/TC
CK6	C_6^*K/TC
DERROR	tolerance used in checks for zero
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVDT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
D2PDT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
EKA	$\exp(\alpha*V)$
EKA2	$\exp(2*\alpha*V)$
EKIT	$\exp(-K^*T/TC)$
I	index
P	pressure (psia)
PART	1-dimensional array containing intermediate values
P1	pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated

T	temperature (°R)
TC	critical temperature (°R)
TERM	1-dimensional array containing intermediate values
TERMA	$\frac{B_6 - C_6 \exp(-K \cdot T/TC)}{\exp(\alpha \cdot V)(1 + \exp(\alpha \cdot V))}$
TERMB	$\frac{C_6}{\exp(\alpha \cdot V)(1 + \exp(\alpha \cdot V))}$
V	specific volume (ft ³ /lbm)
VMC	$V - \beta$
VMC2	$(V - \beta)^2$
VMC3	$(V - \beta)^3$
VMC4	$(V - \beta)^4$
VMC5	$(V - \beta)^5$
VMC6	$(V - \beta)^6$
XMESS	$- \frac{(\alpha \exp(\alpha \cdot V) + Z \cdot C_1 \exp(2 \cdot \alpha \cdot V))}{(\exp(\alpha \cdot V) + C_1 \exp(2 \cdot \alpha \cdot V))^2}$
Z1	$B_2 - C_2 \cdot K \exp(-K \cdot T/TC)/TC$
Z2	$B_3 - C_3 \cdot K \exp(-K \cdot T/TC)/TC$
Z3	$B_4 - C_4 \cdot K \exp(-K \cdot T/TC)/TC$
Z4	$B_5 - C_5 \cdot K \exp(-K \cdot T/TC)/TC$
Z5	$B_6 - C_6 \cdot K \exp(-K \cdot T/TC)/TC$
Z6	$\frac{(1 + 2 \cdot C_1 \exp(\alpha \cdot V))}{\exp(\alpha \cdot V)(1 + \exp(\alpha \cdot V))}$

