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

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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 conjection with the experiments RELAP5-3D/ATHENA will be used to help design and analyzed the data generated by the experiments. Inorder to use RELAP5-3D the thermophysical properties of DOWTHERM A were implemented into the fluids package of the RELAP5-3D/ATHENA computer propgram.

DOWTHERM A properties were implemented in RELAP5-3D/ATHENA using thermophysical property data obtain 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 orginal DOWTHERM A data to verify that the fluid property data generated by the RELAP5-3D/ATHENA code was representitive of the original input data to the generator.

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Tables

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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 conjection 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 Brekeley 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 presssure curve, saturated liquid and vapor density, saturated liquid and vapor enthaply, 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 showen in Table 1.

Table 1: Thermodynamic properties that are contained in file tpfdowa

Quantity	Symbol	SI Units
Temperature	T	K
Pressure	P	Pa
Specific Volume	v	m^3/kg
Specific Internal Energy	u	J/kg
Specific Enthalpy	h	J/kg
Specific Entropy	s	J/kg-K
Coefficient of Isobaric Thermal Expansion	$\beta = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_p$	1/K
Coefficient of Isothermal Compressibility	$\kappa = -\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T$	1/Pa
Specific Heat at Constant Pressure	C_p	J/kg-K
Thermal Conductivity	k	W/m-K
Dynamic Viscosity	μ	Pa-sec

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 properies for density, specific heat, pressure, thermal conductivity, and viscosity from 285.15 K to 698.15 K. The data were copied into an Excel spread sheet, then import into Mathcad where regression analyses were conducted to obtain n^{th} 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 requied 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

Property	a	b	c	d	e	f
Density	1.493E+03	-3.332E+00	1.248E-02	-2.968E-05	3.444E-08	-1.622E-11
Enthalpy	-6.511E+05	4.121E+03	-1.235E+01	2.771E-02	-2.777E-05	1.106E-08
Specific Heat	-2.364E+03	3.946E+01	-1.703E-01	3.904E-04	-4.422E-07	1.979E-10
Conductivity	1.856E-01	-1.600E-04	5.913E-12			
Viscosity	5.135E+00	-8.395E-02	5.971E-04	-2.409E-06	6.029E-09	-9.579E-12

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

$$property = a + bT + cT^2 + dT^3 + eT^4 + fT^5 \quad (1)$$

Shown in Figures 1,2 and 3 are plots of the DOWTHERM A data and the corresponding curve fits for saturated liquid specific volume (m3/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

$$v_f^s = \frac{1}{\rho_f^s} \quad (2)$$

where ρ_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

$$u_f^s = h_f^s - pv_f^s \quad (3)$$

where u_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 v_f^s is the specific volume of the saturated liquid.

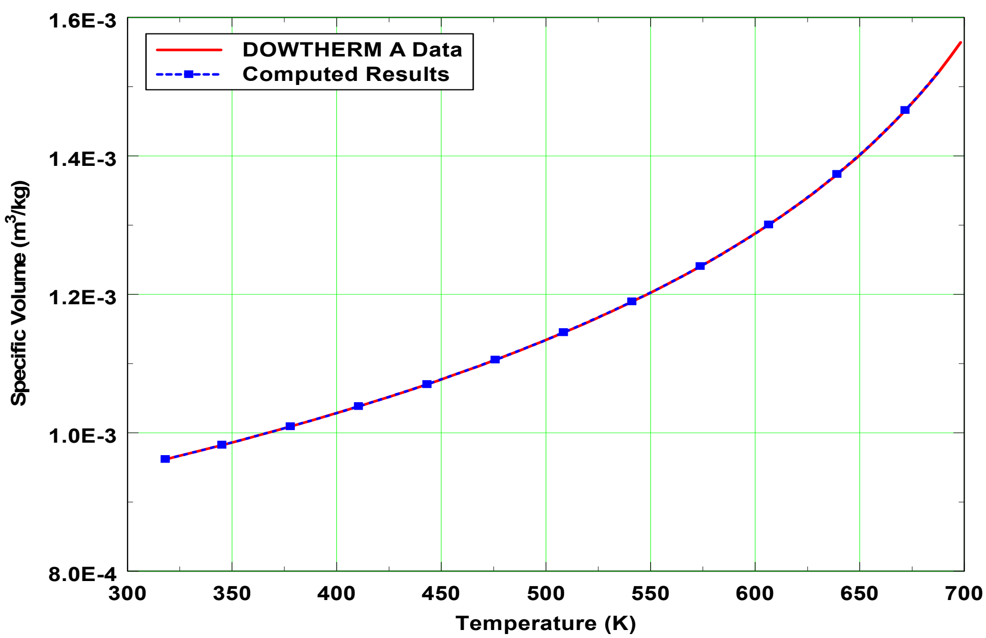


Figure 1: Specific volume of saturated liquid

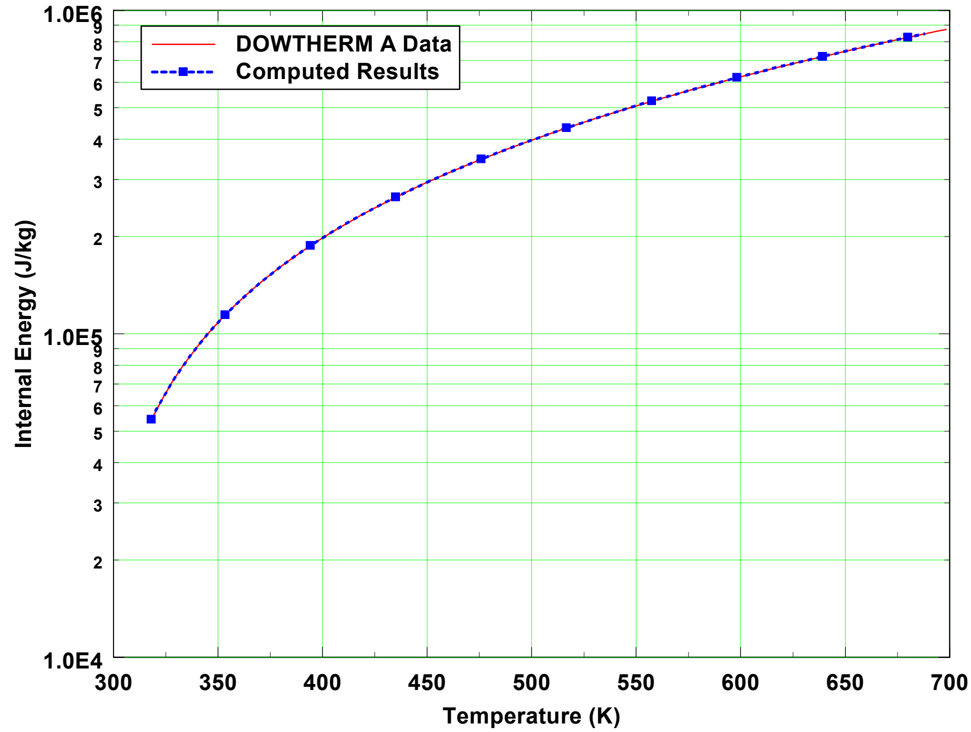


Figure 2: Specific internal energy of saturated liquid

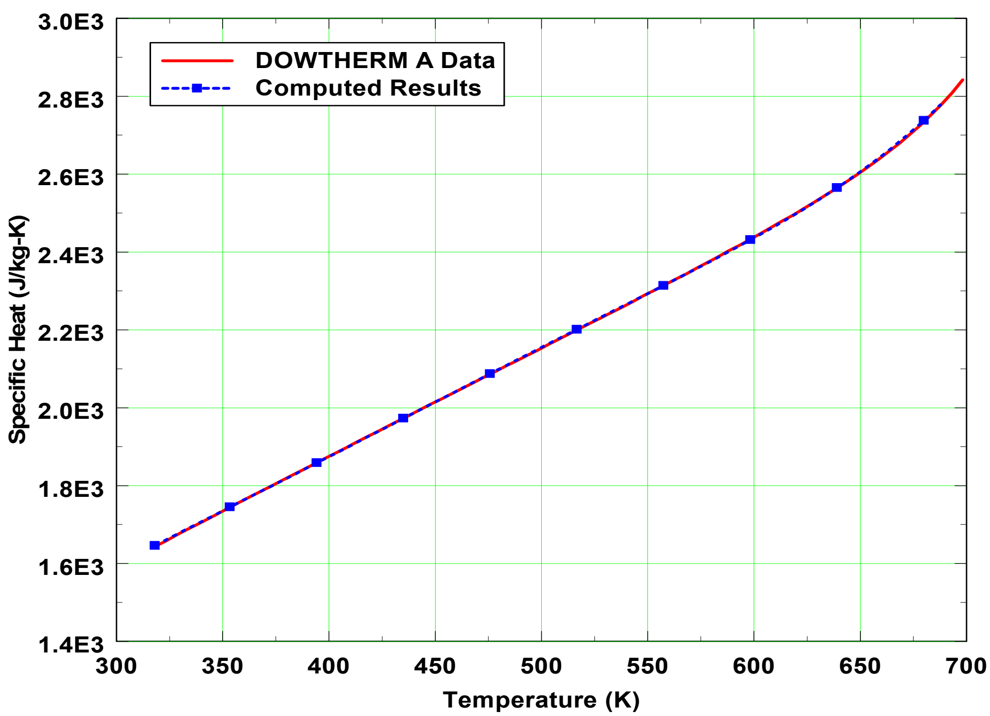


Figure 3: Specific heat capacity at constant pressure of saturated liquid

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

$$\beta_f^s = \frac{1}{v_f^s}\left(\frac{\partial v_f^s}{\partial T}\right)_p \tag{4}$$

however since there is no data give for the thermal expansion coefficient as a function of temperature we will compute β_f^s as follows

$$\beta_f^s \approx \frac{1}{v_f^s\left(p,T\right)}\left(\frac{v_f^s\left(p,T+\delta T\right)-v_f^s\left(p,T-\delta T\right)}{2\delta T}\right)_p \tag{5}$$

The isothermal compressibility for saturated liquid is define as

$$\kappa_f^s = -\frac{1}{v_f^s}\left(\frac{\partial v_f^s}{\partial p}\right)_T \tag{6}$$

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

$$\kappa_f^s \approx -\frac{1}{v_f^s\left(p,T\right)}\left(\frac{v_f^s\left(p+\delta p,T\right)-v_f^s\left(p-\delta p,T\right)}{2\delta p}\right)_T \tag{7}$$

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

$$s_f^s = \frac{u_f^s + p v_f^s}{T} \tag{8}$$

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.

