

Excel Add-In Program for Computation of Thermodynamic Properties of R134a and R718 Refrigerants

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ABSTRACT

Thermodynamic properties of R134a (1,1,1,2-Tetrafluoroethane) and R718 (water) have been developed as a Microsoft Excel add-in called ThermoAnalysis. The mathematical correlations for the thermodynamic properties of R134a and R718 were formulated from well-known equations of state and used to develop ThermoAnalysis based on a computer program in Microsoft Excel Visual Basic for Application language. ThermoAnalysis provides thermodynamic properties for the saturated regions for R134a and R718 refrigerants, and the subcooled and superheated regions of R718 refrigerant. The calculated values are accurate compared to the standard properties tables for refrigerants. A typical thermo-fluid problem was discussed to illustrate how ThermoAnalysis can be used for practical problem solving. Generated properties' data can be easily used in the Excel spreadsheet for process analysis, simulation and design of systems that use R134a and R718. ThermoAnalysis is handy for both students and practicing thermo-fluid engineers.

Keywords

R134a; R718; MS Excel add-in; Visual Basic for Application; Thermodynamic properties

1. INTRODUCTION

Thermodynamic properties such as specific volume, entropy, temperature, enthalpy, pressure, and internal energy of pure substances are important in the analysis and design of various thermodynamic systems. A pure substance is one that is homogeneous in chemical composition and invariable in chemical aggregation [1]. For a pure substance, there are three measurable properties: pressure (P), specific volume (v) and temperature (T). The equation that is used to express the relationship between these properties in the gaseous phase is called the equation of state of the pure substance. A functional p-v-T relationship of a gas can either be theoretical, generalized or an empirical equation fitted from experimental data. The simplest theoretical equation of state is the ideal or perfect gas equation of state representing the behaviour of the gas at low pressures (tending to zero) and high temperatures. Theoretical equations can be used to generate the property data of substances that represents their physical behaviour. However, realistic property data are usually determined from partially-empirical methods and are either provided as charts or tables. Reading properties data from tables and charts takes time and is prone to error. It becomes even more strenuous and time-consuming when trying to read a particular data point that is not explicitly stated and requires interpolation between two points. This limitation of the tables and charts has necessitated and motivated the development of computer

packages for obtaining properties data of substances.

The widespread use of computer in modern-day engineering training has rendered the use of thermodynamic property tables and charts obsolete [2]. Consequently, a number of computer programs have been developed to automate the process of obtaining property data. Taftan Data [3] developed Thermo Utilities v3.5, an MS Excel add-ins software package that can be used to design, analyze or optimize power plants, air conditioning systems and other chemical processes. Lemmon, et al. [4] developed a NIST Reference Fluid, Thermodynamic and Transport Properties (REFPROP) software which provides tables and plots of the thermodynamic and transport properties of industrially important fluids and their mixtures with an emphasis on refrigerants and hydrocarbons. REFPROP can only compute results for saturated properties of refrigerants considered. Tan and Chua [5] developed a Java programming application (Java Applet) for the computation of thermodynamic properties of steam and R134a refrigerants. They presented correlation formulae and results for saturated region but none was presented for superheated and sub-cooled regions, although they stated that their software can compute results for these regions with much less accuracy compared to the saturated region. Java applets for thermodynamic properties may not be available to the majority of users because it requires internet connectivity. On the other hand, Microsoft Office is readily available and it would be advantageous to have Microsoft embedded software for thermodynamic properties instead of Java applets. In ref. [6] a user-friendly MS Excel add-in for the thermodynamic properties of R152a called ThermoProp_R152a was developed. The study showed that the Excel add-in makes it possible to use Excel spreadsheet for direct process analysis, simulation and system design.

In this paper, we present a user-friendly MS Excel add-in package for the thermodynamic properties of R134a and R718 (called 'ThermoAnalysis'), which can aid students and practicing engineers to solve problems in the area of refrigeration and air-conditioning systems. ThermoAnalysis software covers the saturated region of both R134a and R718, and the subcooled and superheated region of R718. An important feature of the present software is that it is an MS Excel-based program. Therefore, its results can be easily applied for spreadsheet problem-solving which can aid real-time simulation of practical problems in classroom settings.

2. EQUATION OF STATE AND PROPERTY CORRELATION FORMULA

The mathematical correlations for the thermodynamic properties of R134a and R718 were formulated from well-known equations of state. An algorithm for computation of the

thermo-properties was developed based on the mathematical correlations. In implementing the algorithm, attention was given to the accuracy of the numerical solution for the mathematical correlations and a maximum relative error bound of 0.01% was used. The algorithm was converted into a computer code in Microsoft Excel Visual Basic for Application (VBA) to develop ThermoAnalysis. An advantage of Excel VBA is that it allows for the application of familiar and user-friendly interfaces to implement an add-in software package. Also, because of its inherent connection with other MS Excel tools, Excel VBA enables direct use of Excel spreadsheet capabilities to generate properties table and for process analysis.

