12가지 냉매(R11, R12, R13, R14, R21, R22, R23, R113, R114, R500, R502, C318)의 상태치계산 프로그램

Development of Computer Program for Computation of 12 Refrigerant Properties

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Abstract

A FORTRAN code has been developed to calculate thermodynamic properties of 12 kinds of refrigerants. Input variables are temperature and pressure or temperature only depending on the saturation. The program output properties are specific volume, saturation pressure, enthalpy, entropy, specific heats and speed of sound. Sample calculations show that output properties are in very good agreements with thermodynamic tables and charts.

서 론

냉매를 사용하는 열역학적인 장치를 설계할 때 상태치표나 그림을 참고하여 설계하는 것이 보통이다. 그렇지만 이러한 방법은번거롭고 정확한 상태치를 구하기 어렵다. 그리고 열역학적인 사이클을 시뮬레이션하기 위해서는 상태치계산 프로그램이 절실히 필요하지만 현재 구할 수 있는 것은 G. T. Kartsounes[1]가 만든 세가지 냉매(R12, R22, R502)에 대한 프로그램뿐이다. 현재는 위의 세 냉매뿐만 아니라 다른 냉매도 많이 사용되므로 본 연구에서는 Kartsounes의 프로그램과 Refrigerant Equation을 참고하여 12가지 냉매의 상태치를 계산할 수 있는 프로그램을 개발하였다. 원래의 Refrigerant Equations 는 영국단위로 되어 있지만 프로그램의 입력과 출력을 SI 단위로 할 수 있도록 프로그래밍하였다.

본 론(프로그램의 이용방법)

프로그램은 Kartsounes의 프로그램과 같이 두개의 Function(SPVOL, TSAT)과 세개의 Subroutine(SATPRT, VAPOR, SPHT)로이루어졌다. Function SPVOL은 증기상태에서 주어진 냉매와 온도와 압력에 대한 비체적을 알 수 있는 프로그램이다. Function TEST는 포화상태에서 주어진 냉매와 압력에 대한 온도를 알 수 있는 프로그램이다.

Subroutine SATPRP는 포화상태에서 냉매와 온도가 주어졌을때 나머지 상태치를 구할 수 있고 Subroutine VAPOR는 주어진 온도와 압력에 대한 비체적, 엔탈피, 엔트로피

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를 구할 수 있으며 Subroutine SPHT는 주어진 온도와 압력에 대하여 C_p, C_v, 음속을 알 수 있다. 변수와 프로그램 사용법은 프로그램중의 Comment에 자세히 설명되어 있다. Subprogram을 사용할때 주의할 점은 변수 NR은 냉매 종류를 가리키는 숫자로서 예를 들어 R12를 선택할 경우는 NR에 숫자 12를 것이 아니라 '12'와 같이 String로 써야한다.

프로그램은 KAIST 기계공학과에 있는 PRIME로 프로그래밍 하였으며 좀 더 논리적이고 보기 쉬운 FORTRAN-77으로 프로그래밍 하였다.

Output discussion

12가지 냉매에 대한 Output 은 구할 수 있는 표 또는 그림과 같이 잘 일치하였다. 예를 들면 R12의 Saturation Output을 Ref. 3의 Table과 비교하면 H_f와 H_g에서 최고 0.8%의 오차를 보이고 다른 상태치는 그 이하의 오차를 나타낸다.

참 고 문 헌

1. G.T. Kartsounes and R.A. Erth, "Computer Calculation of Refrigerants 12, 22, 502", Preprint, ASHRAE Annual Meeting, August, 1971.
2. R.C. Dowing, "Refrigerant Equations", ASHRAE No. 2313.
3. Cordon J. Van Wylen and Richard E. Sonntag, "Fundamentals of Classical Thermodynamics", Second ed. John Wiley and Sons, Inc., 1978.


```
C
C-------------------------------------------------------------
C
C     SUBPROGRAM LIST
C
C       1 : FUNCTION SPVOL
C       2 : FUNCTION TSAT
C       3 : SUBROUTINE SATPRP
C       4 : SUBROUTINE VAPOR
C       5 : SUBROUTINE SPHT
C
C     This program can calculate the properties of following refrigerants
C
C       11 , 12 , 13 , 14 , 21 , 22 , 23 , 113 , 114 , 500 , 502 , C318
C
C-----------------------------]]   Programmer : Lee Ki Bang , KAIST
C
C-------------------------------------------------------------
C
C
```

```
C
      FUNCTION SPVOL(NR,TCE,PPA)
C
C---  PURPOSE
C        TO EVALUATE THE SPECIFIC VOLUME OF THE VAPOR PHASE
C        OF REFRIGERANT GIVEN THE PRESSURE AND TEMPERATURE
C
C---  KINDS OF REFRIGERANT
C        11 , 12 , 13 , 14 , 21 , 22, 23 , 113 , 114 , 500 , 502 , C318
C
C---  DESCRIPTION OF PARAMETERS
C        INPUT
C          NR    -  REFRIGERANT NUMBER ( INSERT THE STRING : EX, '12' FOR R1
C          TCE   -  TEMPERATURE (C)
C          PPA   -  PRESSURE (kPA)
C        OUTPUT
C          SPVOL -  SPECIFIC VOLUME (CU M/KG)
C        COMMON OUTPUT
C          FLAG  -  ERROR STATE
C
C
C---  REMARKS
C        FUNCTION SUBPROGRAM TSAT CALLED BY THIS FUNCTION
C
C
C---  DIMENSION
      LOGICAL FLAG
      COMMON FLAG
      CHARACTER*(*) NR
      REAL R(12),B(12),A2(12),B2(12),C2(12),A3(12),B3(12),C3(12),
     $     A4(12),B4(12),C4(12),A5(12),B5(12),C5(12),A6(12),B6(12),
     $     C6(12),K(12),ALPHA(12),CPR(12),TC(12),TFR(12)
C
C---  EQUATION OF STATE CONSTANTS
C
      DATA R/ 0.078117,0.088734,0.102728,0.1219336,0.10427,0.124098,
     $        0.15327,0.05728,0.062780807,0.10805000,0.096125,
     $        0.053645698 /, B/ 0.00190,0.0065093886,0.00048,0.0015,
     $        0.0,0.002,0.00125,0.0,0.005914907,0.006034229,0.00167,
     $        0.0060114165 /, A2/ -3.126759,-3.40972713,-3.083417,
     $        -2.162959,-7.316,-4.353547,-4.679499,-4.035 ,-2.3856704,
     $        -4.549888,-3.2613344,-1.8947274 /, B2/  1.318523E-3,
     $        1.59434848E-3,2.341695E-3,2.135114E-3,4.6421E-3,
     $        2.407252E-3,3.47277BE-3,2.618E-3,1.0801207E-3,2.308415E-3,
     $        2.05762B7E-3,9.84847456-4 /
      DATA C2/ -35.76999,-56.7627671,-18.212643,-18.941131,0.0,
     $         -44.066868,-159.775232,0.0,-6.5643648,-92.90748,
     $         -24.24879,-28.542156 /
      DATA A3/ -0.025341,
     $        0.0602394465,0.058854,4.404057E-3,-0.20382376,-0.017464,
     $        0.012475,-0.0214,0.034055687,0.08660634,0.034866748,
     $        0.026479892 /, B3/ 4.875121E-5,-1.87961843E-5,-5.671268E-5
     $        ,1.282818E-5,3.593E-4,7.627B9E-5,7.733388E-5,5.00E-5,
     $        -5.3336494E-6,-3.141665E-5,-8.67913I3E-6,-6.8621O1E-6 /
      DATA C3/    1.220367,1.31139908,0.571958,0.539776,0.0,1.483763,
     $        5.941212,0.0,0.16366057,2.742282,0.33274779,0.66384636
     $        /, A4/ 1.687277E-3,-5.4873701E-4,-1.026061E-3,1.921072E-4,
     $        0.0,2.310142E-3,2.068042E-3,0.0,-3.857481E-4,-8.726016E-4,
     $        -8.556677E-4,-2.9365234E-4 /, B4/ -1.805062E-6,0.0,
     $        1.338679E-6,-3.91B263E-7,0.0,-3.605723E-6,-3.6B4238E-6,0.0
     $        ,0.0,0.0,7.02405496-7,0.0 /, C4/ 0.0,0.0,0.0,0.0,0.0,0.0,
     $        0.0,0.0,0.0,0.0,0.022412368,0.0 /, A5/ -2.35893OE-5,
     $        0.0,5.290649E-6,-4.481049E-6,0.0,-3.724044E-5,-3.868546E-5
     $        ,0.0,1.6017659E-6,-1.375958E-6,8.836B967E-6,6.0887086E-7 /
      DATA B5/    2.44B3O3E-8,3.468834E-9,-7.395111E-9,9.062318E-9,0.0,
     $        5.355465E-8,6.455643E-8,0.0,6.2632341E-10,9.14957OE-9,
     $        -7.9168095E-9,8.269634E-10 /, C5/ -1.47837?E-4,
     $        -2.54390678E-5,-3.874233E-5,-4.83667BE-5,0.0,-1.845051E-4,
     $        -7.394214E-4,0.0,-1.0165314E-5,-2.102661E-4,-3.7167231E-4,
     $        -3.849145E-5 /, A6/ 1.0575O4E8,0.0,7.37860IE7,5.838823E7,
     $        0.0,1.363387E8,7.502357E7,0.0,0.0,0.0,0.0,-1.8257766E7,0.0 /
      DATA B6/ -9.4721O3E4,0.0,-7.435565E4,-9.28392JE4,0.0,
     $        -1.672612E5,-1.114202E5,0.0,0.0,0.0,0.5.5816094E4,0.0 /,
     $        C6/ 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,1.5378377E9,
     $        0.0 /, K/ 4.50,5.475,4.00,4.00,0.0,4.2,5.50,0.0,3.0,
     $        5.475,4.2,5.0 /, ALPHA/ 580.0,0.0,625.0,661.199997,0.0,
     $        584.2,520.0,0.0,0.0,0.0,0.0,609.0,0.0 /
      DATA CPR/ 0.0,0.0,0.0,0.0,0.0,
     $        0.0,0.0,0.0,0.0,0.0,0.0,0.0,7E-7,0.0 /, TC/ 848.07,693.3,
     $        543.60,409.50,812.9,664.50,538.33,877.0,753.95,681.59,
     $        639.56,699.27 /
      DATA TFR/ 459.67,459.7,459.67,459.69,459.69,459.69,459.69,459.69,
     $          459.69,459.69,459.67,459.69 /
C
C---  ERROR SETTING
      FLAG= .TRUE.