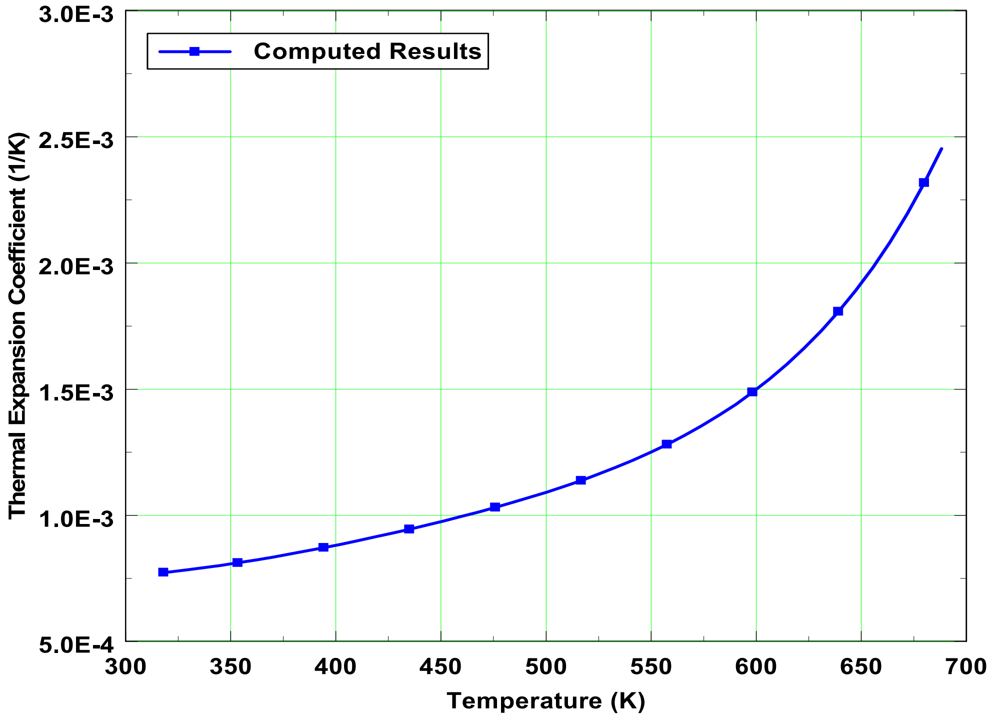


Figure 4: Coefficient of thermal expansion of saturated liquid

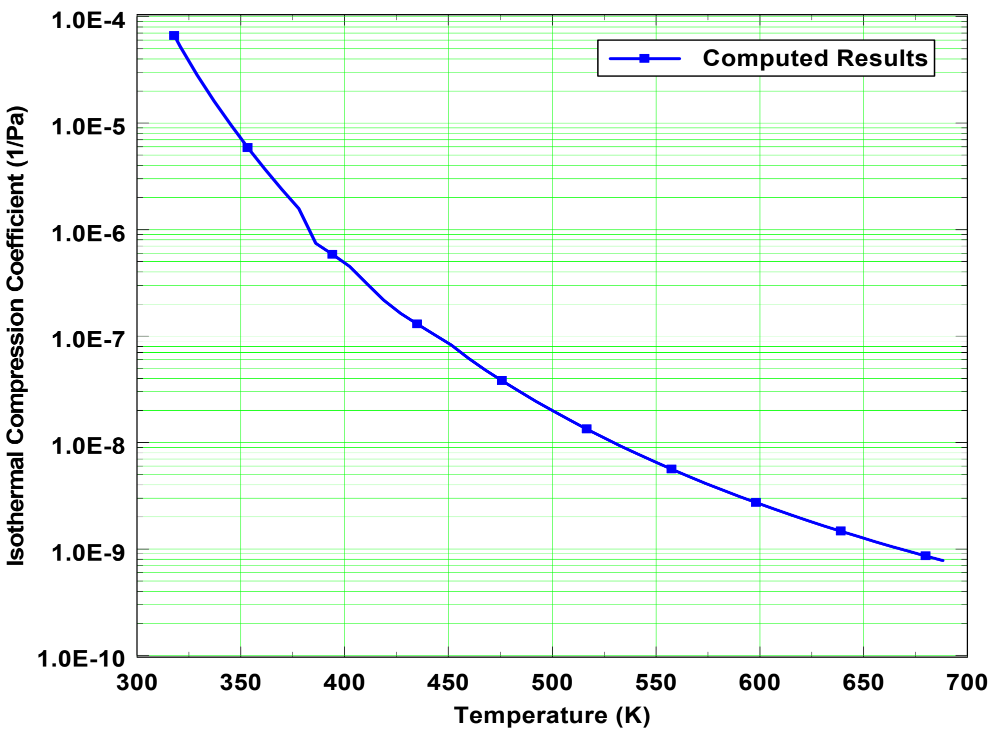


Figure 5: Isothermal compressibility of saturated liquid

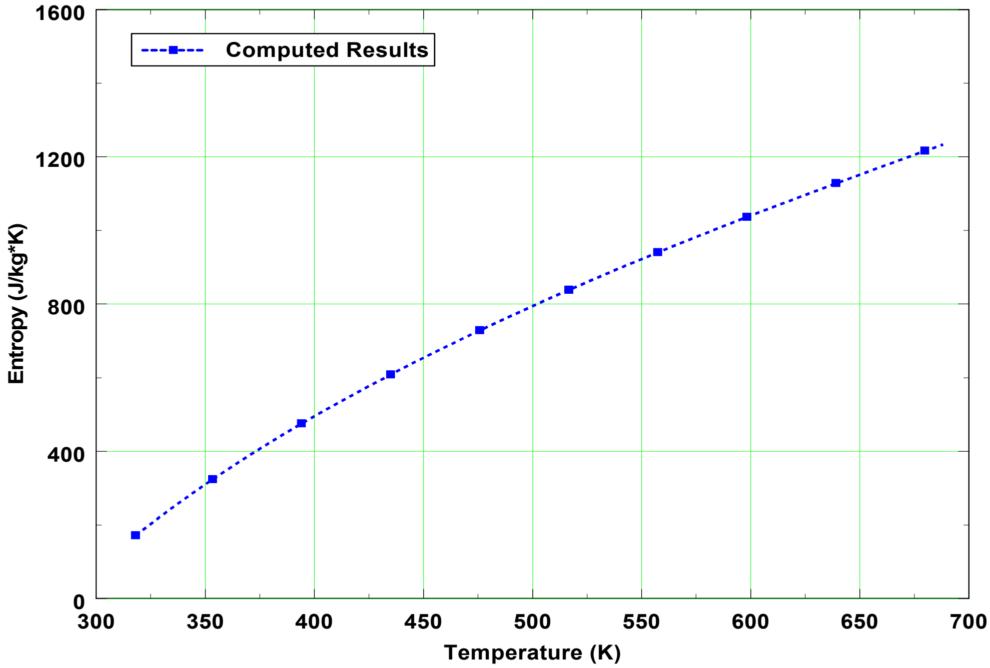


Figure 6: Specific entropy of saturated liquid

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.

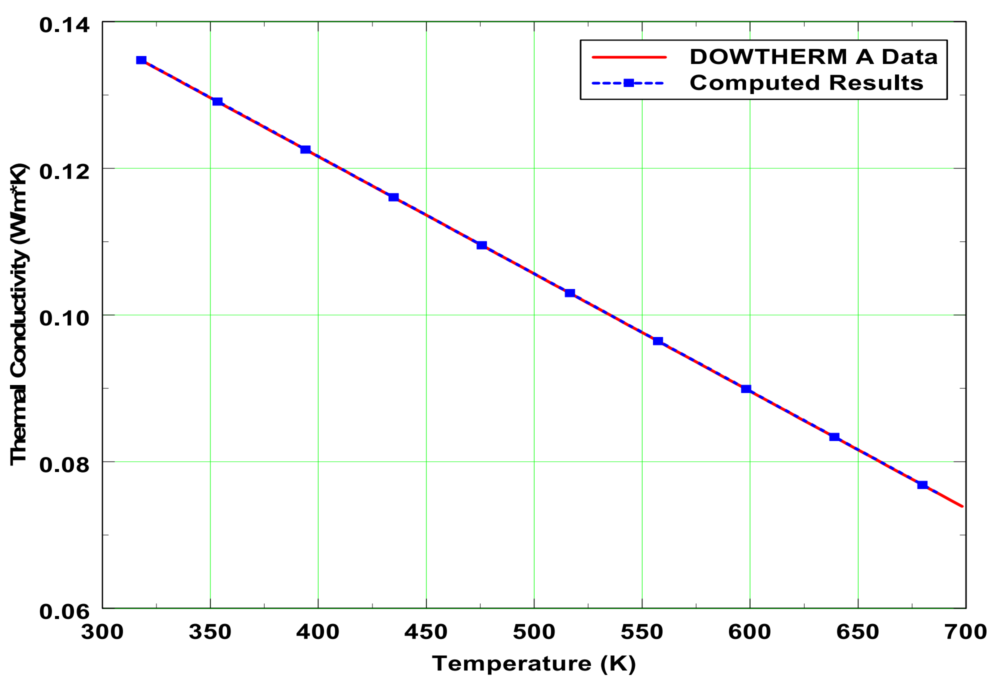


Figure 7: Thermal conductivity of saturated liquid

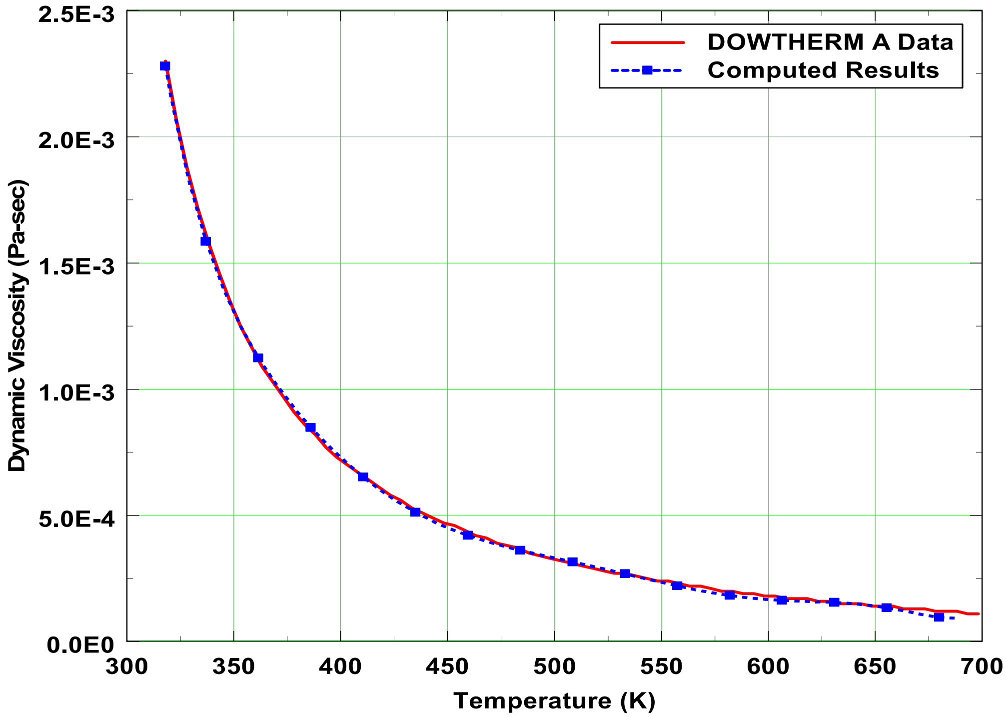


Figure 8: Dynamic viscosity of saturated liquid

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 $\rho(T,P)_f$ 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

$$\rho(T,P)_f = \left(a + bT + cT^2 + dT^3 + eT^4 + fT^5\right)\left(P \cdot dd\right)^{ee}$$
$$\text{where } dd = 1.0E-04, \; ee = 1.0E-03 \tag{9}$$

The remaining computed liquid thermodynamic properties u, s, β, and κ 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 properies for density, specific heat, pressure, thermal conductivity, and viscosity from 285.15 K to 698.15 K. The data were copied into an Excel spread sheet, then import 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 requied 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

Property	a	b	c	d	e	f	
Density	4.391E-05	6.119E-05	-5.401E-08	2.245E-10	-5.422E-13	5.220E-16	0<P≤400
	4.144E-03	4.187E-05	8.414E-09	-3.569E-12	4.893E-16	-2.110E-20	400<P≤11000
	9.454E-02	3.917E-05	-9.340E-12	1.696E-17	-1.010E-23	2.524E-30	P>11000
Enthalpy	4.004E+05	-1.443E+03	7.579E+00	-1.116E-02	1.103E-05	-5.134E-09	
Specific Heat	-5.426E+03	6.248E+01	-2.532E-01	5.432E-04	-5.842E-07	2.508E-10	
Conductivity	-5.137E-03	3.016E-04	4.668E-08				
Viscosity	-5.758E-06	9.618E-08	-4.013E-10	1.011E-12	-1.249E-15	6.114E-19	

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

$$v_g^s = \frac{1}{\rho_g^s} \tag{10}$$

where ρ_g^s is the density of the vapor.

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

$$u_g^s = h_g^s - p v_g^s \tag{11}$$

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.

