Implementation of DOWTHERM A Properties into RELAP5-3D/ATHENA

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April 2010
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Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517
ABSTRACT

DOWTHERM A oil is being considered for use as a heat transfer fluid in experiments to help in the design of heat transfer components for the Next Generation Nuclear Plant (NGNP). In conjunction with the experiments RELAP5-3D/ATHENA will be used to help design and analyze the data generated by the experiments. In order to use RELAP5-3D the thermophysical properties of DOWTHERM A were implemented into the fluids package of the RELAP5-3D/ATHENA computer program.

DOWTHERM A properties were implemented in RELAP5-3D/ATHENA using thermophysical property data obtained from a Dow Chemical Company brochure. The data were curve fit and the polynomial equations developed for each required property were input into a fluid property generator. The generated data was then compared to the original DOWTHERM A data to verify that the fluid property data generated by the RELAP5-3D/ATHENA code was representative of the original input data to the generator.

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1. INTRODUCTION

The RELAP5-3D® program (INL 2009) is being developed to simulate thermal-hydraulic transients in reactor systems that use light water as the working fluid. The ATHENA code is incorporated as a compile-time option in RELAP5-3D that generalizes the capability of the code to simulate systems that use working fluids other than water. DOWTHERM A oil is being considered for use as a heat transfer fluid in experiments to help in the design of heat transfer components for the Next Generation Nuclear Plant (NGNP). In conjunction with these experiments RELAP5-3D/ATHENA will be used to help analyze the data generated from the experiments.

Since RELAP5-3D/ATHENA at the present time does not contain DOWTHERM A thermophysical properties as part of the working fluids package, the use of the code to model thermal hydraulic systems using DOWTHERM A as a working fluid required "tricking" the code into thinking the property file tpfms1 contained DOWTHERM A properties. Jiyanag Yu at the University of California Berkeley developed a fluids generator for DOWTHERM A. Using the generator, the DOWTHERM A thermophysical properties were written in the correct format to the appropriate binary files associated with the tpfms1 property file. The DOWTHERM A property generator used is described in Reference 1. To make it more convenient to use DOWTHERM A properties with RELAP5-3D/ATHENA it was decided to add DOWTHERM A thermophysical properties to the RELAP5-3D/ATHENA fluids package.

DOWTHERM A properties were implemented in RELAP5-3D/ATHENA using thermophysical property data obtain from a Dow Chemical Company brochure [2]. The data (saturated vapor pressure curve, saturated liquid and vapor density, saturated liquid and vapor enthalpy, saturated liquid and vapor specific heat at constant pressure, saturated liquid and vapor thermal conductivity, and saturated liquid and vapor dynamic viscosity) were curve fit and the polynomial equations developed for each required property were input into a DOWTHERM A fluid property generator that is compatible with the RELAP5-3D/ATHENA code fluids package.

The remainder of this report follows the same format as used by Davis in Reference 3 which describes the properties of four molten salts that were added to the RELAP5-3D/ATHENA fluids package.

2. FLUID PROPERTIES

The RELAP5-3D/ATHENA code accesses DOWTHERM A thermodynamic properties by way of tables located in an auxiliary file named tpfdowa. The file tpfdowa contains the follow fluid properties as shown in Table 1.
Table 1: Thermodynamic properties that are contained in file tpfdowa

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>T</td>
<td>K</td>
</tr>
<tr>
<td>Pressure</td>
<td>P</td>
<td>Pa</td>
</tr>
<tr>
<td>Specific Volume</td>
<td>v</td>
<td>m³/kg</td>
</tr>
<tr>
<td>Specific Internal Energy</td>
<td>u</td>
<td>J/kg</td>
</tr>
<tr>
<td>Specific Enthalpy</td>
<td>h</td>
<td>J/kg</td>
</tr>
<tr>
<td>Specific Entropy</td>
<td>s</td>
<td>J/kg-K</td>
</tr>
<tr>
<td>Coefficient of Isobaric Thermal Expansion</td>
<td>$\beta = \frac{1}{v} \left( \frac{\partial v}{\partial T} \right)_p$</td>
<td>1/K</td>
</tr>
<tr>
<td>Coefficient of Isothermal Compressibility</td>
<td>$\kappa = -\frac{1}{v} \left( \frac{\partial v}{\partial P} \right)_T$</td>
<td>1/Pa</td>
</tr>
<tr>
<td>Specific Heat at Constant Pressure</td>
<td>$C_p$</td>
<td>J/kg-K</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>k</td>
<td>W/m-K</td>
</tr>
<tr>
<td>Dynamic Viscosity</td>
<td>$\mu$</td>
<td>Pa-sec</td>
</tr>
</tbody>
</table>

The calculation of the liquid properties (saturated and single phase) along with the liquid transport properties are described in Section 2.1 and 2.2, respectively. The vapor properties (saturated and single phase) along the vapor transport properties are described in Section 2.3 and 2.4 respectively. The vapor pressure curve is described in Section 2.5.

2.1 Saturated Liquid Thermodynamic and Transport Properties

Table 3 in Reference 2 lists the DOWTHERM A saturated liquid properties for density, specific heat, pressure, thermal conductivity, and viscosity from 285.15 K to 698.15 K. The data were copied into an Excel spreadsheet, then imported into Mathcad where regression analyses were conducted to obtain nth degree polynomial coefficients to curve fit the data. In most cases a 5th degree polynomial was adequate in fitting the data. In some cases four curves were required to fit the data range from 318.15 K to 698.15 K. The minimum temperature used to compute the thermal properties of DOWTHERM A was 318.15 K because some of the input data between 285.15 K and 318.15 K were missing from the DOWTHERM A saturated liquid data.

The regression coefficients for each of the saturated liquid properties calculated are shown in Table 2.

Table 2: Curve fit coefficients for saturated liquid properties

<table>
<thead>
<tr>
<th>Property</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.493E+03</td>
<td>-3.332E+00</td>
<td>1.248E-02</td>
<td>-2.968E-05</td>
<td>3.444E-08</td>
<td>-1.622E-11</td>
</tr>
<tr>
<td>Enthalpy</td>
<td>-6.511E+05</td>
<td>4.121E+03</td>
<td>-1.235E+01</td>
<td>2.771E-02</td>
<td>-2.777E-05</td>
<td>1.106E-08</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>-2.364E+03</td>
<td>3.946E+01</td>
<td>-1.703E-01</td>
<td>3.904E-04</td>
<td>-4.422E-07</td>
<td>1.979E-10</td>
</tr>
<tr>
<td>Conductivity</td>
<td>1.856E-01</td>
<td>-1.600E-04</td>
<td>5.913E-12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>5.135E+00</td>
<td>-8.395E-02</td>
<td>5.971E-04</td>
<td>-2.409E-06</td>
<td>6.029E-09</td>
<td>-9.579E-12</td>
</tr>
</tbody>
</table>
To fit the liquid viscosity curve required an 8th degree polynomial, thus the three remaining coefficients for viscosity not shown in Table 2 are $g = 9.433E-15$  
$h = -5.264E-18$ and $i = 1.275E-21$.