C
C---  ASSIGN 'I' ACCORDING TO 'NR'
C
      I=0
      LE=LEN(NR)
      IF( NR(:LE) .EQ.  '11' ) I=1
      IF( NR(:LE) .EQ.  '12' ) I=2
      IF( NR(:LE) .EQ.  '13' ) I=3
      IF( NR(:LE) .EQ.  '14' ) I=4
      IF( NR(:LE) .EQ.  '21' ) I=5
      IF( NR(:LE) .EQ.  '22' ) I=6
      IF( NR(:LE) .EQ.  '23' ) I=7
      IF( NR(:LE) .EQ. '113' ) I=8
      IF( NR(:LE) .EQ. '114' ) I=9
      IF( NR(:LE) .EQ. '500' ) I=10
      IF( NR(:LE) .EQ. '502' ) I=11
      IF( NR(:LE) .EQ.'C318' ) I=12
      IF( I .EQ. 0 ) THEN
        PRINT*,' '
        PRINT*,'      REFRIGERANT NUMBER MISMATCH IN FUNCTION SPVOL'
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'TCE' TO 'TF'
C
      TF= 1.8*TCE+32.0
C
C---  CONVERT 'PPA' TO 'PPSIA'
C
      PPSIA= PPA/6.894757
C
C---  CONVERT 'TF' TO 'T' AND CHECK VALUE
```

```
C
      T=TF+TFR(I)
      IF( T .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN OR EQUAL ZERO '
        PRINT*,'                  IN FUNCTION SPVOL '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE 'TFSAT' AND COMPARE WITH 'TF'
C
      TFSAT=TSAT(NR,PPA)
      IF( FLAG .EQV. .FALSE. ) THEN
        SPVOL= 0.0
        PRINT*,' '
        PRINT*,'    CALL TSAT ERROR IN FUNCTION SPVOL '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C     CONVERT 'C UNIT' TO 'F UNIT'
C
      TFSAT= 1.8*TFSAT+32.0
      IF( TF .LT. (TFSAT-0.01) ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN SATURATION TEMPERATURE'
        PRINT*,'              AT GIVEN PRESSURE IN FUNCTION SPVOL '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CHECK 'PPSIA'
C
      IF( PPSIA .LE. 0.0) THEN
        PRINT*,' '
        PRINT*,'    PRESSURE LESS THAN OR EQUAL ZERO IN FUNCTION SPVOL
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE CONSTANTS
C
      ESO= EXP(-K(I)*T/TC(I))
      ES1= PPSIA
      ES2= R(I)*T
      ES3= A2(I)+B2(I)*T+C2(I)*ESO
      ES4= A3(I)+B3(I)*T+C3(I)*ESO
      ES5= A4(I)+B4(I)*T+C4(I)*ESO
      ES6= A5(I)+B5(I)*T+C5(I)*ESO
      ES7= A6(I)+B6(I)*T+C6(I)*ESO
      ES32= 2.0*ES3
      ES43= 3.0*ES4
      ES54= 4.0*ES5
      ES65= 5.0*ES6
C
C---  COMPUTE INITIAL ESTIMATE OF 'V' FROM IDEAL GAS LAW
C
      VN=R(I)*T/PPSIA - 0.01
C
C---  COMPUTE 'V' TO WITHIN 1.0E-3 BY NEWTON'S ITERATION
C
C     MAXIMUM ITERATION NUMBER : 30
C
      DO 10 ITER=1,30
        V=VN
        V2=V*V
        V3=V2*V
        V4=V3*V
        V5=V4*V
        V6=V5*V
C
        IF( ALPHA(I) .GT. 500.0 ) THEN
C
          F= ES1-ES2/V-ES3/V2-ES4/V3-ES5/V4-ES6/V5
          FP= ES2/V2+ES32/V3+ES43/V4+ES54/V5+ES65/V6
C
        ELSE
          EMAV=EXP(-ALPHA(I)*(V+B(I)))
          EM2AV=   EMAV*EMAV
          F= ES1-ES2/V-ES3/V2-ES4/V3-ES5/V4-ES6/V5-ES7*EM2AV/
     $       (EMAV+CPR(I))
          FP= ES2/V2+ES32/V3+ES43/V4+ES54/V5+ES65/V6+ES7*ALPHA(I)*EM2AV*
     $      (EMAV+2.0*CPR(I))/(EMAV+CPR(I))/(EMAV+CPR(I))
C
        ENDIF
C
        VN= V-F/FP
        IF( ABS((VN-V)/V) .LE. 10.E-3 ) THEN
C
          SPVOL= VN*B(I)
C
C---  CONVERT 'CU FT/LB' TO 'CU M/KG'
C
          SPVOL= SPVOL*0.062428
          FLAG= .TRUE.
          RETURN
C
        ENDIF
10    CONTINUE
C
C---  PRINT ERROR MESSAGE IF
C       NR CAN NOT MATCH
C       TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C       TF IS LESS THAN TFSAT CORRESPONDING TO TSAT= PPSIA
C       MORE THAN 30 ITERATION ARE NEEDED
C
      PRINT*,' '
      PRINT*,'   ITERATION ERROR IN CALLING SUBROUTINE -SPVOL- '
      SPVOL= VN*B(I)
      FLAG= .FALSE.
      RETURN
999   SPVOL= 0
      PRINT*,' '
      PRINT*,'   ERROR IN CALLING SUBROUTINE -SPVOL-'
      FLAG= .FALSE.
      RETURN
      END
C
C ---------------------------------------------------------------
C
      FUNCTION TSAT(NR,PSAT)
C
C---  PURPOSE
C       TO EVALUATE THE SATURATION TEMPERATURE
C       OF REFRIGERANT GIVEN THE SATURATION PRESSURE
C
C---  KINDS OF REFRIGERANT
C       11 , 12 , 13 , 14 , 21 , 22 , 23 , 113 , 114 , 500 , 502 ,C318
C
C---  DESCRIPTION OF PARAMETERS
C       INPUT
C         -NR   -  REFRIGERANT NUMBER ( INSERT THE STRING : EX, '12' FOR R12
C         PSAT  -  SATURATION PRESSURE (kPA)
C       OUTPUT
C         TSAT  -  SATURATION TEMPERATURE (C)
C       COMMON OUTPUT
C         FLAG  -  ERROR STATE
C
C
C---  DIMENSION
      LOGICAL FLAG
      COMMON FLAG
      CHARACTER*(*) NR
      REAL AVP(12),BVP(12),CVP(12),DVP(12),EVP(12),FVP(12)
      REAL TFR(12),LE10,PCRIT(12)
C
C---  VAPOR PRESSURE CONSTANTS
C
      DATA AVP/ 42.14702865,39.88381727,25.9679/5,20.71545389,42.7908,
     $     29.35754453,328.90853,33.0655,27.071306,17.780935,10.644955,
     $     15.63242 /, BVP/ -4344.343807,-3436.632228,-2709.538217,
     $     -2467.505285,-4261.34,-3845.193152,-7952.76913,-4330.98,
     $     -5113.7021,-3422.69717,-3671.153813,-4301.063 /
      DATA CVP/
     $     -12.84596753,-12.47152228,-7.17234391,-4.69017025,-13.0295,
     $     -7.86103122,-144.5142304,-9.2635,-6.3006761,-3.63691,
     $     -0.369835,-2.128401 /, DVP/ 4.0083725E-3,4.7J044244E-3,
     $     2.545154E-3,6.4798076E-4,3.9851E-3,2.1909390E-3,0.24211502,
     $     2.0539E-3,6.913003E-4,5.0272207E-4,-1.746352E-3,-1.19759E-3/
      DATA EVP/   0.0313605356,0.0,0.280301091,0.770707795,0.0,
     $    0.445746703,-2.1280665E-4,0.0,0.78142111,0.4629401,0.8161139,
     $    0.6625898 /, FVP/ 862.07,0.0,546.00,424.0,0.0,686.1,
     $    9.434955E-8,0.0,768.35,695.57,654.0,714.0 /,
     $    TFR/ 459.67,459.7,459.67,459.69,459.6,459.69,459.69,459.6,
     $    459.69,459.67,459.67,459.69 /
      DATA PCRIT/ 639.493042,596.905029,561.295898,543.157593,
     $           744.421143,721.037769,701.366455,463.325378,
     $           473.181823,642.029297,590.998779,403.598510 /
C
C---  ERROR SETTING
C
        FLAG= .TRUE.