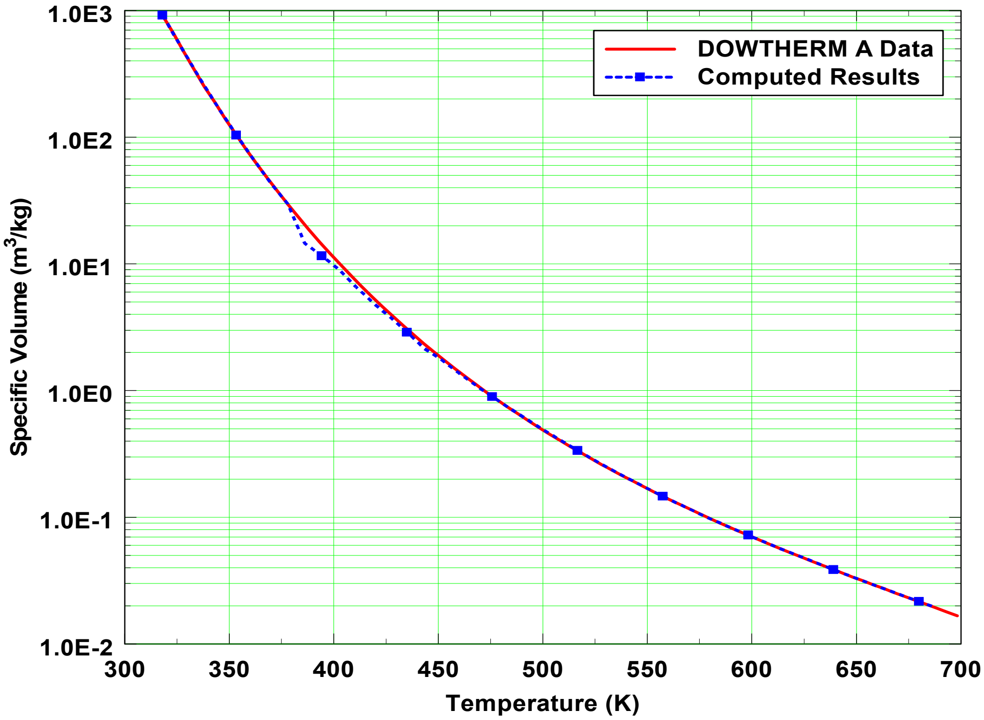


Figure 9: Specific volume of saturated vapor

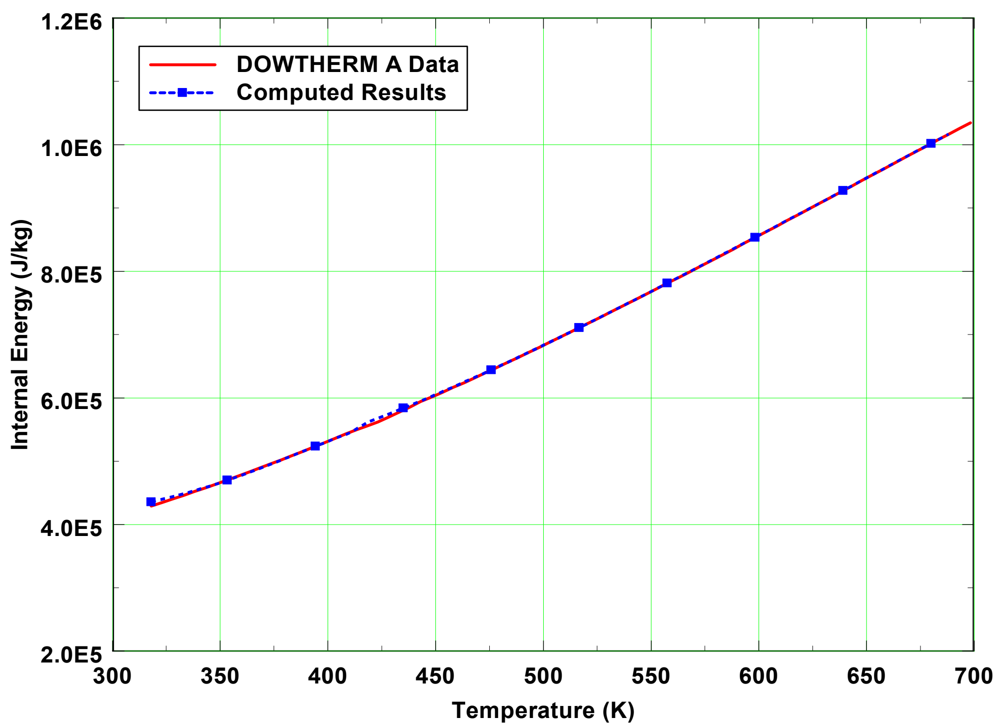


Figure 10: Specific internal energy of saturated vapor

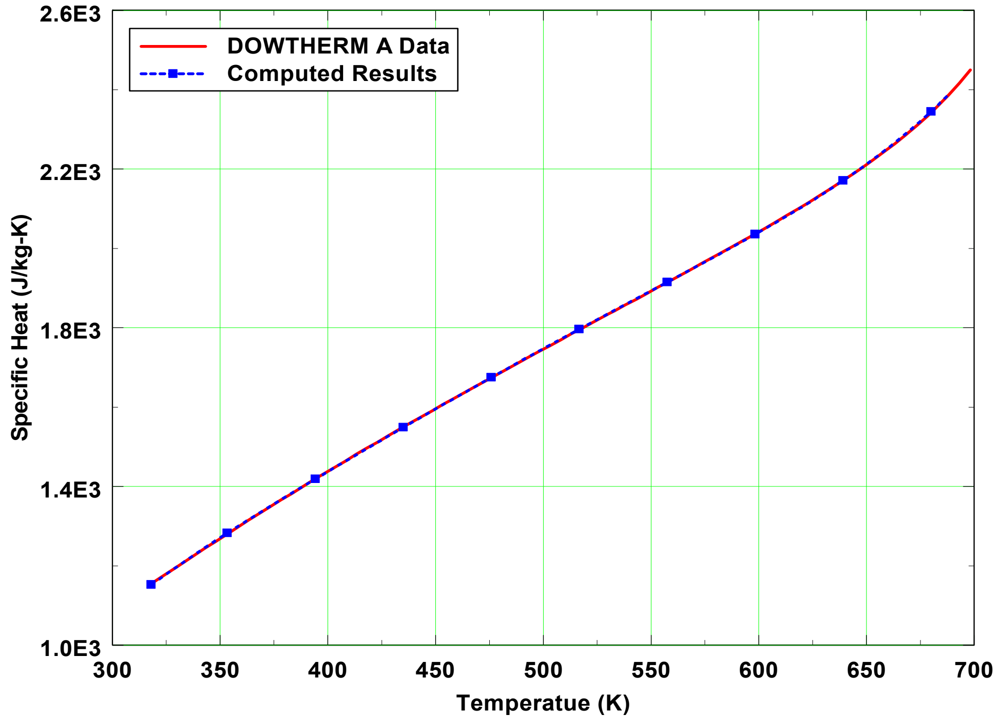


Figure 11: Specific heat capacity at constant pressure of saturated vapor

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

$$\beta_g^s = \frac{1}{v_g^s}\left(\frac{\partial v_g^s}{\partial T}\right)_p \tag{12}$$

however since there is no data give for the thermal expansion coefficient as a function of temperature we will compute β_g^s as follows

$$\beta_g^s \approx \frac{1}{v_g^s(p,T)}\left(\frac{v_g^s(p,T+\delta T)-v_g^s(p,T-\delta T)}{2\delta T}\right)_p \tag{13}$$

The isothermal compressibility for saturated vapor is define as

$$\kappa_g^s = -\frac{1}{v_g^s}\left(\frac{\partial v_g^s}{\partial p}\right)_T \tag{14}$$

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.

$$\kappa_g^s \approx -\frac{1}{v_g^s(p,T)}\left(\frac{v_g^s(p+\delta p,T)-v_g^s(p-\delta p,T)}{2\delta p}\right)_T \tag{15}$$

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

$$s_g^s = \frac{u_g^s + p v_g^s}{T} \tag{16}$$

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

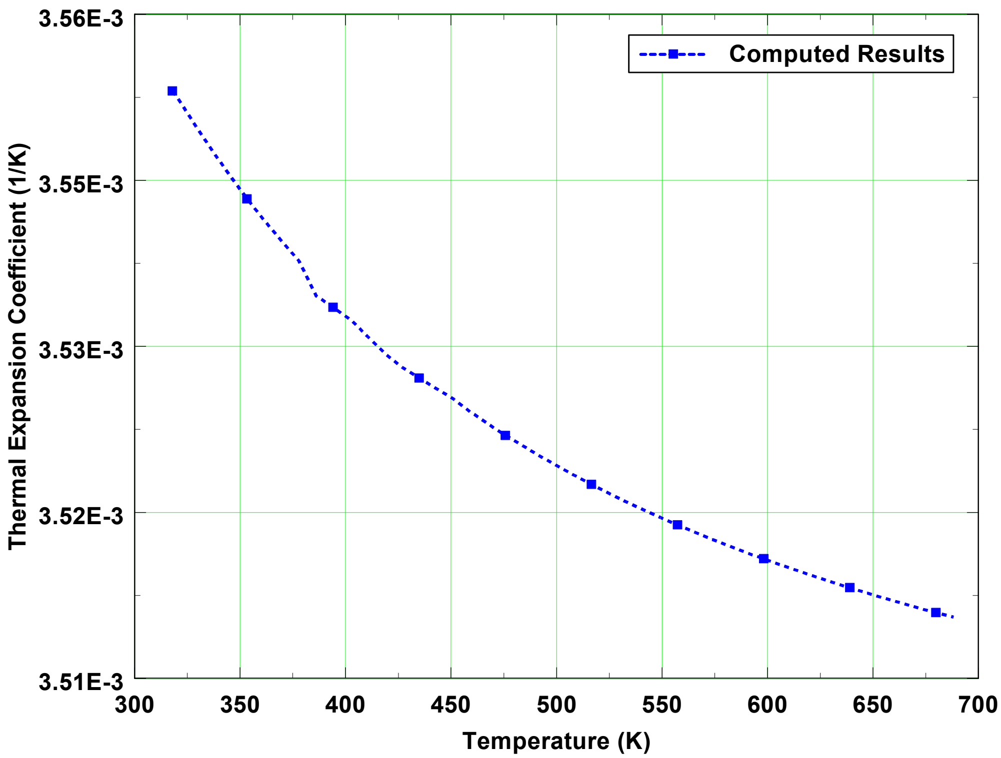


Figure 12: Coefficient of thermal expansion of saturated vapor

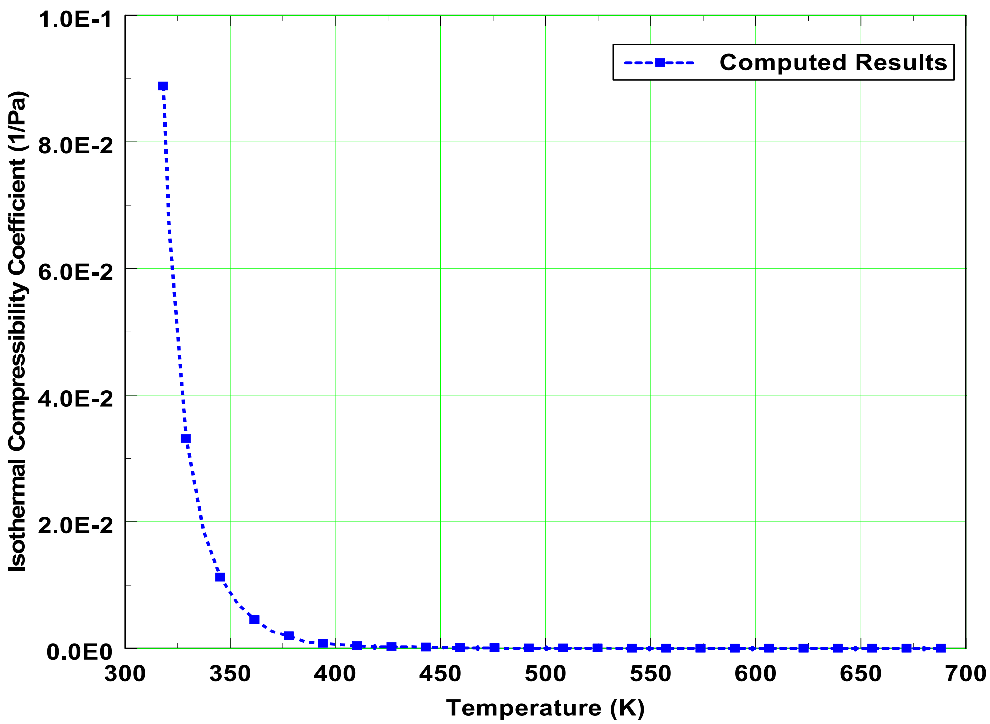
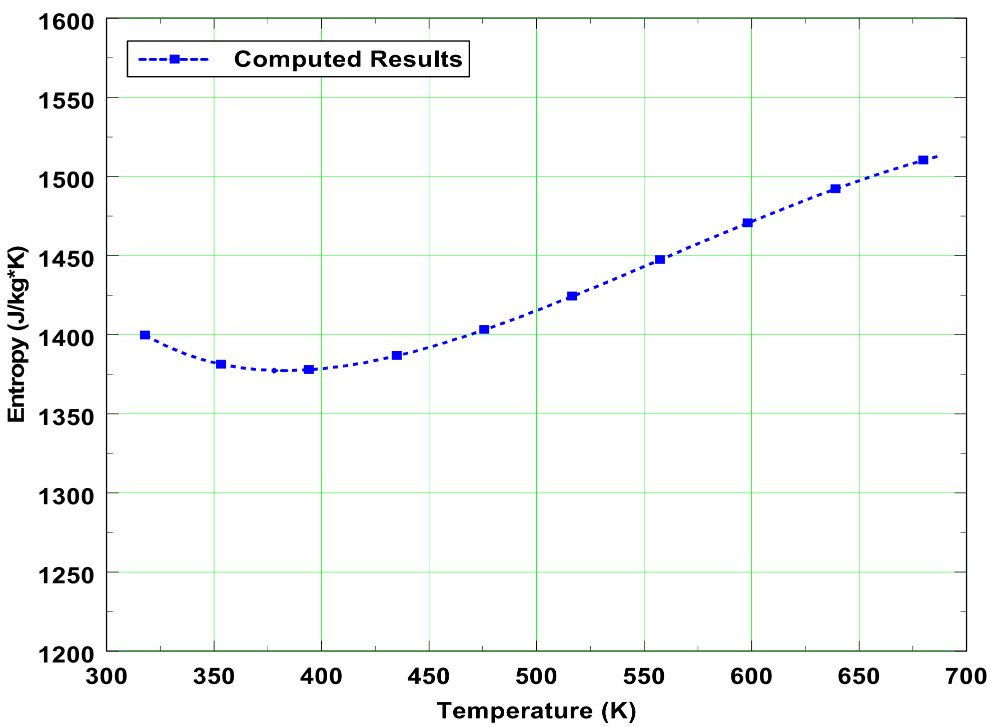


Figure 13: Isothermal compressibility of saturated vapor



1.

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.

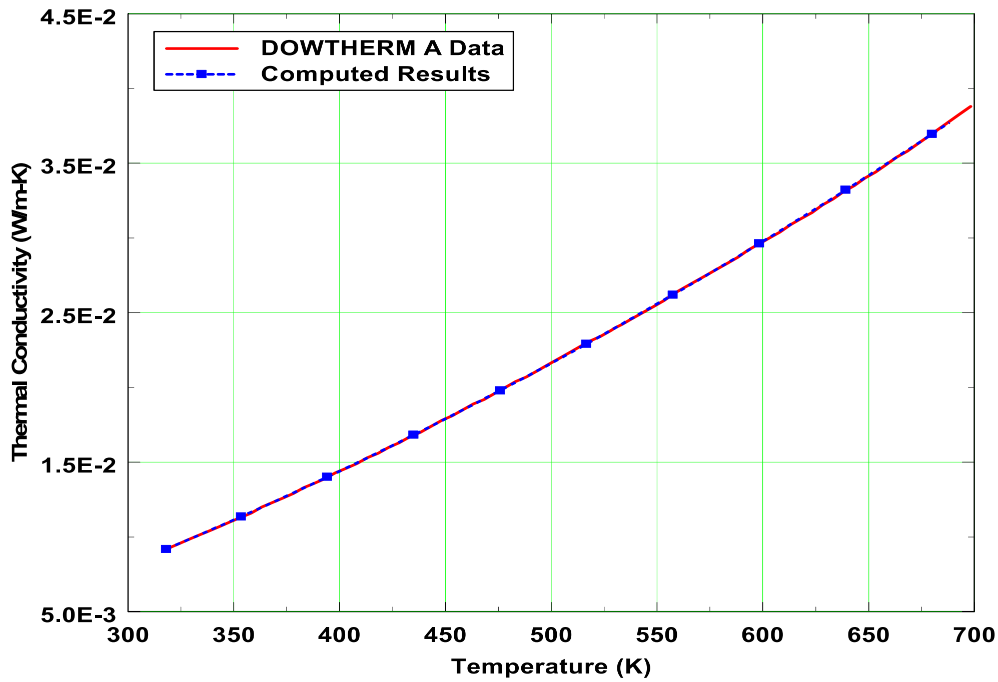


Figure 15: Thermal conductivity of saturated vapor

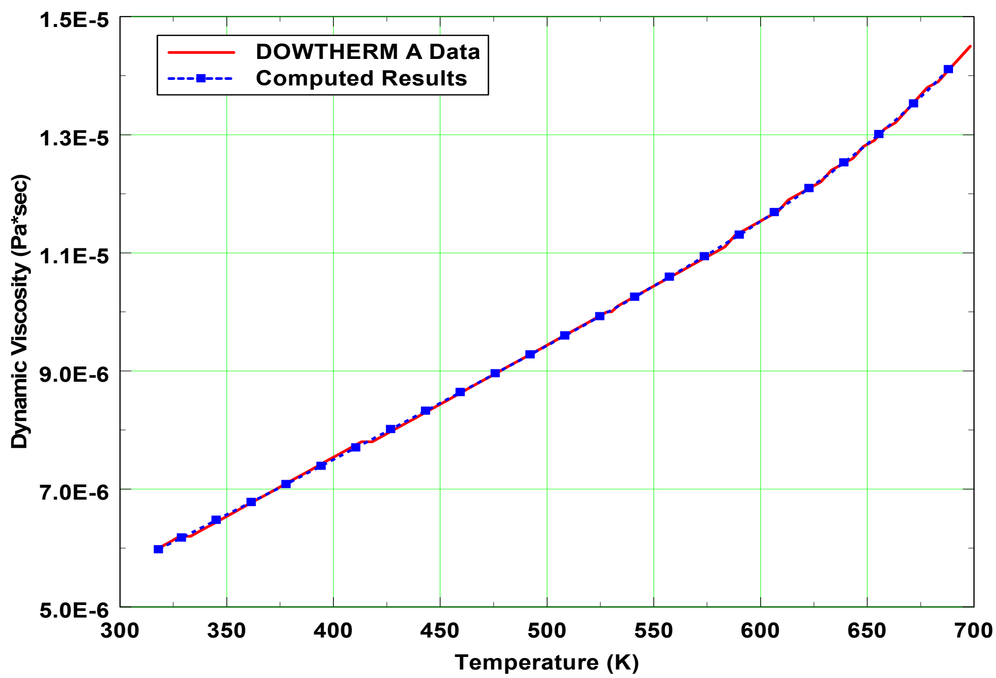


Figure 16: Dynamic viscosity of saturated vapor

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 $\rho\left(T,P\right)_g$ 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

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

The remaining computed vapor thermodynamic properties u, s, β, and κ 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

Property	a	b	c	d	e	f	
Vapor Press	-4.270E+06	3.196E+04	-9.259E+01	1.397E-01	-1.350E-04	7.868E-08	T>448.5
	-7.702E+08	9.309E+06	-4.496E+04	1.085E+02	-1.308E-01	6.304E-05	383.15<T≤448.15
	-7.040E+05	1.090E+04	-6.774E+01	2.113E-01	-3.311E-04	2.086E-07	T≤383.15

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.

