ASTEM97

Based on the
IAPWS IF-97

Water and Steam Properties
for Industrial Use

Implementation by

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Appendix D

Pressure Related Functions

Version 2.0

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Pseudo Code

Water Characteristics in IF97 Region 1

In IF97 Region 1, water exhibits some interesting characteristics. At a given temperature the enthalpy, entropy and internal energy properties as a function of pressure behave non-linearly. There are four characteristic signatures, see Figures 1 through 4, which need to be considered. **ASTEM97** provides routines to detect and address these characteristics.

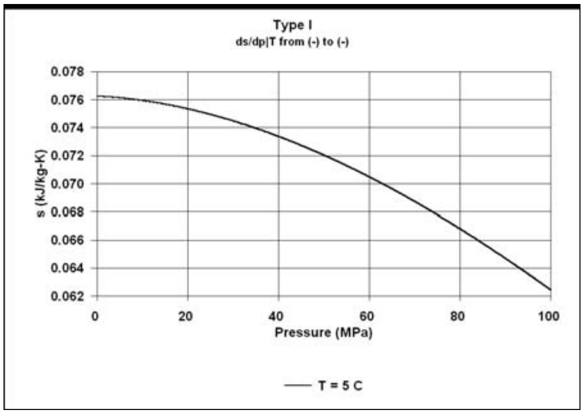

Figure 1 - Type I Characteristic

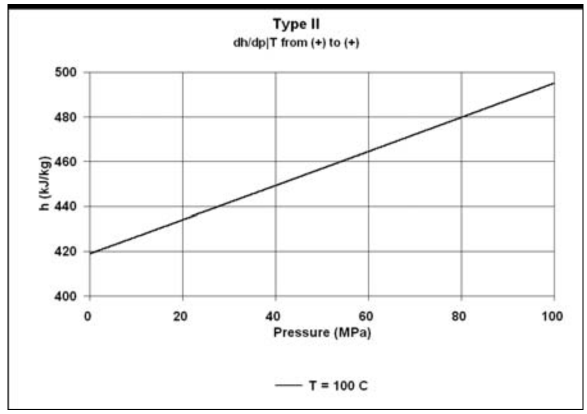

Figure 2 - Type II Characteristic

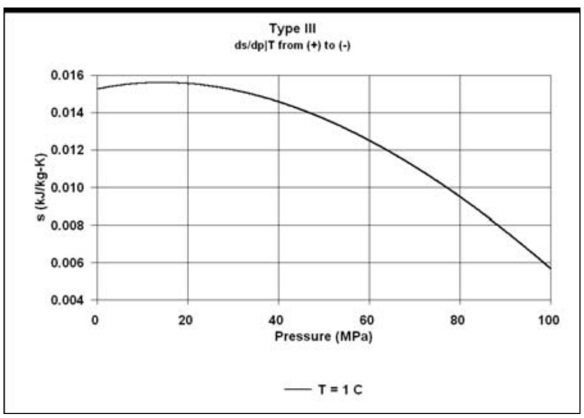

Figure 3 - Type III Characteristic

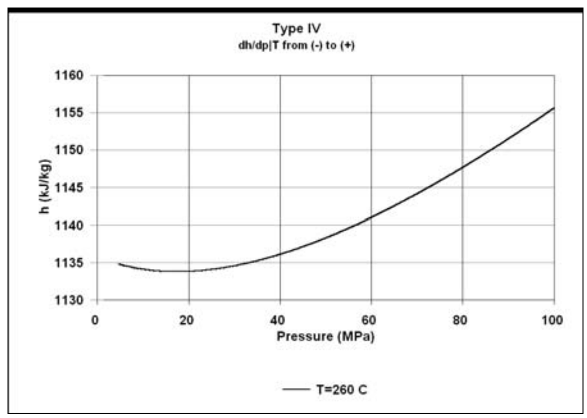

Figure 4 - Type IV Characteristic

For Type III and Type IV, the property value at the low-pressure (saturation pressure at T) can be either less than, equal to or greater than the property value at the high-pressure.

ASTEM97 routines XREG1MM, XREG1PP, XREG1PM and XREG1MP handle the determination of the characteristic and are used to obtain the resulting pressures given the temperature and the property value (**ASTEM97** routines PTH97, PTS97, PTU97 — and PTV97, although the specific volume exhibits a Type I characteristic).

