

MS Excel Spreadsheet Add-in for Thermodynamic Properties and Process Simulation of R152a

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Received 09 January 2013; accepted 22 April 2013

Abstract

Microsoft Excel add-in has been developed for the thermodynamic properties of refrigerant DifluoroEthane (R152a) an alternative refrigerant to R134a, which has no Ozone Depletion Potential. Thermodynamic properties' equations for R152a were formulated from a popular equation of state. The equations were transformed into a computer program in Microsoft Excel-Visual Basic for Application in Integrated Development Environment as an Excel add-in. The add-in is able to compute the thermodynamic properties of R152a refrigerant - specific volume, internal energy, enthalpy, and entropy in the wet, subcooled and superheated-vapor regions. The calculated values are accurate compared to the standard reference properties tables for refrigerants. Computed properties' data can easily be used in the Excel spreadsheet for process analysis, simulation and design of R152a refrigerating plants. The solution scheme and computer language adopted in this work are easy to apply and use as opposed to the available sophisticated and expensive computer software packages; and the MS Excel add-in presented in this paper would be useful to both practicing engineers and engineering students in the area. An application was illustrated by solving a typical problem in R152a refrigerating process analysis.

Key words: Excel add-in; Excel-VBA; Thermodynamic Properties; R152a; Refrigeration.

Oko, C.O.C., Diemuodeke, E.O. (2013). MS Excel Spreadsheet Add-in for Thermodynamic Properties and Process Simulation of R152a. *Energy Science and Technology*, 5(2), XX. Available from: <http://www.cscanada.net/index.php/est/article/view/j.est.1923847920130502.756>. DOI: <http://dx.doi.org/10.3968/j.est.1923847920130502.756>.

INTRODUCTION

Thermodynamic properties of refrigerants are important in refrigerating process analysis and system design. The property data are usually determined semi-empirically and are either tabulated or provided as charts of properties. But, the use of property tables frequently requires interpolation between the tabulated data, which is time consuming and reading the property charts is also strenuous, time consuming and always prone to errors. However, the extensive use of computing facilities in contemporary engineering practice limits the use of property charts (Dromey, 1985). The trend is towards the development of computer packages that are capable of automatic generation of the values of the desired properties, and thus, facilitating their use in engineering analysis. The use of thermodynamics properties computer packages can improve the curiosity of engineering students in the understanding of the properties tables and charts (Tan and Chua, 2003).

Beckman and Klein (1996) developed a commercial software package, which is not affordable by majority of the developing nations, called the Engineering Equation Solver (EES) that has the capability of analyzing thermodynamic and transport properties of many fluids used in engineering. EES incorporates the programming structure of C and FORTRAN with a built-in solver, graphical capabilities and many mathematical functions. Refprop is also a FORTRAN-based commercial software that allows a user to look up thermodynamic properties for most refrigerants currently in use. In addition to pure

refrigerant properties, Refprop (computer software) uses either the Carnahan-Startind-DeSantis (CSD) hard sphere or the Modified Benedict-Webb- Rubin (MBWR) equation of state to calculate the properties of refrigerant mixtures.

The Visual Basic for Applications (VBA) is a macro language available in Microsoft Office applications and in other non-Microsoft software (e.g. Arc Info). Excel is a powerful spreadsheet in Microsoft Office. Even though it was developed primarily for business applications, its ease of use and wide distribution make it a very powerful tool for scientists and engineers (Deane, 2005). Excel and Visual Basic developed separately, and were only linked by Microsoft once it started to use VBA as the macro language for its Office products. VBA follows the syntax of Visual Basic (VB), and an Integrated Development Environment (IDE) is available in the different applications that offer VB. Excel-VBA contains a lot of pre-programmed elements like forms and controls (buttons, text boxes, list boxes, etc.). Many mathematical and non-mathematical functions are accessible through the spreadsheet and which are not available in Visual Basic (Dean et al, 2005). Excel provides graphics, which are relatively easy to manipulate compared with graphics within Visual Basic. Main disadvantage of Excel-VBA is that, one cannot create a stand-alone program with it. That is, the user needs to have Excel in his or her computer to be able to use Excel-VBA programs. However, the Excel add-ins are computer programs (tools) written within the Excel environment that extends the functionality of the basic product (Liengme, 2000). These tools make difficult tasks easier, automate repetitive operations, and add new features. Add-ins can increase productivity by focusing on a single task or function. Most Microsoft Excel add-ins can be divided into two broad categories: add-ins that work with Microsoft Excel (committee), and add-ins that take over the complete workspace (dictators).