C
C
C---  ASSIGN 'I' ACCORDING TO 'NR'
C
      I=0
      LE=LEN(NR)
      IF( NR(:LE) .EQ.  '11' )  I=1
      IF( NR(:LE) .EQ.  '12' )  I=2
      IF( NR(:LE) .EQ.  '13' )  I=3
      IF( NR(:LE) .EQ.  '14' )  I=4
      IF( NR(:LE) .EQ.  '21' )  I=5
      IF( NR(:LE) .EQ.  '22' )  I=6
      IF( NR(:LE) .EQ.  '23' )  I=7
      IF( NR(:LE) .EQ. '113' )  I=8
      IF( NR(:LE) .EQ. '114' )  I=9
      IF( NR(:LE) .EQ. '500' )  I=10
      IF( NR(:LE) .EQ. '502' )  I=11
      IF( NR(:LE) .EQ.'C318' )  I=12
      IF( I .EQ. 0 ) THEN
        PRINT*,' '
        PRINT*,'    REFRIGERANT NUMBER MISMATCH IN FUNCTION TSAT'
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'kPA' TO 'PSIA'
C
      PSAT= PSAT/6.894757
C
C---  CHECK 'PSAT'
C
      IF( PSAT .GT. PCRIT(I) ) THEN
        PRINT*,' '
        PRINT*,'   PRESSURE GREATER THAN CRITICAL PRESSURE '
        PRINT*,'                    IN FUNCTION TSAT  '
        FLAG= .FALSE.
        RETURN
      ENDIF
      IF( PSAT .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    PRESSURE LESS THAN OR EQUAL ZERO '
        PRINT*,'         IN FUNCTION TSAT '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C
C---  COMPUTE INITIAL ESTIMATE BY APPROXIMATE EQUATION
C
      PLOG= ALOG10(PSAT)
      A1= AVP(I)-PLOG
      IF( NR(:LE) .EQ. '23' ) THEN
        TR= 300.0
      ELSEIF( NR(:LE) .EQ. '502'  .OR.  NR(:LE) .EQ. 'C318' ) THEN
        TR= 500.0
      ELSEIF( .TRUE. ) THEN
C       REMAINER
      TR= 0.5*( -A1+SQRT(A1*A1-4*DVP(I)*BVP(I)) )
      ENDIF
C
C     ITERATE TO WITHIN 0.01 USING NEWTON ITERATION
C
```

```
C     MAXIMUM ITERATION NUMBER : 30
C
      LE10= ALOG(10.0)
C
      DO 10 ITER=1,30
        TRO= TR
        IF( NR(:LE) .EQ. '23' ) THEN
          F= AVP(I)*BVP(I)/TRO*CVP(I)*ALOG10(TRO)*DVP(I)*TRO+
     $       EVP(I)*TRO*TRO*FVP(I)*TRO*TRO*TRO - PLOG
          FP= -BVP(I)/TRO/TRO*CVP(I)/LE10/TRO+DVP(I)*2*EVP(I)*TRO+
     $        3*FVP(I)*TRO*TRO
        ELSE
          C= ALOG10( ABS(FVP(I)-TRO) )
          F= AVP(I)*BVP(I)/TRO*CVP(I)*ALOG10(TRO)*DVP(I)*TRO+EVP(I)*
     $       ( (FVP(I)-TRO)/TRO )*C - PLOG
          FP= -BVP(I)/TRO/TRO*CVP(I)/(LE10*TRO)+DVP(I)-EVP(I)*( 1.0/
     $       (LE10*TRO)+FVP(I)*C/TRO/TRO )
        ENDIF
C
        TR= TRO-F/FP
        IF( ABS( TR-TRO ) .LE. 0.01 ) THEN
          TSAT= TR-TFR(I)
C
C---  CONVERT 'F' TO 'C' AND 'PSIA' TO 'kPA'
C
          TSAT= 1/1.8*(TSAT-32.0)
          PSAT= PSAT*6.894757
C
          FLAG= .TRUE.
        RETURN
        ENDIF
C
10    CONTINUE
C
C---  PRINT ERROR MESSAGE IF
C       NR CAN NOT MATCH
C       PSAT IS LESS THAN OR EQUAL TO ZERO
C       NUMBER OF ITERATIONS REQUIRED IS GREATER THAN 30
C
      TSAT= TR-TFR(I)
      PRINT*,' '
      PRINT*,'    ITERATION ERROR IN CALLING SUBROUTINE -TSAT-'
      FLAG= .FALSE.
      RETURN
999   TSAT= 0.0
      PRINT*,'    ERROR IN CALLING SUBROUTINE -TSAT- '
      FLAG= .FALSE.
C
      RETURN
      END
C
C -------------------------------------------------------------
C
      SUBROUTINE SATPRP(NR,TCE,PSAT,VF,VG,HF,HFG,HG,SF,SG)
C
C---  PURPOSE
C       TO EVALUATE THE SATURATION THERMODYNAMIC PROPERTIES
C       OF REFRIGERANT GIVEN THE SATURATION TEMPERATURE
C
C---  KINDS OF REFRIGERANT
C       11 , 12 , 13 , 14 , 21 , 22 , 23 , 113 , 114 , 500 , 502 , C318
C
C---  DESCRIPTION OF PARAMETERS
C       INPUT
C         NR    -  REFRIGERANT NUMBER ( INSERT THE STRING : EX, '12' FOR R12 )
C         TCE   -  TEMPERATURE (C)
C       OUTPUT
C         PSAT  -  SATURATION PRESSURE (kPA)
C         VF    -  SPECIFIC VOLUME OF SATURATED LIQUID (CU M/KG)
C         VG    -  SPECIFIC VOLUME OF SATURATED VAPOR (CU M/KG)
C         HF    -  ENTHALPY OF SATURATED LIQUID (KJ/KG)
C         HFG   -  LATENT ENTHALPY OF VAPORIZATION (KJ/KG)
C         HG    -  ENTHALPY OF SATURATED VAPOR (KJ/KG)
C         SF    -  ENTROPY OF SATURATED LIQUID (KJ/KG-K)
C         SG    -  ENTROPY OF SATURATED VAPOR (KJ/KG-K)
C       COMMON OUTPUT
C         FLAG  -  ERRROR STATE
C---  REMARKS
C         FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C         FUNCTION SUBPROGRAM TSAT AVAILABLE FOR CALCULATING
C         THE SATURATION TEMPERATURE GIVEN THE SATURATION TEMPERATURE
C
C---  DIMENSION
C
      LOGICAL FLAG
      COMMON FLAG
      CHARACTER*(*) NR
      REAL AL(12),BL(12),CL(12),DL(12),EL(12),FL(12),GL(12)
      REAL AVP(12),BVP(12),CVP(12),DVP(12),EVP(12),FVP(12),PCRIT(12)
      REAL A(12),B(12),A2(12),B2(12),C2(12),A3(12),B3(12),C3(12),
     $     A4(12),B4(12),C4(12),A5(12),B5(12),C5(12),A6(12),B6(12),
     $     C6(12),K(12),ALPHA(12),CPR(12),TC(12),TFR(12)
      REAL ACV(12),BCV(12),CCV(12),DCV(12),FCV(12)
      REAL X(12),Y(12),J,KTOTC,LE10,L10E
C
C---  CONSTANTS
C
C---    LIQUID DENSITY CONSTANTS
C
      DATA AL/ 34.57,34.84,36.06996,39.06,116.37962,32.76,32.7758,
     $     112.872,36.32,31.00,35.0,38.70 /
      DATA BL/ 57.63811,
     $         53.341187,54.395124,69.568489,-0.03106808,54.634409,
     $         63.37784,-0.0128,61.146414,43.562,53.48437,70.858318 /
      DATA CL/ 43.6322,0.0,0.0,4.5866114,-0.0000501,36.74892,-25.30533,
     $         0.0000636,0.0,74.709,63.86417,23.609759 /
      DATA DL/ -42.82356,
     $         18.69137,8.512776,36.1716662,0.0,-22.2925657,144.16182,
     $         0.0,16.418015,-87.583,-70.08066,15.989182 /
      DATA EL/ 36.70663,0.0,0.0,-8.058986,0.0,20.4732886,-106.1328,0.0,
     $         0.0,56.483,48.47901,-8.9243856 /, FL/ 0.0,21.98396,
     $         25.87906,0.0,0.0,0.0,0.0,0.0,0.0,17.476838,0.0,0.0,0.0 /
      DATA GL/ 0.0,-3.150994,9.589006,0.0,0.0,0.0,0.0,0.0,0.0,1.119828,
     $         0.0,0.0,0.0 /
C
C---    VAPOR PRESSURE CONSTANTS