The general form of the equation for each property is

$$
property = a + bT + cT^2 + dT^3 + eT^4 + fT^5
$$

(1)

Shown in Figures 1, 2 and 3 are plots of the DOWTHERM A data and the corresponding curve fits for saturated liquid specific volume (m$^3$/kg), saturated liquid specific internal energy (J/kg) and saturated liquid constant pressure specific heat (J/kg-K) respectively. Viewing the figures we see excellent agreement between the given DOWTHERM A data and the computed data using Equation (1) with the appropriate coefficients from Table 2. The specific volume shown in Figure 1 is calculated as

$$
\nu_f = \frac{1}{\rho_f^s}
$$

(2)

where $\rho_f^s$ is the density of the saturated liquid. The saturated specific internal energy of the liquid shown in Figure 2 is obtain from the saturated specific enthalpy of the liquid as

$$
u_f^s = h_f^s - pv_f^s
$$

(3)

where $\nu_f^s$ is the specific internal energy of the saturated liquid, $h_f^s$ is the specific enthalpy of the saturated liquid, $p$ is the pressure and $\nu_f^s$ is the specific volume of the saturated liquid.

![Figure 1: Specific volume of saturated liquid](image-url)
Figure 2: Specific internal energy of saturated liquid

Figure 3: Specific heat capacity at constant pressure of saturated liquid
The next three figures shown are the thermal expansion coefficient (Figure 4), isothermal compressibility coefficient (Figure 5) and the specific entropy (Figure 6). The thermal expansion coefficient for the saturated liquid is defined as

\[ \beta_f^s = \frac{1}{v_f^s} \left( \frac{\partial v_f^s}{\partial T} \right)_p \]  

(4)

however since there is no data given for the thermal expansion coefficient as a function of temperature we will compute \( \beta_f^s \) as follows

\[ \beta_f^s \approx \frac{1}{v_f^s(p,T)} \left( \frac{v_f^s(p,T + \delta T) - v_f^s(p,T - \delta T)}{2\delta T} \right) \]  

(5)

The isothermal compressibility for saturated liquid is defined as

\[ \kappa_f^s = -\frac{1}{v_f^s} \left( \frac{\partial v_f^s}{\partial p} \right)_T \]  

(6)

As with the thermal expansion coefficient there were no data listed for the isothermal compressibility of DOWTHERM A, thus the following difference equation for the isothermal compressibility was used to compute saturated liquid isothermal compressibility coefficients as a function of pressure.

\[ \kappa_f^s \approx -\frac{1}{v_f^s(p,T)} \left( \frac{v_f^s(p + \delta p,T) - v_f^s(p - \delta p,T)}{2\delta p} \right) \]  

(7)

As was done in Reference 1 the saturated liquid specific entropy is approximated using the following equation

\[ s_f^s = \frac{u_f^s + p v_f^s}{T} \]  

(8)

where \( s_f^s \) is the saturated liquid specific entropy, \( u_f^s \) is the saturated liquid specific internal energy, \( p \) is the saturation pressure, \( v_f^s \) is the saturated liquid specific volume, and \( T \) is the saturated temperature.
Figure 4: Coefficient of thermal expansion of saturated liquid

Figure 5: Isothermal compressibility of saturated liquid
Figure 6: Specific entropy of saturated liquid

Displayed in Figures 7 and 8 are the saturated liquid thermal conductivity and dynamic viscosity of DOWTHERM A. The computed results for both thermal conductivity and dynamic viscosity have excellent agreement with the given data.

Figure 7: Thermal conductivity of saturated liquid
Figure 8: Dynamic viscosity of saturated liquid

2.2 Single Phase Liquid Properties

The single phase properties for liquid DOWTHERM A are not given, thus it is assumed that the single phase data is very close to that of saturated data at the same temperature. This is the same approach that was used in Reference [1].

The liquid density $\rho(T,P)$, and the receptacle of the density, the liquid specific volume are both a function of temperature and pressure thus the saturated liquid density is multiplied by a small pressure coefficient as was done in Reference [1]. For example the density of single phase liquid is set to be

$$\rho(T,P) = (a + bT + cT^2 + dT^3 + eT^4 + fT^5)(P \cdot dd)^{ee}$$

where $dd = 1.0E-04$, $ee = 1.0E-03$ (9)

The remaining computed liquid thermodynamic properties $u$, $s$, $\beta$, and $\kappa$ are all functions of the liquid specific volume, therefore they are all functions of pressure and temperature.

The liquid specific heat, the thermal conductivity and the dynamic viscosity are assumed to be pressure independent, thus the three values are assumed equal to the saturated liquid value at the same temperature.
2.3 Saturated Vapor Thermodynamic and Transport Properties

Table 5 in Reference 2 lists the DOWTHERM A saturated vapor properties for density, specific heat, pressure, thermal conductivity, and viscosity from 285.15 K to 698.15 K. The data were copied into an Excel spreadsheet, then imported into Mathcad where regression analyses were conducted to obtain nth degree polynomial coefficients to curve fit the data. In most cases a 5th degree polynomial was adequate in fitting the data. In some cases three or four curves were required to fit the data range from 318.15 K to 698.15 K. The minimum temperature used to compute the thermal properties of DOWTHERM A was 318.15 K because some of the input data between 285.15 K and 318.15 K were missing from the DOWTHERM A saturated vapor data.

The regression coefficients for each of the saturated vapor properties calculated are shown in Table 3.

**Table 3: Curve fit coefficients for saturated vapor properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>4.391E-05</td>
<td>6.119E-05</td>
<td>-5.401E-08</td>
<td>2.245E-10</td>
<td>-5.422E-13</td>
<td>5.220E-16</td>
</tr>
<tr>
<td></td>
<td>4.144E-03</td>
<td>4.187E-05</td>
<td>8.414E-09</td>
<td>-3.569E-12</td>
<td>4.893E-16</td>
<td>-2.110E-20</td>
</tr>
<tr>
<td>Enthalpy</td>
<td>4.004E+05</td>
<td>-1.443E+03</td>
<td>7.579E+00</td>
<td>-1.116E-02</td>
<td>1.103E-05</td>
<td>-5.134E-09</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>-5.426E+03</td>
<td>6.248E+01</td>
<td>-2.532E-01</td>
<td>5.432E-04</td>
<td>-5.842E-07</td>
<td>2.508E-10</td>
</tr>
<tr>
<td>Conductivity</td>
<td>-5.137E-03</td>
<td>3.016E-04</td>
<td>4.668E-08</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shown in Figures 9, 10 and 11 are plots of the DOWTHERM A data and the corresponding curve fits for saturated vapor specific volume (m³/kg), saturated vapor specific internal energy (J/kg) and saturated vapor constant pressure specific heat (J/kg-K) respectively. Viewing the figures we see excellent agreement between the given DOWTHERM A data and the computed data using Equation (1) with the appropriate coefficients from Table 3. The specific volume shown in Figure 9 is calculated as

\[ v_s^g = \frac{1}{\rho_g^s} \]  

(10)

where \( \rho_g^s \) is the density of the vapor.