Most of the computer software packages for the determination of thermodynamic properties and simulation of refrigeration processes require subscription, which are generally expensive for the developing countries. One way to make some of these computer tools available to the developing countries is through the Internet. With the rapid evolution of Internet, there are now several websites that provide online computation of thermodynamic properties for pure substances. There is a good agreement between the results generated by the free online Internet applets and those generated by the commercial desktop application software (Tan and Chua, 2003). However, a report has shown that about 13.5% only of African population has Internet access (Internet World Stats, 2012), therefore, Internet applets for thermodynamic properties may not be available to the majority of African students. Since Microsoft Office is readily available in most computers it suffices, therefore, to say that Microsoft embedded software for thermodynamic properties,

instead of the Internet applets, would be of greater use in regions where there is limited or unreliable Internet access. Zhang and Muehlbauer (2012) developed MS Excel tool, with embedded macros of Visual Basic Application, for simulation of residential heat pump. The Zhan and Muehlbauer (2012) Excel tool cannot compute thermodynamic properties; moreover, is not installable as an add-in.

Therefore, this paper presents a user-friendly committee-type Excel add-in for the thermodynamic properties of R152a, *ThermoProp_R152a*, which provides the facility for their direct use in process analysis using the Excel spreadsheet. The choice of R152a is because it is an alternative to R134a; both refrigerants, R134a and R152a, are replacements for the formerly popular R12, which has been phased out for having Ozone Depletion Potential (ODP) (Ghodbane, 1999; Arora, 2000; Oko, 2012). The computer language adopted in this work is easy to install, use and modify as opposed to the sophisticated and expensive computer software packages used by most researchers in the area (Beckman and Klein, 1996).

1. GOVERNING EQUATIONS

The changes in the specific internal energy (u), specific enthalpy (h) and specific entropy (s) at constant temperature in the vapour phase are, respectively,

$$(u_2 - u_1)_T = \int_1^2 \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv \quad (1)$$

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

$$\text{and } (h_2 - h_1)_T = (u_2 - u_1) + (P_2 v_2 - P_1 v_1) \quad (3)$$

The specific latent heat is given by the Clapeyron equation as

$$(h_{fg}) = \left(\frac{dP_s}{dT_s} \right) T (v_g - v_f) \quad (4)$$

Where v , P , and T are the specific volume (m^3kg^{-1}), the absolute pressure (kPa) and the absolute temperature, respectively; the indices s , f , g , and fg denote saturation, liquid saturation, vapour saturation and latent conditions, respectively.

The saturation vapour correlation for R152a is given as (Arora, 2000)

$$\ln \frac{P_s}{P_c} = \left(\frac{T_c}{T_s} \right) [-7.46588(1 - T_r^s) + 1.89468(1 - T_r^s)^{1.5} - 2.57557(1 - T_r^s)^{2.5}] \quad (5)$$

Where $T_r^s = \frac{T_s}{T_c}$, the index c refers to the critical state and s reduced saturation temperature

The Soave Redlich-Kwong equation of state (Kamei et al, 1990) is used for the analysis of R152a:

$$P = \frac{RT}{v-b} - \frac{A_c[1+m(1-T_r^{0.5})]^2}{v(v+b)} \quad (6)$$

where $A_c=0.42748R^2T_c^2/P_c$, $kPam^6kg$; $b=0.08664RT_c/P_c$, m^3kg^{-1} ; $m=0.48508+1.55171\omega-0.15613\omega^2$; $\omega=-\log P_r^s-1$ at $T_r=0.7$; $T_r=T/T_c$; $P_r^s=P_s/P_c$; $R=\bar{R}/\bar{M}$; $\bar{R}=8.3142$ is the universal gas constant, $kJkmol^{-1}K^{-1}$; \bar{M} is the molecular mass, $kgkmol^{-1}$; T_r is the reduced temperature, dimensionless; ω is acentric factor, dimensionless; is reduced saturation pressure; and R is the gas constant, $kJkg^{-1}K^{-1}$.

