Proceedings of the 2018 International Conference on STEM: A driving force for sustainable development tagged COLENG 2018 INVESTIGATING THE PERFORMANCE OF R134A DOMESTIC REFRIGERATO...

Conference Paper · May 2018

Yussouff Abioduna Abideen
Lagos State University

Samuel Owoeye
University of Agriculture, Abeokuta

Temitayo Samson Ogedengbe
Elizade University

Proceedings of the 2018 International Conference on STEM: A driving force for sustainable development tagged COLENG 2018, Federal University of Agriculture, Abeokuta, May 14-17, 2018

INVESTIGATING THE PERFORMANCE OF R134A DOMESTIC REFRIGERATOR RETROFITTED WITH R290 (PROPANE) AND R600A (ISO-BUTANE) REFRIGERANTS IN THREE DIFFERENT SIZE OF CAPILLARY TUBE IN A REFRIGERATING SYSTEM.

Abiodun .A. YUSSOUFF[1], S.O OWOEYE[2] Abidemi .O. YUSSOUFF[3]
Temitayo S., OGEDENGBE[4], Rasheed O. SAHEED[5],

[1,3] Department of Mechanical, Mechanical Engineering, Lagos University, Lagos , Nigeria.
[2]Department of Mechatronics Engineering, Federal University of Agriculture, Abeokuta, Nigeria
[4]Department of Mechanical Engineering, Elizade University, Ilara - Mokin, Ondo, Nigeria.
[5] Department of Mechanical Engineering, Lagos State Polytechnic, Lagos, Nigeria
**Corresponding author: yussufkoinsola@gmail.com*

ABSTRACT

In Nigeria, most of the vapour compression based refrigeration systems continue to run on halogenated refrigerants due to its excellent thermodynamic and thermo-physical properties. However, the halogenated refrigerants have adverse environmental impacts such as ozone depletion potential and global warming potential. Hence, it is necessary to search for alternatives to halogenated refrigerants. R290 (Propane) and R600a (Iso-butane) are two environmentally friendly refrigerants while R134a (Hydrofluorocarbon) is a common halogenated refrigerant. This study evaluated the performance of R290 and R600a refrigerants retrofitted into an R134a refrigerator. The temperatures at the four units (compressor, condenser, dryer/filter and evaporator) of the refrigerator were taken at different ambient temperature ranging from 15^{o}C to 33^{o}C. Also, pressures at both the inlet and outlet of the compressor were taken using the run time of 8 hours. Propane (R290) and iso-butane (R600a) were both charged in separately into the domestic refrigerator after R134a has been discharged, thoroughly flushed and evacuated. All tests were repeated for R290 and R600a. The data obtained was used to compute the following system performance parameters: refrigeration capacity, compressor power input, Coefficient of Performance (COP) and compression ratio. Average COP, average refrigeration capacities (kW), average compressor power (kW) and compression ratio of 0.499, 0.92, 0.188; 0.55, 0.49, 0.38; 1.82, 1.63, 1.25 and 6.02, 6.38, 6.67 were obtained using R600a, R290 and R134a respectively. The standard deviation for average COP, average refrigeration capacity(kW), average compressor power and average pressure ratio of 0.052,0.218,0.04; 0.023,0.072,0.065; 0.92,0.62,0.43 and 0.17, 0.17, 0.14 were obtained. Overall assessment showed that R600a and R290 have a relatively low compression ratio and better COP. The COP and compression ratio were used to quantify the performance of a refrigeration cycle. Low compression ratio increased refrigeration efficiency and decreased compressor energy consumption which indicated better system performance and reliability providing longer life to the domestic refrigerator. The average refrigeration capacity and compressor power obtained during test using R600a and R290 were higher than those of R134a indicating an effective cooling power of R600a and R290 over R134a

Keywords: Hydrofluorocarbon, Refrigerator, Refrigerants, Capillary tube, Vapour

INTRODUCTION

Refrigerator is a cooling appliance comprising of thermally insulated compartment, which is capable of storing food that may deteriorate at ambient temperature. In a refrigerator, the working fluid employed as heat absorber or cooling agent is called a refrigerant

Refrigeration systems are also used widely for regulating room temperature to make human beings comfortable by means of air-conditioning. Applications of refrigeration are grouped into; household refrigerators, industrial freezers, cryogenics, air-conditionings and heat pumps (Brown *et al.,* 2010).

The capillary tube is often used with low cooling load and small changing load systems, such as domestic refrigerators, water coolers and small air conditioners (Bolaji 2010). On the basis of geometrical shape, the capillary tubes can be classified to straight and coiled capillary tube.

The principle of the effect of capillary tube was first conceived by Kelvin Planck after studying the first law of thermodynamic with the use of the most stable hydro chlorofluorocarbon (HCFC) refrigerant which is now classified as the ozone depletion substance (Sudipta, *et al.,* 2013); Kim *et al.,*2002). The vapour absorption refrigerant system use heat source instead of a motor (compressor) to provide the energy needed to drive the cooling system. It lost much of its importance because of its low coefficient of performance. In1930's after the development of chlorofluorocarbon (CFC) and (HCFC) refrigerants, small refrigeration equipment such as the household refrigerators became widely used with a vapour compression refrigeration system

