Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 4(2): 328-332
© Scholarlink Research Institute Journals, 2013 (ISSN: 2141-7016)
jeteas.scholarlinkresearch.org

Experimental Investigation of Thermal Conductivity and Thermal Diffusivity of New Refrigerants Blends

Akintunde, M.A

Mechanical Engineering Department,
The Federal University of Technology,
P.M.B 704, Akure, Nigeria.

Abstract

This article presents the thermal conductivity and thermal diffusivity of two refrigerants blends undergoing development process. The aim is to investigate and establish these two refrigerant mixtures as atmospheric friendly alternative to R12, which is one of the known ozone depleting refrigerants. The two refrigerants were blended out of two refrigerants (R600a and R134a) already in use as alternative to R12. The two new refrigerants were coded RA1 (50%R600a/50%R134a) and RA2 (70%R600a/30%R134a). Transient Hot Wire (THW) technique was used to measure both the thermal conductivities and thermal diffusivities of these two refrigerants at temperatures range between 300 K and 315 K and pressure ranging between 0.5 to 1.13 MPa. The obtained results were compared with those of R12 under the same experimental conditions. The results show that, the thermal diffusivities of both RA1 and RA2 are higher than that of R12 by 12.56% and 13.38% respectively. Also the thermal conductivities of both RA1 and RA2 were more than that of R12 by 2.9% and 20.68% respectively. These indicated that both refrigerants (RA1 and RA2), in conjunction with earlier investigations, can be used in systems designed for R12.

Keywords: RA1, RA2, diffusivity, conductivity, refrigerant blends, experimentation, measurement.

INTRODUCTION

In the recent past, research interest is focusing on development of alternative refrigerants to the atmospheric offensive chlorofluorocarbon (CFC) refrigerants. In the vent of CFC phase-out, identifying long term alternative refrigerants to meet refrigeration system performance has become an important area of research in refrigeration, and air conducting. The work of many researchers had led to development of many alternatives to dichlorodifluoromethane (R12) and monochlorodifluoromethane (R22) which were considered to be most offensive among the CFCs based on their high Ozone Depletion Potential (ODP), (Calm, 2002; Eckels and Tesene, 2003). Some of the emerged alternatives to R12 are 1,1,1,2tetrafluoroethane (R134a); 1,1,1,trifluoro-2,2, dichloroethane (R123) and for R12 we have R134a, R141b, R410A, R409A, R407C and others.

Recently, because of the issue of Global Warming Potential (GWP) of some of those alternative refrigerants, alternative to R12 is found in R600a, (n-butane), R134a and R406A (mixture of R22/ R600a/ R142b in the ratio 55/4/ percentage by volume). Some of the properties of these three refrigerants are shown in Table 1, (Gopalnavaganan, 1998)

Table 1, Selected Properties of R406A, R134a and R600a

Refrigerants	Molecular weight (g)	Boiling point (^{o}C)	Flammability in air	ODP	GWP
R406A	89.86	-32.7	None	0.036	0
R134a	102.03	-26.1	None	0	1300
R600a	58.1	11.6	Highly flammable	0	0

Utulu (2012) attempted to develop alternative refrigerants to R12. In his work, refrigerants R600a, R134a and R406A were used because of their environmental friendly properties as stated in Table 1. These three refrigerants were blend together as shown in Table 2, (Utulu, 2012).

Table 2 Various ratios of the refrigerant blends

s/n	Code	%R600a	%R134a	%R406A
1.	RA1	50	50	-
2.	RB1	50	-	50
3.	RA2	70	30	-
4.	RB2	70	-	30
5.	RA3	-	20	80
6.	RB3	20	-	80
7.	RA4	-	60	40

It should be stated that, R406A was designed as a drop in replacement for R12 which is compatible with the typical mineral oil lubricants used in R12 systems. Also R600a is a retrofit for R12, and R22 and R134a are among the best alternatives discovered for both R12 and R22, Penas et al., (2008), hence the choice of these three refrigerants.

The refrigerant mixtures in Table 2 were tested in a domestic refrigerator initially designed for R12. The results indicated that the performance of both RA1 and RA2 are similar to that of R12. To further investigate the two refrigerants mixtures their thermal conductivities and diffusivities were investigated in this work.

There are various methods used in the literature for the measurement of thermal conductivity of liquid, gas and vapour. Some of these methods are: axial flow methods; comparative cut bar (ASTM E1225 test method; Guarded or Unguarded heat flow metal method CASTM E518, E1530 test methods); Guarded hot plate method (ASTM C177 test method; hot wire methods (ASTM C1113 test method), (TA, 2012) to mention a few, (Blumm, et al., 2007).