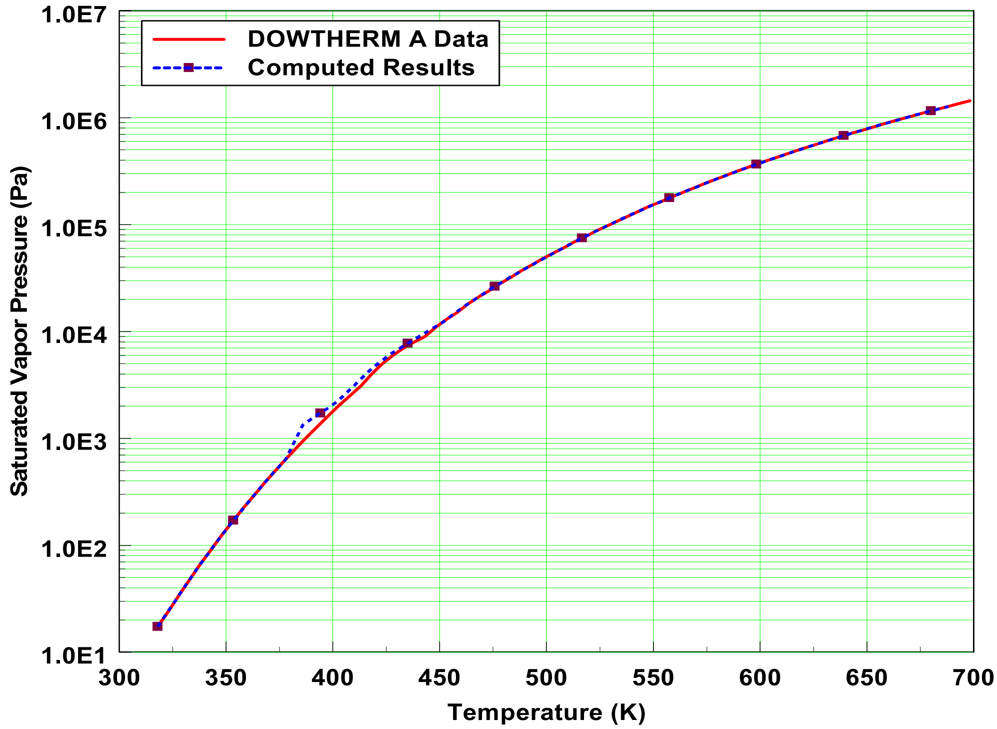


Figure 17: Saturated vapor pressure as a function of temperature

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 Thermdynamic 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

1. Yu, Jiyang, "Thermodynamic Property Package for Oil for RELAP5-3D" Draft Report, University of California, Berkeley, March 2009.
2. DOWTHERM A Heat Transfer Fluid, Product Technical Data, Dow Chemical Company, 1997.
3. Davis, C. B., "Implementation of Molten Salt Properties into RELAP5-3D/ATHENA", INEEL/EXT-05-02658, January 2005.

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

BB :=

	0	1	2	3	4
0	id (SI Units)"	NaN	NaN	NaN	NaN
1	" TEMP"	"TEMP"	" VAPOR"	"VAPOR"	"LIQUID"
2	NaN	NaN	" PRESS."	"PRESS"	"ENTHALPY"
3	" °C"	"K"	" bar"	"Pa"	"kJ/kg"
4	12	285.15	0	0	0
5	15	288.15	0	0	4.9
6	20	293.15	0	0	13.1
7	25	298.15	0	0	21.3
8	30	303.15	0	0	29.5
9	35	308.15	0	0	37.7
10	40	313.15	0	0	46
11	45	318.15	$1.752 \cdot 10^{-4}$	17.522	54.4
12	50	323.15	$2.427 \cdot 10^{-4}$	24.269	...

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

AA :=

	0	1	2	3	4
0	Fluid (SI Units)"	NaN	NaN	NaN	NaN
1	"TEMP"	"TEMP"	"VAPOR"	"VAPOR"	"LIQUID"
2	NaN	NaN	"PRESSURE"	"PRESSURE"	"ENTHALPY"
3	NaN	NaN	NaN	NaN	NaN
4	"°C"	"K"	"bar"	"Pa"	"kJ/kg"
5	12	285.15	0	0	0
6	15	288.15	0	0	4.9
7	20	293.15	0	0	13.1
8	25	298.15	0	0	21.3
9	30	303.15	0	0	29.5
10	35	308.15	0	0	37.7
11	40	313.15	0	0	46
12	45	318.15	$1.752 \cdot 10^{-4}$	17.522	54.4
13	50	323.15	$2.427 \cdot 10^{-4}$	24.269	62.7
14	55	328.15	$3.45 \cdot 10^{-4}$	34.502	71.2
15	60	333.15	$4.837 \cdot 10^{-4}$	48.372	...

Extract Data from BB to obtain the vapor pressure curve by means of curve fitting the data

$i := 0, 1 .. 77$ $\quad TempSat_i := BB_{i+11, 1}$ $\quad PressSat_i := BB_{i+11, 3}$

$j := 0, 1 .. 51$ $\quad TempSatA_j := BB_{j+37, 1}$ $\quad PressSatA_j := BB_{j+37, 3}$

$k := 0, 1 .. 13$ $\quad TempSatB_k := BB_{k+24, 1}$ $\quad PressSatB_k := BB_{k+24, 3}$

$ii := 0, 1 .. 13$ $\quad TempSatC_{ii} := BB_{ii+11, 1}$ $\quad PressSatC_{ii} := BB_{ii+11, 3}$

$coefA := regress(TempSatA, PressSatA, 5)$

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

$a1 := coefA_3$ $\quad a1 = -4.2702 \times 10^{6}$

$b1 := coefA_4$ $\quad b1 = 3.1962 \times 10^{4}$

$c1 := coefA_5$ $\quad c1 = -92.5941$

$d1 := coefA_6$ $\quad d1 = 0.1397$

$e1 := coefA_7$ $\quad e1 = -1.3501 \times 10^{-4}$

$f1 := coefA_8$ $\quad f1 = 7.8679 \times 10^{-8}$

$coefB := regress(TempSatB, PressSatB, 5)$

$$coefB = \begin{pmatrix} 3 \times 10^{0} \\ 3 \times 10^{0} \\ 5 \times 10^{0} \\ -7.7020656 \times 10^{8} \\ 9.3087791 \times 10^{6} \\ -4.4964641 \times 10^{4} \\ 1.0850779 \times 10^{2} \\ -1.3082038 \times 10^{-1} \\ 6.3041277 \times 10^{-5} \end{pmatrix}$$

$a2 := coefB_3$ $a2 = -7.7020656 \times 10^{8}$

$b2 := coefB_4$ $b2 = 9.3087791 \times 10^{6}$

$c2 := coefB_5$ $c2 = -4.4965 \times 10^{4}$

$d2 := coefB_6$ $d2 = 1.0850779 \times 10^{2}$

$e2 := coefB_7$ $e2 = -1.3082038 \times 10^{-1}$

$f2 := coefB_8$ $f2 = 6.3041277 \times 10^{-5}$

$coefC := regress(TempSatC, PressSatC, 5)$

$$coefC = \begin{pmatrix} 3 \times 10^{0} \\ 3 \times 10^{0} \\ 5 \times 10^{0} \\ -7.0401403 \times 10^{5} \\ 1.0900125 \times 10^{4} \\ -6.7738071 \times 10^{1} \\ 2.1131357 \times 10^{-1} \\ -3.3110934 \times 10^{-4} \\ 2.0861096 \times 10^{-7} \end{pmatrix}$$

$a3 := coefC_3$ $a3 = -7.0401403 \times 10^{5}$

$b3 := coefC_4$ $b3 = 1.0900125 \times 10^{4}$

$c3 := coefC_5$ $c3 = -6.7738071 \times 10^{1}$

$d3 := coefC_6$ $d3 = 2.1131357 \times 10^{-1}$

$e3 := coefC_7$ $e3 = -3.3110934 \times 10^{-4}$

$f3 := coefC_8$ $f3 = 2.0861096 \times 10^{-7}$

$$yA(x) := a1 + b1 \cdot x + c1 \cdot x^2 + d1 \cdot x^3 + e1 \cdot x^4 + f1 \cdot x^5$$

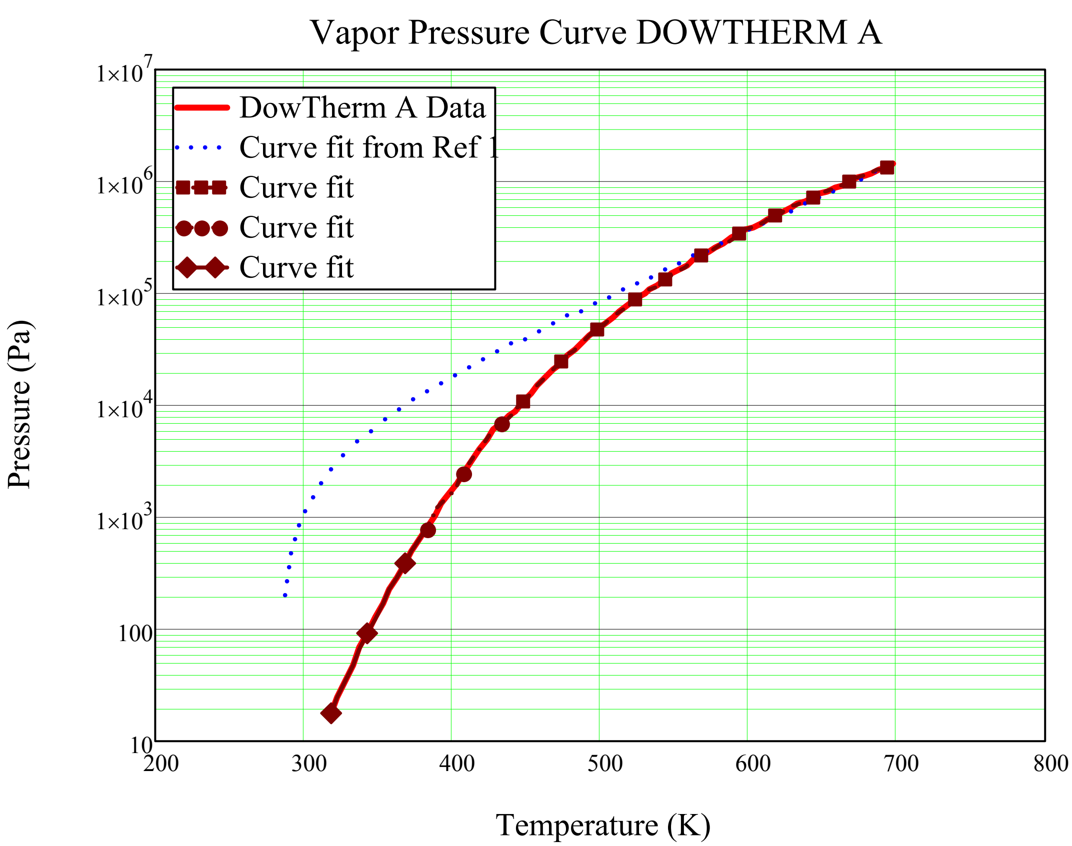
$$yyA_j := yA\left(TempSatA_j\right)$$

$$yB(x) := a2 + b2 \cdot x + c2 \cdot x^2 + d2 \cdot x^3 + e2 \cdot x^4 + f2 \cdot x^5$$

$$yyB_k := yB\left(TempSatB_k\right)$$

$$yC(x) := a3 + b3 \cdot x + c3 \cdot x^2 + d3 \cdot x^3 + e3 \cdot x^4 + f3 \cdot x^5$$

$$yyC_{ii} := yC\left(TempSatC_{ii}\right)$$



Obtain Saturation Temperature as a function of the Saturation Pressure for curve fit of the data

$jj := 0, 1 .. 13$ $\quad PressSatAA_{jj} := PressSat_{jj}$ $\quad TempSatAA_{jj} := TempSat_{jj}$

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

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

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

$coefAA := regress(PressSatAA, TempSatAA, 5)$

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

$a4 := coefAA_{3}$ $\quad a4 = 3.11665 \times 10^{2}$

$b4 := coefAA_{4}$ $\quad b4 = 5.226588 \times 10^{-1}$

$c4 := coefAA_{5}$ $\quad c4 = -2.4482536 \times 10^{-3}$

$d4 := coefAA_{6}$ $\quad d4 = 6.1177729 \times 10^{-6}$

$e4 := coefAA_{7}$ $\quad e4 = -7.2119979 \times 10^{-9}$

$f4 := coefAA_{8}$ $\quad f4 = 3.1726317 \times 10^{-12}$

coefBB := regress (PressSatBB , TempSatBB, 5)