2.1. Mathematical correlations

To determine the thermodynamic properties of a refrigerant or any pure substance, the following minimum experimental data/correlations are required [7]:

- P_s versus T_s where P_s and T_s are the saturated pressure and temperature.
- $P - v - T$ or equation of state for gaseous phase of the refrigerant.
- Liquid density (ρ_L) or specific volume (v_f).
- Liquid specific heat (C_f).
- Constant pressure specific heat (C_{p0}) or constant volume specific heat C_{v0} ($= C_{p0} - R$) of the gaseous phase.

The latent heat was calculated from the Clapeyron equation [7] as shown:

$$h_{fg} = \frac{dP_s}{dT_s} T (v_g - v_f) \quad (1)$$

The other properties to be calculated are the internal energy (u), enthalpy (h) and entropy (s). Equations (2 – 5) are used to calculate for the isothermal changes in u , h , s in the gaseous phase.

$$(u_2 - u_1)_T = \int_1^2 \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv \quad (2)$$

$$(h_2 - h_1)_T = - \int_1^2 \left[T \left(\frac{\partial P}{\partial T} \right)_p - v \right] dP \quad (3)$$

$$(s_2 - s_1)_T = \int_1^2 \left(\frac{\partial v}{\partial T} \right)_v dP \quad (4)$$

$$(s_2 - s_1)_T = \int_1^2 \left(\frac{\partial P}{\partial T} \right)_v dv \quad (5)$$

Equation (2) for internal energy change requires a p -explicit equation of state, whereas equation (3) for enthalpy change requires a v -explicit equation of state. For R134a, only the p -explicit equation of state is available and the enthalpy change was calculated from internal energy change using the relation in equation (6).

$$(h_2 - h_1)_T = (u_2 - u_1) + (P_2 v_2 - P_1 v_1)_T \quad (6)$$

2.1.1. Correlation for R134a Refrigerant

HFC-134a Refrigerant (1,1,1,2-tetrafluoroethane) also known as R134a is one of the most promising refrigerants that is environmentally friendly [5]. Two equations of state are commonly used to compute the thermodynamic properties of R134a. These are the Modified Benedict-Web-Rubin (MBWR) equation of state and the Martin-Hou equation of state (fit from MBWR data). For this work, the MBWR equation of state was used because the Martin-Hou equation

of state is less accurate, particularly in the superheated region [8].

The MBWR equation of state provides the most accurate fit of thermodynamic data for R134a over a wide range of temperatures and pressures. The data fit and calculation of constants for HFC-134a were performed at the National Institute of Standards and Technology (NIST) [4]. All constants were calculated in SI units which is consistent with the unit system of the present work. The MBWR equation of state is given as follows:

$$\frac{P}{100} = \sum_{n=1}^9 \frac{a_n}{V^n} + e^{-V_c^2/V^2} \sum_{n=10}^{15} \frac{a_n}{V^{2n-17}} \quad (7)$$

where a_n represents temperature-dependent coefficients which are given as [8]:

$$\begin{aligned} a_1 &= RT_s \\ a_2 &= b_1 T_s + b_2 T_s^{0.5} + b_3 + b_4/T_s + b_5/T_s^2 \\ a_3 &= b_6 T_s + b_7 + b_8/T_s + b_9/T_s^2 \\ a_4 &= b_{10} T_s + b_{11} + b_{12}/T_s \\ a_5 &= b_{13} \\ a_6 &= b_{14}/T_s + b_{15}/T_s^2 \\ a_7 &= b_{16}/T_s \\ a_8 &= b_{17}/T_s + b_{18}/T_s^2 \\ a_9 &= b_{19}/T_s^2 \\ a_{10} &= b_{20}/T_s^2 + b_{21}/T_s^3 \\ a_{11} &= b_{22}/T_s^2 + b_{23}/T_s^4 \\ a_{12} &= b_{24}/T_s^2 + b_{25}/T_s^3 \\ a_{13} &= b_{26}/T_s^2 + b_{27}/T_s^4 \\ a_{14} &= b_{28}/T_s^2 + b_{29}/T_s^3 \\ a_{15} &= b_{30}/T_s^2 + b_{31}/T_s^3 + b_{32}/T_s^4 \end{aligned}$$

where T_s is in K , V is in liters/mole, $V_c = 0.199334$ liters/mole, P is in kPa , and $R = 0.08314471$ (bar [abs]) (liters/mole) K , $T_c = 101.08$ °C, $P_c = 4060.3$ kPa [abs]. The values of MBWR coefficients (b_1 to b_{32}) for HFC-134a can be found in [8].