4

$$DPDT = Q(2,3)/VMB + (Q(3,4) - CKZ*EKIT)/VMB2$$

$$+ Q(3,5) - CK3*EKIT)/VMB3 + (Q(3,6) - CK4*EKIT)/VMB + (Q(3,7) - CK5*EKIT)/VMB5 + TERMA$$

$$D2PDZ = Q(2,12)*2*EKIT/TC*2*(Q(4,4)/VMB2 + Q(4,5)/VMB3 + Q(4,6)/VMB4 + Q(4,7)/VMB5 + TERMB$$

$$Z1 = Q(3,4) - Q(2,12)*Q(4,4)*EKIT/TC$$

$$Z2 = Q(3,5) - Q(2,12)*Q(4,5)*EKIT/TC$$

$$Z3 = Q(3,6) - Q(2,12)*Q(4,6)*EKIT/TC$$

$$Z4 = Q(3,7) - Q(2,12)*Q(4,7)*EKIT/TC$$

$$Z5 = Q(3,8) - Q(2,12)*Q(4,8)*EKIT/TC$$

$$DPDVT = -Q(3,7)/VMB2 - 2.0*Z1/VMB3 - 3.0*Z2/VMB4 - 4.0*Z3/VMB5 - 5.0*Z4/VMB6 - Z5*Z6$$

RETURN

```

1      C *****
2      C *
3      C *
4      C *
5      C *
6      C *
7      C *
8      C *****
9      C SUBROUTINE EOS(P,T,V,DPDT,DPLV,DPLVDT,D2PDT2)
10     C COMMON/FREON1/W(4,12),TTOLER,BTOLER,LIMIT,DEKOR,NTYPE
11     C DIMENSION TERM (6), PART (7)
12     C DPLV = 0.0
13     C P1=0.0
14     C VMB=V-Q(3,3)
15     C EKIT=-Q(2,12)*T/(Q(4,3)+Q(1,11))
16     C EKIT=EXP(EKIT)
17     C EKA=Q(3,12)*V
18     C EKA2=2.00*Q(3,12)*V
19     C IF (ABS (EKA).LE.DERROR) GO TO 105
20     C IF (ABS(EKA).GT.50.0) GO TO 105
21     C EKA = EXP(EKA)
22     C EKA2 = EXP(EKA2)
23     C GO TO 115
24     105 EKA = 0.0
25     EKA2 = 0.0
26     115 TERM(1) = Q(2,3)*1/VMB
27     DO 125 I = 2,5
28     TERM(I) = (Q(2,I+2)+Q(3,I+2)*T+Q(4,I+2)*EKIT)/VMB**I
29     125 P1 = P1 +TERM(I)
30     IF (ABS(EKA).LE.DERROR) TERM (6) = 0.0
31     IF (ABS(EKA).LE.DERROR) GO TO 120
32     TERM (6) = (Q(2,6) + Q(3,6)*T+Q(4,6)*EKIT)/(EKA*(1.0+Q(1,12)*E
33     1KA))
34     120 P1 = P1 + TERM(1) + TERM(6)

```

```

35      P=P1
36      140 PART (1) = Q(2,3)*T/VMB**2
37      DO 150 I = 2,5
38          PART(I) = FLOAT (I)*(Q(2,I+2)+Q(3,I+2)*T+Q(4,I+2)*EKIT)/VMB**(I+1
39          1)
40      150 UPDV = UPDV + PART (1)
41          IF (ABS (EKA).LE.DERROR) PART (6) = 0.0
42          IF (ABS (EKA).LE.DERROR) GO TO 145
43          IF (EKA2.GT.30.0) EKA2 = 0.0
44          XMESS = (Q(3,12)*EKA+2.0*Q(3,12)*Q(1,12)*EKA2)/((EKA+Q(1,12)*E
45          1KA2)**2)
46          XMESS = -XMESS
47          PART (6) = (Q(2,6)+Q(3,6)*T+Q(4,6)* EKIT)*XMESS
48      145 UPDV =-(UPDV+PART(1) + PART (6))
49          VMB2=VMB*VMB
50          VMB3=VMB2*VMB
51          VMB4=VMB2**2
52          VMB5=VMB4*VMB
53          VMB6=VMB3*VMB3
54          TC=Q(4,3)+Q(1,11)
55          CK2=Q(4,4)*Q(2,12)/TC
56          CK3=Q(4,5)*Q(2,12)/TC
57          CK4=Q(4,6)*Q(2,12)/TC
58          CK5=Q(4,7)*Q(2,12)/TC
59          CK6=Q(4,8)*Q(2,12)/TC
60          EKA=Q(3,12)*V
61          IF (ABS(EKA).LE.DERROR) GO TO 100
62          IF (EKA.GT.30.0) GO TO 100
63          EKA=EXP(EKA)
64          TERMA=(Q(3,8)-CK6*EKIT)/(EKA*(1.0+Q(1,12)*EKA))
65          TERMB=Q(4,8)/(EKA*(1.0+Q(1,12)*EKA))
66          Z6=Q(3,12)*(1.0+2.0*Q(1,12)*EKA)/(EKA*(1.0+Q(1,12)*EKA))
67          GO TO 180
68      100 TERMA=0.0
69          TERMB=0.0

```

```

70      Z0=0.0
71      LNA=0.0
72      180  DPDT=G(2,3)/VMB+(G(3,4)-CK2*EKIT)/VMB2+(G(3,5)-CK3*EKIT)/VMB3+
73      1      (G(3,6)-CK4*EKIT)/VMB4+(G(3,7)-CK5*EKIT)/VMB5+TERMA
74      D2PDT2=G(2,12)**2*EKIT/TC**2*(Q(4,4)/VMB2+Q(4,5)/VMB3+Q(4,6)/VMB4+
75      1      Q(4,7)/VMB5+IERMB)
76      Z1=G(3,4)-G(2,12)*Q(4,4)*EKIT/TC
77      Z2=G(3,5)-G(2,12)*Q(4,5)*EKIT/TC
78      Z4=G(3,7)-G(2,12)*Q(4,7)*EKIT/TC
79      Z3=G(3,6)-G(2,12)*Q(4,6)*EKIT/TC
80      Z5=G(3,8)-G(2,12)*Q(4,8)*EKIT/TC
81      DPDUV1=-G(3,2)/VMB2-2.0*Z1/VMB3-3.0*Z2/VMB4-4.0*Z3/VMB5-5.0*Z4/
82      1      VMB6-Z5*Z6
83      175  RETURN
84      END

```

FLQDEN DESCRIPTION

FLQDEN calculates the saturated liquid specific volume and its derivative with respect to temperature given temperature. One of three equations is selected depending on the refrigerant to be evaluated.