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

$a5 := coefBB_3$ $\quad a5 = 3.6046486\times 10^{2}$

$b5 := coefBB_4$ $\quad b5 = 3.3908292\times 10^{-2}$

$c5 := coefBB_5$ $\quad c5 = -8.3471991\times 10^{-6}$

$d5 := coefBB_6$ $\quad d5 = 1.1262937\times 10^{-9}$

$e5 := coefBB_7$ $\quad e5 = -7.0086055\times 10^{-14}$

$f5 := coefBB_8$ $\quad f5 = 1.5631488\times 10^{-18}$

coefCC := regress (PressSatCC , TempSatCC, 5)

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

$a6 := coefCC_3$ $\quad a6 = 4.2350153\times 10^{2}$

$b6 := coefCC_4$ $\quad b6 = 2.7182873\times 10^{-3}$

$c6 := coefCC_5$ $\quad c6 = -3.4561189\times 10^{-8}$

$d6 := coefCC_6$ $\quad d6 = 2.6853777\times 10^{-13}$

$e6 := coefCC_7$ $\quad e6 = -1.0494985\times 10^{-18}$

$f6 := coefCC_8$ $\quad f6 = 1.5912214\times 10^{-24}$

$coefDD := regress(PressSatDD, TempSatDD, 5)$

$$coefDD = \begin{pmatrix} 3\times 10^{0} \\ 3\times 10^{0} \\ 5\times 10^{0} \\ 4.9952136\times 10^{2} \\ 4.1580955\times 10^{-4} \\ -5.5337146\times 10^{-10} \\ 5.0373204\times 10^{-16} \\ -2.4616154\times 10^{-22} \\ 4.8748475\times 10^{-29} \end{pmatrix}$$

$a7 := coefDD_3$ $\quad a7 = 4.9952136\times 10^{2}$

$b7 := coefDD_4$ $\quad b7 = 4.1580955\times 10^{-4}$

$c7 := coefDD_5$ $\quad c7 = -5.5337146\times 10^{-10}$

$d7 := coefDD_6$ $\quad d7 = 5.0373204\times 10^{-16}$

$e7 := coefDD_7$ $\quad e7 = -2.4616154\times 10^{-22}$

$f7 := coefDD_8$ $\quad f7 = 4.8748475\times 10^{-29}$

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

$ttAA_{jj} := tAA\left(PressSatAA_{jj}\right)$

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

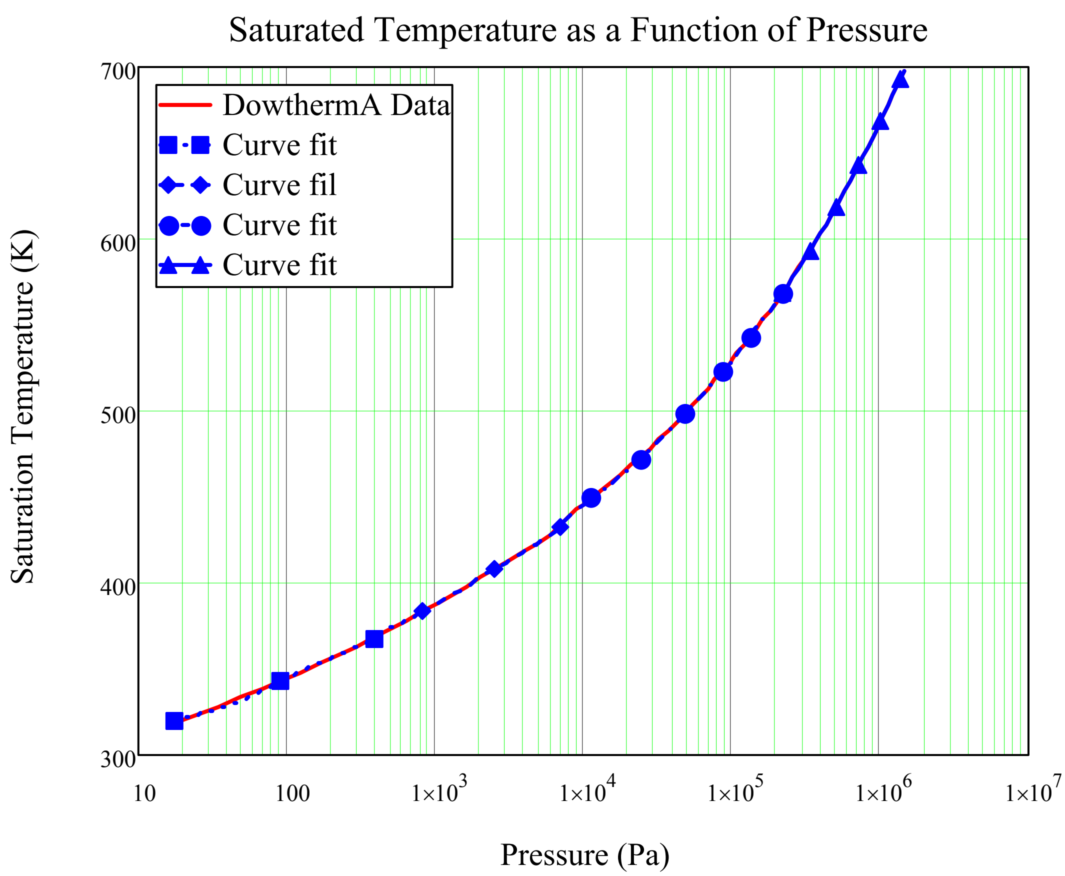
$ttBB_{kk} := tBB\left(PressSatBB_{kk}\right)$

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

$ttCC_{ll} := tCC\left(PressSatCC_{ll}\right)$

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

$ttDD_{mm} := tDD\left(PressSatDD_{mm}\right)$


Saturated Temperature as a Function of Pressure
Saturation Temperature (K)
700
600
500
400
300
DowthermA Data
Curve fit
Curve fil
Curve fit
Curve fit
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
Pressure (Pa)

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

$kk := 0, 1 .. 83$

$SLDT_{kk} := BB_{kk+4,1}$ $SLD_{kk} := BB_{kk+4,9}$ $SLVT_{kk} := SLDT_{kk}$ $SLV_{kk} := \frac{1}{SLD_{kk}}$

$coefLD := regress(SLDT, SLD, 5)$

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

$a8 := coefLD_3$ $a8 = 1.4924628\times 10^{3}$

$b8 := coefLD_4$ $b8 = -3.331716\times 10^{0}$

$c8 := coefLD_5$ $c8 = 1.2479716\times 10^{-2}$

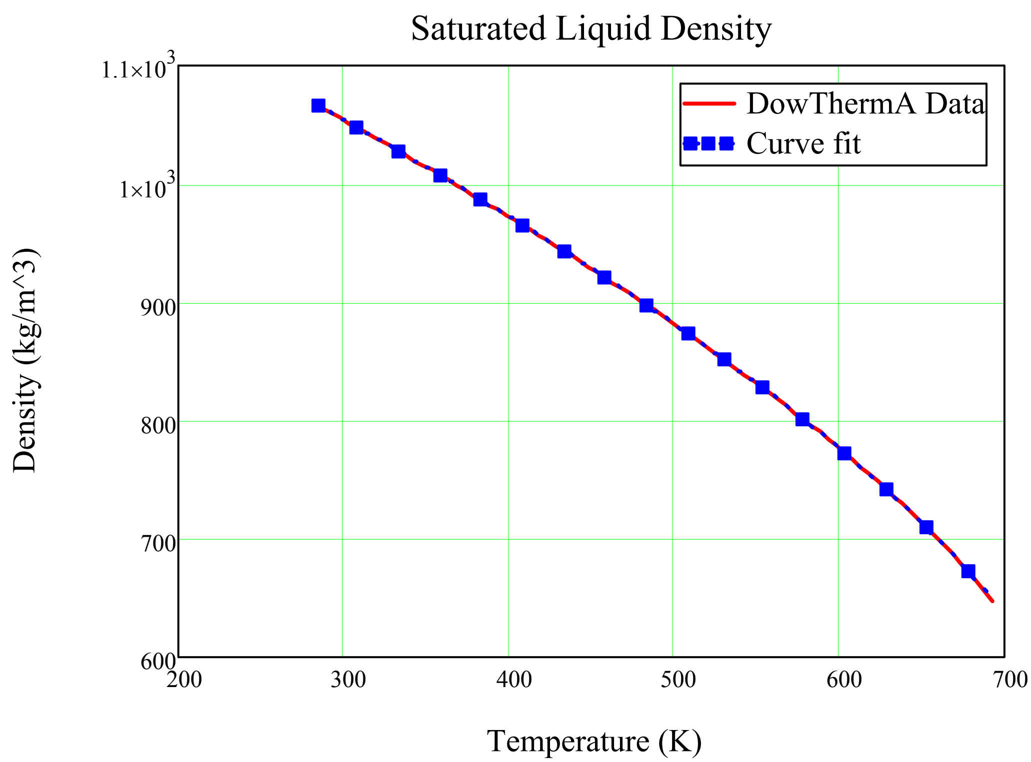
$d8 := coefLD_6$ $d8 = -2.9684039\times 10^{-5}$

$e8 := coefLD_7$ $e8 = 3.4437643\times 10^{-8}$

$f8 := coefLD_8$ $f8 = -1.6215295\times 10^{-11}$

$yLD(T) := a8 + b8\cdot T + c8\cdot T^2 + d8\cdot T^3 + e8\cdot T^4 + f8\cdot T^5$

$yyLD_{kk} := yLD\left(SLDT_{kk}\right)$



Liquid Saturated Enthalpy

$ELT_i := BB_{i+6,1}$ $EL_i := BB_{i+6,4} \cdot 1000$

coefLE := regress (ELT, EL, 5)

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

$a9 := coefLE_3$ $a9 = -6.5113067 \times 10^{5}$

$b9 := coefLE_4$ $b9 = 4.1213664 \times 10^{3}$

$c9 := coefLE_5$ $c9 = -1.2345938 \times 10^{1}$

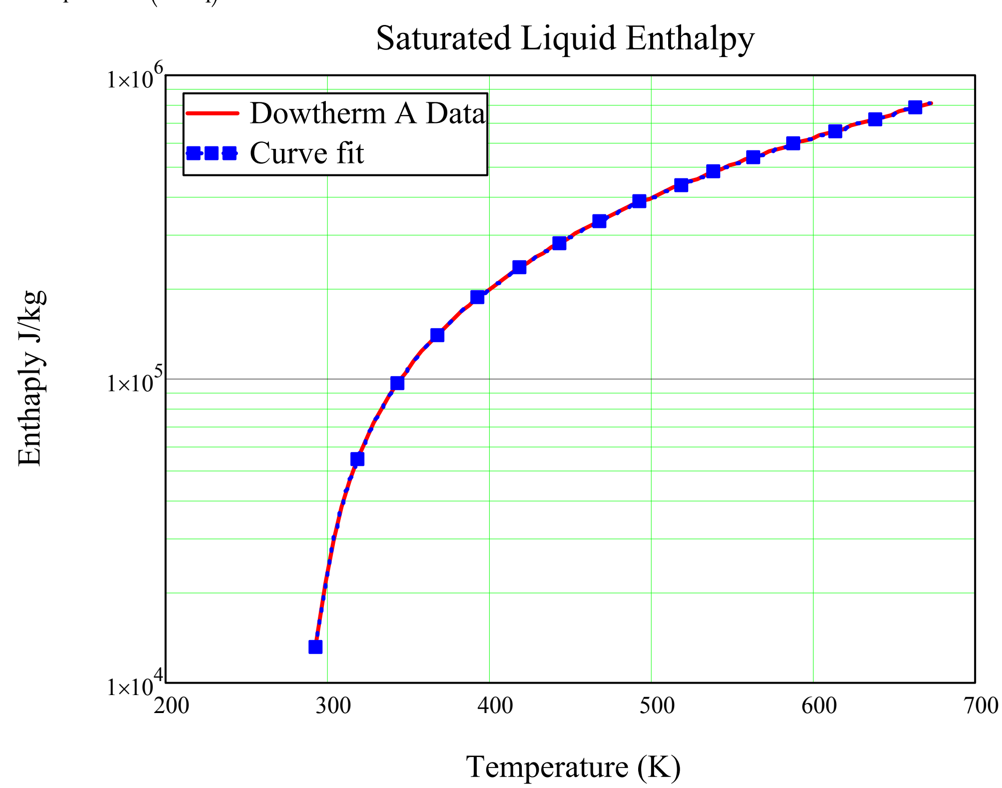
$d9 := coefLE_6$ $d9 = 2.7710651 \times 10^{-2}$