Saturation liquid volume (v_g):

Equation (7) was used to evaluate the saturation vapour volume (v_g).

Saturation liquid volume (v_f):

The saturation liquid volume was evaluated using the following equation:

$$\begin{aligned} \rho_l &= 528.1464 + 755.1834(1 - T_r)^{1/3} \\ &\quad + 1028.676(1 - T_r)^{2/3} \\ &\quad - 949.1172(1 - T_r) \\ &\quad + 593.566(1 - T_r)^{4/3} \end{aligned} \quad (8)$$

where $T_r = T_s/T_c$ is in K , ρ_l is in kg/m^3 and $v_f = 1/\rho_l$.

Latent heat of vaporization (H_{fg}):

The latent heat of vaporization was evaluated using the following equation:

$$\begin{aligned} H_{fg} &= P_s \left[-\frac{P_2}{T_s^2} + P_3 + 2P_4 T_s - \frac{P_5}{T_s} \right. \\ &\quad \left. - \left(\frac{P_5 P_6 \ln(P_6 - T_s)}{T_s} \right) v_{fg} \right] \end{aligned} \quad (9)$$

Differentiating equation (7) with respect to temperature and substituting it into equation (2), and then substituting the resulting equation into equation (6) gives the vapour phase enthalpy. The vapour phase internal energy was then obtained using the equation: $u_g = h_g - P v_g$. Substituting the differential of equation (7) with respect to temperature into equation (5), we have the vapour phase entropy.

2.1.2. Correlation for R718 Refrigerant (Water)

Water as a refrigerant (R718) is one of the oldest refrigerants used for refrigeration applications because of its availability and excellent thermo-chemical properties. The most accurate equations that model the thermodynamic properties of water are given by the International Association for the Properties of Water and Steam (IAPWS) for different regions which cover the following temperature and pressure range [9, 10]. For the purpose of this work, the following equations were used:

Reference constants

$$T_c = 647.096 \text{ K} \quad \alpha_0 = 1000 \text{ J/kg} \quad p_c = 22.064 \text{ MPa}$$

$$\phi_0 = \alpha_0/T_c \quad \rho_c = 322 \text{ kg/m}^3$$

Saturated vapour pressure

$$\ln\left(\frac{p}{p_c}\right) = \frac{T_c}{T} [a_1\tau + a_2\tau^{1.5} + a_3\tau^3 + a_4\tau^{3.5} + a_5\tau^4 + a_6\tau^{7.5}] \quad (10)$$

with

$$\begin{aligned} a_1 &= -7.85951783 & a_4 &= 22.6807411 \\ a_2 &= 1.84408259 & a_5 &= -15.9618719 \\ a_3 &= -11.7866497 & a_6 &= 1.80122502 \end{aligned}$$

Saturated densities

The density of the saturated liquid was calculated from:

$$\frac{\rho'}{\rho_c} = 1 + b_1\tau^{1/3} + b_2\tau^{2/3} + b_3\tau^{5/3} + b_4\tau^{16/3} + b_5\tau^{43/3} + b_6\tau^{110/3} \quad (11)$$

with

$$\begin{aligned} b_1 &= 1.99274064 & b_4 &= -1.75493479 \\ b_2 &= 1.09965342 & b_5 &= -45.5170352 \\ b_3 &= -0.510839303 & b_6 &= -6.746944 \times 10^5 \end{aligned}$$

The density of the saturated vapour was calculated from:

$$\ln\left(\frac{\rho''}{\rho_c}\right) = c_1\tau^{2/6} + c_2\tau^{4/6} + c_3\tau^{8/6} + c_4\tau^{18/6} + c_5\tau^{37/6} + c_6\tau^{71/6} \quad (12)$$

with

$$\begin{aligned} c_1 &= -2.0315024 & c_4 &= -17.2991605 \\ c_2 &= -2.68302940 & c_5 &= -44.7586581 \\ c_3 &= -5.38626492 & c_6 &= -63.9201063 \end{aligned}$$

Saturated specific enthalpy and specific entropy

Auxiliary equations:

$$\frac{\alpha}{\alpha_0} = d_\alpha + d_1\theta^{-19} + d_2\theta + d_3\theta^{4.5} + d_4\theta^5 + d_5\theta^{54.5} \quad (13)$$

$$\begin{aligned} \frac{\phi}{\phi_0} &= d_\phi + \frac{19}{20}d_1\theta^{-20} + d_2\ln\theta + \frac{9}{7}d_3\theta^{3.5} + \frac{5}{4}d_4\theta^5 \\ &+ \frac{109}{107}d_5\theta^{53.5} \end{aligned} \quad (14)$$

with

$$\begin{aligned} d_1 &= -5.65134998 \times 10^{-8} & d_4 &= -135.003439 \\ d_2 &= 2.69066631 & d_5 &= 0.981825814 \\ d_3 &= 127.287297 & d_\alpha &= -1135.905627715 \\ d_\phi &= 2319.5246 \end{aligned}$$