EQUATIONS

NTYPE = 1

$$1/V_L = A_L + B_L (1-T/TC)^{1/3} + C_L (1-T/TC)^{2/3} + D_L (1-T/TC) + E_L (1-T/TC)^{4/3}$$

$$\frac{dV_L}{dT} = V_L^2 \left(\frac{B_L}{3*TC} (1-T/TC)^{-2/3} + \frac{2*C_L}{3*TC} (1-T/TC)^{-1/3} + \frac{4*E_L}{3*TC} (1-T/TC)^{1/3} \right)$$

NTYPE = 2

$$1/V_L = A_L + B_L (TC-T) + C_L (TC-T)^{1/2} + D_L (TC-T)^{1/3} + E_L (TC-T)^2$$

$$\frac{dV_L}{dT} = V_L^2 (B_L + C_L (TC-T)^{-1/2} / 2 + D_L (TC-T)^{-2/3} / 3 + 2*E_L (TC-T))$$

NTYPE = 3

$$1/V_L = A_L + B_L *T + C_L *T^2$$

$$\frac{dV_L}{dT} = -V_L^2 (B_L + 2*C_L *T)$$

VARIABLE SYMBOL TABLE

DL	saturated liquid density (lbm/ft ³)
DVLDT	$\frac{dV_L(T)}{dT}$
NTYPE	saturated liquid specific volume equation selector
P1	temporary value
P2	temporary value
P3	temporary value
P4	temporary value
Q	2-dimensional array containing the coefficients for the fluid to be evaluated
T	temperature function

TC

critical temperature ($^{\circ}\text{R}$)

TR

temperature ($^{\circ}\text{R}$)

T3

3*TC ($^{\circ}\text{R}$)

VL

saturated liquid specific volume (ft^3/lbm)