$e9 := coefLE_7$ $e9 = -2.7764463 \times 10^{-5}$

$f9 := coefLE_8$ $f9 = 1.1056661 \times 10^{-8}$

$$yEL(T) := a9 + b9 \cdot T + c9 \cdot T^2 + d9 \cdot T^3 + e9 \cdot T^4 + f9 \cdot T^5$$

$$yyEL_i := yEL\left(ELT_i\right)$$



Saturated Liquid Specific Heat

$i := 0, 1 .. 84$

$CPLT_i := BB_{i+4,1}$ $\quad$ $CPL_i := BB_{i+4,7} \cdot 1000$

$coefCPL := regress(CPLT, CPL, 5)$

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

$a10 := coefCPL_3$ $\quad$ $a10 = -2.3634842 \times 10^{3}$

$b10 := coefCPL_4$ $\quad$ $b10 = 3.9461021 \times 10^{1}$

$c10 := coefCPL_5$ $\quad$ $c10 = -1.7024546 \times 10^{-1}$

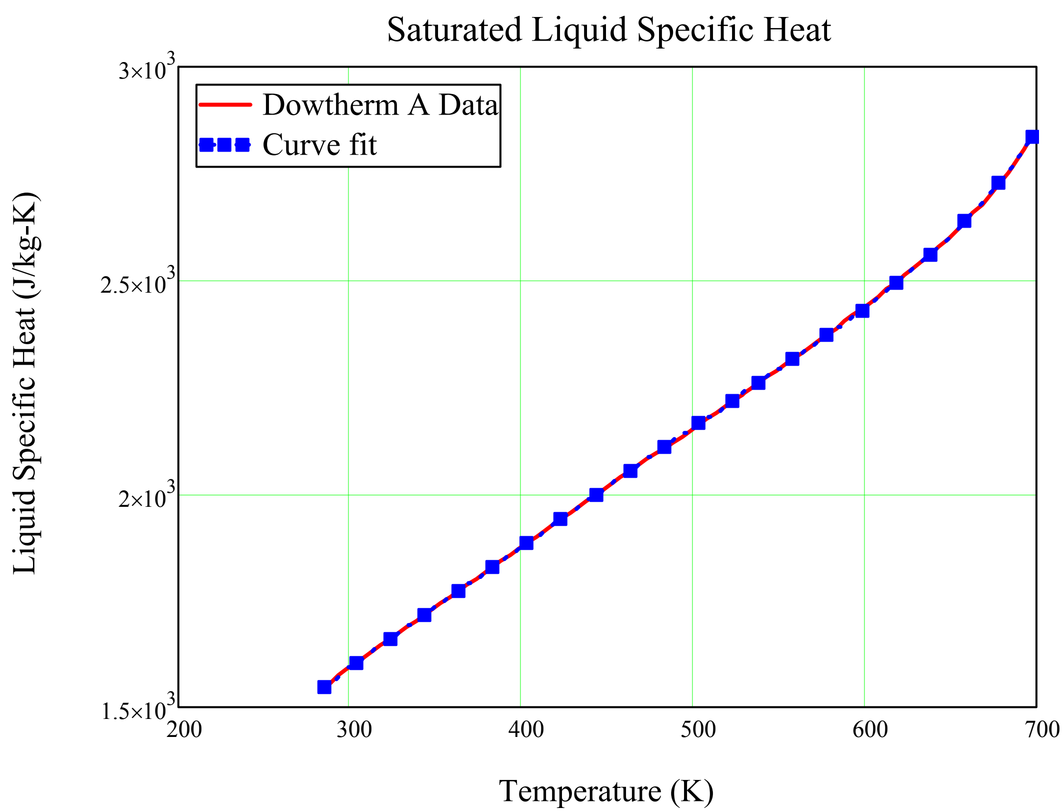
$d10 := coefCPL_6$ $\quad$ $d10 = 3.903868 \times 10^{-4}$

$e10 := coefCPL_7$ $\quad$ $e10 = -4.421524 \times 10^{-7}$

$f10 := coefCPL_8$ $\quad$ $f10 = 1.9792489 \times 10^{-10}$

$yCPL(T) := a10 + b10 \cdot T + c10 \cdot T^2 + d10 \cdot T^3 + e10 \cdot T^4 + f10 \cdot T^5$

$yyCPL_i := yCPL\left(CPLT_i\right)$


Saturated Liquid Specific Heat
Dowtherm A Data
Curve fit
Liquid Specific Heat (J/kg-K)
3×10^3
2.5×10^3
2×10^3
1.5×10^3
200
300
400
500
600
700
Temperature (K)

Liquid Thermal Conductivity

$i := 0, 1 .. 84$

$TCLT_i := BB_{i+4,1}$ $\quad$ $TCL_i := BB_{i+4,8}$

$coefTCL := regress(TCLT, TCL, 2)$

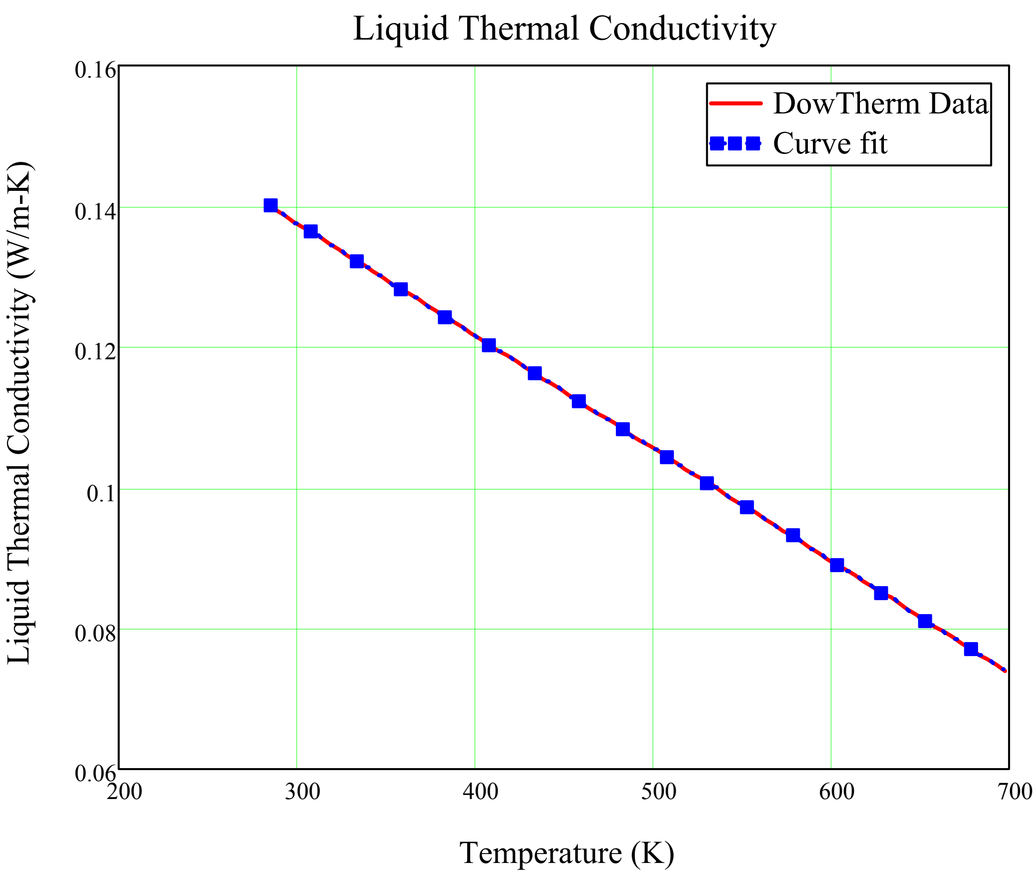
$$coefTCL = \begin{pmatrix} 3 \times 10^{0} \\ 3 \times 10^{0} \\ 2 \times 10^{0} \\ 1.8560707 \times 10^{-1} \\ -1.60008 \times 10^{-4} \\ 5.9133304 \times 10^{-12} \end{pmatrix}$$

$a11 := coefTCL_3$ $\quad$ $a11 = 1.8560707 \times 10^{-1}$

$b11 := coefTCL_4$ $\quad$ $b11 = -1.60008 \times 10^{-4}$

$c11 := coefTCL_5$ $\quad$ $c11 = 5.9133304 \times 10^{-12}$

$ytTCL(T) := a11 + b11 \cdot T + c11 \cdot T^2$ $\quad$ $yyTCL_i := ytTCL\left(TCLT_i\right)$



Liquid Viscosity

$i := 0, 1 .. 84$

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

coefVL :=

	0
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	$1.274782 \cdot 10^{-21}$

coefVL =

$a12 := coefVL_3$ $a12 = 5.1346826 \times 10^{0}$

$b12 := coefVL_4$ $b12 = -8.395359 \times 10^{-2}$

$c12 := coefVL_5$ $c12 = 5.9705155 \times 10^{-4}$

$d12 := coefVL_6$ $d12 = -2.4092211 \times 10^{-6}$

$e12 := coefVL_7$ $e12 = 6.0292345 \times 10^{-9}$

$f12 := coefVL_8$ $f12 = -9.5788095 \times 10^{-12}$

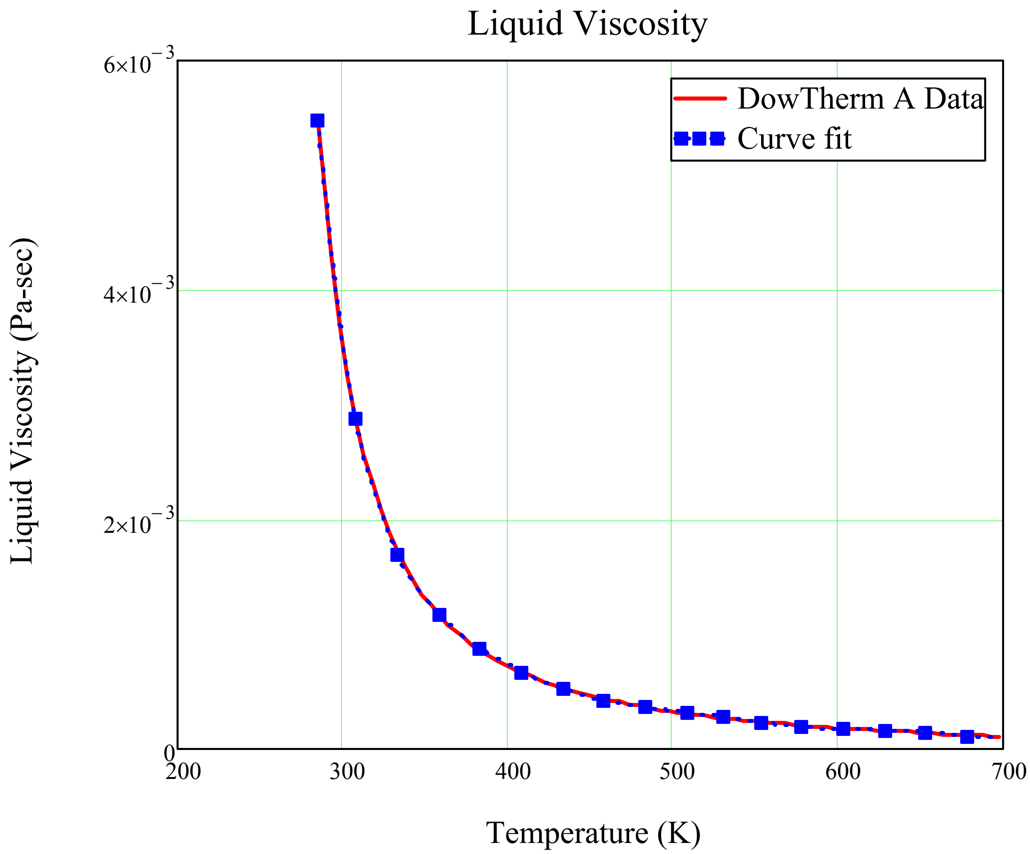
$g12 := coefVL_9$ $g12 = 9.4330297 \times 10^{-15}$

$h12 := coefVL_{10}$ $h12 = -5.2643677 \times 10^{-18}$

$i12 := coefVL_{11}$ $i12 = 1.274782 \times 10^{-21}$

$$yVL(T) := a12 + b12 \cdot T + c12 \cdot T^2 + d12 \cdot T^3 + e12 \cdot T^4 + f12 \cdot T^5 + g12 \cdot T^6 + h12 \cdot T^7 + i12 \cdot T^8$$

$$yyVL_i := yVL\left(VLT_i\right)$$


Liquid Viscosity
DowTherm A Data
Curve fit
Liquid Viscosity (Pa-sec)
6×10^−3
4×10^−3
2×10^−3
0
200
300
400
500
600
700
Temperature (K)

Saturated Vapor Density(function of temperature)

$kk := 0, 1 .. 77$

$ii := 0, 1 .. 29$

$jj := 0, 1 .. 48$

$SVDT_{kk} := AA_{kk+12, 1}$ $\quad SVD_{kk} := AA_{kk+12, 8}$ $\quad SVVT_{kk} := SVDT_{kk}$

$SVDT1_{ii} := AA_{ii+12, 1}$ $\quad SVD1_{ii} := AA_{ii+12, 8}$ $\quad SVV_{kk} := \frac{1}{SVD_{kk}}$

$SVDT2_{jj} := AA_{jj+41, 1}$ $\quad SVD2_{jj} := AA_{jj+41, 8}$

$coefVD1 := regress(SVDT1, SVD1, 5)$

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

$a13 := coefVD1_{3}$ $\quad a13 = -1.4782864 \times 10^{1}$

$b13 := coefVD1_{4}$ $\quad b13 = 2.4583636 \times 10^{-1}$

$c13 := coefVD1_{5}$ $\quad c13 = -1.6311806 \times 10^{-3}$

$d13 := coefVD1_{6}$ $\quad d13 = 5.4074108 \times 10^{-6}$

$e13 := coefVD1_{7}$ $\quad e13 = -8.9697241 \times 10^{-9}$

$f13 := coefVD1_{8}$ $\quad f13 = 5.9645469 \times 10^{-12}$

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

$$yyVD1_{ii} := yVD1\left(SVDT1_{ii}\right)$$

$$\text{coefVD2} := \text{regress}(\text{SVDT2}, \text{SVD2}, 5)$$

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

$a14 := \text{coefVD2}_3$ $\quad a14 = -3.8236587 \times 10^{3}$

$b14 := \text{coefVD2}_4$ $\quad b14 = 3.5205390 \times 10^{1}$

$c14 := \text{coefVD2}_5$ $\quad c14 = -1.2954953 \times 10^{-1}$

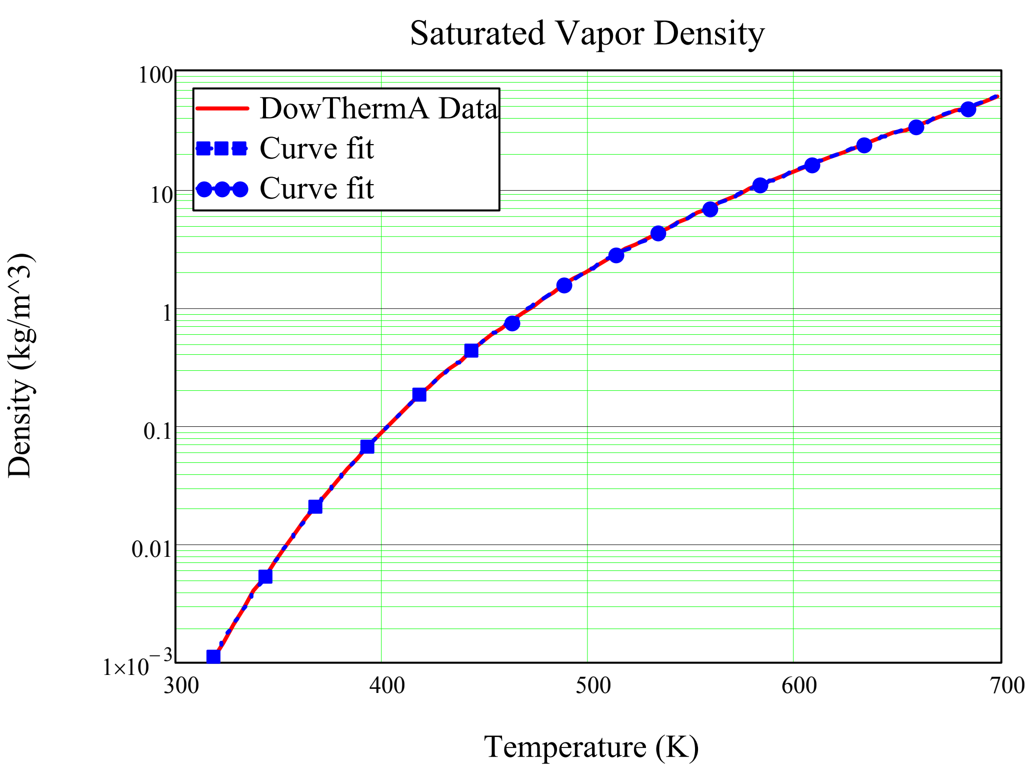
$d14 := \text{coefVD2}_6$ $\quad d14 = 2.3859569 \times 10^{-4}$