The specific enthalpy of the saturated liquid was calculated from:

$$h' = \alpha + \frac{T}{\rho'} \frac{dp}{dT} \quad (15)$$

Equation (15) yields the specific enthalpy of the saturated liquid when used in conjunction with Equations (10), (11), and (13).

The specific enthalpy of the saturated vapour was calculated from:

$$h'' = \alpha + \frac{T}{\rho''} \frac{dp}{dT} \quad (16)$$

Equation (16) yields the specific enthalpy of the saturated liquid when used in conjunction with Equations (10), (12), and (13).

The specific entropy of the saturated liquid was calculated from:

$$s' = \phi + \frac{1}{\rho'} \frac{dp}{dT} \quad (17)$$

Equation (17) yields the specific enthalpy of the saturated liquid when used in conjunction with Equations (10), (11), and (14).

The specific entropy of the saturated vapour was calculated from:

$$s'' = \phi + \frac{1}{\rho''} \frac{dp}{dT} \quad (18)$$

Equation (18) yields the specific enthalpy of the saturated liquid when used in conjunction with Equations (10), (12), and (14).

These equations are valid from the triple point to the critical point. This corresponds to

$$273.16 \text{ K} \leq T \leq 647.096 \text{ K}$$

Sub-cool region

The basic equation for this region is a fundamental equation for the specific Gibbs free energy g . This equation is expressed in dimensionless form as $\gamma = g/(RT)$, and can be represented as:

$$\frac{g(p, T)}{RT} = \gamma(\pi, \tau) = \sum_{i=1}^{34} n_i (7.1 - \pi)^{I_i} (\tau - 1.222)^{J_i} \quad (19)$$

where $\pi = p/p^*$ and $\tau = T^*/T$ with $p^* = 16.53 \text{ MPa}$ and $T^* = 1386 \text{ K}$, $R = 0.461526 \text{ kJ/kg}^{-1}\text{K}^{-1}$. The coefficient n_i and exponents I_i and J_i can be found in [9, 10].

Superheat region

The basic equation for this region is a fundamental equation for the specific Gibbs free energy g . This equation is expressed in dimensionless form, $\gamma = g/(RT)$, and it is separated into two parts, an ideal-gas part, γ^o , and a residual part, γ^τ , such that it is expressed as:

$$\frac{g(p, T)}{RT} = \gamma(\pi, \tau) = \gamma^o(\pi, \tau) + \gamma^\tau(\pi, \tau) \quad (20)$$

The ideal-gas part, γ^o , and the residual part, γ^τ , of the dimensionless Gibbs free energy equation are given as:

$$\gamma^o = \ln \pi + \sum_{i=1}^9 n_i^o \tau^{J_i^o} \quad (21)$$

$$\gamma^\tau = \sum_{i=1}^{43} n_i \pi^{I_i} (\tau - 0.5)^{J_i} \quad (22)$$

where $\pi = p/p^*$ and $\tau = T^*/T$ with $p^* = 1 \text{ MPa}$ and $T^* = 540 \text{ K}$, $R = 0.461526 \text{ kJ/kg}^{-1}\text{K}^{-1}$. The coefficients n_i^o and n_i and exponents J_i^o , I_i and J_i can be found in [9, 10].

All other thermodynamic properties can be derived from the basic equations by using the appropriate combination of the dimensionless Gibbs free energy (γ) and its derivatives. Relations between the relevant thermodynamic properties, γ and its derivatives can be found in refs. [9, 10].

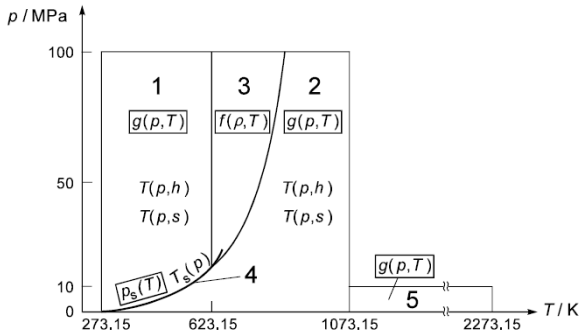


Fig 1: Thermodynamic classification of the five regions for R718 [9]

Figure 1 shows the five regions for which empirical equations for R718 have been developed. Details of the equations for these five regions can be found in the IAPWS publications [9, 10].