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *
6      C      *
7      C      *
8      C      *
9      C      *
10     C      *
11     C      *
12     C      *
13     C      *
14     C      *
15     C      *
16     C      *
17     C      *
18     C      *
19     C      *
20     C      *
21     C      *
22     C      *
23     C      *
24     C      *
25     C      *
26     C      *
27     C      *
28     C      *
29     C      *
30     C      *
31     C      *
32     C      *
33     C      *
34     C      *

```

F L Q D E N

THIS SUBROUTINE COMPUTES THE SATURATED LIQUID SPECIFIC VOLUME
GIVEN TEMPERATURE USING ONE OF THREE EQUATIONS.

SUBROUTINE FLQDEN(VL,TR,DVLDT)
COMMON/FREON1/Q(4,12),TTOLER,BTOLER,LIMIT,DERROR,NTYPE
IC=Q(4,5)+Q(1,11)
100 GO TO (200,300,400), NTYPE
200 P1=1.0/3.0
P2=2.0/3.0
P3=4.0/3.0
T=1.0-TR/IC
DL=Q(1,4)+Q(1,5)*T**P1+Q(1,6)*T**P2+Q(1,7)*T**P3
VL=1.0/DL
T3=3.0*TC
DVLDT=VL**2*(Q(1,5)/(T3*T**P2)+2.0*Q(1,6)/(T3*T**P1)+Q(1,7)/TC
1 +4.0*Q(1,8)/(T3*T**P1))
RETURN
300 P1=1.0
P2=1.0/2.0
P3=1.0/3.0
P4=2.0/3.0
T=TC-TR
DL=Q(1,4)+Q(1,5)*T**P1+Q(1,6)*T**P2+Q(1,7)*T**P3+Q(1,8)*T**2
VL=1.0/DL
DVLDT=VL**2*(Q(1,5)+Q(1,6)/(2.0*T**P2)+Q(1,7)/(3.0*T**P4)+2.0*
1 Q(1,8)*T)
RETURN
400 DL=Q(1,4)+Q(1,5)*TR+Q(1,6)*TR**2
VL=1.0/DL

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UPLDT=VL**2*(-U(1,5)-U(1,6)*2.0*TR)
RETURN
END

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4. The fourth item is a copy of the original document.

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HFIND DESCRIPTION

HFIND searches for the specific volume and temperature in the vapor region given pressure and enthalpy. A two variable Newton-Raphson iteration technique is used for the search.

EQUATIONS

$$\text{Jacobian} = \left(\frac{\partial P(V,T)}{\partial V} \right) \left(\frac{\partial h(V,T)}{\partial T} \right) - \left(\frac{\partial P(V,T)}{\partial T} \right) \left(\frac{\partial h(V,T)}{\partial V} \right)$$

$$V_{i+1} = V_i - \left[\frac{(P(V,T) - P_{\text{KNOWN}}) \frac{\partial h(V,T)}{\partial T} - (h(V,T) - h_{\text{KNOWN}}) \frac{\partial P(V,T)}{\partial T}}{\text{Jacobian}} \right]_i$$

$$T_{i+1} = T_i - \left[\frac{(h(V,T) - h_{\text{KNOWN}}) \frac{\partial P(V,T)}{\partial V} - (P(V,T) - P_{\text{KNOWN}}) \frac{\partial h(V,T)}{\partial V}}{\text{Jacobian}} \right]_i$$

VARIABLE SYMBOL TABLE

BTOLER	lower tolerance on convergence and saturation tests
DHDT	$\frac{\partial h(V,T)}{\partial T}$
DHDV	$\frac{\partial h(V,T)}{\partial V}$
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVRT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
D2PDT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
H	known enthalpy (Btu/lbm)
HVAL	calculated enthalpy (Btu/lbm)
I	index
LIMIT	maximum number of iterations allowed in any one search

M2	unit number for printer
P	known pressure (psia)
PCAL	calculated pressure (psia)
T	temperature (°R)
TLAST	last temperature calculated to be used in next iteration
TTOLER	upper tolerance on convergence and saturation tests
V	specific volume (ft ³ /lbm)
VLAST	last specific volume calculated, to be used in next iteration
XJACOB	Jacobian of pressure and enthalpy

C
C
C
C
C
C
C
C