C
      DATA AVP/ 42.14702865,39.88381727,25.967975,20.71545389,42.7908,
     $     29.35754453,328.90853,33.0655,27.071306,17.780935,10.644955,
     $     15.63242 /, BVP/ -4344.343807,-3436.632228,-2709.538217,
     $     -2467.505285,-4261.34,-3845.193152,-7952.76913,-433.98,
     $     -5113.7021,-3422.69717,-3671.153813,-4301.063 /
      DATA CVP/
     $     -12.84596753,-12.47152228,-7.17234391,-4.69017025,-13.0295,
     $     -7.86103122,-144.5142304,-9.2635,-6.3086761,-3.63691,
     $     -0.369835,-2.128401 /, DVP/ 4.0083725E-3,4.73044244E-3,
     $     2.545154E-3,6.4798076E-4,3.9851E-3,2.1909390E-3,0.24211502,
     $     2.0539E-3,6.913003E-4,5.027220?E-4,-1.746352E-3,-1.19759E-3/
      DATA EVP/   0.0313605356,0.0,0.0,280301091,0.770707795,0.0,
     $     0.445746703,-2.1280665E-4,0.0,0.78142111,0.4629401,0.8161139,
     $     0.6625898 /, FVP/ 862.07,0.0,546.00,424.0,0.0,686.1,
     $     9.434955E-8,0.0,768.35,695.57,654.0,714.0 /,
     $     TFR/ 459.67,459.7,459.67,459.69,459.6,459.69,459.69,459.6,
     $     459.69,459.67,459.67,459.69 /
      DATA PCRIT/ 639.493042,596.905029,561.295898,543.157593,
     $            744.421143,721.837769,701.366455,463.325378,
     $            473.181823,642.029297,590.998779,403.598510 /
C
C     EQUATION OF STATE CONSTANTS
C
      DATA R/ 0.078117,0.088734,0.102728,0.1219336,0.10427,0.124098,
     $        0.15327,0.05728,0.062780807,0.10805000,0.096125,
     $        0.053645698 /, B/ 0.00190,0.0065093886,0.0048,0.0015,
     $        0.0,0.002,0.00125,0.0,0.005914907,0.006034229,0.00167,
     $        0.0060114165 /, A2/ -3.126759,-3.40972713,-3.083417,
     $        -2.162959,-7.316,-4.353547,-4.679499,-4.035 ,-2.3856704,
     $        -4.549888,-3.2613344,-1.8947274 /, B2/  1.318523E-3,
     $        1.5943848E-3,2.341695E-3,2.135114E-3,4.6421E-3,
     $        2.407252E-3,3.477778E-3,2.618E-3,1.0801207E-3,2.308415E-3,
     $        2.0576287E-3,9.8484745E-4 /
      DATA C2/ -35.76999,-56.7627671,-18.212643,-18.941131,0.0,
     $         -44.066868,-159.775232,0.0,-6.5643648,-92.90748,
     $         -24.24879,-28.542156 /
      DATA A3/ -0.025341,
     $         0.0602394465,0.058854,4.404057E-3,-0.203B2376,-0.017464,
     $         0.012475,-0.0214,0.034055687,0.08660634,0.034866748,
     $         0.026479892 /, B3/ 4.875121E-5,-1.87961843E-5,-5.671268E-5
     $        ,1.282818E-5,3.593E-4,7.62789E-5,7.73338BE-5,5.00E-5,
     $        -5.3336494E-6,-3.141665E-5,-8.6791313E-6,-6.862101E-6 /
      DATA C3/     1.220367,1.31139908,0.571958,0.539776,0.0,1.483763,
     $         5.941212,0.0,0.16366057,2.742282,0.33274779,0.66384636
     $        /, A4/ 1.687277E-3,-5.487370?E-4,-1.026061E-3,1.921072E-4,
     $         0.0,2.310142E-3,2.068042E-3,0.0,-3.857481E-4,-8.726016E-4,
     $         -8.5765677E-4,-2.4565234E-4 /, B4/ -1.805062E-6,0.0,
     $         1.338679E-6,-3.91B263E-7,0.0,-3.605723E-6,-3.6842JBE-6,0.0
     $        ,0.0,0.0,7.0240549E-7,0.0 /, C4/ 0.0,0.0,0.0,0.0,0.0,0.0,
     $         0.0,0.0,0.0,0.0,0.0,0.022412368,0.0 /, A5/ -2.358930E-5,
     $         0.0,5.290649E-6,-4.481049E-6,0.0,-3.724044E-5,-3.868546E-5
     $        ,0.0,1.6017659E-6,-1.375958E-6,8.8368967E-6,6.0887086E-7 /
      DATA B5/    2.448303E-8,3.468834E-9,-7.395111E-9,9.062318E-9,0.0,
     $         5.355465E-8,6.455643E-8,0.0,6.2632341E-10,9.149570E-9,
     $         -7.9168095E-9,8.269634E-10 /, C5/ -1.478379E-4,
     $         -2.5439067BE-5,-3.874233E-5,-4.83667BE-5,0.0,-1.845051E-4,
     $         -7.394214E-4,0.0,-1.0165314E-5,-2.102661E-4,-3.7167231E-4,
     $         -3.849145E-5 /, A6/ 1.057504E8,0.0,7.378601E7,5.838823E7,
     $         0.0,1.363387E8,7.502357E7,0.0,0.0,0.0,-3.8257766E7,0.0 /
      DATA B6/ -9.472103E4,0.0,-7.435565E4,-9.263923E4,0.0,
     $         -1.672612E5,-1.114202E5,0.0,0.0,0.0,5.5816094E4,0.0 /,
     $         C6/ 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,1.5378377E9,
     $         0.0 /, K/ 4.50,5.475,4.00,4.00,0.0,4.2,5.50,0.0,3.0,
     $         5.475,4.2,5.0 /, ALPHA/ 580.0,0.0,625.0,661.199997,0.0,
     $         584.2,520.0,0.0,0.0,0.0,0.0,609.0,0.0 /
      DATA CPR/ 0.0,0.0,0.0,0.0,0.0,
     $         0.0,0.0,0.0,0.0,0.0,0.0,0.0,7E-7,0.0 /, TC/ 848.07,693.3,
     $         543.60,409.50,812.9,664.50,538.33,877.0,753.95,681.59,
     $         639.56,699.27 /
C
C---    SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C
      DATA ACV/ 0.023815,8.0945E-3,0.01602,0.0300559282,0.0427,
     $         0.02812836,0.07628087,0.07963,0.0175,0.026803537,
     $         0.020419,0.0225178157 /
      DATA BCV/ 2.798823E-4,3.32662E-4,2.823E-4,2.3704335E-4,1.40E-4,
     $         2.255408E-4,-7.561805E-6,1.159E-4,3.49E-4,2.837340BE-4,
     $         2.996802E-4,3.699078?4E-4 /
      DATA CCV/ -2.123734E-7,-2.413896E-7,-1.159E-7,-2.8566007?E-8,0.0,
     $         -6.509607E-8,3.9065696E-7,0.0,-1.67E-7,-9.7167893E-8,
     $         -1.409043E-7,-1.64842522E-7 /
      DATA DCV/ 5.999018E-11,6.72363E-11,0.0,-2.953388O5E-11,0.0,0.0,
     $         -2.454905E-10,0.0,0.0,0.0,0.0,2.210861E-11,2.152780846E-11/
      DATA FCV/ -336.80703,0.0,0.0,0.0,0.0,0.0,257.341,0.0,0.0,0.0,0.0,
     $         0.0,0.0 /
C
C---    ENTHALPY AND ENTROPY OF VAPOR CONSTANTS
C
      DATA X/ 50.5418,39.556551,20.911,86.102162,76.28905,62.4009,
     $        41.8154,25.190,25.3396621,46.4734,35.308,12.19214242 /
      DATA Y/ -0.0918395,-0.016537936,-0.05676,0.36172528,-0.110514,
     $        -0.0453335,-0.2554,-0.40552,-0.11513718,-0.09012707564,
     $        -0.07444,-0.16828871 /
C
C---  ERROR SETTING
      FLAG= .TRUE.