2.2 Statement Algorithm for implementation of ThermoAnalysis

The thermodynamic property analysis was carried out in the following steps:

Start

1. Input data

- (i) choose the refrigerant for analysis
- (ii) choose the phase of the refrigerant (saturated liquid, saturated vapour, mixed vapour-liquid, superheated vapour or sub-cooled liquid);
- (iii) specify the desired (unknown) property (specific enthalpy, specific entropy, specific volume, temperature, pressure, specific internal energy, or quality);
- (iv) choose the corresponding dependent variable(s) which could be any one variable (for saturated states) or two variables (for other states);
- (v) enter the value(s) of the dependent variable(s)

2. Compute the desired unknown property;

3. Output the desired data (property name and numerical value);

4. Use the output for process analysis, if desired;

5. Generate table of properties, if desired;

Stop.

The above algorithm was used to develop ThermoAnalysis.

2.3 Using ThermoAnalysis

2.3.1 Installation

To start with, the ThermoAnalysis software must be installed as an Excel Add-in using the standard procedure of installing an Add-ins. The following steps can be used to install ThermoAnalysis.

- a) Save the Thermoanalysis excel file as an excel AddIns.
- b) Go to File, Options, then Add-Ins
- c) On the displayed interface, go down to manager, then click GO...
- d) On the new displayed interface, check the Thermoanalysis option and click OK.

Now, the software is ready for use.

2.3.2 Application

After installation, depending on the Microsoft Excel version used, 'Add-Ins' or 'ThermoAnalysis' would show on the menu bar. If 'Add-Ins' reflects on the menu bar as shown in Figure 2, then clicking on the Add-Ins menu displays the 'ThermoAnalysis' menu.

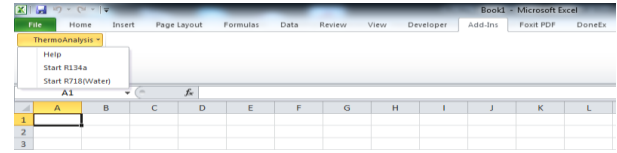


Fig 2: Excel worksheet showing the start drop-down menu

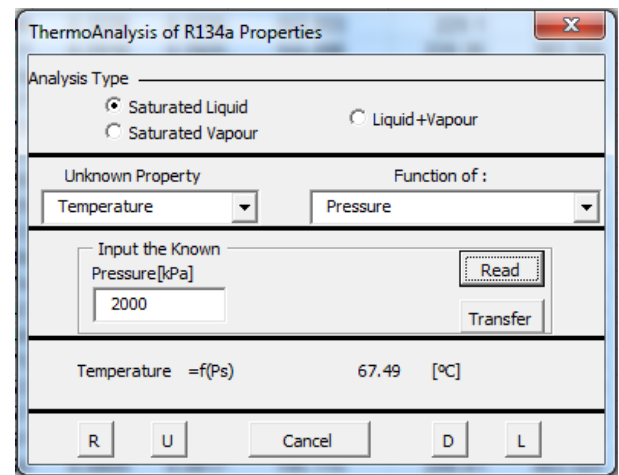


Fig 3: ThermoAnalysis user interface showing property computation of R134a

On the other, if 'ThermoAnalysis' is displayed on the menu bar after installation, clicking on it would display the 'ThermoAnalysis' menu. After clicking on the ThermoAnalysis menu, a drop-down menu list appears requiring the user to choose the refrigerant for analysis (either R134a or R718). By clicking on the desired refrigerant, the user interface shown in Figure 3 appears. Figure 3 is the user interface for R134a and a similar interface is applicable for R718. The user interface is very simple to use and like most Microsoft interfaces, requires the user to select the relevant options by clicking and entering the input values in the spaces provided. Clicking the 'Read' button computes the selected property while the 'Transfer' button transfers the computed results to Excel worksheet.

3. RESULTS AND DISCUSSION

3.1 Validation of ThermoAnalysis

The tabulated data generated from the software for the saturated properties of R134a and R718 are shown in the appendix. These data agree with standard properties tables for R134a and R718 as shown by the relative percentage difference charts in Figures 4 and 5. The reference data used to plot the RPD chart R134a were obtained from ref. [7] while that for R718 were obtained from steam tables in ref [12]. The RPD charts show that the deviations incurred in this work are within acceptance limits of engineering purposes.