Pressure Related Functions

These functions return pressure (or quality) based on the user provided temperature and second variable (v, u, h or s). A temperature and density function, PTR3, is available for evaluating IF-97 Region 3 pressure given temperature and density. ***NOTE***: PTR3 should not be used to determine saturation pressure, use PSAT97. For two-phase conditions, the return value is quality (X) unless the user selects to have the pressure returned by setting an internal flag (ISET97(11,1)). Or, if the return value is less than P_{MIN} (611.213 Pa), the saturation pressure can be obtained from a call to PSAT97 at T.

Mid-Level	Low-Level (Called by Mid-Level)					Density Based (User called)
PTH97(T,h)	PVAR97(T,VAR,IVAR,IREG)					PTR3(T,ρ)
PTS97(T,s)	VAR IVAR	v 1	u 2	h 3	s 4	
PTU97(T,u)						
PTV97(T,v)						

The specification of temperature with enthalpy, internal energy or entropy does not always result in a unique fluid state point. The fluid could be two-phase or subcooled, and even represent more than one subcooled pressure state when in IF97 Region 1. See Figures 5, 6 and 7. Following a call to one of these functions, the user should check the return flag value (IRTN = IERR97(1)). To accommodate multiply pressure returns based on temperature, function PTMANS97 provides the user interface to these values.

The significance of the IRTN return value is shown below:

IRTN	Return Value	PTMANS97(1)	PTSMANS97(2)
1,2,3,5 or 8, 9	Pressure	-1 (no valid result)	-1 (no valid result)
4 or 6	Quality (IFLAG=0) Pressure (IFLAG=1)	-1 (no valid result)	-1 (no valid result)
10	Pressure	Pressure	-1 (no valid result)
11	Pressure	-1 (no valid result)	Quality (IFLAG=0) Pressure (IFLAG=1)
12	Pressure	Pressure	Quality (IFLAG=0) Pressure (IFLAG=1)

Note: When multiple pressure values are found (IRTN = 11 or 12), the function returns the lower value and PTMAN97 is used to retrieve the other values.

Some examples of the characteristics of these parameters and **ASTEM97**'s handling of these situations are presented here.

Based on Figure 5, the call P_{ANS} = PTU97(274.15,4.25) will return IERR97(1) = 12, with three answers: P_{ANS} = 6,047,208 Pa, and two additional answers: PTMANS97(1) = 57,486,155 Pa, and PTMANS97(2) = 3.12E-05 (if IFLAG97(11) is set to 1 before the call, then the third value returned is PTMANS97(2) = 657.09 Pa).

Based on Figure 6, the call P_{ANS} = PTS97(274.15,0.0155) will return IERR97(1) = 12, with three answers: P_{ANS} = 6,163,933 Pa, and two additional answers: PTMANS97(1) = 22,690,009 Pa, and PTMANS97(2) = 657.09 Pa (IFLAG97(11) was set to 1 before the call, otherwise the third value returned is PTMANS97(2) = 2.63E-05, the quality).

Based on Figure 7, the call P_{ANS} = PTH97(563.15,1283) will return IERR97(1) = 10, with two answers: P_{ANS} = 17,689,198 Pa, and one additional answer: PTMANS97(1) = 92,682,115 Pa (PTMANS97(2) = -1.0, indicated a non-valid return.)