$e14 := \text{coefVD2}_7$ $\quad e14 = -2.2068000 \times 10^{-7}$

$f14 := \text{coefVD2}_8$ $\quad f14 = 8.2509961 \times 10^{-11}$

$$\text{yVD2}(T) := a14 + b14 \cdot T + c14 \cdot T^2 + d14 \cdot T^3 + e14 \cdot T^4 + f14 \cdot T^5$$

$$\text{yyVD2}_{jj} := \text{yVD2}\left(\text{SVDT2}_{jj}\right)$$



Saturated Vapor Density (function of pressure)

$kkk := 0, 1 .. 77 \quad iii := 0, 1 .. 16 \quad jjj := 0, 1 .. 51 \quad mmm := 0, 1 .. 10$

$SVDP_{kkk} := AA_{kkk+12, 3} \qquad SVD_{kkk} := AA_{kkk+12, 8}$

$SVDP09_{mmm} := AA_{mmm+12, 3} \qquad SVD09_{mmm} := AA_{mmm+12, 8}$

$SVDP10_{iii} := AA_{iii+22, 3} \qquad SVD10_{iii} := AA_{iii+22, 8}$

$SVDP11_{jjj} := AA_{jjj+38, 3} \qquad SVD11_{jjj} := AA_{jjj+38, 8}$

$coefVDP0 := regress(SVDP09, SVD09, 5)$

$$coefVDP0 = \begin{pmatrix} 3\times 10^{0} \\ 3\times 10^{0} \\ 5\times 10^{0} \\ 4.3907887\times 10^{-5} \\ 6.1186085\times 10^{-5} \\ -5.4005346\times 10^{-8} \\ 2.2447957\times 10^{-10} \\ -5.4216865\times 10^{-13} \\ 5.2196703\times 10^{-16} \end{pmatrix}$$

$a21 := coefVDP0_{3} \qquad a21 = 4.3907887\times 10^{-5}$

$b21 := coefVDP0_{4} \qquad b21 = 6.1186085\times 10^{-5}$

$c21 := coefVDP0_{5} \qquad c21 = -5.4005346\times 10^{-8}$

$d21 := coefVDP0_{6} \qquad d21 = 2.2447957\times 10^{-10}$

$e21 := coefVDP0_{7} \qquad e21 = -5.4216865\times 10^{-13}$

$f21 := coefVDP0_{8} \qquad f21 = 5.2196703\times 10^{-16}$

$yVDP0(P) := a21 + b21\cdot P + c21\cdot P^{2} + d21\cdot P^{3} + e21\cdot P^{4} + f21\cdot P^{5}$

$yyVDP0_{mmm} := yVDP0\left(SVDP09_{mmm}\right)$

$coefVDP1 := regress(SVDP10, SVD10, 5)$

$$coefVDP1 = \begin{pmatrix} 3\times10^{0} \\ 3\times10^{0} \\ 5\times10^{0} \\ 4.1436614\times10^{-3} \\ 4.1869059\times10^{-5} \\ 8.4148018\times10^{-9} \\ -3.5687549\times10^{-12} \\ 4.8933523\times10^{-16} \\ -2.1103999\times10^{-20} \end{pmatrix}$$

$a15 := coefVDP1_3$ $a15 = 4.1436614\times10^{-3}$

$b15 := coefVDP1_4$ $b15 = 4.1869059\times10^{-5}$

$c15 := coefVDP1_5$ $c15 = 8.4148018\times10^{-9}$

$d15 := coefVDP1_6$ $d15 = -3.5687549\times10^{-12}$

$e15 := coefVDP1_7$ $e15 = 4.8933523\times10^{-16}$

$f15 := coefVDP1_8$ $f15 = -2.1103999\times10^{-20}$

$yVDP1(P) := a15 + b15\cdot P + c15\cdot P^2 + d15\cdot P^3 + e15\cdot P^4 + f15\cdot P^5$

$yyVDP1_{iii} := yVDP1\left(SVDP10_{iii}\right)$

$coefVDP2 := regress(SVDP11, SVD11, 5)$

$$coefVDP2 = \begin{pmatrix} 3\times10^{0} \\ 3\times10^{0} \\ 5\times10^{0} \\ 9.4541624\times10^{-2} \\ 3.9168528\times10^{-5} \\ -9.3398726\times10^{-12} \\ 1.6964024\times10^{-17} \\ -1.0100497\times10^{-23} \\ 2.5237283\times10^{-30} \end{pmatrix}$$

$a16 := coefVDP2_3$ $a16 = 9.4541624\times10^{-2}$

$b16 := coefVDP2_4$ $b16 = 3.9168528\times10^{-5}$

$c16 := coefVDP2_5$ $c16 = -9.3398726\times10^{-12}$

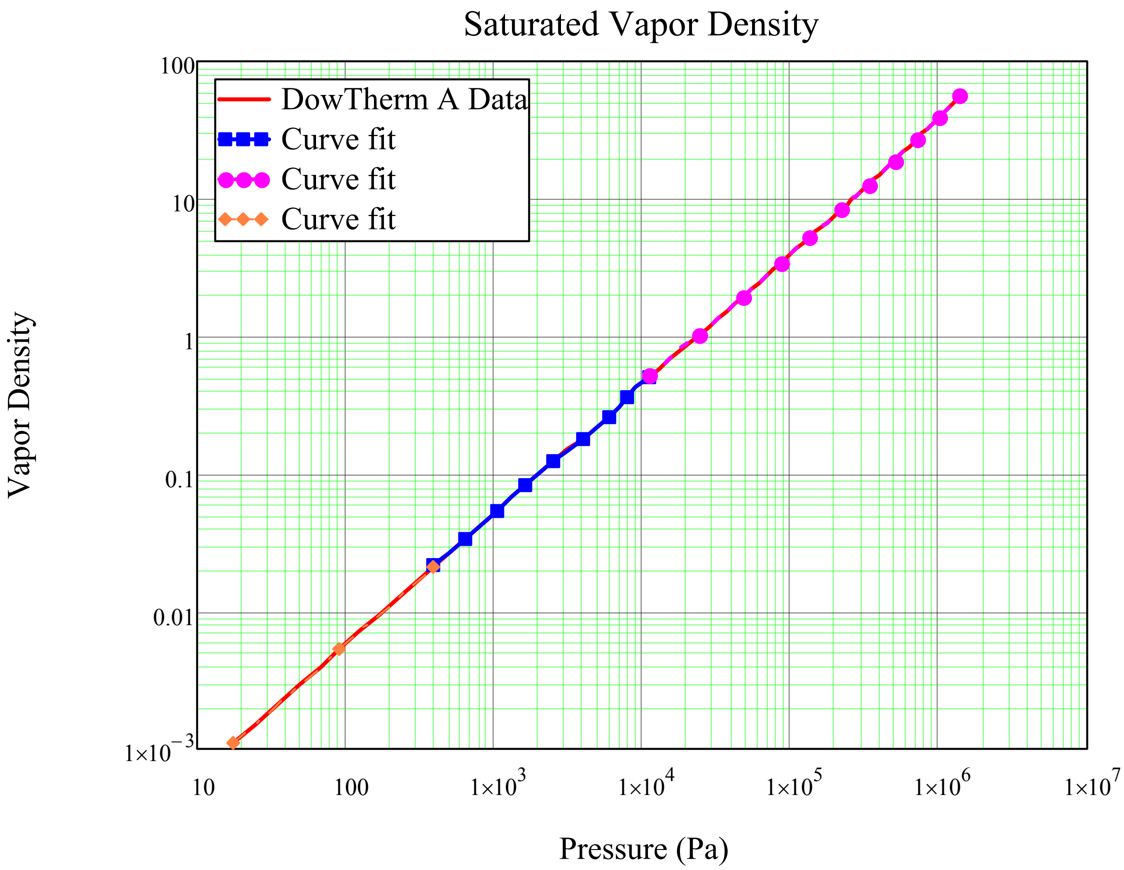
$d16 := coefVDP2_6$ $d16 = 1.6964024\times10^{-17}$

$e16 := coefVDP2_7$ $e16 = -1.0100497\times10^{-23}$

$f16 := coefVDP2_8$ $f16 = 2.5237283\times10^{-30}$

$yVDP2(P) := a16 + b16\cdot P + c16\cdot P^2 + d16\cdot P^3 + e16\cdot P^4 + f16\cdot P^5$

$yyVDP2_{jjj} := yVDP2\left(SVDP11_{jjj}\right)$


Saturated Vapor Density
DowTherm A Data
Curve fit
Curve fit
Curve fit
Vapor Density
100
10
1
0.1
0.01
1×10−3
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
Pressure (Pa)

Saturated Vapor Enthalpy

$iii := 0, 1 .. 30$ $\quad$ $jjj := 0, 1 .. 47$

$EVT_{kkk} := AA_{kkk+12, 1}$ $\quad$ $EV_{kkk} := AA_{kkk+12, 6} \cdot 1000$

$EVT1_{kkk} := AA_{kkk+12, 1}$ $\quad$ $EV1_{kkk} := AA_{kkk+12, 6} \cdot 1000$

$EVT2_{jjj} := AA_{jjj+42, 1}$ $\quad$ $EV2_{jjj} := AA_{jjj+42, 6} \cdot 1000$

$coefVE := regress(EVT1, EV1, 5)$

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

$a17 := coefVE_{3}$ $\quad$ $a17 = 4.0037648 \times 10^{5}$

$b17 := coefVE_{4}$ $\quad$ $b17 = -1.4430833 \times 10^{3}$

$c17 := coefVE_{5}$ $\quad$ $c17 = 7.5788702 \times 10^{0}$

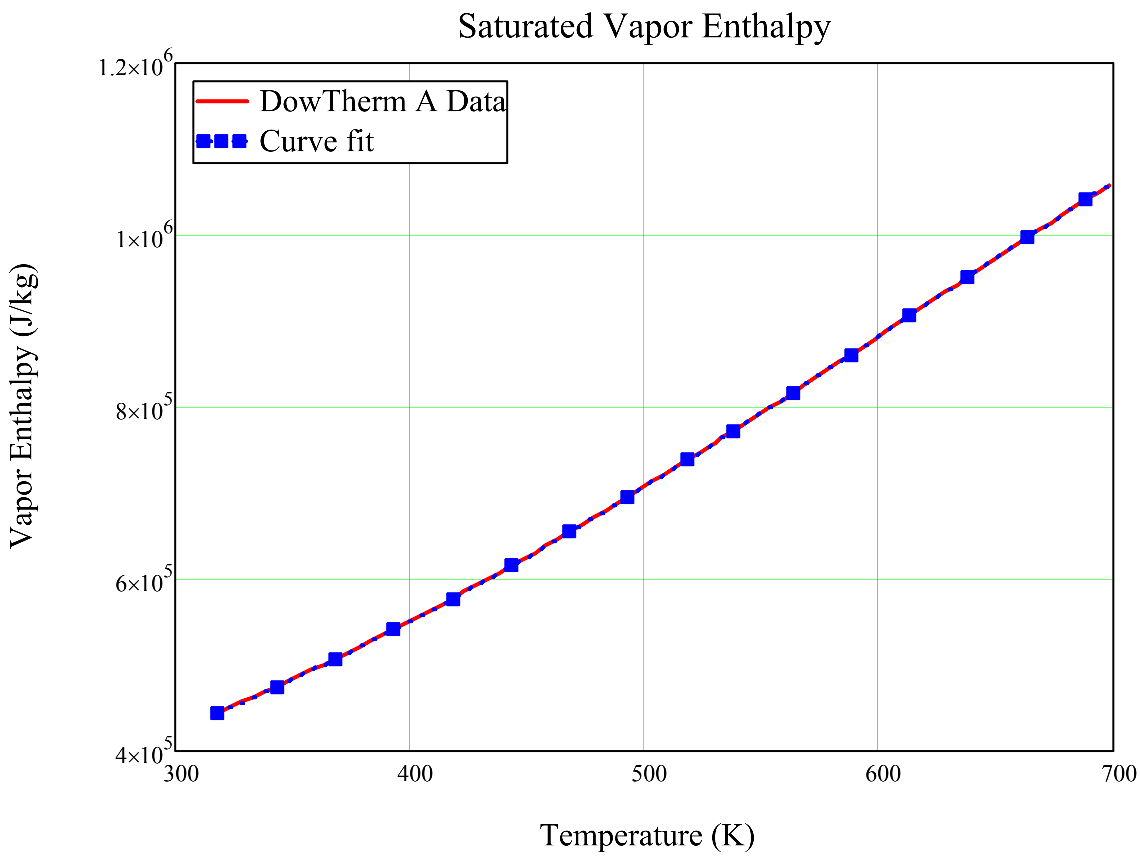
$d17 := coefVE_{6}$ $\quad$ $d17 = -1.1160471 \times 10^{-2}$