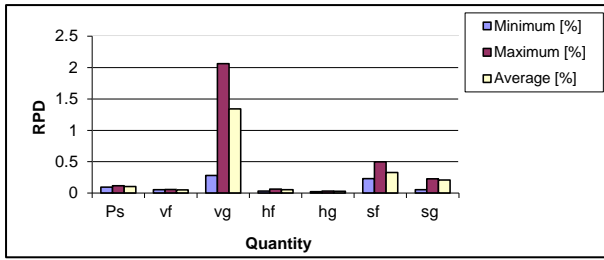


Fig 4: Relative percentage deviation (RPD) for saturated region of R134a

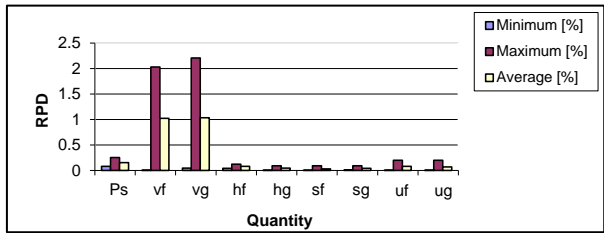


Fig 5: Relative percentage deviation (RPD) for saturated region of R718

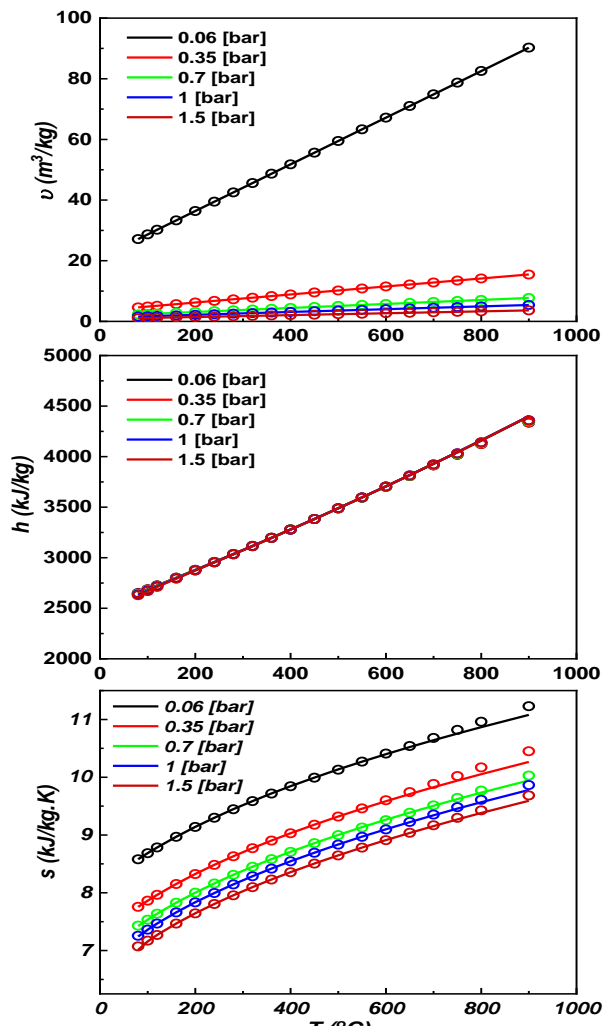


Fig 6: Plot of specific volume, enthalpy and entropy against temperature at varying pressures for superheated data of R718: Current work – lines, ref. [11] – circle marker

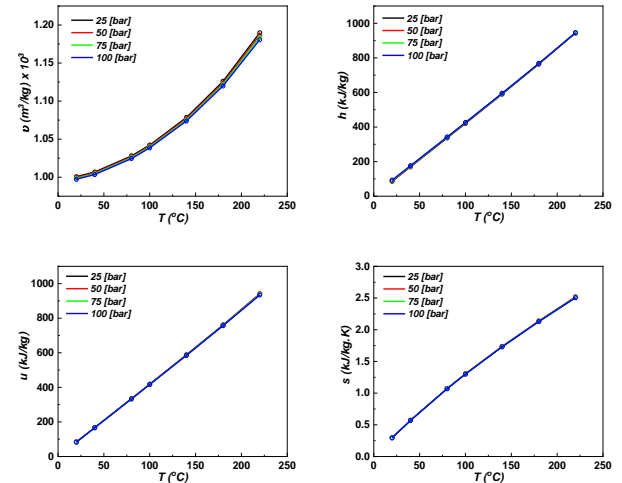


Fig 7: Plot of specific volume, enthalpy, internal energy and entropy against temperature at varying pressures for subcooled data of R718: Current work – lines, ref. [13] – circle marker

Therefore, we can conclude from Figures 4 to 7 that ThermoAnalysis gives reliable estimates of the thermodynamic properties for the saturate region of R314a and the saturated, superheated and subcooled regions of R718.

3.2 Example of problem-solving using ThermoAnalysis

To demonstrate the application of ThermoAnalysis, we consider a typical thermodynamic problem on refrigeration that can be used in the classroom setting.