The specific internal energy shown in Figure 10 is obtained from the enthalpy of the vapor as

\[ u_g^s = h_g^s - pv_g^s \]  

(11)

where \( u_g^s \) is the specific internal energy of the saturated vapor, \( h_g^s \) is the specific enthalpy of the saturated vapor, \( p \) is the pressure and \( v_g^s \) is the specific volume of the saturated vapor.
Figure 9: Specific volume of saturated vapor

Figure 10: Specific internal energy of saturated vapor
The next three figures shown are the saturated vapor thermal expansion coefficient (Figure 12), saturated vapor isothermal compressibility coefficient (Figure 13) and the saturated vapor specific entropy (Figure 14). The thermal expansion coefficient for the saturated vapor is defined as

$$\beta_s^g = \frac{1}{v_s^g} \left( \frac{\partial v_s^g}{\partial T} \right)_p$$  \hspace{1cm} (12)

however since there is no data given for the thermal expansion coefficient as a function of temperature we will compute $\beta_s^g$ as follows

$$\beta_s^g \approx \frac{1}{v_s^g(p,T)} \left( \frac{v_s^g(p,T+\delta T) - v_s^g(p,T-\delta T)}{2\delta T} \right)_p$$  \hspace{1cm} (13)

The isothermal compressibility for saturated vapor is defined as

$$\kappa_s^g = -\frac{1}{v_s^g} \left( \frac{\partial v_s^g}{\partial p} \right)_T$$  \hspace{1cm} (14)

As with the thermal expansion coefficient there were no data listed for the saturated vapor isothermal compressibility of DOWTHERM A, thus the follow finite difference equation for the isothermal compressibility was used to compute saturated vapor isothermal compressibility coefficients as a function of pressure.
\[ \kappa_g^s \approx -\frac{1}{v_g^s(p, T)} \left( \frac{v_g^s(p + \delta p, T) - v_g^s(p - \delta p, T)}{2\delta p} \right)_T \]  

(15)

As was done in Reference 1 the saturated vapor specific entropy is approximated using the following equation

\[ s_g^s = \frac{u_g^s + pv_g^s}{T} \]  

(16)

where \( s_g^s \) is the saturated vapor specific entropy, \( u_g^s \) is the saturated vapor specific internal energy, \( p \) is the saturation pressure, \( v_g^s \) is the saturated vapor specific volume, and \( T \) is the saturated temperature.

![Figure 12: Coefficient of thermal expansion of saturated vapor](image-url)
Figure 13: Isothermal compressibility of saturated vapor

Figure 14: Specific entropy of saturated vapor
Displayed in Figures 15 and 16 are the saturated vapor thermal conductivity and dynamic viscosity of DOWTHERM A. The computed results for both thermal conductivity and dynamic viscosity have excellent agreement with the given data.

Figure 15: Thermal conductivity of saturated vapor

Figure 16: Dynamic viscosity of saturated vapor
2.4 Single Phase Vapor Properties

The single phase properties for vapor DOWTHERM A are not given, thus it is assumed that the single phase data is very close to that of saturated data at the same temperature. This is the same approach that was used in Reference [1].

The vapor density \( \rho(T, P) \) and the receptacle of the density, the vapor specific volume are both a function of temperature and pressure thus the saturated vapor density is multiplied by a small temperature coefficient as was done in Reference [1]. For example the density of single phase vapor is set to be

\[
\rho(T, P) = (a + bP + cP^2 + dP^3 + eP^4 + fP^5) \frac{283.15}{T} \tag{17}
\]

The remaining computed vapor thermodynamic properties \( u, s, \beta, \) and \( \kappa \) are all functions of the vapor specific volume, therefore they are all functions of pressure and temperature.

The vapor specific heat, the thermal conductivity and the dynamic viscosity are assumed to be pressure independent, thus the three values are assumed equal to the saturated vapor value at the same temperature.

2.5 Vapor Pressure Curve

The vapor pressure curve shown in Figure 17 was generated by curve fitting the pressure temperature data contained in table 3 of reference [2]. The regression coefficients for the vapor pressure curve are shown in table 4.

**Table 4: Curve fit coefficients for vapor pressure curve**

<table>
<thead>
<tr>
<th>Property</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapor Press</td>
<td>-4.270E+06</td>
<td>3.196E+04</td>
<td>-9.259E+01</td>
<td>1.397E-01</td>
<td>-1.350E-04</td>
<td>7.868E-08</td>
</tr>
<tr>
<td></td>
<td>-7.702E+08</td>
<td>9.309E+06</td>
<td>-4.496E+04</td>
<td>1.085E+02</td>
<td>-1.308E-01</td>
<td>6.304E-05</td>
</tr>
<tr>
<td></td>
<td>-7.040E+05</td>
<td>1.090E+04</td>
<td>-6.774E+01</td>
<td>2.113E-01</td>
<td>-3.311E-04</td>
<td>2.086E-07</td>
</tr>
</tbody>
</table>

The vapor pressure curve presented in Figure 17 more closely represent the DOWTHERM A data at temperatures between 350 K and 600 K than the curve shown in Reference 1.
3. VERIFICATION

The verification of the thermodynamic properties is discussed in Section 3.1. The verification of the transport properties is discussed in Section 3.2.

3.1 Thermodynamic Properties

The saturated thermodynamic properties for DOWTHERM A implemented into RELAP5-3D/ATHENA fluids package were verified by comparing the thermodynamic properties data generated by the fluid generator with the data contained in Reference [2]. Overall, the result obtained with the fluid generator were in excellent agreement with those listed in Reference [2] as seen in Figures 1, 2, 3, 9, 10, 11.
3.2 Transport Properties

The saturated transport properties for DOWTHERM A implemented into RELAP5-3D/ATHENA fluids package were verified by comparing the transport properties data generated by the fluid generator with the data contained in Reference [2]. Overall, the result obtained with the fluid generator were in excellent agreement with those listed in Reference [2] as seen in Figures 7, 8, 15, 16.
4. REFERENCES

APPENDIX A

Thermodynamic Properties of DOWTHERM A
**Thermodynamic Properties of Dowtherm A**

Table BB contains the Saturated Liquid Properties of Dowtherm A Fluid (SI units) - DATA

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>id (SI Units)&quot;</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>1</td>
<td>&quot; TEMP&quot;</td>
<td>&quot;TEMP&quot;</td>
<td>&quot; VAPOR&quot;</td>
<td>&quot;VAPOR&quot;</td>
<td>&quot;LIQUID&quot;</td>
</tr>
<tr>
<td>2</td>
<td>NaN</td>
<td>NaN</td>
<td>&quot; PRESS.&quot;</td>
<td>&quot;PRESS&quot;</td>
<td>&quot;ENTHALPY&quot;</td>
</tr>
<tr>
<td>3</td>
<td>°C</td>
<td>&quot;K&quot;</td>
<td>&quot; bar&quot;</td>
<td>&quot;Pa&quot;</td>
<td>&quot;kJ/kg&quot;</td>
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<tr>
<td>4</td>
<td>12</td>
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<tr>
<td>5</td>
<td>15</td>
<td>288.15</td>
<td>0</td>
<td>0</td>
<td>4.9</td>
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<tr>
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<td>25</td>
<td>298.15</td>
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<td>0</td>
<td>21.3</td>
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<tr>
<td>8</td>
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<td>303.15</td>
<td>0</td>
<td>0</td>
<td>29.5</td>
</tr>
<tr>
<td>9</td>
<td>35</td>
<td>308.15</td>
<td>0</td>
<td>0</td>
<td>37.7</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>313.15</td>
<td>0</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>11</td>
<td>45</td>
<td>318.15</td>
<td>1.752·10⁻⁴</td>
<td>17.522</td>
<td>54.4</td>
</tr>
<tr>
<td>12</td>
<td>50</td>
<td>323.15</td>
<td>2.427·10⁻⁴</td>
<td>24.269</td>
<td>...</td>
</tr>
</tbody>
</table>