The saturation liquid density (ρ_f) and the zero-pressure isobaric specific heat capacity (c_{p0}) for R152a are given, respectively, as (Arora, 2000)

$$\frac{\rho_f}{\rho_c} = 1 + 1.86756(1 - T_r^s)^{0.326} + (1 - T_r^s)^{0.836} \quad (7)$$

$$\text{and } c_{p0} = 0.13141 + 3.6288 \times 10^{-3}T - 3.04459 \times 10^{-7}T^2 + 5.14119 \times 10^{-10}T^3 \quad (8)$$

where ρ_f and ρ_c are in kgm^{-3} , and c_{p0} is in $kJkg^{-1}K^{-1}$

With the knowledge of two thermodynamic properties one can find the quality (α) of the refrigerant at the given state in the wet region, saturated mixture:

$$\alpha = \frac{\varphi - \varphi_f}{\varphi_{fg}} \quad (9)$$

where φ , φ_f and $\varphi_{fg}=\varphi_g-\varphi_f$ are some thermodynamic properties in the wet region, corresponding saturated liquid property and the corresponding latent property of evaporation, respectively; and .

The formulations for the specific enthalpy (h), specific entropy (s) and specific internal energy (u) are obtained for R152a in the vapour phase by integrating the equation of state, equation (6), and applying equations (1), (2) and (3), respectively, as follows:

$$h = h_0 - RT + Pv + \int_{T_0}^T c_{p0} dT + \frac{A_c}{b} [I(T) - TG(T)] \ln \frac{v}{v+b} \quad (10)$$

$$s = s_0 + \int_{T_0}^T c_{p0} \frac{dT}{T} + R \ln \frac{(v-b)P}{RT} - \frac{A_c}{b} G(T) \ln \frac{(v^{id}+b)/(v+b)}{v^{id}/v} \quad (11)$$

and

$$u = h_0 - RT + \int_{T_0}^T C_{p0} dT + \frac{A_c}{b} [I(T) - TG(T)] \ln \frac{v}{v+b} \quad (12)$$

Where $G(T)=0.808334T_c^{-1}-1.707408(TT_c)^{-1/2}$;

$I(T)=1.899074 - 0.899074(TT_c^{-1})^2$; $v^{id} = \frac{RT}{P_0}$; the

index "0" refers to the reference state property; and the superscript "id" refers to the ideal state property.

The specific latent heat h_{fg} is obtained by integrating equation (5) and then substituting the result into equation (4) to get

$$h_{fg} = TP_s \left(7.46588 \frac{T_c}{T_s^2} - 1.26312 \frac{T_c^{2/3}}{T_s^{5/3}} + 1.030228 \frac{T_c^{2/5}}{T_s^{7/5}} \right) (v_g - v_f) \quad (13)$$

The values of the molecular mass, the critical pressure and critical temperature for R152a are, respectively, $\bar{M}=66.051[kg/kmol]$; $P_c=4760[kPa]$ and $T_c=113.3[^\circ C]$ (Arora, 2000).

The acentric factor (ω) for the analysis of R152a properties used here is $\omega=0.265142$; the reference state properties (RSP) used in this work are: $P_o= 4.0[kPa]$; $T_o = 273.15[K]$; $h_o = 512.9060[kJ/kg]$; and $s_o = 2.6652[kJ/kgK]$.

2. COMPUTATIONAL ALGORITHM

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

Start

1. Input data

(i) obtain the phase of R152a (wet, saturated vapour, saturated liquid, subcooled liquid or superheated vapour);

(ii) specify the desired (unknown) property (specific enthalpy, specific entropy, specific volume, temperature, pressure, specific internal energy, or quality);

(iii) obtain the value(s) of any one (for saturated states) or two (for other states) known properties;

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.