$e17 := coefVE_{7}$ $\quad$ $e17 = 1.1033323 \times 10^{-5}$

$f17 := coefVE_{8}$ $\quad$ $f17 = -5.1344363 \times 10^{-9}$

$$yEV(T) := a17 + b17 \cdot T + c17 \cdot T^{2} + d17 \cdot T^{3} + e17 \cdot T^{4} + f17 \cdot T^{5}$$

$$yyEV_{kkk} := yEV\left(EVT1_{kkk}\right)$$


Saturated Vapor Enthalpy
DowTherm A Data
Curve fit
Vapor Enthalpy (J/kg)
1.2×10^6
1×10^6
8×10^5
6×10^5
4×10^5
300
400
500
600
700
Temperature (K)

Saturated Vapor Specific Heat

$CPVT_{kkk} := AA_{kkk+12,1}$ $CPV_{kkk} := AA_{kkk+12,12} \cdot 1000$

$coefCPV := regress(CPVT, CPV, 5)$

$$coefCPV = \begin{pmatrix} 3\times 10^{0} \\ 3\times 10^{0} \\ 5\times 10^{0} \\ -5.4257162\times 10^{3} \\ 6.2481899\times 10^{1} \\ -2.5315506\times 10^{-1} \\ 5.4316452\times 10^{-4} \\ -5.8419137\times 10^{-7} \\ 2.5078084\times 10^{-10} \end{pmatrix}$$

$a18 := coefCPV_3$ $a18 = -5.4257162\times 10^{3}$

$b18 := coefCPV_4$ $b18 = 6.2481899\times 10^{1}$

$c18 := coefCPV_5$ $c18 = -2.5315506\times 10^{-1}$

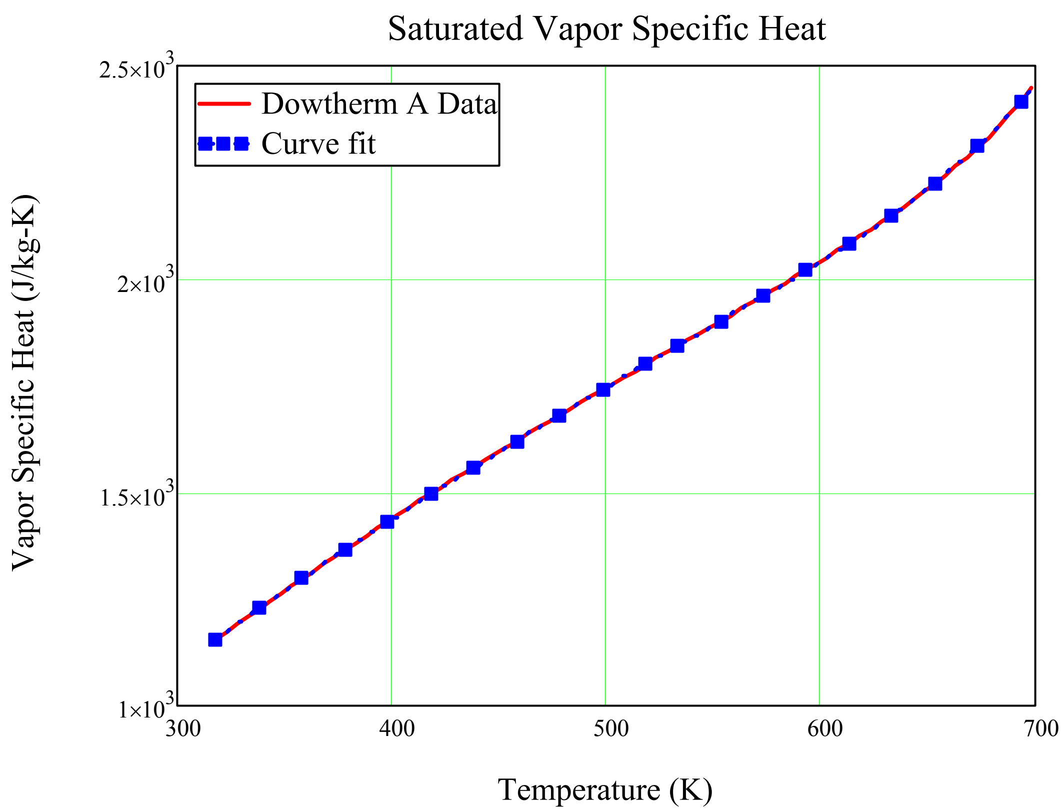
$d18 := coefCPV_6$ $d18 = 5.4316452\times 10^{-4}$

$e18 := coefCPV_7$ $e18 = -5.8419137\times 10^{-7}$

$f18 := coefCPV_8$ $f18 = 2.5078084\times 10^{-10}$

$$yCPV(T) := a18 + b18\cdot T + c18\cdot T^{2} + d18\cdot T^{3} + e18\cdot T^{4} + f18\cdot T^{5}$$

$$yyCPV_{kkk} := yCPV\left(CPVT_{kkk}\right)$$



Vapor Thermal Conductivity

$TCVT_{kkk} := AA_{kkk+12,1}$ $\quad$ $TCV_{kkk} := AA_{kkk+12,10}$

$coefTCV := regress(TCVT, TCV, 2)$

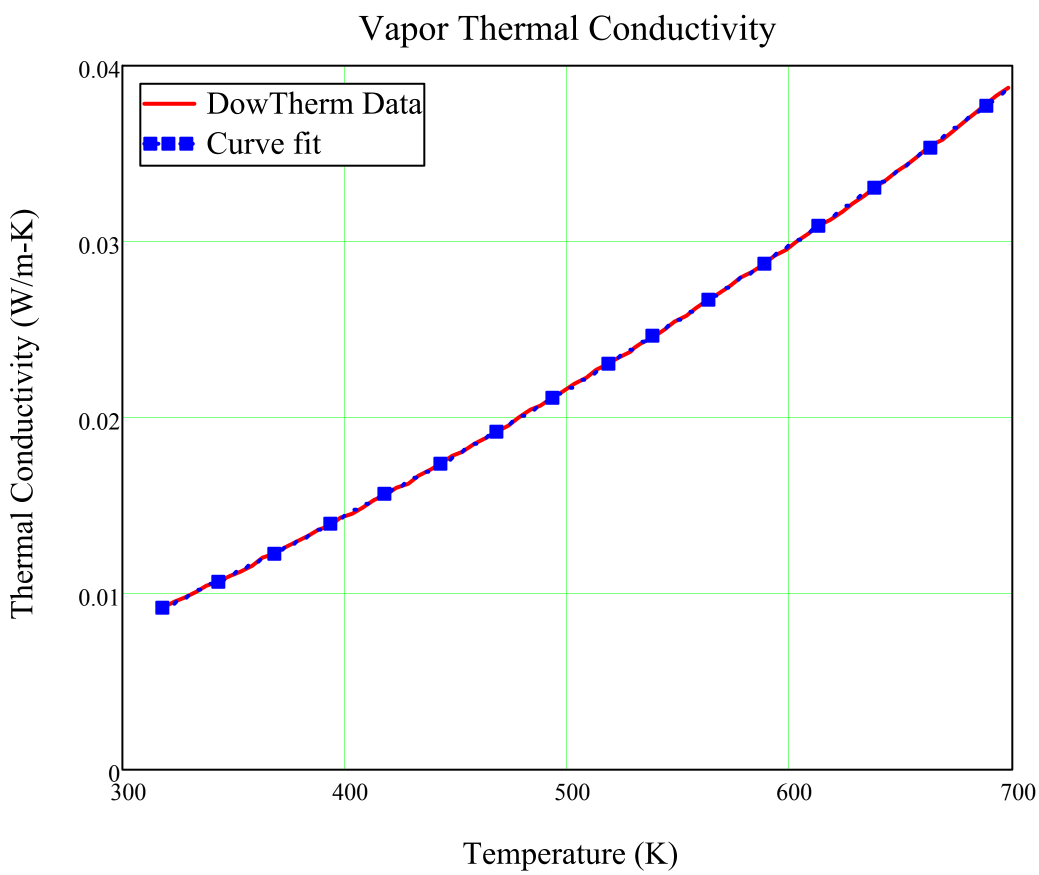
$$coefTCV = \begin{pmatrix} 3 \times 10^{0} \\ 3 \times 10^{0} \\ 2 \times 10^{0} \\ -5.1371078 \times 10^{-3} \\ 3.0160784 \times 10^{-5} \\ 4.6682186 \times 10^{-8} \end{pmatrix}$$

$a19 := coefTCV_3$ $\quad$ $a19 = -5.1371078 \times 10^{-3}$

$b19 := coefTCV_4$ $\quad$ $b19 = 3.0160784 \times 10^{-5}$

$c19 := coefTCV_5$ $\quad$ $c19 = 4.6682186 \times 10^{-8}$

$ytTCV(T) := a19 + b19 \cdot T + c19 \cdot T^2$ $\quad$ $yyTCV_{kkk} := ytTCV(TCVT_{kkk})$


Vapor Thermal Conductivity
DowTherm Data
Curve fit
0.04
0.03
0.02
0.01
0
300
400
500
600
700
Thermal Conductivity (W/m-K)
Temperature (K)

Vapor Viscosity

$VVT_{kkk} := AA_{kkk+12,1}$ $\quad$ $VV_{kkk} := AA_{kkk+12,9} \cdot 10^{-3}$

$coefVV := regress(VVT, VV, 5)$

$$coefVV = \begin{pmatrix} 3 \times 10^{0} \\ 3 \times 10^{0} \\ 5 \times 10^{0} \\ -5.7576644 \times 10^{-6} \\ 9.6177368 \times 10^{-8} \\ -4.0133099 \times 10^{-10} \\ 1.0111926 \times 10^{-12} \\ -1.249214 \times 10^{-15} \\ 6.1138665 \times 10^{-19} \end{pmatrix}$$

$a20 := coefVV_3$ $\quad$ $a20 = -5.7576644 \times 10^{-6}$

$b20 := coefVV_4$ $\quad$ $b20 = 9.6177368 \times 10^{-8}$

$c20 := coefVV_5$ $\quad$ $c20 = -4.0133099 \times 10^{-10}$

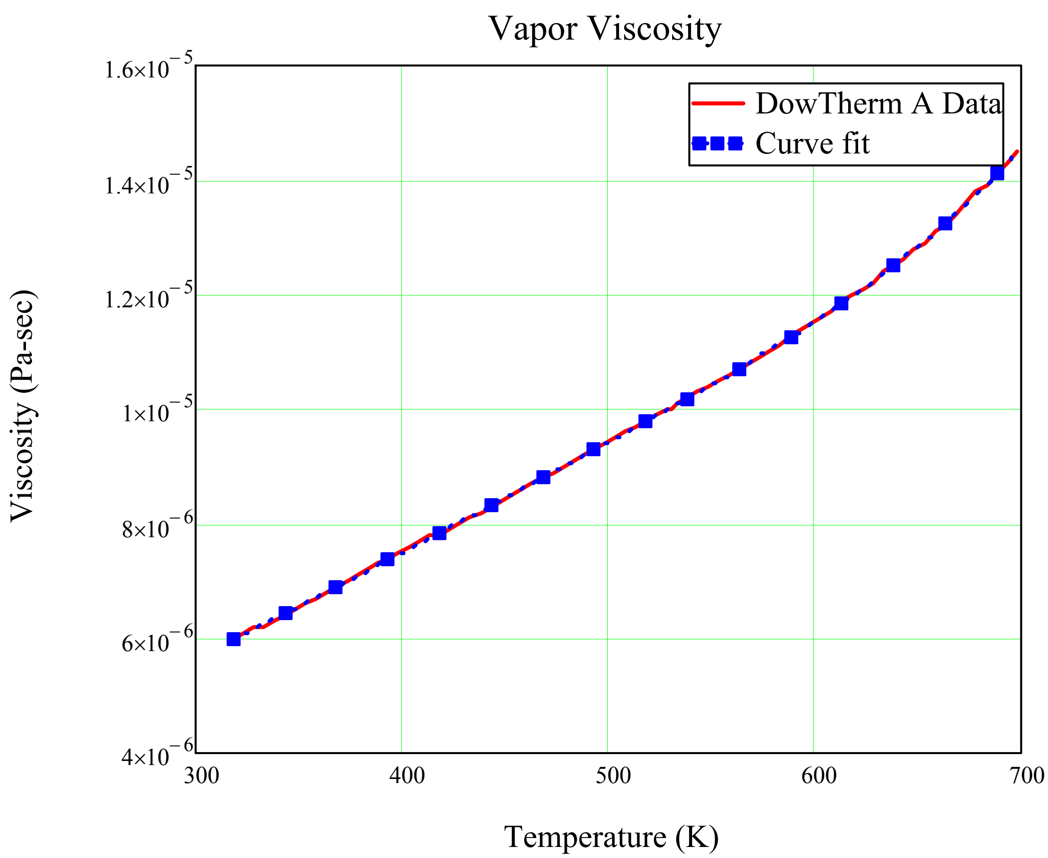
$d20 := coefVV_6$ $\quad$ $d20 = 1.0111926 \times 10^{-12}$

$e20 := coefVV_7$ $\quad$ $e20 = -1.249214 \times 10^{-15}$

$f20 := coefVV_8$ $\quad$ $f20 = 6.1138665 \times 10^{-19}$

$yVV(T) := a20 + b20 \cdot T + c20 \cdot T^2 + d20 \cdot T^3 + e20 \cdot T^4 + f20 \cdot T^5$

$yyVV_{kkk} := yVV\left(VVT_{kkk}\right)$


Vapor Viscosity
DowTherm A Data
Curve fit
Viscosity (Pa-sec)
Temperature (K)
1.6×10^−5
1.4×10^−5
1.2×10^−5
1×10^−5
8×10^−6
6×10^−6
4×10^−6
300
400
500
600
700