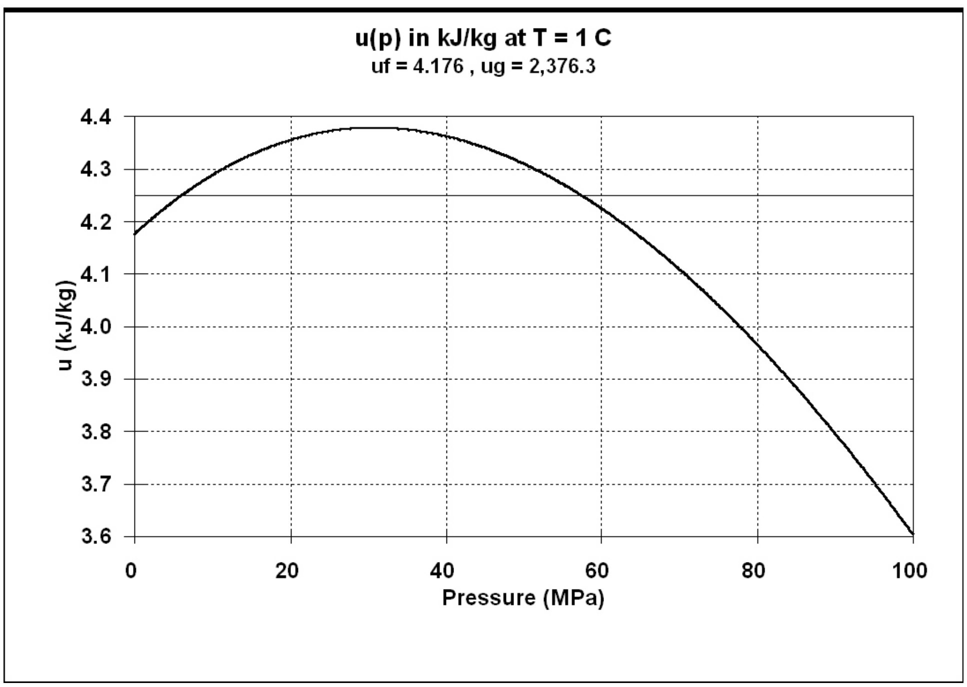

Figure 5 - u(p) at T = 1 °C

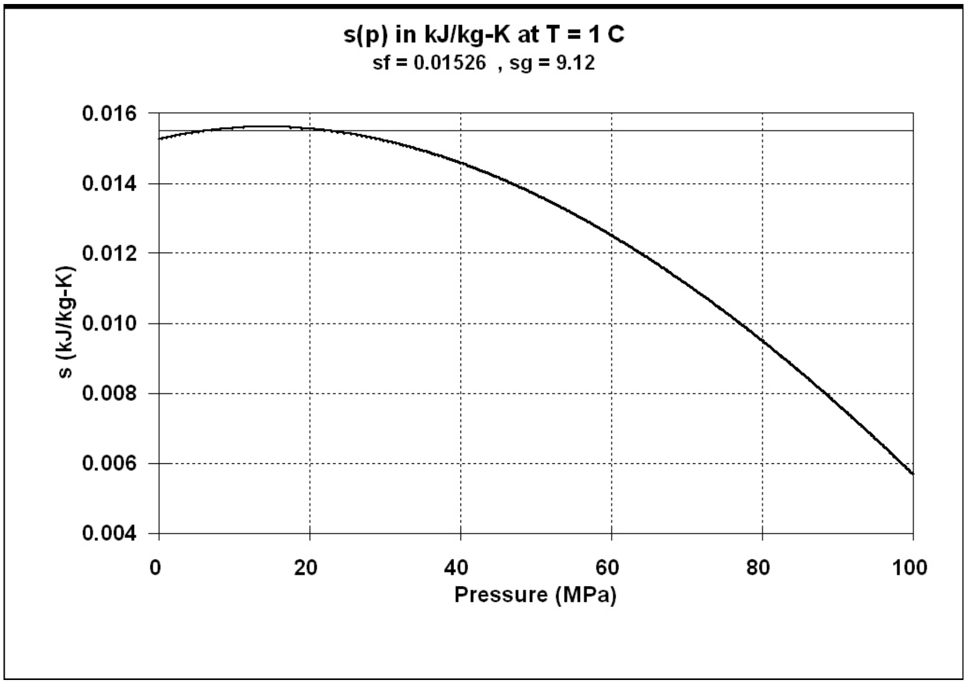

Figure 6 - s(p) at T = 1 °C

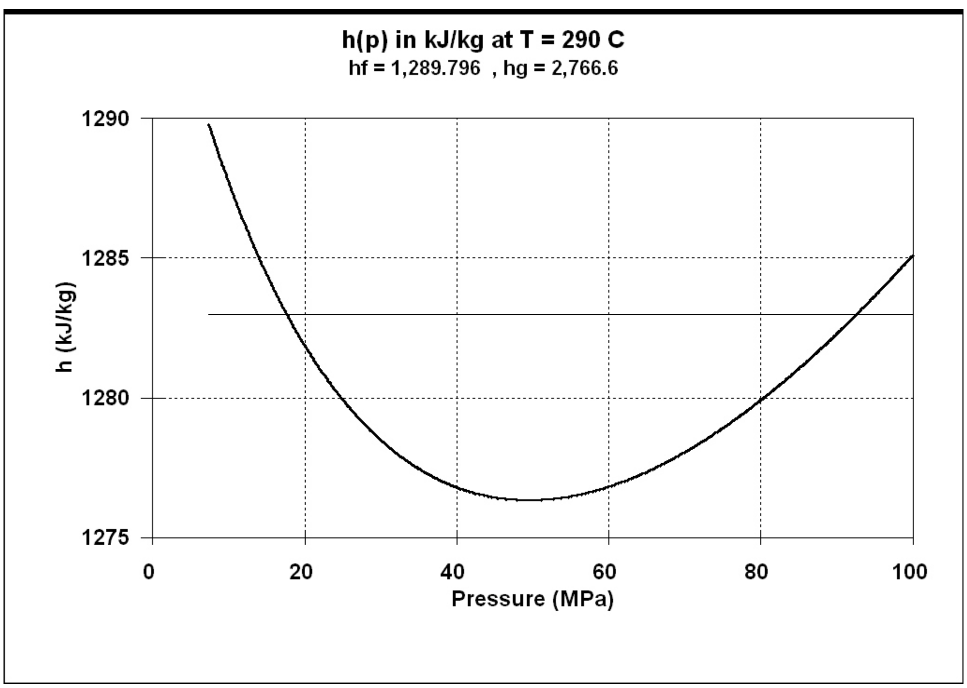

Figure 7 - h(p) at T = 290 °C

Pseudo Code Example 1 PTU97, PTS97, PTH97

```
IQUAL = ISET97( 11 , 0 ) { DEFAULT QUALITY }
P1 = PTU97(274.15,4.25)
IRTN = IERR97(1)    { RESULT ITRN = 12   }
                    { P1 = 6047208.01    }
P2 = PTMANS97(1)    { P2 = 57486154.98   }
P3 = PTMANS97(2)    { P3 = 3.119898E-005 }

IPRS  = ISET97( 11 , 1 ) {SPECIFY PRESSURE }
P1 = PTS97(274.15,0.0155)
IRTN = IERR97(1)    { RESULT ITRN = 12   }
                    { P1 = 6163933.47    }
P2 = PTMANS97(1)    { P2 = 22690008.85   }
P3 = PTMANS97(2)    { P3 = 657.088       }
IRESET = ISET97( 11 , 0 ) {RESET FLAG}

P1 = PTH97(563.15,1283.)
IRTN = IERR97(1)    { RESULT ITRN = 10   }
                    { P1 = 17689197.65   }
P2 = PTMANS97(1)    { P2 = 92682115.47   }
P3 = PTMANS97(2)    { P3 = -1.0          }
```

Based on Figure 8, the call P_{ANS} = PTH97(283.15,92.02) will return IERR97(1) = 11, with two answers: P_{ANS} = 52,774,518.39 Pa, and one additional answer: PTMANS97(2) = 0.020184 (quality). PTMANS97(1) = -1.0, indicated a non-valid return, no second subcooled pressure.