Problem statement

An R134a hermetic (directly-coupled motor) reciprocating compressor with 4 percent clearance is to be designed for 7.5 [TR] capacity at 4°C evaporating and 40°C condensing temperatures. The compression index is assumed to be 1.15 [-]. The pressure drops at suction and discharge valves were be assumed as 0.2 and 0.4 bar respectively. Determine:

- Power consumption of the compressor
- COP of the cycle
- Volumetric efficiency of the compressor.

Solution

The solution process and the results obtained using ThermoAnalysis are show in Table 1.

4. CONCLUSION

A software package, called ThermoAnalysis, that can compute the thermodynamic property data for R134a and R718 was developed as an MS Excel Add-ins using Excel Visual Basic for Applications. A main feature of ThermoAnalysis is that it can compute data for the sub-cooled and superheat regions for R718, which is not readily available in similar programs [4, 5]. The software package, also takes advantage of the computational and spreadsheet capabilities of MS Excel to generate property tables as shown in the appendix. Although the generated data showed some deviations from experimental data and previous works, the deviations are well within the acceptable range for engineering purposes. Finally, we demonstrate how ThermoAnalysis can be used to solve refrigeration and air-conditioning problems using a typical example that is suitable for classroom exercise. This implies that ThermoAnalysis would be a good teaching and learning resource for courses on

thermodynamics, refrigeration and air-conditioning. Furthermore, it can be a useful and cost-effective resource in

actual engineering professional practices that involves the use of properties data.

Table 1: Solution to refrigeration problem using ThermoAnalysis

RESULTS SHEET				
INPUT DATA				
S/NO	QUANTITY	SYMBOL	UNIT	VALUE
1	Compressor Capacity	TR	TR	7.5
2	Evaporating Temperature	T_e	$^{\circ}C$	4
3	Condensing Temperature	T_c	$^{\circ}C$	40
4	Compressor Index	N	-	1.15
5	Suction Pressure Drop	ΔP_s	bar	0.2
6	Discharge Pressure Drop	ΔP_d	bar	0.4
7	Compressor Clearance	C	-	0.04
DATA OBTAINED FROM THERMOANALYSIS				
S/NO	QUANTITY	SYMBOL	UNIT	VALUE
1	Evaporating Pressure at $4^{\circ}C$	P_o	bar	3.3765
2	Condensing Pressure at $40^{\circ}C$	P_k	bar	10.164
3	Enthalpy of the suction vapour at $4^{\circ}C$	h_1	kJ/kg	407.25
4	Specific volume of the suction vapour at $4^{\circ}C$	v_1	m^3/kg	0.0618
5	Enthalpy of the liquid from the condenser at $4^{\circ}C$	$h_3=h_4$	kJ/kg	254.62
OUTPUT DATA				
S/NO	QUANTITY	SYMBOL	UNIT	VALUE
1	Suction Pressure	P_s	bar	3.1765
2	Discharge Pressure	P_d	bar	9.7640
3	Refrigerating effect	q_o	kJ/kg	152.6300
4	Specific work	w	kJ/kg	23.7400
5	Mass flow rate	m	Kg/s	0.1728
6	Power consumption of the compressor	W	kW	4.1027
7	Coefficient of performance	COP	-	6.4292
8	Volumetric efficiency of the compressor	η_v	-	0.8394

5. DECLARATION

The author declared that there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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8. APPENDIX