```
*****  
*  
* H F I N D  
*  
* THIS SUBROUTINE FINDS TEMPERATURE AND DENSITY GIVEN PRESSURE  
* AND ENTHALPY FOR SUPERHEATED VAPOR STATES.  
*  
*****  
SUBROUTINE HFIND(I,P,V,H)  
PARAMETER M2=6  
COMMON/FREON1/G(4,12),TTOLER,BTOLER,LIMIT,DEERROR,NTYPE  
VLAST=V  
TLAST=T  
CALL EOS(PCAL,T,v,DPDT,DPDV,DPDVUT,DP2DT2)  
CALL ENTHAL(PCAL,T,v,HCAL,DHDT,DHDV)  
DO 1000 I=1,LIMIT  
XJACOB=DPDV*DHDV-DPDT*DHDV  
V=VLAST-((PCAL-P)*DHDV-(HCAL-H)*DPDT)/XJACOB  
T=TLAST-((HCAL-H)*DPDV-(PCAL-P)*DHDV)/XJACOB  
IF(T.LE.0.0) T=TLAST/10.0  
IF(V.LE.0.0) V=VLAST/10.0  
CALL EOS(PCAL,T,v,DPDT,DPDV,DPDVUT,DP2DT2)  
CALL ENTHAL(PCAL,T,v,HCAL,DHDT,DHDV)  
IF(PCAL/P.LT.TTOLER.AND.PCAL/P.GT.BTOLER.AND.HCAL/H.LT.  
1 TTOLER.AND.HCAL/H.GT.BTOLER) GO TO 1050  
IF(ABS(T-TLAST).LT.1.0E-04.AND.ABS(V-VLAST).LT.1.0E-07) GO TO 1050  
VLAST=V  
TLAST=T  
1000 CONTINUE  
WRITE(M2,9000) LIMIT  
1050 RETURN  
9000 FORMAT(' ',1UX,'HFIND FAILED TO CONVERGE IN ',I5,' ITERATIONS')  
END
```

PRINTF DESCRIPTION

PRINTF prints the final results of FREON if NPRIN does not equal zero.

VARIABLE SYMBOL TABLE

FTYPE	fluid type to which properties have been determined
H	enthalpy (Btu/lbm)
HL	saturated liquid enthalpy (Btu/lbm)
HV	saturated vapor enthalpy (Btu/lbm)
NPRIN	print selector
M2	unit number for printer
P	pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated
S	entropy (Btu/lbm°R)
SL	saturated liquid entropy (BTU/lbm °R)
SV	saturated vapor entropy (BTU/lbm °R)
T	temperature (°R)
V	specific volume (ft ³ /lbm)
VL	saturated liquid specific volume (ft ³ /lbm)
VV	saturated vapor specific volume (ft ³ /lbm)

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *
6      C      *
7      C      *
8      C      *****
9      C      SUBROUTINE PRINTF(T,P,QUAL,V,H,S,VV,HV,SV,VL,HL,SL,FTYPE,NPRIN)
10     C      PARAMETER M2=6
11     C      COMMON/FREON1/6(4,12),TTOLER,BTOLER,LIMIT,DEKORR,NTYPE
12     C      T=T-W(1,11)
13     C      IF(NPRIN.EQ.0) RETURN
14     C      WRITE(M2,9000) FTYPE
15     C      WRITE(M2,9010) T,P
16     C      IF(QUAL.LE.1.0.AND.QUAL.GE.0.0) GO TO 3280
17     C      IF(QUAL.GT.1.0) WRITE(M2,9020)
18     C      IF(QUAL.LT.0.0) WRITE(M2,9030)
19     C      GO TO 3370
20     C      3280 WRITE(M2,9040) QUAL
21     C      WRITE(M2,9050)
22     C      WRITE(M2,9070) HV,HL
23     C      WRITE(M2,9080) SV,SL
24     C      WRITE(M2,9060) VV,VL
25     C      3370 WRITE(M2,9090)
26     C      WRITE(M2,9070) H
27     C      WRITE(M2,9080) S
28     C      WRITE(M2,9060) V
29     C      9000 FORMAT(1H1,4X,'***THERMODYNAMIC PROPERTIES OF ',A4,' USING MARTIN-
30     C      1HOU EQUATION OF STATE***')
31     C      9010 FORMAT(1H ,4X,'TEMPERATURE = ',F7.1,'DEG.F',/,5X,'PRESSURE = ',
32     C      1 F10.5,'PSIA')
33     C      9020 FORMAT(1H ,4X,'SUPERHEATED VAPOR',////////)
34     C      9030 FORMAT(1H ,4X,'COMPRESSED LIQUID-APPROXIMATED BY SATURATED LIQUID'
35     C      1 ,////////)

```



```

35 9040 FORMAT(1H ,4X,'SATURATED LIQUID-VAPOR EQUILIBRIUM',/,5X,'QUALITY =
36 1 ',F6.4)
37 9050 FORMAT(1H ,/,/,35X,'SATURATED',8X,'SATURATED',/,35X,'VAPOR',12X,
38 1 'LIQUID',/,5X,6J('H'))
39 9060 FORMAT(1H ,4X,'SPECIFIC VOLUME (CU.FT/LBM)',5X,F9.4,8X,F9.4,/////
40 1 /)
41 9070 FORMAT(1H ,4X,'ENTHALPY',8X,'(BTU/LBM)',5X,F9.3,8X,F9.3)
42 9080 FORMAT(1H ,4X,'ENTROPY',9X,'(BTU/LBM-R)',5X,F9.6,8X,F9.6)
43 9090 FORMAT(1H ,////////)
44 RETURN
45 END

```

SATN DESCRIPTION

SATN determines the saturated vapor and liquid properties given temperature and the saturated vapor and liquid specific volumes. Saturated liquid properties are determined from the Clapeyron equation.