3. SOFTWARE IMPLEMENTATION

The software was developed in Microsoft Excel Visual Basic for Application (Excel-VBA) as an Excel add-in, called *ThermoProp_R152a*, using all the relevant correlations for the thermodynamic property analysis of R152a, given in section 1, the Governing Equations, and following the computational Algorithm presented in section 2. Some of the procedures are iterative with an error bound of 0.01% (Kreyszig, 2005). The user interface in the software was designed using the control toolbox of Excel-VBA IDE. The interface retrieves and supplies information on any of the thermodynamic properties. A command button control on the form is used to run a macro that implements a particular function. After initiating the computation, by clicking on the *start* drop menu, results are transferred to a pre-selected cell in an active worksheet of the Microsoft Excel. The thermodynamic analysis is initiated by entering formulas into cells and referencing the addresses of cells that hold numerical values that are relevant to a particular analysis. The worksheet automatically does the numerical computation using the formulas entered into the cells.

3.1 Using ThermoProp_R152a

After a successful installation of the software as an Excel Add-in, click on the ThermoProp_R152a menu

on the menu bar and then click on the Start button of the ThermoProp_R152a menu as shown in figure 1.

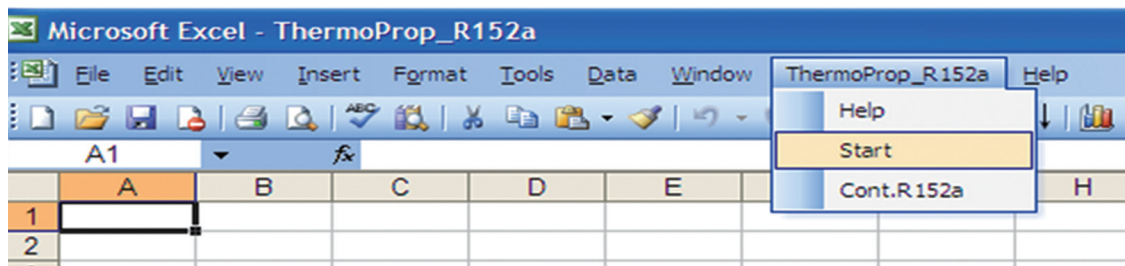


Figure 1
Excel Worksheet Showing the Start Drop Menu

By clicking on the start button of the ThermoProp_R152a menu, the window shown in figure 2 appears. Select the analysis type (Saturated Liquid, Saturated Vapour, Liquid + Vapour, Superheated Vapour or SubCooled liquid) by clicking on relevant command button. Select the unknown property from the combo box captioned *unknown property*. In the combo box captioned *function of* select one known property (for an unknown saturated property) or two known properties (for

other cases). Key in the numerical values of the known properties into the text boxes in the frame captioned *Input the known*. The computational process commences by clicking on the command button captioned *Read*. Results are shown in the *output* frame below the *input the known* frame. Numerical results may also be transferred to the worksheet by clicking on the command button captioned *transfer*. The process continues for another state point by clicking on the Cont.R152a drop menu shown in figure 1.