The most commonly used method for liquid, gas and vapour is the Hot Wire Method (HWM). It is a transient radial flow technique which requires isotropic specimens. It is mostly refers to as Transient Hot Wire (THW) technique. It is normally used to measure thermal properties of liquids with relatively low thermal conductivity.

Tsvetkov et al., (1994) used transit coaxial cylinder technique, to measure thermal conductivities of liquid R123, (1,1,1, trigluoro-2,2-dichloroethane; R134a and pentafluoroethane (R125). The conductivities were measured between temperatures ranging from 114 and 20°C under pressure up to 10 MPa. In their work, the apparatus was firstly calibrated using four established fluid. They used existing equations to compare the experimental results. Thermal conductivities of R134a, and R141b within temperature range of 240-307 K at saturation vapour pressure were reported by Papadaki et al., (1993). The apparatus used for the measurement is the transient hot wire (THW) instrument made out of the insulted tantalum wires. Their result was estimated to have an accuracy of 1.1%.

Other researchers used THW methods for the measurement of thermal conductivities of fluids include; Laesecke et al., (1992); Gross et al., (1992); Baginsky and Shipitsyna (2009); Assael and Karagiannidis (1993); Jain et al., (2008); Codreanu et al., (2007); Akintunde, M.A. (2006) Akintunde, M.A. (2011) and host of others. The methods used are generally similar to one another. Variation comes in, in the properties of wires used, applied voltage and current in the instrument, which is basically determined by the envisaged thermal properties of the fluid sample to be measured.

The experimental set up, used here was modified from the THW technique used by Codreanu et al., (2007). The rig used by Codreanu et al., (2007) was used to measure thermal conductivity of nanofluids, a class of cooling liquids prepared by suspending very small volume concentrations of nanoparticles in deionized water or ethylene glycol.

MATERIALS AND METHOD

Transient hot wire (THW) method used in measuring thermal conductivity, is based on detection of transient/temporal rise in temperature of a thin wire buried in the test sample. The measurement of transient temperature is achieved by passing a step-wise electrical current through the wire by the usage of variable resistance box (rheostat). The wire therefore is the heat source and produces a time dependent temperature field in the test sample.

According to Assael et al., (1995), the theoretical model describing the THW is derived from the analytical solution of the heat conduction equation for line heat sources of radius r (r→0) and length L (L→∞) of negligible thermal mass, which is perfectly embedded, with no thermal contact resistance, in an unbounded heat sink, initially at uniform temperature T_0. The sink should be homogenous, isotropic and of constant thermal transient properties. Under these conditions it is assumed that the wire will instantly liberate applied heat into the sample. Then if q is the heat applied per unit length and ΔT is the change in temperature, r the wire radius and *k* is the required thermal conductivity of the sample, hence equation (1) modeled the temperature variation with time and the wire radius, Codreanu et al., (2007).

$$\Delta T(r,t) = \frac{q}{4\pi k} \ln\left(\frac{4at}{r^2 C}\right) \qquad (1)$$

where: ‘*a*’ is the thermal diffusivity of the sample; C = e^{γ} (γ = 0.5772157) known as Euler’s constant, and t is the time interval.
From equation (1), knowing that, q, k, r, C, *a*, are all constants then the equation can be written as show in equation (2).

$$\Delta T(r,t) = \frac{q}{4\pi k}\left\{\ln\left(\frac{4a}{Cr^2}\right) + \ln(t)\right\} \qquad (2a)$$

$$\Delta T(r,t) = \beta \ln\left(\frac{4a}{Cr^2}\right) + \beta \ln(t) \qquad (2b)$$

Equation (2) is a form of straight line of the form (equation (3)).

$$Y = C + \beta \ln(t) \qquad (3)$$

Therefore, when the temperature rise is plotted against ln(t) will give a straight line with intercept. The thermal conductivity ‘k’ will be estimated from the slope and the diffusivity from the intercept by back substitution of the thermal conductivity.

From the theoretical point of view, the schematic block diagramme of THW is shown in Fig 1.