Table AA contains the Saturated Vapor Properties of Dowtherm A Fluid (SI units) - DATA

<table>
<thead>
<tr>
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<th>3</th>
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<td>Fluid (SI Units)&quot;</td>
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<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
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<tr>
<td>1</td>
<td>&quot; TEMP&quot;</td>
<td>&quot;TEMP&quot;</td>
<td>&quot; VAPOR&quot;</td>
<td>&quot;VAPOR&quot;</td>
<td>&quot;LIQUID&quot;</td>
</tr>
<tr>
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<td>NaN</td>
<td>NaN</td>
<td>&quot;PRESSURE&quot;</td>
<td>&quot;PRESSURE&quot;</td>
<td>&quot;ENTHALPY&quot;</td>
</tr>
<tr>
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<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>4</td>
<td>°C</td>
<td>&quot;K&quot;</td>
<td>&quot; bar&quot;</td>
<td>&quot;Pa&quot;</td>
<td>&quot;kJ/kg&quot;</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>15</td>
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<td>0</td>
<td>0</td>
<td>4.9</td>
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<tr>
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<td>20</td>
<td>293.15</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>29.5</td>
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<td>308.15</td>
<td>0</td>
<td>0</td>
<td>37.7</td>
</tr>
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<td>40</td>
<td>313.15</td>
<td>0</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>12</td>
<td>45</td>
<td>318.15</td>
<td>1.752·10⁻⁴</td>
<td>17.522</td>
<td>54.4</td>
</tr>
<tr>
<td>13</td>
<td>50</td>
<td>323.15</td>
<td>2.427·10⁻⁴</td>
<td>24.269</td>
<td>62.7</td>
</tr>
<tr>
<td>14</td>
<td>55</td>
<td>328.15</td>
<td>3.45·10⁻⁴</td>
<td>34.502</td>
<td>71.2</td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td>333.15</td>
<td>4.837·10⁻⁴</td>
<td>48.372</td>
<td>...</td>
</tr>
</tbody>
</table>
Extract Data from BB to obtain the vapor pressure curve by means of curve fitting the data

\[
i := 0, 1..77 \quad \text{TempSat}_i := BB_{i+11,1} \quad \text{PressSat}_i := BB_{i+11,3}
\]

\[
j := 0, 1..51 \quad \text{TempSat}_j := BB_{j+37,1} \quad \text{PressSat}_j := BB_{j+37,3}
\]

\[
k := 0, 1..13 \quad \text{TempSat}_k := BB_{k+24,1} \quad \text{PressSat}_k := BB_{k+24,3}
\]

\[
ii := 0, 1..13 \quad \text{TempSat}_{ii} := BB_{ii+11,1} \quad \text{PressSat}_{ii} := BB_{ii+11,3}
\]

\[
\text{coefA} := \text{regress}(\text{TempSatA}, \text{PressSatA}, 5)
\]

\[
\text{coefA} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-4.2701724 \times 10^6 \\
3.1962428 \times 10^4 \\
-9.2594121 \times 10^1 \\
1.3973546 \times 10^{-1} \\
-1.3501202 \times 10^{-4} \\
7.8679025 \times 10^{-8}
\end{pmatrix}
\]

\[
a1 := \text{coefA}_3 \quad a1 = -4.2702 \times 10^6
\]

\[
b1 := \text{coefA}_4 \quad b1 = 3.1962 \times 10^4
\]

\[
c1 := \text{coefA}_5 \quad c1 = -92.5941
\]

\[
d1 := \text{coefA}_6 \quad d1 = 0.1397
\]

\[
e1 := \text{coefA}_7 \quad e1 = -1.3501 \times 10^{-4}
\]

\[
f1 := \text{coefA}_8 \quad f1 = 7.8679 \times 10^{-8}
\]
\text{coefB} := \text{regress}(\text{TempSatB}, \text{PressSatB}, 5)

\begin{align*}
\text{coefB} &= \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-7.7020656 \times 10^8 \\
9.3087791 \times 10^6 \\
-4.4964641 \times 10^4 \\
1.0850779 \times 10^2 \\
-1.3082038 \times 10^{-1} \\
6.3041277 \times 10^{-5}
\end{pmatrix} \\
\text{a}_2 &:= \text{coefB}_3 \\
\text{b}_2 &:= \text{coefB}_4 \\
\text{c}_2 &:= \text{coefB}_5 \\
\text{d}_2 &:= \text{coefB}_6 \\
\text{e}_2 &:= \text{coefB}_7 \\
\text{f}_2 &:= \text{coefB}_8
\end{align*}

\text{coefC} := \text{regress}(\text{TempSatC}, \text{PressSatC}, 5)

\begin{align*}
\text{coefC} &= \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-7.0401403 \times 10^5 \\
1.0900125 \times 10^4 \\
-6.7738071 \times 10^1 \\
2.1131357 \times 10^{-1} \\
-3.3110934 \times 10^{-4} \\
2.0861096 \times 10^{-7}
\end{pmatrix} \\
a_3 &:= \text{coefC}_3 \\
b_3 &:= \text{coefC}_4 \\
c_3 &:= \text{coefC}_5 \\
d_3 &:= \text{coefC}_6 \\
e_3 &:= \text{coefC}_7 \\
f_3 &:= \text{coefC}_8
\end{align*}
\[ y_A(x) := a_1 + b_1 \cdot x + c_1 \cdot x^2 + d_1 \cdot x^3 + e_1 \cdot x^4 + f_1 \cdot x^5 \]

\[ y_{yA_j} := y_A \left(\text{TempSat}_A_j\right) \]

\[ y_B(x) := a_2 + b_2 \cdot x + c_2 \cdot x^2 + d_2 \cdot x^3 + e_2 \cdot x^4 + f_2 \cdot x^5 \]

\[ y_{yB_k} := y_B \left(\text{TempSat}_B_k\right) \]

\[ y_C(x) := a_3 + b_3 \cdot x + c_3 \cdot x^2 + d_3 \cdot x^3 + e_3 \cdot x^4 + f_3 \cdot x^5 \]

\[ y_{yC_{ii}} := y_C \left(\text{TempSat}_C_{ii}\right) \]
Obtain Saturation Temperature as a function of the Saturation Pressure for curve fit of the data

\[ jj := 0, 1 .. 13 \]
\[ PressSatAA_{jj} := PressSat_{jj} \]
\[ TempSatAA_{jj} := TempSat_{jj} \]

\[ kk := 0, 1 .. 13 \]
\[ PressSatBB_{kk} := PressSat_{kk+13} \]
\[ TempSatBB_{kk} := TempSat_{kk+13} \]

\[ ll := 0, 1 .. 25 \]
\[ PressSatCC_{ll} := PressSat_{ll+26} \]
\[ TempSatCC_{ll} := TempSat_{ll+26} \]

\[ mm := 0, 1 .. 26 \]
\[ PressSatDD_{mm} := PressSat_{mm+51} \]
\[ TempSatDD_{mm} := TempSat_{mm+51} \]