EQUATIONS

$$h_L = h_V - \text{CONVR} \left(\frac{dP_{\text{SAT}}}{dT} \right) (V_V - V_L) * T$$
$$S_L = S_V - \text{CONVR} \left(\frac{dP_{\text{SAT}}}{dT} \right) (V_V - V_L)$$

VARIABLE SYMBOL TABLE

DELTH	$(h_L - h_g)$ calculated from (Clapeyron equation)
DHDT	$\frac{\partial h(V, T)}{\partial T}$
DHDV	$\frac{\partial h(V, T)}{\partial V}$
DPSDT	$\frac{dP_{\text{SAT}}}{dT}$
DPSDT2	$\frac{d^2 P_{\text{SAT}}}{dT^2}$
DSDT	$\frac{\partial S(V, T)}{\partial T}$
DSDV	$\frac{\partial S(V, T)}{\partial V}$
DVLDT	$\frac{dV_L}{dT}$
H	enthalpy (Btu/lbm)
HL	saturated liquid enthalpy (Btu/lbm)
HV	saturated vapor enthalpy (Btu/lbm)
PSIA	pressure (psia)
RJ	conversion factor = 0.185053
S	entropy (Btu/lbm°R)

SL

saturated liquid entropy (Btu/lbm[°]R)

SV

saturated vapor entropy (Btu/lbm[°]R)

T

temperature (°R)

V

specific volume (ft³/lbm)

VL

saturated liquid specific volume (ft³/lbm)

VV

saturated vapor specific volume (ft³/lbm)

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4
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23

C
C
C
C
C
C
C

```

*****
*
*               S A T N
*
*   THIS SUBROUTINE COMPUTES THE SATURATED VAPOR-LIQUID
*   *PROPERTIES GIVEN TEMPERATURE AND SPECIFIC VOLUME.
*
*****
SUBROUTINE SATN(PSIA,T,V,HV,SV,HL,SL,VL)
COMMON/FREON1/Q(4,12),TTOLER,BTOLER,LIMIT,DERROR,NTYPE
CALL FLQDEN(VL,T,DVLDT)
RJ=0.185053
CALL ENTHAL(PSIA,T,V,H,DHDT,DHDTV)
CALL DRVPT(DPSUT,PSIA,T,DPSDT2)
DELTH=RJ*DPSUT*(V-VL)*T
HL=H-DELTH
CALL ENTROP(T,V,S,DSUT,DSDV)
SL=S-DELTH/T
VV=V
HV=H
SV=S
RETURN
END

```

SFIND DESCRIPTION

SFIND searches for the specific volume and temperature in the vapor region given pressure and entropy. A two variable Newton-Raphson iteration technique is used for the search.

EQUATIONS

$$\text{Jacobian} = \left(\frac{\partial P(V,T)}{\partial V} \right) \left(\frac{\partial S(V,T)}{\partial T} \right) - \left(\frac{\partial P(V,T)}{\partial T} \right) \left(\frac{\partial S(V,T)}{\partial V} \right)$$
$$V_{i+1} = V_i - \left[\frac{(P(V,T) - P_{\text{KNOWN}}) \frac{\partial S(V,T)}{\partial T} - (S(V,T) - S_{\text{KNOWN}}) \frac{\partial P(V,T)}{\partial T}}{\text{Jacobian}} \right]_i$$
$$T_{i+1} = T_i - \left[\frac{(S(V,T) - S_{\text{KNOWN}}) \frac{\partial P(V,T)}{\partial V} - (P(V,T) - P_{\text{KNOWN}}) \frac{\partial S(V,T)}{\partial T}}{\text{Jacobian}} \right]_i$$

VARIABLE SYMBOL TABLE

BTOLER	lower tolerance on convergence and saturation tests
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVRT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
D2PDT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
DSDT	$\frac{\partial S(V,T)}{\partial T}$
DSDV	$\frac{\partial S(V,T)}{\partial V}$
I	index
LIMIT	maximum number of iterations allowed in any one search
M2	unit number for printer
P	known pressure (psia)