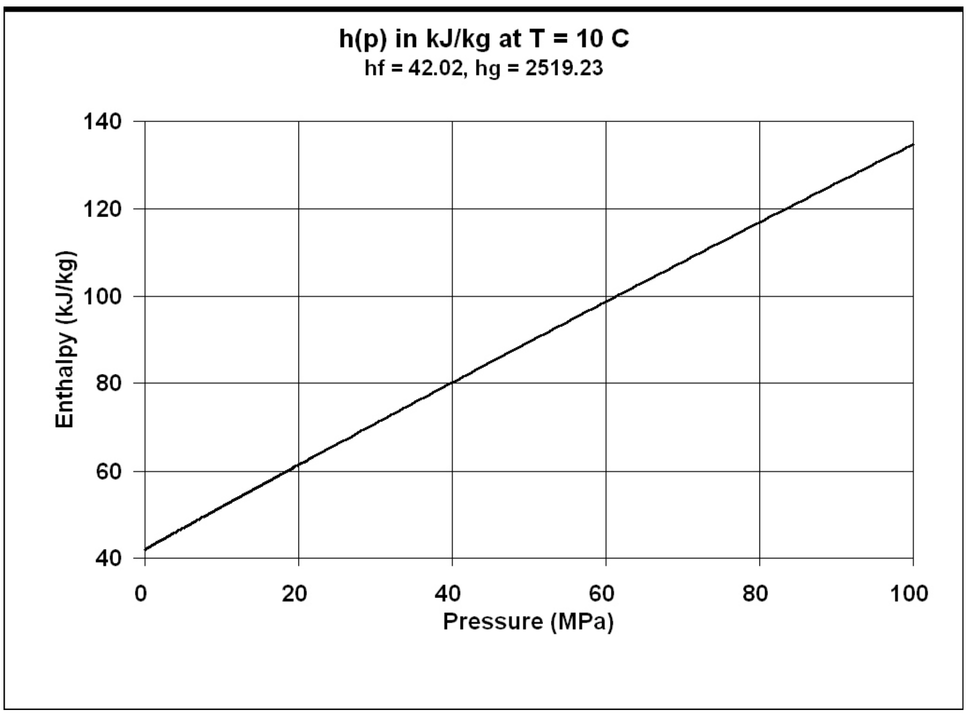

Figure 8 - h(p) at T = 10 °C

```
Pseudo Code Example 2 PTH97 WITH IRTN = 11
```

```
IQUAL = ISET97( 11 , 0 ) { DEFAULT QUALITY }
T_IN = 283.15            { K, 10 C }
H_IN =  92.02            { KJ/KG   }
P1 = PTU97(T_IN,H_IN)
IRTN = IERR97(1)         { RESULT ITRN = 11   }
                         { P1 = 52774518.39   }
P2 = PTMANS97(1)         { P2 =       -1.0    }
P3 = PTMANS97(2)         { P3 = 2.0183568E-05 }

PSAT = PSAT97(T_IN)
                         { PSAT = 1228.18 PA  }
```

Special Consideration

Following a call to PTH97, PTS97 or PTU97 when a property exhibits a Type III or Type IV behavior, PTMANS97(3) contains the pressure at the curve minima or maxima value, where the derivative of the property with respect to pressure at a constant temperature is equal to zero. The value should be retrieved following a call to PTH97, PTS97 or PTU97. ***NOTE***: PTMANS97(3) usually contains temperature data results from calls to metastable or backward equations.

Following a call to ITEM97(T,VAR,IVAR) when a property exhibits a Type III or Type IV behavior, PTMANS97(3) contains the pressure at the curve minima or maxima value, where the derivative of the property with respect to pressure at a constant temperature is equal to zero. The value should be retrieved following a call to ITEM97(T,VAR,IVAR). In addition, the property value at the minima or maxima can be retrieved from PTMANS97(4); the property value at the maximum pressure (PMAX, 100 MPa) can be retrieved from PTMANS97(5); and the property value at the minimum pressure (p_{sat} at T) can be retrieved from PTMANS97(6). ***NOTE***: PTMANS97(3) usually contains temperature data results from calls to metastable or backward equations.

```
Pseudo Code Example 3 Using ITEM97 to Retrieve Data
```

```
{ RETRIEVE DATA AT T = 563.15 K, H VALUE NOT NEEDED, IVAR = 3 }

  I_DUMMY = ITEM97(563.15,H_DUMMY,3)
                           { SEE FIGURE 7          }
  P_MIN_MAX = PTMANS97(3)  { RETURNS 49,560,234 PA }
  H_MIN_MAX = PTMANS97(4)  { RETURNS 1276.330 KJ/KG}
  H_MAXP    = PTMANS97(5)  { RETURNS 1285.097 KJ/KG}
  H_MINP    = PTMANS97(6)  { RETURNS 1289.796 KJ/KG}
```

At a constant temperature, the enthalpy, internal energy and entropy of water in IF97 Region 1 can exhibit some non-linear characteristic. A map was developed using **ASTEM97** for these properties, to identify the temperature range over which when $d_{var}/dp|T = 0$. Figure 9 shows the results for ds/dp|T and du/dp|T. Figure 10 shows the results for dh/dp|T.