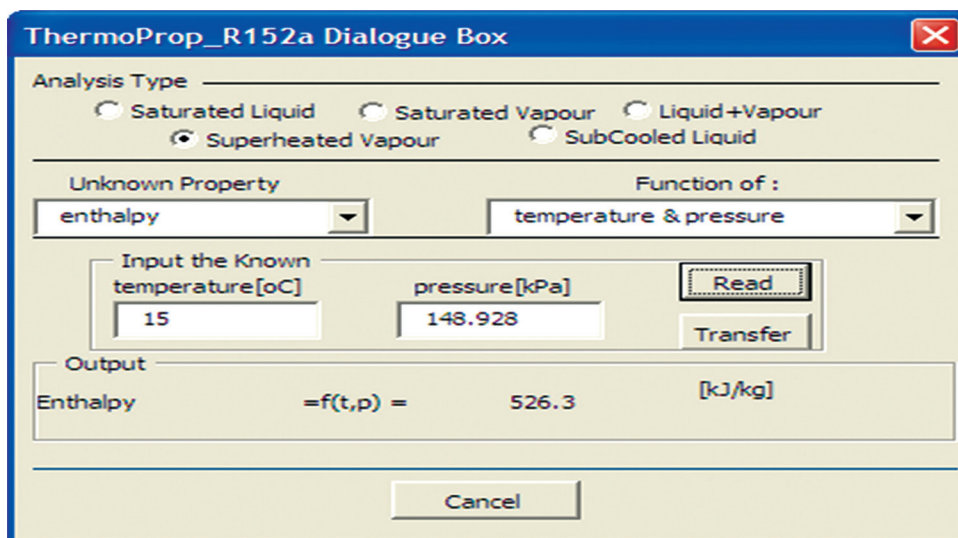


Figure 2
Final Computation Step with Result

3.2 Applications of ThermoProp-R152a

As an excel add-in, ThermoProp-R152a is designed to aid students as well as practising refrigerating system engineers in their design, analysis and/or performance analysis work with R152a by automatically providing the needed R152a property data. For example, consider the following analysis problem:

A refrigerator with R152a operates at temperatures of 35 °C and -15 °C for the condenser and evaporator respectively. If a regenerator is installed in the system, the mass flow rate of the refrigerant is 3.2 kgs⁻¹ and

temperature of refrigerant leaving the regenerator is 15 °C, determine the coefficient of performance (COP), capacity of the plant, power consumption of plant and heat transfer rate in the condenser.

Solution

(1). Input Data

Condenser temperature, $T_k = 35\text{ }^\circ\text{C}$; Evaporator temperature, $T_e = -15\text{ }^\circ\text{C}$; Regenerator vapour exit temperature, $T_{re} = 15\text{ }^\circ\text{C}$; Mass flow rate, $m_f = 3.2\text{ kgs}^{-1}$;

(2). Sketches and Diagram

(3). Assumption
 Isentropic compression, ($s_{1a} = s_2$); zero heat loss in regenerator.

(4). Analysis
 The solution obtained with ThermoProp_R152a is presented in figure 4.