PCAL	calculated pressure (psia)
S	known entropy (Btu/lbm [°] R)
SCAL	calculated entropy (Btu/lbm [°] R)
T	temperature (°R)
TLAST	last temperature calculated, to be used in next iteration
TTOLER	upper tolerance on convergence and saturation tests
V	specific volume (ft ³ /lbm)
VLAST	last specific volume calculated, to be used in next iteration
XJACOB	Jacobian of pressure and entropy

```

1 C *****
2 C *
3 C *
4 C *
5 C *
6 C *
7 C *
8 C *****
9 C
10 C SUBROUTINE SFIND(T,P,V,S)
11 C PARAMETER M2=6
12 C COMMON/FREON1/G(4,12),ITOLER,BTOLER,LIMIT,DERROR,NTYPE
13 C VLAST=V
14 C TLAST=T
15 C CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,D2PDT2)
16 C CALL ENTROP(T,V,SCAL,DSDT,DSDV)
17 C DO 1000 I=1,LIMIT
18 C XJACOB=DPDV*DSDT-DPDT*DSDV
19 C V=VLAST-((PCAL-P)*DSDT-(SCAL-S)*DPDT)/XJACOB
20 C T=TLAST-((SCAL-S)*DPDV-(PCAL-P)*DSDV)/XJACOB
21 C IF(T.LE.0.0) T=TLAST/10.0
22 C IF(V.LE.0.0) V=VLAST/10.0
23 C CALL ENTROP(T,V,SCAL,DSDT,DSDV)
24 C CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,D2PDT2)
25 C IF(PCAL/P.LT.ITOLER.AND.PCAL/P.GT.BTOLER.AND.SCAL/S.LT.
26 C 1 ITOLER.AND.SCAL/S.GT.BTOLER) GO TO 1050
27 C IF(ABS(T-TLAST).LT.1.0E-04.AND.ABS(V-VLAST).LT.1.0E-07) GO TO 1050
28 C VLAST=V
29 C TLAST=T
30 C 1000 CONTINUE
31 C WRITE(M2,9000) LIMIT
32 C 1050 RETURN
33 C 9000 FORMAT(' ',10X,'***SFIND FAILED TO CONVERGE IN ',I5,' ITERATIONS')
34 C END

```

VOLUME DESCRIPTION

VOLUME searches for the specific volume in the vapor region given temperature and pressure by using a single variable Newton-Raphson iteration technique.

EQUATIONS

$$V_{i+1} = V_i - \left[\frac{P(V,T) - P_{\text{KNOWN}}}{\frac{\partial P(V,T)}{\partial V}} \right]_i$$

VARIABLE SYMBOL TABLE

BTOLER	lower tolerance on convergence and saturation tests
DPDT	$\frac{\partial P(V,T)}{\partial T}$
DPDV	$\frac{\partial P(V,T)}{\partial V}$
DPDVDT	$\frac{\partial^2 P(V,T)}{\partial V \partial T}$
DP2DT2	$\frac{\partial^2 P(V,T)}{\partial T^2}$
I	index
LIMIT	maximum number of iterations allowed in any one search
M2	unit number for printer
P	known pressure (psia)
PCAL	calculated pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated
T	temperature (°R)
TTOLER	upper tolerance on convergence and saturation tests
V	specific volume (ft ³ /lbm)
VLAST	last specific volume calculated, V_i to be used in next iteration (ft ³ /lbm)

```

1      C      *****
2      C      *
3      C      *
4      C      *
5      C      *
6      C      *
7      C      *
8      C      *
9      C      *
10     C      *
11     C      *
12     C      *
13     C      *
14     C      *
15     C      *
16     C      *
17     C      *
18     C      *
19     C      *
20     C      *
21     C      *
22     C      *
23     C      *
24     C      *
25     C      *
26     C      *

```

V O L U M E

```

*   THIS SUBROUTINE FINDS THE VAPOR DENSITY BY USE OF THE NEWTON-
*   RAPHSON ITERATION METHOD, GIVEN PPRESSURE AND TEMPERATURE.
*
*****
SUBROUTINE VOLUME(T,P,V)
PARAMETER M2=6
COMMON/FREON1/4(4,12),TTOLER,BTOLER,LIMIT,DERROR,NTYPE
V=G(2,3)*T/P
VLAST=V
CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,DP2DT2)
DO 1000 I=1,LIMIT
V=VLAST-((PCAL-P)/DPDV)
IF(V.LE.0.0) V=VLAST/10.0
CALL EOS(PCAL,T,V,DPDT,DPDV,DPDVDT,DP2DT2)
IF(PCAL/P.LT.TTOLER.AND.PCAL/P.GT.BTOLER.OR.ABS(V-VLAST).LT.
1    1.0E-10) RETURN
VLAST=V
1000 CONTINUE
WRITE(M2,9000) LIMIT
9000 FORMAT(11X,'***VOLUME FAILED TO CONVERGE IN ',I5,' ITERATIONS')
RETURN
END

```

VPEQM DESCRIPTION

VPEQM calculates the saturation pressure given temperature or searches for the saturation temperature given pressure. The Newton-Raphson iteration technique is used for the saturation temperature search.