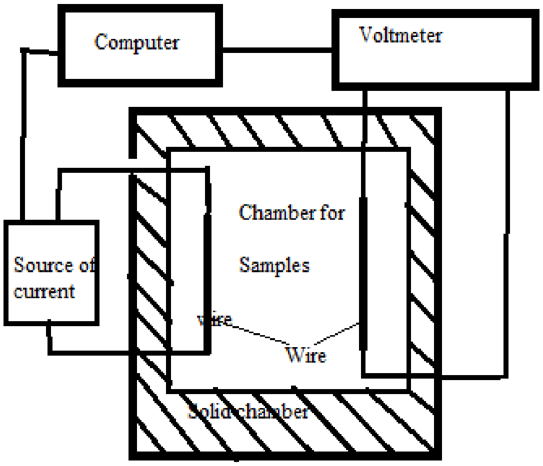

Fig 1, Schematic block diagram of THW technique

The apparatus consist of a solid hollow block where the liquid sample is poured and the measuring instruments as indicated. A computer is required because the time taken for the transfer of heat is in milliseconds. The measurement consists of a programmable current source applied for a very short time. The ultimate sequentially measured the signals from the heat sensor for very short time intervals on the other of milliseconds. The computer acquired data, and converts the voltage registered data into temperature data and this is converted to thermal conducting data by equation (4).

$$k = \frac{q}{4\pi} \cdot \frac{\ln(t_2 - t_1)}{T_2 - T_1} \qquad (4)$$

Though the experiment is very simple, but it must be noted that special attention must be paid to the environmental conditions because it do affects the repeatability of the experiment especially when transport properties are to be compared.

RESULT AND DISCUSSION

The change in temperature ΔT (K) was measured at 40 (ms) time interval; follow the suggestions of Penas, et al., (2007) and Codreanu et al., (2007). The result for both RA1 and RA2 are shown in Fig 2. Since the measuring instrument is a transient apparatus, the measurement should be taken within a very limited time. The result shown is Fig 2 was taken within 1,800 (ms) (1.8s). As indicated in the figure, the initial results, between 0 (ms) and 180 (ms) were affected by the heat capacity of the wire. It should be noted that the length of wire was supposed to be infinitely long ($L \rightarrow \infty$) and the radius $r \rightarrow 0$. Whereas in this study a wire of 35μm diameter and 703 mm long (the longer the better) was used. An electric current of 300 mA was passed and the wire resistance was estimated to be 8.4 ohms. The heat flux (q per unit length, as in equation (1)) was estimated to be 1.0754 W/m. These specifications were used to minimize end effects. Also at steady state conditions not indicated in the figure after 2500 ms the effect also was notices. Hence these two extremes were neglected in the calculations.

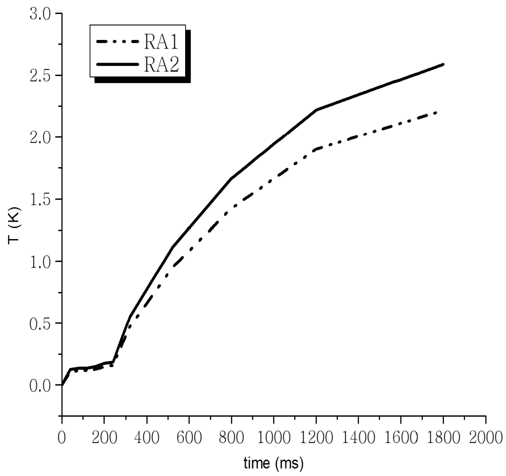

Fig. 2 Experimental results for both RA1 and RA2.

As suggested by equations (2) and (3), a plot of temperature against the natural logarithm of time is as shown in Fig 3. The straight line obtained justifies both the theory and the experiment.

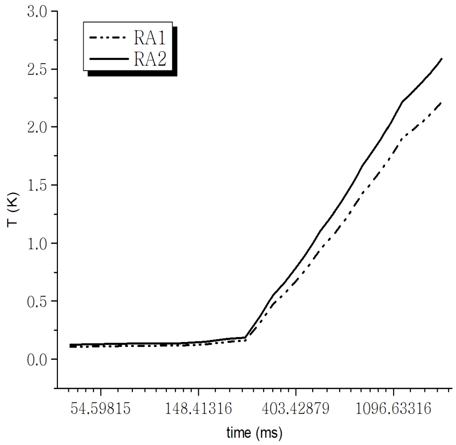

Fig. 3 Logarithmic plot of experimental results

Also the trendline (linear) for both RA1 and RA2 and shown in Figs 4 and 5 respectively. The analysis as generated by using "origin 6.0" are shown in Tables 3 and 4, therefore the straight line representations are shown in equations (5) and 6 for RA1 and RA2 respectively.