\[ \text{coefAA} := \text{regress}(\text{PressSatAA, TempSatAA}, 5) \]

\[
\text{coefAA} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
3.11665 \times 10^2 \\
5.226588 \times 10^{-1} \\
-2.4482536 \times 10^{-3} \\
6.1177729 \times 10^{-6} \\
-7.2119979 \times 10^{-9} \\
3.1726317 \times 10^{-12}
\end{pmatrix}
\]

\[ a4 := \text{coefAA}_3 \]
\[ a4 = 3.11665 \times 10^2 \]
\[ b4 := \text{coefAA}_4 \]
\[ b4 = 5.226588 \times 10^{-1} \]
\[ c4 := \text{coefAA}_5 \]
\[ c4 = -2.4482536 \times 10^{-3} \]
\[ d4 := \text{coefAA}_6 \]
\[ d4 = 6.1177729 \times 10^{-6} \]
\[ e4 := \text{coefAA}_7 \]
\[ e4 = -7.2119979 \times 10^{-9} \]
\[ f4 := \text{coefAA}_8 \]
\[ f4 = 3.1726317 \times 10^{-12} \]
coefBB := regress (PressSatBB , TempSatBB, 5)

coefBB = 
\[
\begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
3.6046486 \times 10^2 \\
3.3908292 \times 10^{-2} \\
-8.3471991 \times 10^{-6} \\
1.1262937 \times 10^{-9} \\
-7.0086055 \times 10^{-14} \\
1.5631488 \times 10^{-18}
\end{pmatrix}
\]

\[
a5 := \text{coefBB}_3 \quad a5 = 3.6046486 \times 10^2 \\
b5 := \text{coefBB}_4 \quad b5 = 3.3908292 \times 10^{-2} \\
c5 := \text{coefBB}_5 \quad c5 = -8.3471991 \times 10^{-6} \\
d5 := \text{coefBB}_6 \quad d5 = 1.1262937 \times 10^{-9} \\
e5 := \text{coefBB}_7 \quad e5 = -7.0086055 \times 10^{-14} \\
f5 := \text{coefBB}_8 \quad f5 = 1.5631488 \times 10^{-18}
\]

coefCC := regress (PressSatCC , TempSatCC, 5)

coefCC = 
\[
\begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
4.2350153 \times 10^2 \\
2.7182873 \times 10^{-3} \\
-3.4561189 \times 10^{-8} \\
2.6853777 \times 10^{-13} \\
-1.0494985 \times 10^{-18} \\
1.5912214 \times 10^{-24}
\end{pmatrix}
\]

\[
a6 := \text{coefCC}_3 \quad a6 = 4.2350153 \times 10^2 \\
b6 := \text{coefCC}_4 \quad b6 = 2.7182873 \times 10^{-3} \\
c6 := \text{coefCC}_5 \quad c6 = -3.4561189 \times 10^{-8} \\
d6 := \text{coefCC}_6 \quad d6 = 2.6853777 \times 10^{-13} \\
e6 := \text{coefCC}_7 \quad e6 = -1.0494985 \times 10^{-18} \\
f6 := \text{coefCC}_8 \quad f6 = 1.5912214 \times 10^{-24}
\]
coefDD := regress (PressSatDD, TempSatDD, 5)

\[
\text{coefDD} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
4.9952136 \times 10^2 \\
4.1580955 \times 10^{-4} \\
-5.537146 \times 10^{-10} \\
5.0373204 \times 10^{-16} \\
-2.4616154 \times 10^{-22} \\
4.8748475 \times 10^{-29}
\end{pmatrix}
\]

a7 := coefDD_3 
\[ a7 = 4.9952136 \times 10^2 \]

b7 := coefDD_4 
\[ b7 = 4.1580955 \times 10^{-4} \]

c7 := coefDD_5 
\[ c7 = -5.537146 \times 10^{-10} \]

d7 := coefDD_6 
\[ d7 = 5.0373204 \times 10^{-16} \]

e7 := coefDD_7 
\[ e7 = -2.4616154 \times 10^{-22} \]

f7 := coefDD_8 
\[ f7 = 4.8748475 \times 10^{-29} \]

tAA (x) := a4 + b4 \cdot x + c4 \cdot x^2 + d4 \cdot x^3 + e4 \cdot x^4 + f4 \cdot x^5

ttAA_{jj} := tAA(\text{PressSatAA}_{jj})

tBB(x) := a5 + b5 \cdot x + c5 \cdot x^2 + d5 \cdot x^3 + e5 \cdot x^4 + f5 \cdot x^5

ttBB_{kk} := tBB(\text{PressSatBB}_{kk})

tCC(x) := a6 + b6 \cdot x + c6 \cdot x^2 + d6 \cdot x^3 + e6 \cdot x^4 + f6 \cdot x^5

ttCC_{ll} := tCC(\text{PressSatCC}_{ll})

tDD(x) := a7 + b7 \cdot x + c7 \cdot x^2 + d7 \cdot x^3 + e7 \cdot x^4 + f7 \cdot x^5

ttDD_{mm} := tDD(\text{PressSatDD}_{mm})
Saturated Temperature as a Function of Pressure

- DowthermA Data
- Curve fit
- Curve fit
- Curve fit
- Curve fit
Next we will determine the curve fit for the liquid saturated density as a function of temperature.

\[ k_k := 0, 1 \ldots 83 \]

\[
\begin{align*}
  SLDT_{kk} & := BB_{kk+4, 1} \\
  SLD_{kk} & := BB_{kk+4, 9} \\
  SLVT_{kk} & := SLDT_{kk} \\
  SLV_{kk} & := \frac{1}{SLD_{kk}}
\end{align*}
\]

\[
\text{coefLD} := \text{regrss} \left( SLDT, SLD, 5 \right)
\]

\[
\text{coefLD} = \begin{pmatrix}
  3 \times 10^0 \\
  3 \times 10^0 \\
  5 \times 10^0 \\
  1.4924628 \times 10^3 \\
  -3.331716 \times 10^0 \\
  1.2479716 \times 10^{-2} \\
  -2.9684039 \times 10^{-5} \\
  3.4437643 \times 10^{-8} \\
  -1.6215295 \times 10^{-11}
\end{pmatrix}
\]

\[
a_8 := \text{coefLD}_3 \\
b_8 := \text{coefLD}_4 \\
c_8 := \text{coefLD}_5 \\
d_8 := \text{coefLD}_6 \\
e_8 := \text{coefLD}_7 \\
f_8 := \text{coefLD}_8
\]

\[
y_{LD}(T) := a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3 + e_8 \cdot T^4 + f_8 \cdot T^5
\]

\[
yy_{LD_{kk}} := y_{LD}(SLDT_{kk})
\]
Saturated Liquid Density

Liquid Saturated Enthalpy

\[ \text{ELT}_i := \text{BB}_{i+6,1} \]

\[ \text{EL}_i := \text{BB}_{i+6,4} \cdot 1000 \]
coefLE := regress (ELT, EL, 5)

$$\begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-6.5113067 \times 10^5 \\
4.1213664 \times 10^3 \\
-1.2345938 \times 10^1 \\
2.7710651 \times 10^{-2} \\
-2.7764463 \times 10^{-5} \\
1.1056661 \times 10^{-8}
\end{pmatrix}$$