Table A1: ThermoAnalysis data for saturated R134a

T _s [°C]	P _s [kPa]	v _f x10 ³ [m ³ /kg]	v _{fg} [m ³ /kg]	v _g [m ³ /kg]	h _f [kJ/kg]	h _{fg} [kJ/kg]	h _g [kJ/kg]	S _f [kJ/kgK]	S _{fg} [kJ/kgK]	S _g [kJ/kgK]
-40	51.641	0.705	0.3557	0.3564	150.503	230.21	380.713	0.7969	0.9874	1.7843
-38	57.239	0.708	0.3228	0.3235	152.933	229.1	382.033	0.8088	0.9743	1.7831
-36	63.318	0.711	0.2918	0.2925	155.096	228.26	383.356	0.8193	0.9625	1.7818
-34	69.908	0.714	0.2653	0.266	157.432	227.25	384.682	0.8304	0.9502	1.7806
-32	77.037	0.717	0.2417	0.2424	159.711	226.3	386.011	0.841	0.9384	1.7794
-30	84.739	0.72	0.2204	0.2211	162.173	225.17	387.343	0.852	0.9261	1.7781
...										
0	292.822	0.772	0.0701	0.0709	200	205.44	405.44	1	0.7521	1.7521
2	314.62	0.776	0.0654	0.0662	202.243	204.1	406.343	1.0091	0.7418	1.7509
4	337.646	0.78	0.061	0.0618	204.772	202.48	407.252	1.0192	0.7306	1.7498
6	361.946	0.784	0.0569	0.0577	207.486	200.68	408.166	1.0297	0.7189	1.7486
8	387.564	0.788	0.0532	0.054	209.917	199.17	409.087	1.039	0.7084	1.7474
10	414.548	0.793	0.0497	0.0505	212.713	197.3	410.013	1.0495	0.6968	1.7463
...										
90	3243.471	1.193	0.0024	0.0036	367.228	84.17	451.398	1.4702	0.2318	1.702
92	3378.755	1.227	0.002	0.0032	374.816	76.99	451.806	1.4901	0.2108	1.7009
94	3518.951	1.269	0.0016	0.0029	383.085	69.08	452.165	1.5116	0.1882	1.6998
96	3664.444	1.322	0.0013	0.0026	388.921	63.27	452.191	1.5274	0.1714	1.6988
98	3815.826	1.396	0.0009	0.0023	397.882	53.86	451.742	1.5526	0.1451	1.6977
100	3974.244	1.528	0.0006	0.0021	404.76	46.71	451.47	1.5715	0.1252	1.6967
101.08	4063.826	1.892	0	0.0019	450.664	0	450.664	1.6961	0	1.6961

Table A2: ThermoAnalysis data for saturated R718

T _s [°C]	P _s [bar]	v _f x10 ⁻² [m ³ /kg]	v _{fg} [m ³ /kg]	v _g [m ³ /kg]	h _f [kJ/kg]	h _{fg} [kJ/kg]	h _g [kJ/kg]	S _f [kJ/kgK]	S _{fg} [kJ/kgK]	S _g [kJ/kgK]	u _f [kJ/kg]	u _{fg} [kJ/kg]	u _g [kJ/kg]
0.01	0.006117	0.10002	206.0035	206.0045	0	2500.7	2500.7	0	9.155	9.155	0	2375	2375
2	0.00706	0.10001	179.7747	179.7757	8.4	2496.1	2504.5	0.031	9.071	9.102	8	2369	2378
4	0.008135	0.10001	157.1342	157.1352	16.8	2491.3	2508.1	0.061	8.989	9.05	17	2363	2380
6	0.009353	0.10001	137.6506	137.6516	25.2	2486.7	2511.9	0.091	8.908	8.999	25	2358	2383
8	0.010729	0.10002	120.8453	120.8463	33.6	2482	2515.6	0.121	8.828	8.949	34	2352	2386
10	0.012281	0.10003	106.3175	106.3185	42	2477.3	2519.3	0.151	8.749	8.9	42	2347	2389
...													
200	15.54939	0.11565	0.126	0.1272	852.2	1939.8	2792	2.33	4.1	6.43	850	1744	2594
202	16.21055	0.11597	0.121	0.1222	861.2	1931.9	2793.1	2.349	4.066	6.415	859	1736	2595
204	16.89339	0.11628	0.1162	0.1174	870.2	1924	2794.2	2.368	4.032	6.4	868	1728	2596
206	17.59841	0.11661	0.1116	0.1128	879.3	1916	2795.3	2.387	3.998	6.385	877	1720	2597
208	18.32609	0.11694	0.1073	0.1085	888.4	1907.9	2796.3	2.406	3.965	6.371	886	1711	2597

210	19.0769 2	0.11727	0.1031	0.1043	897.5	1899.7	2797.2	2.424	3.932	6.356	895	1703	2598
.
360	186.66	0.1895	0.0051	0.007	1761.4	720.2	2481.6	3.916	1.138	5.054	1726	625	2351
362	191.208 5	0.19376	0.0047	0.0066	1782.4	677.7	2460.1	3.948	1.067	5.015	1745	589	2334
364	195.855 9	0.1987	0.0042	0.0062	1805	630.8	2435.8	3.982	0.99	4.972	1766	548	2314
366	200.606 4	0.20459	0.0038	0.0058	1829.8	578.2	2408	4.019	0.905	4.924	1789	503	2292
368	205.464 9	0.21192	0.0033	0.0054	1857.7	517.2	2374.9	4.061	0.807	4.868	1814	450	2264
370	210.438 2	0.22172	0.0028	0.005	1890.8	442.8	2333.6	4.111	0.689	4.8	1844	384	2228
372	215.536 5	0.23697	0.002	0.0044	1935	340.6	2275.6	4.178	0.528	4.706	1884	297	2181
373.95	220.64	0.31056	0	0.0031	2086.6	0	2086.6	4.41	0	4.41	2018	0	2018