$$\Delta T = 1.20483 \ln(t) - 6.39962 \qquad (5)$$

$$\Delta T = 1.02729 \ln(t) - 5.4494 \qquad (6)$$

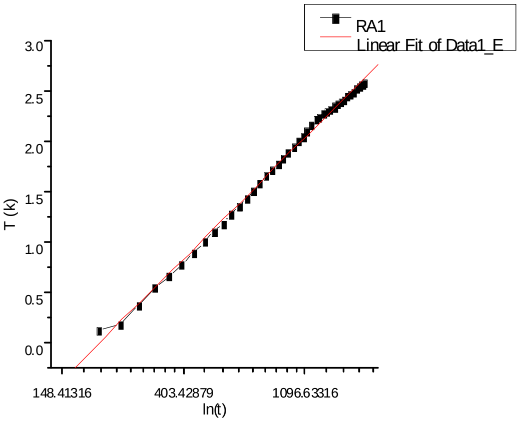

Fig. 4 Trend line for RA1

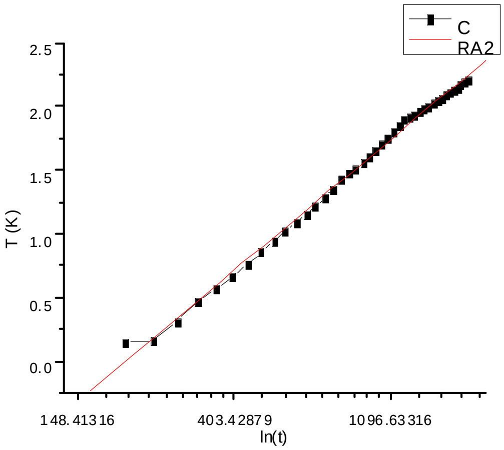

Fig. 5 Trend line for RA2

Table 3. The analysis of the straight line for RA1

Parameter	Value	Error
A B	-5.44914 1.02729	0.0696 0.01026
R 0.99806	SD N 0.0387 41	P 0.0001

Table 4. The analysis of the straight line for RA2

Parameter	Value	Error
A B	- 6.39962 1.02729	0.07262 0.0107
R 0.99847	SD N 0.04038 41	P 0.0001

The slopes (RA1, RA2) (1.20483, 1.02792) and the corresponding intercepts are (-6.39962, -5.44914). From equation (2) the slope (β) was given as

$$\beta = \frac{q}{4\pi k} \tag{7}$$

Rearranging equation (7), the thermal conductivity is given by equation (8).

$$k = \frac{q}{4\pi\beta} \tag{8}$$

Hence '*k*' was calculated to be 0.0816 W/m.K and 0.0957W/m.K respectively for RA1 and RA2. The actual value for R-12 is 0.071 W/m.K. The value for RA1 is 14.93% above that of R-12 and the obtained value for RA2 is 34.79% above that of R12. Although when R-12 was tested under the same experimental conditions with both RA1 and RA2 a value of 0.0793 was estimated. Under this experimental condition therefore; the percentage discrepancy from the actual value of R-12 was estimated to be, 2.9% and 20.68% respectively for RA1 and RA2.

From equations (2) and (5) the value of the diffusivity (*a*) was estimated as follows:

$$a = \frac{Cr^2}{4} EXP\left(\frac{\delta}{\beta}\right) \tag{9}$$

where: δ is the intercept on the ΔT-axis, substituting the values as indicated in equations (5) and (6). The diffusivities (*a*) for RA1 and RA2 were estimated to be, 2.76384 X 10^{-8} m^2/s and 2.74386 X 10^{-8} m^2/s respectively for RA1 and RA2, while the value for R12 under this experimental condition is 2.43772 X 10^{-8} m^2/s. The percentage errors were estimated to be 12.56% and 13.38% respectively for RA1 and RA2.

CONCLUSION

A transient hot wire (THW) technique has been used in this study to measure both the thermal conductivity and thermal diffusivity of two refrigerants blends. These two refrigerant mixtures are RA1(50%R600a/50%R134a) and RA2(70%R600a /30%R134a). These two refrigerant mixtures were worked upon by Utulu (2012). They were used to run domestic refrigerators deigned for R12 (CF_2Cl_2). The thermal conductivities and the thermal diffusivities of the mixtures were measured within temperature range of 300 K and 315 K and pressure range from 0.5 to 1.13 MPa, and compared with those of R-12 under the same experimental conditions in the liquid state based on the saturation conditions of R-12. The thermal diffusivities for both RA1 and RA2 were found to be 0.0816 W/m.K and 0.0957 W/m.K respectively. The values were found to be 2.9% and 20.68% respectively above the value of thermal conductivity of R12 under these experimental conditions. Also the values of thermal diffusivities for both RA1 and RA2 were found to be 2.7634 X 10^{-8} m^2/s and 2.74386x10^{-8} m^2/s respectively while that of R-12 was found to be 2.43772x10^{-8} m^2/s. This shows that the values for RA1 and RA2 were 12.56% and 13.38% respectively above that R12. The aim is to use RA1 and RA2 as replacement or alternative to R12. With this experimental results and the previous work done by Utulu (2012) both refrigerants are suitable as alternative to R12. The only set buck discovered is that the COP of the system using RA1 or RA2 is lower than that of R12 under the same evaporator and condenser temperatures. Since the measurements were done were measured within temperature range of 300 K and 315 K and pressure range from 0.5 to 1.13 MPa, the results are not valid outside his range. Judging from the errors indicated in Tables 3 and 4, the instrument uncertainty was estimated to be 0.071% and 0.078%, respectively for RA1 and RA2.