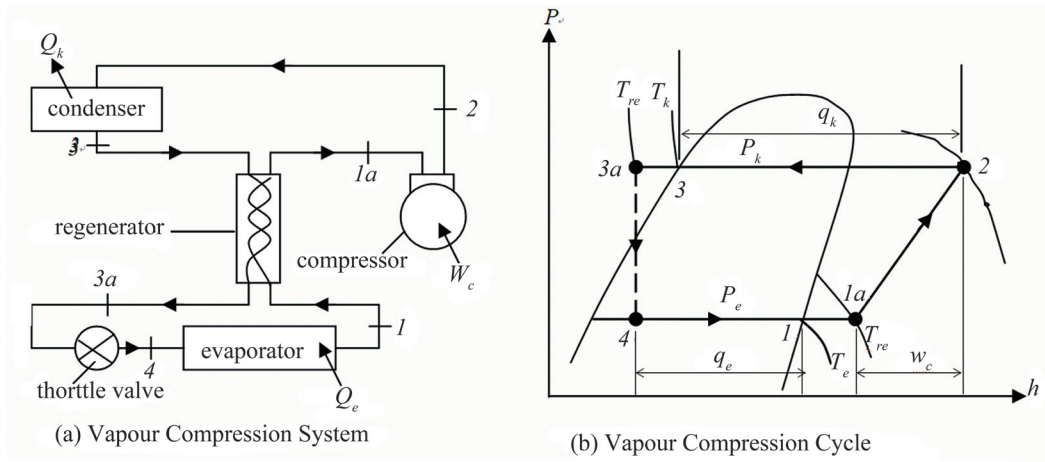


Figure 3
 Vapour Compression System and Vapour Compression Cycle

F36		$f_x = 3.2 * ABS(F23)$						
	A	B	C	D	E	F	G	H
1	On the saturation line, $P_k(T_k)$, $P_e(T_e)$, $h_1(T_e)$ and $h_3(T_k)$, so that:							
2			Condenser pressure (P_k) =			793.324	kPa	
3			Evaporator pressure (P_e) =			148.928	kPa	
4			Evaporator saturation vapour enthalpy (h_1) =			495.939	kJ/kg	
5			Condenser saturation liquid enthalpy (h_3) =			279.718	kJ/kg	
6								
7	In the superheated vapour region, $h_{1a}(T_{re}, P_e)$, $s_{1a}(T_{re}, P_e)$ and $h_2(s_{1a}, P_k)$, so that:							
8			Compressor inlet enthalpy h_{1a} =			526.3	kJ/kg	
9			Compressor inlet entropy s_{1a} =			2.535	kJ/kg K	
10			Compressor exit enthalpy h_2 =			589.674	kJ/kg	
11								
12	From regenerator energy balance and the assumption of a zero heat loss in the regenerator, then							
13			Throttle valve inlet enthalpy $h_{3a} = h_3 - (h_{1a} - h_1)$					
14				Or $h_{3a} =$		249.357	kJ/kg	
15	The refrigerating effect is given as							
16			$q_e = h_1 - h_{3a}$					
17				Or, $q_e =$		246.582	kJ/kg	
18	The specific work of the compressor is given as							
19			$abs(w_c) = h_2 - h_{1a}$					
20				Or, $abs(w_c) =$		63.374	kJ/kg	
21	The specific heat rejected in the condenser,							
22			$q_k = h_2 - h_3 = w_c - q_e$					
23				Or, $q_k =$		-309.956	kJ/kg	
24	The coefficient of performance of the plant is given							
25			$COP = q_e / abs(w_c)$					
26				Or, COP =		3.8909	-	
27	The capacity of plant is given by							
28			$Q_e = m_r q_e$					
29				Or, $Q_e =$		789.062	kW	
30								
31	The power consumption by the plant is given as							
32			$W_c = m_r w_c$					
33				Or, $abs(W_c) =$		202.797	kW	
34	The heat transfer rate in condenser is given as							
35			$Q_k = m_r (w_c - q_e) = m_r q_k$					
36				Or, $Q_k =$		991.859	kW	

Figure 4
 Analysis Results with ThermoProp_R152a

4. RESULTS AND DISCUSSION

Figure 4 shows results obtained with the ThermoProp_R152a, with its application with refrigerating system that uses refrigerant R152a. Figure 5 shows the relative percentage deviation (RPD) of the various R152a properties generated by ThermoProp_R152a from those

provided by Arora (2000) in the temperature range from -40 °C to 60 °C. The maximum deviation of 4.5 % occurs in the value of the saturated vapour specific volume (v_g). This may be due to the approximate nature of the correlations used here or may be associated with the difficulty in measuring the specific volume of vapour, but are within the acceptance range for most applications.

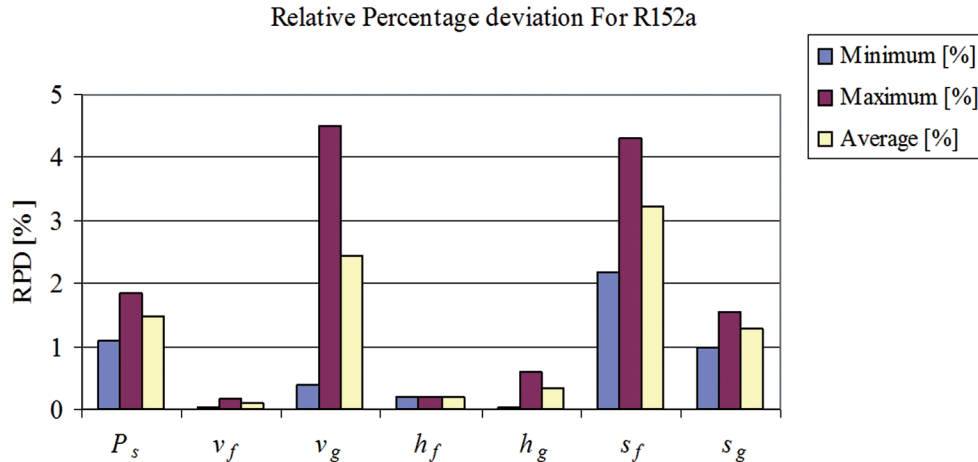


Figure 5
RPD of ThermoProp_R152a Data from Data Presented by Arora (2000)