C
      J= 0.185053
      LE10= ALOG(10.0)
      L10E= ALOG10( EXP(1.0) )
C
C
C---  ASSIGN 'I' ACCORDING TO 'NR'
C
      I=0
      LE=LEN(NR)
      IF( NR(:LE) .EQ.  '11' )  I=1
      IF( NR(:LE) .EQ.  '12' )  I=2
      IF( NR(:LE) .EQ.  '13' )  I=3
      IF( NR(:LE) .EQ.  '14' )  I=4
      IF( NR(:LE) .EQ.  '21' )  I=5
      IF( NR(:LE) .EQ.  '22' )  I=6
      IF( NR(:LE) .EQ.  '23' )  I=7
      IF( NR(:LE) .EQ. '113' )  I=8
      IF( NR(:LE) .EQ. '114' )  I=9
      IF( NR(:LE) .EQ. '500' )  I=10
      IF( NR(:LE) .EQ. '502' )  I=11
      IF( NR(:LE) .EQ.'C318' )  I=12
      IF( I .EQ. 0 ) THEN
        PRINT*,' '
```

```
        PRINT*,'    REFRIGERANT NUMBER MISMATCH IN SUBROUTINE SATPRP'
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'TCE' TO 'TF'
C
      TF= 1.8*TCE+32.0
C
C---  CONVERT 'TF' TO 'T' AND CHECK VALUE
C
      T= TF+TFR(I)
      IF( T .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN OR EQUAL ZERO '
        PRINT*,'              IN SUBROUTINE SATPRP '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  COMPARE 'T' WITH 'TC(I)'
C
      IF( T .GT. TC(I) ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE GREATER THAN CRITICAL TEMPERATURE '
        PRINT*,'              IN SUBROUTINE SATPRP '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATION OF SATURATION PESSURE
C
      IF( NR .EQ. '23' ) THEN
        PSAT= 10.0**( AVP(I)+BVP(I)/T+CVP(I)*ALOG10(T)+DVP(I)*T+EVP(I)*
     $              T*T+FVP(I)*T*T*T )
      ELSE
        PSAT= 10.0**( AVP(I)+BVP(I)/T+CVP(I)*ALOG10(T)+DVP(I)*T+EVP(I)*
     $        ((FVP(I)-T)/T)*ALOG10(ABS(FVP(I)-T)) )
      ENDIF
C
C
C---  CONVERT 'PSIA UNIT' TO 'kPA UNIT'
C
      PSAT1= PSAT*6.894757
C---  CALCULATE 'VG'
C
      VG= SPVOL(NR,TCE,PSAT1)
C
C---  CONVERT ' CU M/KG ' TO ' CU FT/LB '
C
      VG= VG/0.062427961
      IF( FLAG .EQV. .FALSE. ) THEN
        PRINT*,' '
        PRINT*,'    CALL SPVOL ERROR IN SUBROUTINE SATPRP '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE 'VF'
C
      IF( ( NR(:LE).EQ.'21' ) .OR. ( NR(:LE).EQ.'113' ) ) THEN
        VF= 1.0/( AL(I)+BL(I)*T+CL(I)*T*T )
      ELSE
        TR1= 1.0-T/TC(I)
        VF= 1.0/( AL(I)+BL(I)*TR1**(1.0/3.0)+CL(I)*TR1**(2.0/3.0)+
     $            DL(I)*TR1+EL(I)*TR1**(4.0/3.0)+FL(I)*TR1**(1.0/2.0)+
     $            GL(I)*TR1**2 )
      ENDIF
C
C---  CALCULATE 'HFG' BY CLAUSIUS CLAPEYPON EQUATION
C
      IF( NR .EQ. '23' ) THEN
        HFG= (VG-VF)*PSAT*LE10*( -BVP(I)/T+CVP(I)/LE10+DVP(I)*T+
     $       2*EVP(I)*T*T+3*FVP(I)*T*T*T )*J
      ELSE
        HFG= (VG-VF)*PSAT*LE10*( -BVP(I)/T+CVP(I)/LE10+DVP(I)*T-
     $       EVP(I)*(L10E+FVP(I)*ALOG10(ABS(FVP(I)-T)))/T) )*J
      ENDIF
C
      SFG= HFG/T
C
C---  CALCULATE 'HG' AND 'SG'
C
      T2= T*T
      T3= T2*T
      T4= T3*T
      VR= VG-B(I)
      VR2= 2.0*VR**2
      VR3= 3.0*VR**3
      VR4= 4.0*VR**4
      KTDTC= K(I)*T/TC(I)
      EKTDTC= EXP(-KTDTC)
      EMAV= EXP(-ALPHA(I)*VG)
      H1= ACV(I)*T+BCV(I)*T2/2.0+CCV(I)*T3/3.0+DCV(I)*T4/4.0-FCV(I)/T
      H2= J*PSAT*VG
      H3= A2(I)/VR+A3(I)/VR2+A4(I)/VR3+A5(I)/VR4
      H4= C2(I)/VR+C3(I)/VR2+C4(I)/VR3+C5(I)/VR4
      S1= ACV(I)*ALOG(T)+BCV(I)*T+CCV(I)*T2/2.0+DCV(I)*T3/3.0-
     $    FCV(I)/(2.0*T2)
      S2= J*R(I)*ALOG(VR)
      S3= B2(I)/VR+B3(I)/VR2+B4(I)/VR3+B5(I)/VR4
      S4= H4
C
      IF( ALPHA(I) .GT. 500.0 ) THEN
        EMAV= 0.0
        IF( CPR(I) .GT. 0.0 ) THEN
          HO= 1.0/ALPHA(I)*(EMAV-CPR(I)*ALOG(1.0+EMAV/CPR(I)))
        ELSE
          HO= 1.0/ALPHA(I)*EMAV
        ENDIF
      ELSE
        HO= 0.0
      ENDIF
C
      H3= H3+A6(I)*HO
      H4= H4+C6(I)*HO
      S3= S3+B6(I)*HO
      S4= S4+C6(I)*HO
      HG= H1+H2+J*H3+J*EKTDTC*(1.0+KTDTC)*H4+X(I)
      SG= S1+S2-J*S3+J*EKTDTC*K(I)/TC(I)*S4+Y(I)
C
C---  CALCULATE 'HF' AND 'SF'
C
      HF= HG-HFG
      SF= SG-SFG
C
C---  CONVERT 'ENGLISH UNIT' TO 'SI UNIT'
C
      PSAT= PSAT1
      VF= VF*0.062427961
      VG= VG*0.062427961
      HF= HF*2.326
      HFG= HFG*2.326
      HG= HG*2.326
      SF= SF*4.1868
      SG= SG*4.1868
C
      FLAG= .TRUE.
      RETURN
C
C---  PRINT ERROR MESSAGE IF
C       NR CAN NOT MATCH
C       IF IS LESS THAN THE CRITICAL TEMPERATURE
C       TF IS GREATER THAN THE CRITICAL TEMPERATURE
C
999   PRINT*,' '
      PRINT*,'    ERROR IN CALLING SUBROUTINE -SATPRP-'
      FLAG= .FALSE.