$$a_9 := \text{coefLE}_3 \quad a_9 = -6.5113067 \times 10^5$$

$$b_9 := \text{coefLE}_4 \quad b_9 = 4.1213664 \times 10^3$$

$$c_9 := \text{coefLE}_5 \quad c_9 = -1.2345938 \times 10^1$$

$$d_9 := \text{coefLE}_6 \quad d_9 = 2.7710651 \times 10^{-2}$$

$$e_9 := \text{coefLE}_7 \quad e_9 = -2.7764463 \times 10^{-5}$$

$$f_9 := \text{coefLE}_8 \quad f_9 = 1.1056661 \times 10^{-8}$$

$$y_{\text{EL}}(T) := a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3 + e_9 \cdot T^4 + f_9 \cdot T^5$$

$$y_{\text{yEL}} := \hat{y}_{\text{EL}}(\hat{T})$$

**Saturated Liquid Enthalpy**

---

**Dowtherm A Data**
**Curve fit**
Saturated Liquid Specific Heat

\[ i := 0, 1 \ldots 84 \]

\[ \text{CPLT}_i := \text{BB}_i + 4, 1 \quad \text{CPL}_i := \text{BB}_i + 4, 7 \times 1000 \]

\[ \text{coefCPL} := \text{regress} \left( \text{CPLT}, \text{CPL}, 5 \right) \]

\[ \text{coefCPL} = \begin{pmatrix} 3 \times 10^0 \\ 3 \times 10^0 \\ 5 \times 10^0 \\ -2.3634842 \times 10^3 \\ 3.9461021 \times 10^1 \\ -1.7024546 \times 10^{-1} \\ 3.903868 \times 10^{-4} \\ -4.421524 \times 10^{-7} \\ 1.9792489 \times 10^{-10} \end{pmatrix} \]

\[ a_{10} := \text{coefCPL}_3 \quad a_{10} = -2.3634842 \times 10^3 \]

\[ b_{10} := \text{coefCPL}_4 \quad b_{10} = 3.9461021 \times 10^1 \]

\[ c_{10} := \text{coefCPL}_5 \quad c_{10} = -1.7024546 \times 10^{-1} \]

\[ d_{10} := \text{coefCPL}_6 \quad d_{10} = 3.903868 \times 10^{-4} \]

\[ e_{10} := \text{coefCPL}_7 \quad e_{10} = -4.421524 \times 10^{-7} \]

\[ f_{10} := \text{coefCPL}_8 \quad f_{10} = 1.9792489 \times 10^{-10} \]

\[ y_{\text{CPL}}(T) := a_{10} + b_{10} \cdot T + c_{10} \cdot T^2 + d_{10} \cdot T^3 + e_{10} \cdot T^4 + f_{10} \cdot T^5 \]

\[ y_{y\text{CPL}_1} := y_{\text{CPL}}(\text{CPLT}_1) \]
Saturated Liquid Specific Heat

Liquid Specific Heat (J/kg-K)

Temperature (K)

Dowtherm A Data

Curve fit
Liquid Thermal Conductivity

\[ i := 0, 1 \ldots 84 \]

\[ TCL_i := BB_{i+4,1} \]

\[ TCL_i := BB_{i+4,8} \]

\[ \text{coefTCL} := \text{regress} \left( TCL, TCL, 2 \right) \]

\[
\text{coefTCL} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
2 \times 10^0 \\
1.8560707 \times 10^{-1} \\
-1.60008 \times 10^{-4} \\
5.9133304 \times 10^{-12}
\end{pmatrix}
\]

\[ a11 := \text{coefTCL}_3 \]

\[ a11 = 1.8560707 \times 10^{-1} \]

\[ b11 := \text{coefTCL}_4 \]

\[ b11 = -1.60008 \times 10^{-4} \]

\[ c11 := \text{coefTCL}_5 \]

\[ c11 = 5.9133304 \times 10^{-12} \]

\[ yTCL(T) := a11 + b11 \cdot T + c11 \cdot T^2 \]

\[ yTCL : yTCL \left( TCL_i \right) \]

Liquid Thermal Conductivity

![Graph showing liquid thermal conductivity vs temperature](image-url)
Liquid Viscosity

\[ i := 0, 1 \ldots 84 \]

\[ VLT_i := BB_{i+4, 1} \quad VL_i := BB_{i+4, 6} \cdot 10^{-3} \]

\[
\text{coefVL} :=
\begin{array}{c|c}
0 & 3 \cdot 10^0 \\
1 & 3 \cdot 10^0 \\
2 & 8 \cdot 10^0 \\
3 & 5.1346826 \cdot 10^0 \\
4 & -8.395359 \cdot 10^{-2} \\
5 & 5.9705155 \cdot 10^{-4} \\
6 & -2.4092211 \cdot 10^{-6} \\
7 & 6.0292345 \cdot 10^{-9} \\
8 & -9.5788095 \cdot 10^{-12} \\
9 & 9.4330297 \cdot 10^{-15} \\
10 & -5.2643677 \cdot 10^{-18} \\
11 & 1.274782 \cdot 10^{-21} \\
\end{array}
\]

\[ a_{12} := \text{coefVL}_3 \quad a_{12} = 5.1346826 \times 10^0 \]

\[ b_{12} := \text{coefVL}_4 \quad b_{12} = -8.395359 \times 10^{-2} \]

\[ c_{12} := \text{coefVL}_5 \quad c_{12} = 5.9705155 \times 10^{-4} \]

\[ d_{12} := \text{coefVL}_6 \quad d_{12} = -2.4092211 \times 10^{-6} \]

\[ e_{12} := \text{coefVL}_7 \quad e_{12} = 6.0292345 \times 10^{-9} \]

\[ f_{12} := \text{coefVL}_8 \quad f_{12} = -9.5788095 \times 10^{-12} \]

\[ g_{12} := \text{coefVL}_9 \quad g_{12} = 9.4330297 \times 10^{-15} \]

\[ h_{12} := \text{coefVL}_{10} \quad h_{12} = -5.2643677 \times 10^{-18} \]

\[ i_{12} := \text{coefVL}_{11} \quad i_{12} = 1.274782 \times 10^{-21} \]

\[ y_{VL}(T) := a_{12} \cdot T + b_{12} \cdot T^2 + c_{12} \cdot T^3 + d_{12} \cdot T^4 + e_{12} \cdot T^5 + f_{12} \cdot T^6 + g_{12} \cdot T^7 + h_{12} \cdot T^8 \]

\[ \text{yyVL}_i := y_{VL}(VLT_i) \]
DowTherm A Data
Curve fit

Liquid Viscosity

Temperature (K)

Liquid Viscosity (Pa-sec)
Saturated Vapor Density (function of temperature)