CONCLUSION

Most computer software packages for the determination of thermodynamic properties and simulation of refrigeration processes require subscriptions, which are generally expensive for people from the developing countries, especially the African countries. Internet applets seem to be veritable tools for thermodynamic properties of refrigerants. However, report has shown that absolute majority of African population has no Internet access, which makes the available Internet applets not useful to African students. Microsoft Office is available in nearly all the computers used by African students, therefore, Microsoft embedded software for thermodynamic properties, instead of Internet applets, would be useful in regions where there is a limited Internet access. The present work presents computer software, ThermoProp_R152a, developed in Microsoft Excel Visual Basic for Application (Excel-VBA) as Excel add-in. The add-in is able to compute the thermodynamic properties of R152a refrigerant - specific volume, internal energy, enthalpy, and entropy in the states of saturated, compressed liquid, and superheated vapour. Also, the add-in is provided in an easily accessible Microsoft Excel environment to facilitate the thermal design, analysis and performance evaluation efforts of students as well as practising refrigerating system engineers. Of course, the add-in is a veritable tool for the effective teaching of mechanical engineering students how to design and simulate vapour compression refrigeration systems. The solution scheme and computer

language adopted in this work are easy to apply and use as opposed to the sophisticated and expensive computer software used by most researchers in the area. The accuracy of its output is good enough for engineering practice and, therefore, strongly recommended it as a teaching tool, which would be useful in regions where there is limited internet access. Similar add-in for psychrometric and drying processes has been developed (Oko and Diemuodeke, 2010), which has been proven by Huayamave (2010) to be very useful.

REFERENCES

- Arora, C. P. (2000). *Refrigeration and Air Conditioning*. Tata McGraw-Hill, New Delhi.
- Beckman, W and Klein, S. (1996). *Engineering Equation Solver (EES) User manual*. McGraw Hill, New York.
- Dromey, R. G. (1982). *How to Solve It by Computer*. Prentice Hall International, New York.
- Deane A. (2005). Developing Mathematics Creativity with Spreadsheets. *Journal of the Korea Society of Mathematical Education, Research in Mathematical Education*, 9(3), 187–201.
- Deane A., Erich N., & Robert S. S. (2005). *Mathematical Modeling and Visualization with Microsoft Excel, KAIST*. Retrieved from <http://www.mathnet.or.kr/kaist2005/article/arganbright.pdf>, 21/06/2006.
- Ghodbane, M. (1999). An Investigation of R152a and Hydrocarbon Refrigerants in Mobile Air Conditioning. *SAE Technical Paper Series*, No. 1999-01-0874.

- Huayamave, V. A. (2010). *Designing of Energy Efficient Indoor Environments Using a Localized Radial Basis Function Meshless Method*. M.Eng thesis, University of Central Florida, Florida.
- Internet World Stats (2012). *Internet Users, Population and Facebook Statistics for Africa 2012*. Retrieved from <http://www.internetworldstats.com/stats1.htm#africa>, 31/01/2013.
- Kamei, A., Piao, C. C., Sato, H. and Watanabe, K. (1990). Thermodynamic Charts and Cycle Performance of HCF-134a and HCF-152a, *ASHRAE Trans*, 96(1), 141-149.
- Kreyszig, E. (2005). *Advanced Engineering Mathematics, 8th ed*. John Willy & Sons Inc, New York.
- Liengme, V. B. (2000) *A Guide to Microsoft Excel For Scientist and Engineers*. Butterworth Heinemann, Woburn.
- Oko, C. O. C. & Diemuodeke, E. O. (2010). Analysis of Air-conditioning and Drying Processes Using Spreadsheet Add-in for Psychrometric Data. *Journal of Engineering Science and Technology*, 3(1), 7–13.
- Oko, C. O. C. (2012). *Engineering Thermodynamics: An Algorithmic Approach, (2nd ed)*. University of Port Harcourt Press, Port Harcourt.
- Tan, F. L. & Chua, P. S. K. (2003). Java Applet on Computation of Thermodynamic Properties of Steam and R134a refrigerant. *Computer Applications in Engineering Education*, 11(4), 211 – 225.
- Zhang, M. and Muehlbauer, J. (2012). Life Cycle Climate Performance Model for Residential Heat Pump Systems. *International Refrigeration and Air Conditioning Conference, July 16-19, Purdue, USA*.