      RETURN
      END
C
C ------------------------------------------------------------
C
      SUBROUTINE VAPOR(NR,TCE,PPA,VVAP,HVAP,SVAP)
C
C---  PURPOSE
C       TO EVALUATE THE THERMODYNAMIC PROPERTIES
C       OF THE SUPERHEATED VAPOR PHASE
C       OF REFRIGERANT GIVEN THE TEMPERATURE AND PRESSURE
C
C---  KINDS OF REFRIGERANT
C       11 , 12 , 13 , 14 , 21 , 22 , 23 , 113 , 114 , 500 , 502 , C318
C
C---  DESCRIPTION OF PARAMETERS
C       INPUT
C         NR    -  REFRIGERANT NUMBER ( INSERT THE STRING : EX, '12' FOR R12 )
C         TCE   -  TEMPERATURE (C)
C         PPA   -  PRESSURE (kPA)
C       OUTPUT
C         VVAP  -  SPECIFIC VOLUME OF VAPOR (CU M/KG)
C         HVAP  -  ENTHALPY OF VAPOR (KJ/KG)
C         SVAP  -  ENTROPY OF VAPOR (KJ/KG-K)
C       COMMON OUTPUT
C         FLAG  -  ERROR STATE
C
C---  REMARKS
C       FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C       FUNCTION SUBPROGRAM TSAT CALLED BY THIS SUBROUTINE
C
C---  DIMENSION
C
C
      LOGICAL FLAG
      COMMON FLAG
      CHARACTER*(*) NR
      REAL R(12),B(12),A2(12),B2(12),C2(12),A3(12),B3(12),C3(12),
     $     A4(12),B4(12),C4(12),A5(12),B5(12),C5(12),A6(12),B6(12),
     $     C6(12),K(12),ALPHA(12),CPR(12),TC(12),TFR(12)
      REAL ACV(12),BCV(12),CCV(12),DCV(12),FCV(12)
      REAL X(12),Y(12),J,KTDTC,LE10,L10E
C
C---  CONSTANTS
C
C
C---   EQUATION OF STATE CONSTANTS
C
      DATA R/ 0.078117,0.088734,0.102728,0.1219336,0.10427,0.124098,
     $        0.15327,0.05728,0.062780807,0.10805000,0.096125,
     $        0.053645698 /, B/ 0.00190,0.0065093886,0.0048,0.0015,
     $        0.0,0.002,0.00125,0.0,0.005914907,0.006034229,0.00167,
     $        0.0060114165 /, A2/ -3.126759,-3.40972713,-3.083417,
     $        -2.162959,-7.316,-4.353547,-4.679499,-4.035 ,-2.3856704,
     $        -4.549888,-3.2613344,-1.8947274 /, B2/  1.318523E-3,
     $        1.59434848E-3,2.341695E-3,2.135114E-3,4.6421E-3,
     $        2.407252E-3,3.472778E-3,2.618E-3,1.080120?E-3,2.308415E-3,
     $        2.0576287E-3,9.8484745E-4 /
      DATA C2/ -35.76999,-56.7627671,-18.212643,-18.941131,0.0,
     $          -44.066868,-159.775232,0.0,-6.5643648,-92.90748,
     $          -24.24879,-28.542156 /
      DATA A3/ -0.025341,
     $         0.0602394465,0.058854,4.404057E-3,-0.20382376,-0.017464,
     $         0.012475,-0.0214,0.034055687,0.08660634,0.034866748,
     $         0.026479892 /, B3/ 4.875121E-5,-1.87961043E-5,-5.671268E-5
     $        ,1.282818E-5,3.593E-4,7.62789E-5,7.733388E-5,5.00E-5,
     $        -5.3336494E-6,-3.141665E-5,-8.6791313E-6,-6.862101E-6 /
      DATA C3/    1.220367,1.31139908,0.571958,0.539776,0.0,0.1.483763,
     $         5.941212,0.0,0.16366057,2.742282,0.33274779,0.66384636
     $        /, A4/ 1.687277E-3,-5.4873701E-4,-1.026061E-3,1.921072E-4,
     $         0.0,2.310142E-3,2.068042E-3,0.0,-3.857481E-4,-8.726016E-4,
     $         -8.5765677E-4,-2.4565234E-4 /, B4/ -1.805062E-6,0.0,
     $         1.338679E-6,-3.918263E-7,0.0,-3.605723E-6,-3.684238E-6,0.0
     $        ,0.0,0.0,7.0240549E-7,0.0 /, C4/ 0.0,0.0,0.0,0.0,0.0,0.0,
     $         0.0,0.0,0.0,0.0222412368,0.0 /, A5/ -2.358930E-5,
     $         0.0,5.290649E-6,-4.481049E-6,0.0,-3.724044E-5,-3.868546E-5
     $        ,0.0,1.6017659E-6,-1.375958E-6,8.836896?E-6,6.0887086E-7 /
      DATA B5/    2.448303E-8,3.468838E-9,-7.395111E-9,9.06231RE-9,0.0,
     $         5.355465E-8,6.455643E-8,0.0,6.263234?E-10,9.149570E-9,
     $         -7.9168095E-9,8.269634E-10 /, C5/ -1.478379E-4,
     $         -2.5439067BE-5,-3.874233E-5,-4.836678E-5,0.0,-1.845051F-4,
     $         -7.394214E-4,0.0,-1.0165314E-5,-2.102661IE-4,-3.7167231E-4,
     $         -3.849145E-5 /, A6/ 1.057504E8,0.0,7.37860IE7,5.838823E7,
     $         0.0,1.363387E8,7.502357E7,0.0,0.0,0.0,-3.8257766E7,0.0 /
      DATA B6/ -9.472103E4,0.0,-7.435565E4,-9.263923E4,0.0,
     $         -1.672612E5,-1.114202E5,0.0,0.0,0.0,5.5816094E4,0.0 /,
     $         C6/ 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,1.537837?E9,
     $         0.0 /, K/ 4.50,5.475,4.00,4.000,0.0,4.2,5.50,0.0,3.0,
     $         5.475,4.2,5.0 /, ALPHA/ 580.0,0.0,625.0,661.199997,0.0,
     $       ?,584.2,520.0,0.0,0.0,0.0,609.0,0.0 /
```

```
      DATA CPR/ 0.0,0.0,0.0,0.0,0.0,
     $        0.0,0.0,0.0,0.0,0.0,0.0,0.0,7E-7,0.0 /, TC/ 848.07,693.1,
     $        543.60,409.50,812.9,664.50,538.33,877.0,753.95,681.59,
     $        639.56,699.27 /
      DATA TFR/ 459.67,459.7,459.67,459.69,459.69,459.69,459.69,459.69,459.69,
     $          459.69,459.69,459.67,459.69 /
C
C---    SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C
      DATA ACV/ 0.023815,8.0945E-3,0.01602,0.0300559282,0.0427,
     $          0.02812836,0.07628087,0.07963,0.0175,0.026803537,
     $          0.020419,0.0225178157 /
      DATA BCV/ 2.798823E-4,3.32662E-4,2.823E-4,2.3704335E-4,1.40E-4,
     $          2.25540BE-4,-7.561805E-6,1.159E-4,3.49E-4,2.8373408E-4,
     $          2.996802E-4,3.699078I4E-4 /
      DATA CCV/ -2.123734E-7,-2.413896E-7,-1.159E-7,-2.85660077E-8,0.0,
     $          -6.509607E-8,3.90656696E-7,0.0,-1.67E-7,-9.7167893E-8,
     $          -1.409043E-7,-1.64842522E-7 /
      DATA DCV/ 5.999018E-11,6.72363E-11,0.0,-2.95338805E-11,0.0,0.0,
     $          -2.454905E-10,0.0,0.0,0.0,2.210861E-11,2.152780846E-11/
      DATA FCV/ -336.80703,0.0,0.0,0.0,0.0,257.341,0.0,0.0,0.0,0.0,
     $          0.0,0.0 /
C
C---    ENTHALPY AND ENTROPY OF VAPOR CONSTANTS
C
      DATA X/ 50.5418,39.556551,20.911,86.102162,76.209985,62.4009,
     $        41.8154,25.198,25.3396621,46.4/34,35.308,12.19214242 /
      DATA Y/ -0.0918395,-0.0165379936,-0.05676,0.36172528,-0.110514,
     $        -0.0453335,-0.2554,-0.40552,-0.11513718,-0.090127/0564,
     $        -0.07444,-0.16828871 /
C
C---  ERROR SETTING
      FLAG= .TRUE.