$kk := 0, 1.. 77$

$ii := 0, 1.. 29$

$jj := 0, 1.. 48$

$SVDT_{kk} := AA_{kk+12, 1}$

$SVD_{kk} := AA_{kk+12, 8}$

$SVVT_{kk} := SVDT_{kk}$

$SVDT1_{ii} := AA_{ii+12, 1}$

$SVD1_{ii} := AA_{ii+12, 8}$

$SVVT_{kk} := SVDT_{kk}$

$SVDT2_{jj} := AA_{jj+41, 1}$

$SVD2_{jj} := AA_{jj+41, 8}$

$SVVT_{kk} := SVDT_{kk}$

$coefVD1 := \text{regress} (SVDT1, SVD1, 5)$

$$
coefVD1 = \begin{pmatrix}
3 	imes 10^0 \\
3 	imes 10^0 \\
5 	imes 10^0 \\
-1.4782864 	imes 10^1 \\
2.4583636 	imes 10^{-1} \\
-1.6311806 	imes 10^{-3} \\
5.4074108 	imes 10^{-6} \\
-8.9697241 	imes 10^{-9} \\
5.9645469 	imes 10^{-12}
\end{pmatrix}
$$

$a13 := coefVD1_3$

$a13 = -1.4782864 \times 10^1$

$b13 := coefVD1_4$

$b13 = 2.4583636 \times 10^{-1}$

$c13 := coefVD1_5$

$c13 = -1.6311806 \times 10^{-3}$

$d13 := coefVD1_6$

$d13 = 5.4074108 \times 10^{-6}$

$e13 := coefVD1_7$

$e13 = -8.9697241 \times 10^{-9}$

$f13 := coefVD1_8$

$f13 = 5.9645469 \times 10^{-12}$

$$yVD1(T) := a13 + b13 \cdot T + c13 \cdot T^2 + d13 \cdot T^3 + e13 \cdot T^4 + f13 \cdot T^5$$

$$yyVD1_{ii} := yVD1(SVDT1_{ii})$$
coefVD2 := regress (SVDT2, SVD2, 5)

\[
\text{coefVD2} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-3.8236587 \times 10^3 \\
3.520539 \times 10^1 \\
-1.2954953 \times 10^{-1} \\
2.3859569 \times 10^{-4} \\
-2.2068 \times 10^{-7} \\
8.2509961 \times 10^{-11}
\end{pmatrix}
\]

a14 := coefVD23 = \(-3.8236587 \times 10^3\)
b14 := coefVD24 = \(3.520539 \times 10^1\)
c14 := coefVD25 = \(-1.2954953 \times 10^{-1}\)
d14 := coefVD26 = \(2.3859569 \times 10^{-4}\)
e14 := coefVD27 = \(-2.2068000 \times 10^{-7}\)
f14 := coefVD28 = \(8.2509961 \times 10^{-11}\)

\[
yVD2(T) := a14 + b14 \cdot T + c14 \cdot T^2 + d14 \cdot T^3 + e14 \cdot T^4 + f14 \cdot T^5
\]

\[
yyVD2_{jj} := yVD2(SVDT2_{jj})
\]

\[\text{Saturated Vapor Density}\]

\[\text{Density (kg/m}^3\)\]

\[\text{Temperature (K)}\]
Saturated Vapor Density (function of pressure)

\[ \text{k} \text{k} \text{k} := 0, 1..77 \quad \text{i} \text{i} \text{i} := 0, 1..16 \quad \text{j} \text{j} \text{j} := 0, 1..51 \quad \text{m} \text{m} \text{m} := 0, 1..10 \]

\[
\begin{aligned}
\text{SVDP}_{\text{k} \text{k} \text{k}} &:= \text{AA}_{\text{k} \text{k} \text{k}+12, 3} \\
\text{SVDP0}_{\text{m} \text{m} \text{m}} &:= \text{AA}_{\text{m} \text{m} \text{m}+12, 3} \\
\text{SVDP10}_{\text{i} \text{i} \text{i}} &:= \text{AA}_{\text{i} \text{i} \text{i}+22, 3} \\
\text{SVDP11}_{\text{j} \text{j} \text{j}} &:= \text{AA}_{\text{j} \text{j} \text{j}+38, 3}
\end{aligned}
\]

\[
\begin{aligned}
\text{SVD}_{\text{k} \text{k} \text{k}} &:= \text{AA}_{\text{k} \text{k} \text{k}+12, 8} \\
\text{SVD0}_{\text{m} \text{m} \text{m}} &:= \text{AA}_{\text{m} \text{m} \text{m}+12, 8} \\
\text{SVD10}_{\text{i} \text{i} \text{i}} &:= \text{AA}_{\text{i} \text{i} \text{i}+22, 8} \\
\text{SVD11}_{\text{j} \text{j} \text{j}} &:= \text{AA}_{\text{j} \text{j} \text{j}+38, 8}
\end{aligned}
\]

coeffVDP0 := regress (SVDP09, SVD09, 5)

coeffVDP0 = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
4.3907887 \times 10^{-5} \\
6.1186085 \times 10^{-5} \\
-5.4005346 \times 10^{-8} \\
2.2447957 \times 10^{-10} \\
-5.4216865 \times 10^{-13} \\
5.2196703 \times 10^{-16}
\end{pmatrix}

\begin{aligned}
a21 &= \text{coeffVDP0}_3 \\
b21 &= \text{coeffVDP0}_4 \\
c21 &= \text{coeffVDP0}_5 \\
d21 &= \text{coeffVDP0}_6 \\
e21 &= \text{coeffVDP0}_7 \\
f21 &= \text{coeffVDP0}_8
\end{aligned}

\begin{aligned}
a21 &= 4.3907887 \times 10^{-5} \\
b21 &= 6.1186085 \times 10^{-5} \\
c21 &= -5.4005346 \times 10^{-8} \\
d21 &= 2.2447957 \times 10^{-10} \\
e21 &= -5.4216865 \times 10^{-13} \\
f21 &= 5.2196703 \times 10^{-16}
\end{aligned}

\[ y\text{VDP0}(P) := a21 + b21 \cdot P + c21 \cdot P^2 + d21 \cdot P^3 + e21 \cdot P^4 + f21 \cdot P^5 \]

\[ y\text{yVDP0}_{\text{m} \text{m} \text{m}} := y\text{VDP0}(\text{SVDP0}_{\text{m} \text{m} \text{m}}) \]
coefVDP1 := regress (SVDP10, SVD10, 5)

\[\text{coefVDP1} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
4.1436614 \times 10^{-3} \\
4.1869059 \times 10^{-5} \\
8.4148018 \times 10^{-9} \\
-3.5687549 \times 10^{-12} \\
4.8933523 \times 10^{-16} \\
-2.1103999 \times 10^{-20}
\end{pmatrix}\]

\[a_{15} := \text{coefVDP1}_3 \quad a_{15} = 4.1436614 \times 10^{-3}\]

\[b_{15} := \text{coefVDP1}_4 \quad b_{15} = 4.1869059 \times 10^{-5}\]

\[c_{15} := \text{coefVDP1}_5 \quad c_{15} = 8.4148018 \times 10^{-9}\]

\[d_{15} := \text{coefVDP1}_6 \quad d_{15} = -3.5687549 \times 10^{-12}\]

\[e_{15} := \text{coefVDP1}_7 \quad e_{15} = 4.8933523 \times 10^{-16}\]

\[f_{15} := \text{coefVDP1}_8 \quad f_{15} = -2.1103999 \times 10^{-20}\]

\[y_{VDP1}(P) := a_{15} + b_{15} \cdot P + c_{15} \cdot P^2 + d_{15} \cdot P^3 + e_{15} \cdot P^4 + f_{15} \cdot P^5\]