EQUATIONS

$$\log_{10} P_{\text{SAT}} = A + B/T + C \cdot \log_{10} T + D \cdot T + E \left(\frac{F-T}{T} \right) \log_{10} (F-T)$$

VARIABLE SYMBOL TABLE

DELP	P_{KNOWN}
DELT	$\frac{P_{\text{KNOWN}} - P_{\text{CALCULATED}}}{\frac{dP_{\text{SAT}}}{dT}}$ - change in temperature for next temperature iteration
DPDT	$\frac{dP_{\text{SAT}}}{dT}$
D2PDT2	$\frac{d^2 P_{\text{SAT}}}{dT^2}$
ERROR	$\frac{P_{\text{KNOWN}} - P_{\text{CALCULATED}}}{P_{\text{KNOWN}}}$
FT	F-T
ITR	index
LIMIT	maximum number of iterations allowed in any one search
LOGP	$\log_{10} P_{\text{SAT}}$
M	flag indicating which of temperature or pressure is known m = 1 temperature is known else pressure is known
P1	known pressure (psia)
P2	calculated pressure (psia)
Q	2-dimensional array containing the coefficients for the fluid to be evaluated

T	temperature (°R)
TC	critical temperature (°R)
T1	initial guess for temperature search (°R)
T2	T^2
T3	T^3
TMISS	difference of initial guess and the value of temperature passed to VPEQM

```

1      C *****
2      C *
3      C *           V P E Q M
4      C *   THIS SUBROUTINE CALCULATES THE SATURATION PRESSURE OR
5      C * TEMPERATURE GIVEN THE OTHER
6      C *
7      C *****
8      SUBROUTINE VPEQM(P1,T,M)
9      PARAMETER M2=6
10     COMMON/FREUN1/Q(4,12),TTOLER,BTOLER,LIMIT,DERROR,NTYPE
11     REAL LOGP
12     TC=Q(4,3)+Q(1,11)
13     IF (M.EQ.1) GO TO 100
14     T1 = ABS(Q(2,1)/(ALOG10(P1)-Q(1,1)))
15     TMISS = (T1-T)/ T1
16     IF (ABS(TMISS).GT..2D + 00) T = T1
17     DO 105 ITR=1,LIMIT
18     T2 = T*T
19     T3 = T*T2
20     FT = Q(2,2)-T
21     IF (FT.LT..1E-20) FT = 1.0
22     LOGP=Q(1,1)+Q(2,1)/T+Q(3,1)*ALOG10(T)+Q(4,1)*T+Q(1,2)*FT/T*ALOG10(
23     1 FT)
24     P2 = 10.0 **LOGP
25     IF(M.EQ.1 ) P1 = P2
26     DELP = P1-P2
27     ERROR = DELP/P1
28     IF(ABS(ERROR).LT..1D-06) GO TO 110
29     CALL DRVPT(DPDT,P2,T,D2PDT2)
30     DELT = DELP/DPDT
31     T = T + DELT
32     IF(T.GT.TC) T=TC
33     105 CONTINUE
34     WRITE (M2, 115) LIMIT

```

35
36
37

110 RETURN
115 FORMAT(1H ,4X,'***VPEQM FAILED TO CONVERGE IN',I6,'ITERATIONS')
END

References

1. Mechtly, E. A., The International System of Units, Physical Constants and Conversion Factors, 2nd Revision, NASA, Washington, D.C. 1973
2. Downing, R. C., and Knight, B. W., Computer Program for Calculating Properties of "FREON" Refrigerants, RT-52, Du Pont Chemical Corporation, 1971
3. General Equations, X-88F, Du Pont Chemical Corporation