C
      J= 0.185053
      LE10= ALOG(10.0)
      L10E= ALOG10( EXP(1.0) )
C
C
C---  ASSIGN 'I' ACCORDING TO 'NR'
C
      I=0
      LE=LEN(NR)
      IF( NR(:LE) .EQ.  '11' )  I=1
      IF( NR(:LE) .EQ.  '12' )  I=2
      IF( NR(:LE) .EQ.  '13' )  I=3
      IF( NR(:LE) .EQ.  '14' )  I=4
      IF( NR(:LE) .EQ.  '21' )  I=5
      IF( NR(:LE) .EQ.  '22' )  I=6
      IF( NR(:LE) .EQ.  '23' )  I=7
      IF( NR(:LE) .EQ.  '113' )  I=8
      IF( NR(:LE) .EQ.  '114' )  I=9
      IF( NR(:LE) .EQ.  '500' )  I=10
      IF( NR(:LE) .EQ.  '502' )  I=11
      IF( NR(:LE) .EQ.'C318' )  I=12
      IF( I .EQ. 0 ) THEN
        PRINT*,' '
        PRINT*,'    REFRIGERANT NUMBER MISMATCH IN SUBROUTINE VA  POR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'TCE' TO 'TF'
C
      TF=1.8*TCE+32.0
C
C---  CONVERT 'PPA' TO 'PPSIA'
C
      PPSIA= PPA/6.894757
C---  CONVERT 'TF' TO 'T' AND CHECK VALUE
C
      T= TF+TFR(I)
      IF( T .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN OR EQUAL ZERO '
        PRINT*,'          IN SUBROUTINE VAPOR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE 'TSAT' AND COMPARE WITH 'TF'
C
      TFSAT= TSAT(NR,PPSIA)
      IF( FLAG .EQV. .FALSE. ) THEN
        PRINT*,' '
        PRINT*,'    CALL TSAT ERROR IN SUBROUTINE VAPOR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'C' TO ' F'
C
      TFSAT= 1.8*TFSAT + 32.0
C
      IF( TF .LT. TFSAT ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN SATURATION TEMPERATURE'
        PRINT*,'          IN SUBROUTINE VAPOR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CHECK 'PPSIA'
C
      IF( PPSIA .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    PRESSURE LESS THAN OR EQUAL ZERO '
        PRINT*,'          IN SUBROUTINE VAPOR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE 'VVAP'
C
      VVAP= SPVOL(NR,TCE,PPA)
C
C---  CONVERT ' CU M/KG ' TO ' CU FT/LB '
C
      VVAP= VVAP/0.062427961
      IF( FLAG .EQV. .FALSE. ) THEN
        PRINT*,' '
        PRINT*,'    CALL SPVOL ERROR IN SUBROUTINE VAPOR '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CALCULATE 'HVAP' AND 'SVAP'
C
      TZ= T*T
      T3= TZ*T
      T4= T3*T
      VR= VVAP-B(I)
      VR2= 2.0*VR**2
      VR3= 3.0*VR**3
      VR4= 4.0*VR**4
      KTDTC= K(I)*T/TC(I)
      EKTDTC= EXP(-KTDTC)
      EMAV= EXP(-ALPHA(I)*VVAP)
      H1= ACV(I)*T+BCV(I)*TZ/2.0+CCV(I)*T3/3.0+DCV(I)*T4/4.0-FCV(I)/T
      H2= J*PPSIA*VVAP
      H3= A2(I)/VR+A3(I)/VR2+A4(I)/VR3+A5(I)/VR4
      H4= C2(I)/VR+C3(I)/VR2+C4(I)/VR3+C5(I)/VR4
      S1= ACV(I)*ALOG(T)+BCV(I)*T+CCV(I)*T2/2.0+DCV(I)*T3/3.0-
     $    FCV(I)/(2.0*T2)
      S2= J*R(I)*ALOG(VR)
      S3= B2(I)/VR+B3(I)/VR2+B4(I)/VR3+B5(I)/VR4
      S4= H4
C
      IF( ALPHA(I) .GT. 500.0 ) THEN
        EMAV= 0.0
        IF( CPR(I) .GT. 0.0 ) THEN
          HO= 1.0/ALPHA(I)*(EMAV-CPR(I)*ALOG(1.0+EMAV/CPR(I)))
        ELSE
          HO= 1.0/ALPHA(I)*EMAV
        ENDIF
      ELSE
        HO= 0.0
      ENDIF
C
      H3= H3+A6(I)*HO
      H4= H4+C6(I)*HO
      S3= S3+B6(I)*HO
      S4= S4+C6(I)*HO
      HVAP= H1+H2+J*H3+J*EKTDTC*(1.0+KTDTC)*H4+X(I)
      SVAP= S1+S2-J*S3+J*EKTDTC*K(I)/TC(I)*S4+Y(I)
C
C---  CONVERT 'ENGLISH UNIT' TO 'SI UNIT'
C
      VVAP= VVAP*0.062428
      HVAP= HVAP*2.326
      SVAP= SVAP*4.1868
C
      FLAG= .TRUE.
      RETURN
C
C---  PRINT ERROR MESSAGE IF
C       NR CAN NOT MATCH
C       TF IS LESS THAN OR EQUAL TO ZERO DEGEE R
C       TF IS LESS THAN TFSAT CORRESPONDING TO PSAT = PPSIA
C       PPSIA IS LESS THAN OR EQUAL TO ZERO
C
999   PRINT*,' '
      PRINT*,'    ERROR IN CALLING SUBROUTINE -VAPOR-'
      FLAG= .FALSE.
      RETURN
      END
C
C -------------------------------------------------------------
C
      SUBROUTINE SPHT(NR,TCE,PPA,CV,CP,GAMMA,SONIC)
C
C---  PURPOSE
C       TO CALCULATE SPECIFIC HEAT AT CONSTANT VOLUME,
C       SPECIFIC HEAT AT CONSTANT PRESSURE, SPECIFIC
C       HEAT RATIO, AND SONIC VELOCITY FOR
C       GIVEN REFRIGERANT
C
C---  KINDS OF REFRIGERANT
C       11 , 12 , 13 , 14 , 21 , 22 , 23 , 113 , 114 , 500 , 502 , C318
C---  DESCRIPTION OF PARAMETERS
C         INPUT
C           NR      -  REFRIGERANT NUMBER ( INSERT THE STRING ; EX, '12' FOR
C           TCE     -  TEMPERATURE (C)
C           PPA     -  PRESSURE (kPA)
C         OUTPUT
C           CV      -  SPECIFIC HEAT AT CONSTANT VOLUME (KJ/KG-K)
C           CP      -  SPECIFIC HEAT AT CONSTANT PRESSURE (KJ/KG-K)
C           GAMMA   -  SPECIFIC HEAT RATIO
C           SONIC   -  SONIC VELOCITY (M/S)
C         COMMON OUTPUT
C           FLAG    -  ERROR STATE
C---  REMARKS
C       FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C       FUNCTION SUBPROGRAM ISAT CALLED BY THIS SUBROUTINE
C
C---  DIMENSION
C
C
      LOGICAL FLAG
      COMMON FLAG
      CHARACTER*(*) NR
      REAL R(12),B(12),A2(12),B2(12),C2(12),A3(12),B3(12),C3(12),
     $     A4(12),B4(12),C4(12),A5(12),B5(12),C5(12),A6(12),B6(12),
     $     C6(12),K(12),ALPHA(12),CPR(12),TC(12),TFR(12)
      REAL ACV(12),BCV(12),CCV(12),DCV(12),FCV(12)
      REAL J
C
C---  CONSTANTS
C
C
C---    EQUATION OF STATE CONSTANTS
C
      DATA R/ 0.078117,0.088734,0.102728,0.1219336,0.10427,0.124098,
     $        0.15327,0.05728,0.062780807,0.1080500U,0.096125,
     $        0.053645698 /, B/ 0.00190,0.0065093886,0.0048,0.0015,
     $        0.0,0.002,0.00125,0.0,0.005914907,0.006034229,0.00167,
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     $        0.0060114165 /, A2/ -3.126759,-3.4C972713,-3.083417,
     $         -2.162959,-7.316,-4.353547,-4.679499,-4.035 ,-2.3856704,
     $        ,-4.549888,-3.2613344,-1.8947274 /, B2/  1.318523E-3,
     $         1.5943484BE-3,2.341695E-3,2.135114E-3,4.6421E-3,
     $         2.407252E-3,3.472778E-3,2.618E-3,1.0801207E-3,2.308415E-3,
     $         2.05762B7E-3,9.8484745E-4 /
      DATA C2/  -35.76999,-56.7627671,-18.212643,-18.941131,0.0,
     $          -44.066868,-159.775232,0.0,-6.5643648,-92.90748,
     $          -24.24879,-28.542156 /
      DATA A3/ -0.025341,
     $         0.0602394465,0.058854,4.404057E-3,-0.20382376,-0.017464,
     $         0.012475,-0.0214,0.034055687,0.08660634,0.034866748,
     $         0.026479892 /, B3/ 4.875121E-5,-1.87961843E-5,-5.671268E-5