\[y_{yVDP1_{iii}} := y_{VDP1}(SVDP10_{iii})\]

coefVDP2 := regress (SVDP11, SVD11, 5)

\[\text{coefVDP2} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
9.4541624 \times 10^{-2} \\
3.9168528 \times 10^{-5} \\
-9.3398726 \times 10^{-12} \\
1.6964024 \times 10^{-17} \\
-1.0100497 \times 10^{-23} \\
2.5237283 \times 10^{-30}
\end{pmatrix}\]

\[a_{16} := \text{coefVDP2}_3 \quad a_{16} = 9.4541624 \times 10^{-2}\]

\[b_{16} := \text{coefVDP2}_4 \quad b_{16} = 3.9168528 \times 10^{-5}\]

\[c_{16} := \text{coefVDP2}_5 \quad c_{16} = -9.3398726 \times 10^{-12}\]

\[d_{16} := \text{coefVDP2}_6 \quad d_{16} = 1.6964024 \times 10^{-17}\]

\[e_{16} := \text{coefVDP2}_7 \quad e_{16} = -1.0100497 \times 10^{-23}\]

\[f_{16} := \text{coefVDP2}_8 \quad f_{16} = 2.5237283 \times 10^{-30}\]

\[y_{VDP2}(P) := a_{16} + b_{16} \cdot P + c_{16} \cdot P^2 + d_{16} \cdot P^3 + e_{16} \cdot P^4 + f_{16} \cdot P^5\]

\[y_{yVDP2_{jjj}} := y_{VDP2}(SVDP11_{jjj})\]
Saturated Vapor Density

- DowTherm A Data
- Curve fit
- Curve fit
- Curve fit

Vapor Density vs. Pressure (Pa)
Saturated Vapor Enthalpy

\[ \text{i}ii := 0, 1..30 \quad \text{j}jj := 0, 1..47 \]

\[ \text{EVT}_{kkk} := AA_{kkk+12,1} \quad \text{EV}_{kkk} := AA_{kkk+12,6\times10^0} \]

\[ \text{EVT}_{1\_kkk} := AA_{kkk+12,1} \quad \text{EV}_{1\_kkk} := AA_{kkk+12,6\times10^0} \]

\[ \text{EVT}_{2\_jjj} := AA_{jjj+42,1} \quad \text{EV}_{2\_jjj} := AA_{jjj+42,6\times10^0} \]

\[ \text{coefVE} := \text{regress} \left( \text{EVT1, EV1, 5} \right) \]

\[ \text{coefVE} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
4.0037648 \times 10^5 \\
-1.4430833 \times 10^3 \\
7.5788702 \times 10^0 \\
-1.1160471 \times 10^{-2} \\
1.1033323 \times 10^{-5} \\
-5.1344363 \times 10^{-9}
\end{pmatrix} \]

\[ a_{17} := \text{coefVE}_3 \quad a_{17} = 4.0037648 \times 10^5 \]

\[ b_{17} := \text{coefVE}_4 \quad b_{17} = -1.4430833 \times 10^3 \]

\[ c_{17} := \text{coefVE}_5 \quad c_{17} = 7.5788702 \times 10^0 \]

\[ d_{17} := \text{coefVE}_6 \quad d_{17} = -1.1160471 \times 10^{-2} \]

\[ e_{17} := \text{coefVE}_7 \quad e_{17} = 1.1033323 \times 10^{-5} \]

\[ f_{17} := \text{coefVE}_8 \quad f_{17} = -5.1344363 \times 10^{-9} \]

\[ \text{yEV(T)} := a_{17} + b_{17} \cdot T + c_{17} \cdot T^2 + d_{17} \cdot T^3 + e_{17} \cdot T^4 + f_{17} \cdot T^5 \]

\[ \text{yyEV}_{kkk} := \text{yEV( EVT}_{1\_kkk}) \]
Saturated Vapor Enthalpy

- DowTherm A Data
- Curve fit
Saturated Vapor Specific Heat

\[
\begin{align*}
CPVT_{kkk} &:= AA_{kkk+12,1} \\
CPV_{kkk} &:= AA_{kkk+12,12}^{100} \\
coefCPV &:= \text{regress} \left( CPVT, CPV, 5 \right)
\end{align*}
\]

\[
\text{coefCPV} = \left( \begin{array}{c}
3 \times 10^0 \\
3 \times 10^0 \\
5 \times 10^0 \\
-5.4257162 \times 10^3 \\
6.2481899 \times 10^1 \\
-2.5315506 \times 10^{-1} \\
5.4316452 \times 10^{-4} \\
-5.8419137 \times 10^{-7} \\
2.5078084 \times 10^{-10}
\end{array} \right)
\]

\[
y_{CPV(T)} := a_{18} + b_{18} \cdot T + c_{18} \cdot T^2 + d_{18} \cdot T^3 + e_{18} \cdot T^4 + f_{18} \cdot T^5
\]

\[
yy_{CPV_{kkk}} := y_{CPV} \left( CPVT_{kkk} \right)
\]
Dowtherm A Data

Curve fit

Temperature (K)

Saturated Vapor Specific Heat

Vapor Specific Heat (J/kg-K)

Vapor Thermal Conductivity

\[ TCV_{kkk} := AA_{kkk+12, 1} \]

\[ TCV_{kkk} := AA_{kkk+12, 10} \]

\[
\text{coefTCV} := \text{regress} (TCVT, TCV, 2)
\]

\[
\text{coefTCV} = \begin{pmatrix}
3 \times 10^0 \\
3 \times 10^0 \\
2 \times 10^0 \\
-5.1371078 \times 10^{-3} \\
3.0160784 \times 10^{-5} \\
4.6682186 \times 10^{-8}
\end{pmatrix}
\]

\[ a19 := \text{coefTCV}_3 \quad a19 = -5.1371078 \times 10^{-3} \]

\[ b19 := \text{coefTCV}_4 \quad b19 = 3.0160784 \times 10^{-5} \]

\[ c19 := \text{coefTCV}_5 \quad c19 = 4.6682186 \times 10^{-8} \]

\[ yTCV(T) := a19 + b19 \cdot T + c19 \cdot T^2 \]

\[ yyTCV_{kkk} := yTCV(TCV_{kkk}) \]
Vapor Viscosity

\[ VVT_{kkk} := AA_{kkk+12}, 1 \]

\[ VV_{kkk} := AA_{kkk+12}, 9 \times 10^{-3} \]

\[
\text{coefVV} := \begin{pmatrix}
3 \times 10^0 \\
5 \times 10^0 \\
-5.757664\times 10^{-6} \\
9.6177368\times 10^{-8} \\
-4.0133099\times 10^{-10} \\
1.0111926\times 10^{-12} \\
-1.249214\times 10^{-15} \\
6.1138665\times 10^{-19}
\end{pmatrix}
\]

\[ y(V)(T) := a_{20} + b_{20} \cdot T + c_{20} \cdot T^2 + d_{20} \cdot T^3 + e_{20} \cdot T^4 + f_{20} \cdot T^5 \]

\[ yy_{kkk} := y(V)(VVT_{kkk}) \]
Vapor Viscosity

Temperature (K)

Viscosity (Pa-sec)

DowTherm A Data
Curve fit