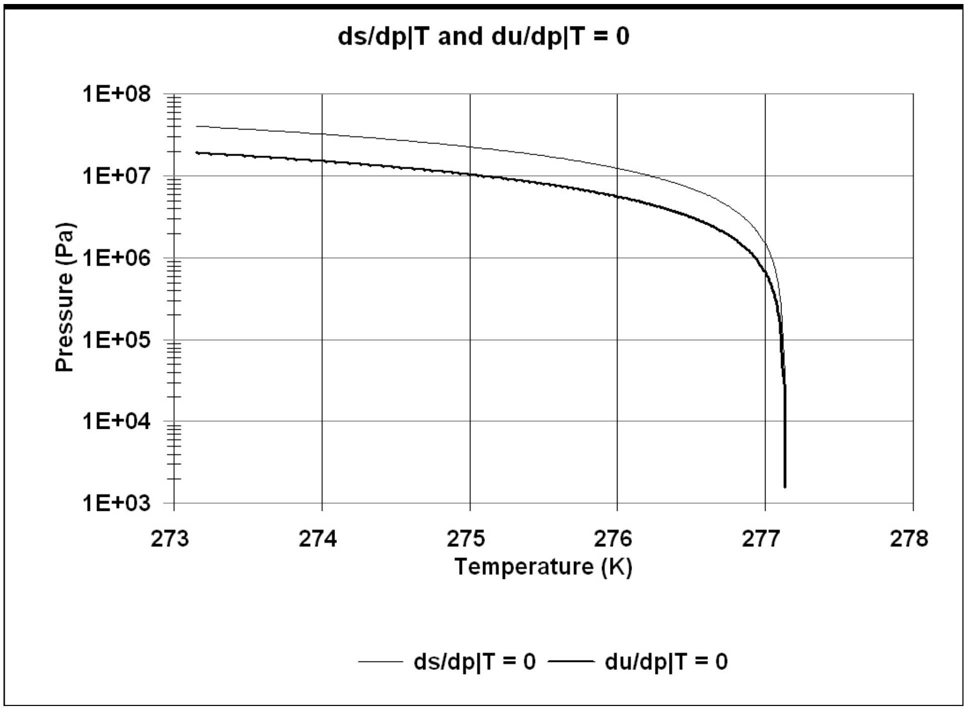

Figure 9 - ds/dp|T and du/dp|T = 0

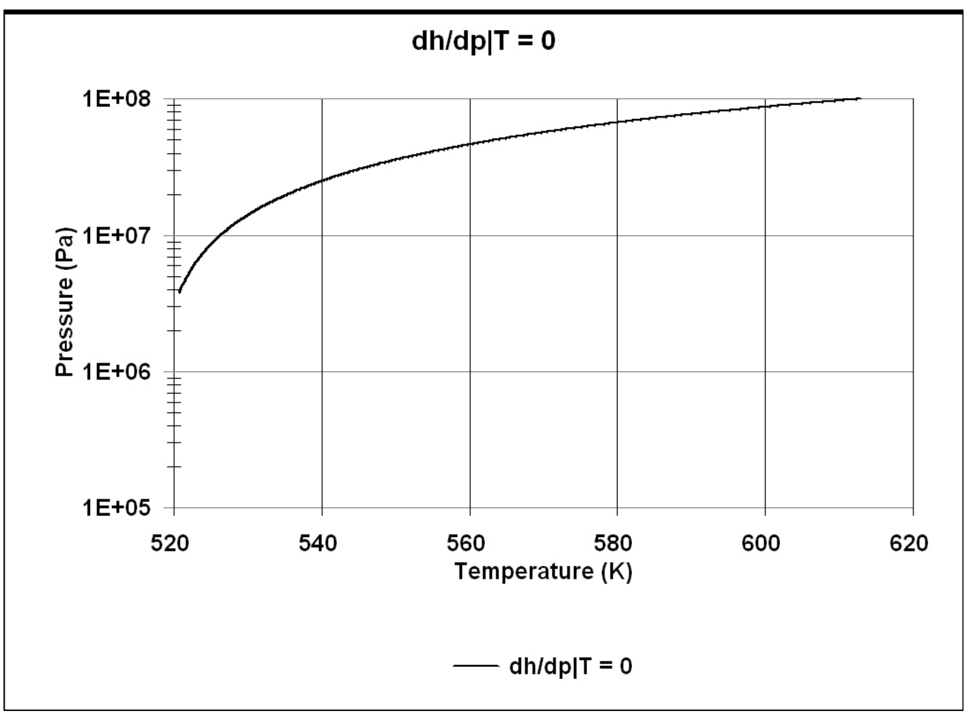

Figure 10 - dh/dp|T = 0

PTH97 returns $\partial h/\partial p|_T = 0$ in PTMANS97(3). Recognizing that $\partial h/\partial p|_T$ is the Joule-Thomson coefficient, the Joule-Thomson inversion can readily be obtained in **ASTEM97**. Consider the pseudo code below:

Pseudo Code Example 4 Joule-Thompson Inversion

```
{ SETUP A TEMPERATURE INCREMENT LOOP }
   DO 100 TEMP = 273.15 TO 623.15 BY 10.0   { TEMP IN K }
{ CALL ITEM97 WITH A DUMMY ARGUMENT FOR H, H_DUMMY }
   I_DUMMY = ITEM97(TEMP,H_DUMMY,3)         {IVAR = 3 FOR ENTHALPY }
{ RETRIEVE THE PRESSURE AT DH/DP|T = 0 }
   P_ZERO = PTMANS97(3)
{ SET UP RETURN VALUE }
   H_RETURN = -1.0
{ CHECK FOR A TYPE III OR TYPE IV CONDITION }
   IF( ISET97(2) = 3 OR ISET97(2) = 4 ) THEN
{ THEN RETRIEVE THE ENTHALPY AT DH/DP|T = 0  }
   H_RETURN = PTMANS97(4))
   ENDIF
{ NOW HAVE ENTHALPY,PRESSURE DATA FOR THE JOULE-THOMPSON INVERSION
  FOR H_RETURN NOT EQUAL TO -1.0 AND PRESSURE IN IF97 RANGE        }
```

Figure 11 shows the results from the pseudo code example for the Joule-Thompson inversion (J-T curve). Also shown is the saturation fluid enthalpy curve (H-f curve).

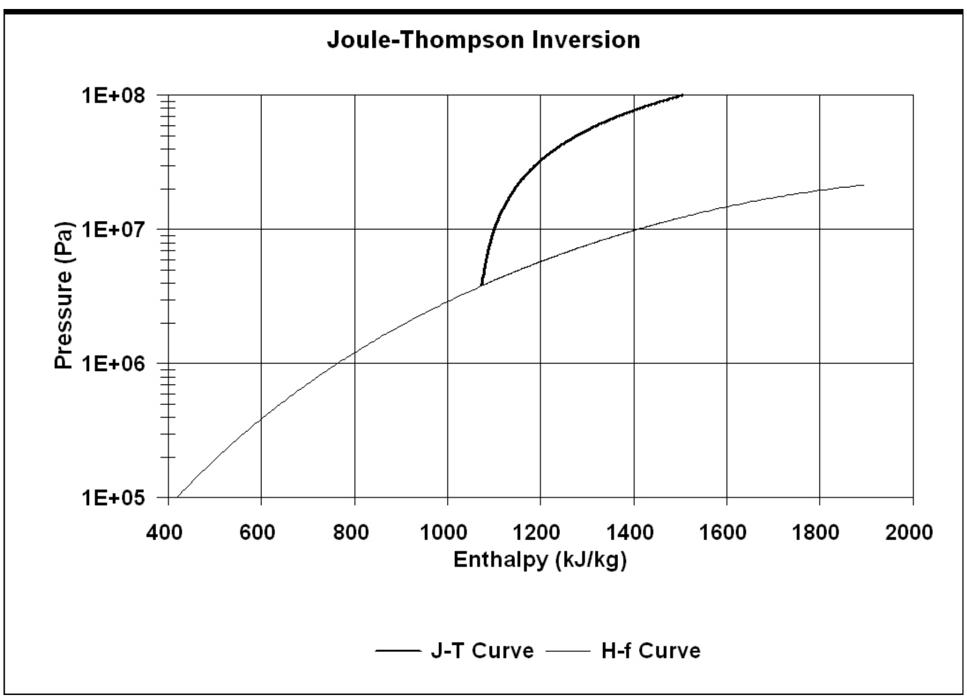

Figure 11 - Joule-Thomson Inversion Curve