     $        ,1.282818E-5,3.593E-4,7.62789E-5,7.733388E-5,5.00E-5,
     $        -5.3336494E-6,-3.141665E-5,-8.6791313E-6,-6.862101E-6 /
      DATA C3/    1.220367,1.31139908,0.571958,0.539776,0.0,1.483763,
     $         5.941212,0.0,0.16366057,2.742282,0.33274779,0.66384636
     $        /, A4/ 1.682777E-3,-5.4873701E-4,-1.026C61E-3,1.921072E-4,
     $         0.0,7.310142E-3,7.060042E-3,0.0,-3.0574A1E-4,-8.726016E-4,
     $         -8.5765677E-4,-2.4565234E-4 /, B4/ -1.B05C62E-6,0.0,
     $         1.338679E-6,-3.918263E-7,0.0,-3.605723E-6,-3.684238E-6,0.0
     $        ,0.0,0.0,7.0240549E-7,0.0 /, C4/ 0.0,0.0,0.0,0.0,0.0,0.0,0.0,
     $         0.0,0.0,0.0,0.0,0.0,0.022417368,0.0 /, A5/ -2.358930E-5,
     $         0.0,5.290849E-6,-4.481049E-6,0.0,-3.724044E-5,-3.860546E-5
     $        ,0.0,1.6017659E-6,-1.3759S8E-6,8.8368967E-6,6.0E87086E-7 /
      DATA B5/    2.448303E-8,3.468834E-9,-7.395111E-9,9.062318E-9,0.0,
     $         5.355465E-8,6.455643E-8,0.0,6.2632341E-10,9.149570E-9,
     $         -7.9168095E-9,8.269634E-10 /, C5/ -1.478379E-4,
     $         -2.54390678E-5,-3.874233E-5,-4.836678E-5,0.0,-1.845051E-4,
     $         -7.394214E-4,0.0,-1.0165314E-5,-2.102661E-4,-3.7167231E-4,
     $         -3.849145E-5 /, A6/ 1.057504E8,0.0,7.378601E7,5.838823E7,
     $         0.0,1.363387E8,7.502357E7,0.0,0.0,0.0,-3.8257766E7,0.0 /
      DATA B6/ -9.472103E4,0.0,-7.435565E4,-9.263923E4,0.0,
     $         -1.672612E5,-1.114202E5,0.0,0.0,0.0,5.5B16C94E4,0.0 /,
     $         C6/ 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,1.537837E9,
     $         0.0 /, K/ 4.50,5.475,4.00,4.00,0.0,4.2,5.50,0.0,3.0,
     $         5.475,4.2,5.0 /, ALPHA/ 580.0,0.0,625.0,661.199997,0.0,
     $         584.2,520.0,0.0,0.0,0.0,609.0,0.0 /
      DATA CPR/ 0.0,0.0,0.0,0.0,
     $         0.0,0.0,0.0,0.0,0.0,0.0,7E-7,0.0 /, TC/ 848.07,693.3,
     $         543.60,409.50,B12.9,664.50,538.33,877.0,753.95,6E1.55,
     $         639.56,699.27 /
      DATA TFR/ 459.67,459.7,459.67,459.69,459.69,459.69,459.69,459.69,459.69,
     $         459.69,459.65,459.67,459.69 /
C
C---    SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C
      DATA ACV/ 0.023815,8.0945E-3,0.01602,0.0300559282,0.0427,
     $         0.02812836,0.07628087,0.07963,0.0175,0.026803537,
     $         0.020419,0.0225178157 /
      DATA BCV/ 2.798823E-4,3.3266ZE-4,2.823E-4,2.3704335E-4,1.4CE-4,
     $         2.255408E-4,-7.561805E-6,1.159E-4,3.49E-4,2.8373408E-4,
     $         2.996802E-4,3.699078l4E-4 /
      DATA CCV/ -2.123734E-7,-2.413896E-7,-1.159E-7,-2.85660077E-8,0.0,
     $         -6.5096C7E-8,3.9065696E-7,0.0,-1.67E-7,-9.7167893E-8,
     $         -1.409043E-7,-1.64042522E-7 /
      DATA DCV/ 5.999018E-11,6.72363E-11,0.0,-2.953388O5E-11,0.0,0.0,
     $        -2.454905E-10,0.0,0.0,0.0,0.0,2.21D861E-11,2.152780846E-11/
      DATA FCV/ -336.80703,0.0,0.0,0.0,0.0,0.257.341,0.0,0.0,0.0,0.0,
     $         0.0,0.0 /
C
C
C---  ERROR SETTING
      FLAG= .TRUE.
C
      J= 0.185053
      LE10= ALOG(10.0)
      L10E= ALOG10( EXP(1.0) )
C
C
C---  ASSIGN 'I' ACCORDING TO 'NR'
C
      I=0
      LE=LEN(NR)
      IF( NR(:LE) .EQ.  '11' )  I=1
      IF( NR(:LE) .EQ.  '12' )  I=2
      IF( NR(:LE) .EQ.  '13' )  I=3
      IF( NR(:LE) .EC.  '14' )  I=4
      IF( NR(:LE) .EQ.  '21' )  I=5
      IF( NR(:LE) .EQ.  '22' )  I=6
      IF( NR(:LE) .EQ.  '23' )  I=7
      IF( NR(:LE) .EC.  '113' )  I=8
      IF( NR(:LE) .EQ.  '114' )  I=9
      IF( NR(:LE) .EQ.  '500' )  I=10
      IF( NR(:LE) .EQ.  '502' )  I=11
      IF( NR(:LE) .EQ.'C318' )  I=12
      IF( I .EQ. 0 ) THEN
        PRINT*,' '
        PRINT*,'    REFRIGERANT NUMBER MISMATCH '
        PRINT*,'          IN SUBROUTINE SPHT '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT 'TCE' TO 'TF'
C
      TF= 1.8*TCE+32.0
C
C---  CONVERT 'PPA' TO 'PPSIA'
C
      PPSIA= PPA/6.894757
C
C---  CONVERT 'TF' TO 'T' AND CHECK VALUE
C
      T= TF+TFR(I)
      IF( T .LE. 0.0 ) THEN
        PRINT*,' '
        PRINT*,'    TEMPERATURE LESS THAN OR EQUAL ZERO '
        PRINT*,'          IN SUBROUTINE SPHT '
        FLAG= .FALSE.
      ENDIF
C
C---  CALCULATE 'TFSAT' AND COMPARE WITH 'TF'
C
      TFSAT= TSAT(NR,PPSIA)
      IF( FLAG .EQV. .FALSE. ) THEN
        PRINT*,' '
        PRINT*,'    CALL TSAT ERROR IN SUBROUTINE SPHT '
        FLAG= .FALSE.
        RETURN
      ENDIF
C
C---  CONVERT ' CU M/KG ' TO ' CU FT/LB '
C
      VVAP= VVAP/0.062427961
C
C---  CALCULATION OF DERIVATIVES
C
      V1= VVAP-B(I)
      V2= V1*V1
      V3= V2*V1
      V4= V3*V1
      V5= V4*V1
      V6= V5*V1
      EK1TC= EXP(-K(I)*T/TC(I))
C
      IF( ALPHA(I) .GT. 500 ) THEN
        FDPDV= 0.0
        FDPDP= 0.0
      ELSE
        FDPDV= -ALPHA(I)*( 1+2*CPR(I) )/(1+CPR(I))/(1+CPR(I))*
     $          ( A6(I)*B6(I)*T+CE(I)*EK1TC )
        FDPDT= ( B6(I)-K(I)*C6(I)*EK1TC/TC(I) )/(1+CPR(I))
      ENDIF
      DPDV= -R(I)*T/V2-2.0*( A2(I)+B2(I)*T+C2(I)*EK1TC )/V3-3.0*( A3(I)+
     $      B3(I)*T+C3(I)*EK1TC )/V4-4.0*( A4(I)+B4(I)*T+C4(I)*EK1TC )/
     $      V5-5.0*( A5(I)+B5(I)*T+C5(I)*EK1TC )/V6 + FDPDV
      DPDT= R(I)/V1+( B2(I)-K(I)*C2(I)*EK1TC/TC(I) )/V2+( B3(I)-K(I)*
     $      C3(I)*EK1TC/TC(I) )/V3+( B4(I)-K(I)*C4(I)*EK1TC/TC(I) )/V4
     $      +( B5(I)-K(I)*C5(I)*EK1TC/TC(I) )/V5 + FDPDT
C
        FCCV= 0.0
C
C---  CALCULATE 'CV'
C
      CV= ACV(I)+BCV(I)*T+CCV(I)*T**2+DCV(I)*T**3+FCV(I)/T**2-( J*K(I)
     $    **2*T*EK1TC/TC(I)**2 )*( C2(I)/V1+C3(I)/2.0/V2+C4(I)/3.0/V3
     $    +C5(I)/4.0/V4 + FCCV )
C
C---  CALCULATE 'CP'
C
      CP= CV-J*T*DPDT**2/DPDV
C
C---  CALCULATE 'GAMMA'
C
      GAMMA= CP/CV
C
C---  CALCULATE 'SONIC'
C
      SONIC= VVAP*SQRT( 857.36091*T*DPDT**2/CV-4633.056*DPDV )
C
C---  CONVERT 'ENGLISH UNIT' TO 'SI UNIT'
C
      CV= CV*4.1868
      CP= CP*4.1868
      SONIC= SONIC*0.3048
C
      FLAG= .TRUE.
      RETURN
C
C---  PRINT ERROR MESSAGE IF
C     NR CAN NOT MATCH
C     TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C     TF IS LESS THAN TFSAT CORRESPONDING TO PSAT = PPSIA
C---  PPSIA IS LESS THAN OR EQUAL TO ZERO
C
999   PRINT*,' '
      PRINT*,'    ERROR IN CALLING SUBROUTINE -SPHT-'
C
      FLAG= .FALSE.
      RETURN
      END
C
C-------------------------------------------------------
C
```