REFERENCE

Akintunde, M. A. (2004) "Theoretical Design Model for Vapour Compression Refrigeration Systems". – AMSE Periodicals, France. Vol. 73 No: 5, pp 1 – 14.

Akintunde, M. A. (2006), "Experimental Investigation and Modeling of Moisture Solubility in R-12 and R-134a. AU Journal of Technology, Bangkok, Thailand. Vol. 9 No: 4, pp 261 – 266.

Akintunde, M.A. (2011), "Validation of a Vapour Compression Refrigeration System Design Model". American Journal of Scientific and Industrial Research (AJSIR). Volume 2, Number 4, pp 504 - 510

Assael, M.I; Castro C.A; Roder, H.M and Wakeham W.A (1991). Measurement of thermal properties of fluids. Experimental thermodynamics, Blackwell scientific publications, Oxford.

Assael, M.J and Kavagiannidis, E (1993). Measurements of the thermal conductivity of R12, R123 and R134a in the temperature range 250-340 at pressures up to 30 MPa. International Journal of Thermophyscis. Vol 14, issue 2, pp 183-197.

Baginskg, A.V and Shipitsyma, A.S (2009). Thermal conductivity and thermal diffusivity of the R134a refrigerants in the liquid state. Journal of Thermophysics and Aeromechnanics. Vol 16 issue 2, pp 267- 273.

Blumm, j.; Lindemann, A.; Niedrig, B., and Campell, R. (2007). Measurement of selected Thermophysical Properties of the NPL certified reference materials stainless steel. International journal of Thermophysics. Vol. 28 No.2, pp 674 – 677.

Calm, J. M. (2002), Emission and environmental impacts from Air-Conditioning and refrigeration. International journal of refrigeration, Vol. 25 No: p, pp 293 – 305.

Codreanu, C. Codreanu, N.I; and Obreja, N.V.N (2007). Experimental set-up for the measurement of the thermal conductivity of liquids. Romanian Journal of information science and Technology. Vol 10, No 3, pp 215-231.

Eckels, S.J and Tesene, B.A (2003). A Comparison of R22, R134a, R410A and R407C, Condensation Performance in Smooth and Enhance Tubes: Part 1, Heat Transfer ASHIRAE Transaction, pp 428-441.

Gross, U.; Song, Y.W; Hahne, E. (1992). Thermal conductivity of the new refrigerants R134a, R152a and R123 measured by the transient hot wire method. Themophysics Division 838.02, National Institute of Standard and Technology, Bloulder. Vol 13, issue 6, pp 957-983.

Jain, A and Goodson, K.E; (2008). Measurement of the thermal conductivity and heat capacity of freestanding shape memory thin films using the 3w method. ASME Journal of heat transfer .Vol. 130, pp 1-7

Laesecke, R.A; Perkins, C.A and Castro, N; (1992). Thermal conductivity of R134a. Themophysics Division 838.02, National Institute of Standard and Techology, Bloulder. Vol 80, pp 268-274.

Papadaki; M; Schmitt, M.; Seitz, A.; Stephan, K.; Taoxis, B.; and Wakeham, W.A (1993). Thermal conductivity of R134a and Ra41b within the temperature range 240- 307 at the saturation vapour pressure. International Journal of Thermphysics. Vol. 14 issue 2, pp 173- 181.

Penas, J.R.V; Zarate, J.M.O and Khayat, M (2008). Measurement of the thermal conductivity of nanofluids by the multicurrent hot wire method. Journal of applied physics. Vol 104, pp 1-8

Tsvetkov, O.B; Laptev, Y.A and Asambaev, A.G (1994). Thermal conductivity of refrigerants R123, R134a and R125 at low temperatures. International Journal of thermophysics. Vol. 15 issue 2, pp 203-214.

Utulu, A.N (2012). Development of alternative refrigerants to Freon-12. M.Eng. Thesis, Department of Mechanical Engineering, the Federal University of Technology, Akure, Nigeria.