A refrigeration system using alternative refrigerants must be modified or newly designed because the thermo-physical properties of these alternative refrigerants differ from those of conventional refrigerants (Kim *et al.,* 2002). In order to maintain or improve the performance of the cycle, the operating characteristics of individual components of the system should be clarified for use with the new alternative refrigerants. Capillary tubes, short tube orifices and thermostatic expansion valves have been used in refrigerators and heat pumps as refrigerant flow regulating devices in vapour compression plants for several years. Capillary tubes and short tube orifices are constant area expansion devices. In some cases, they can be substitutes for more expensive and complex thermostatic valves. The principle of operation of the capillary tube is the flow resistance caused by a long, narrow tube, throttling the refrigerant pressure. Capillary Tube is widely used because of its pressure balance efficiency, low cost, a copper seamless coil tube with constant throttle on the refrigerant, installed with filter drier, which remove moisture from the system. The design of capillary solely depends on variables such as, tube length, and tightness of the tube windings and temperature of the tubing. In non-adiabatic situation (isenthalpic), the capillary tube forms a counter flow heat exchanger with the suction line that joins the evaporator and the compressor when the pressure of the sub cooled liquid refrigerant flowing through the non-adiabatic capillary tubes drops below the saturation value that makes part of the refrigerant flashes into vapourt hat result in two-phase flow. This complexity causes numerous difficulties in selection of exact capillary tube length which make it a "trial and error" in practical laboratory until accurate result is finally achieved.

In a vapour compression refrigerating system, the fluid used is referred to as the "refrigerant". Over a long period of time, different refrigerants have been applied in the system, but recently there is a growing need for efficient and environmental friendly refrigerants (Akash and Said 2003). The rate of depletion of the ozone layer, which absorbs the sun's high energy ultraviolet rays and thus protect all living things including human, is at a high level according to various researchers (Maclaine-Cross, 1997). The general consensus for the cause of this is that CFCs and HCFCs are large class of chlorine containing chemicals, which migrate to the stratosphere where they react with ozone (O_3) breaking it down to oxygen (O_2) (Nazeer *et al.,* 2013). Later, chlorine atoms continue to convert more ozone to oxygen. According to them the major cause was that chlorine particles caused the removal of ozone from the atmosphere. Different sectors have called for the elimination of chlorofluorocarbons (CFC). The 1992 meeting of the United Nations Environment Program called for the phase-out of CFCs by 1996 (Mohanraj *et al.,* 2009). Alternative refrigerants should be found to replace the existing CFCs.

The American Household Appliances Manufacturers (AHAM) has identified some hydrofluorocarbon (HFC) refrigerants such as R152a as better replacements for R12 in domestic refrigerators. "Freon" is a trade name for a family of haloalkane refrigerants manufactured by DuPont and other companies. These refrigerants were commonly used due to their superior stability and safety properties: they were not flammable or toxic as the fluids they replaced, such as sulphur dioxide. However, these chlorine-bearing refrigerants reach the upper atmosphere when they escape. In the stratosphere, CFCs break up due to UV-radiation, releasing their chlorine atoms. These chlorine atoms act as catalysts in the breakdown of ozone, thus causing severe damage to the ozone layer that shields the Earth's surface from the Sun's strong UV radiation (Middlebrook and Tolbert, 2000). The chlorine will remain active as a catalyst unless it binds with another particle, forming a stable molecule. (CFC) refrigerants in common usage include R11 and R12. Newer refrigerants that have reduced ozone depletion effect include hydrochlorofluorocarbons (HCFCs) such as R22 used in most homes today and HFCs (such as R134a, used in most cars and domestic refrigerators) have replaced most CFCs use. HCFCs in turn are being phased out under the Montreal Protocol and replaced by hydro-fluorocarbons (HCFs), such as R410A, which lack chlorine (Maclaine-Cross, 1994). With references to previous challenges on R134a refrigerant, this research was to Investigating the Performance of R134a domestic refrigerator Retrofitted with R290 (Propane) and R600a (Iso-butane) Refrigerants in three different Size of Capillary Tube in a Refrigerating.

MATERIALS AND METHODS

Materials

1. Capillary Tube
2. Condenser
3. Evaporator
4. hermetic compressor
5. Filter-dryer
6. Pressure gauge
7. Refrigerant (R600A, R134A and
8. R290A)

9. Athermeter.

Methodology

In investigating the performance of R134a domestic refrigerator retrofitted with R290 (Propane) and R600a (Iso-butane) refrigerants in a vapour compression refrigerating system, a 60 litres experimental refrigerator was bought whereby the compressor, condenser and evaporator were changed to ensure compatibility. R134a, R290 and R600a refrigerants were charged in separately for testing the performance of the system, such as refrigerating capacity, compressor power input, pressure ratio and coefficient of performance (COP), of the system. These were evaluated for the alternative refrigerants and compared with those of the existing refrigerant (R134a).
Three refrigerants (R134a, R290 and R600a) were selected and their performances in vapour compression refrigeration system (retrofitted domestic refrigerator) were investigated. (Satar et al 2007).

The Thermodynamic working condition of the system, design Parameters and theoretical analysis.

Analyzing the refrigeration compressor, the basic equation is

$$W_c = m_R(h_2 - h_1) = \frac{V\rho}{\eta(h2-h1)} \quad (1)$$

Where V = the swept volume (m^3/h); W_c = the compressor power input (kW), ρ_1 = the density of refrigerant at the compressor inlet (kg/m^3), m_R = refrigerant mass flow rate (kg/s), η = the compressor efficiency, (h_2-h_1) is the enthalpy difference (kJ/kg) required to compress the refrigerant from the evaporation pressure P_e to the condensing pressure Pc.

The thermodynamic behavior of the evaporator and the medium to be cooled is given as:

$$Q_{evap} = m_R(h_1 - h_4) = k_e A_e \Delta Tm_e = m_c cp_c \Delta T_c \quad (2)$$

The mean logarithmic temperature difference is defined s:

$$\Delta Tm = \Delta T_2 - \frac{\Delta T1}{\left[In\left(\frac{\Delta T2}{\Delta T1}\right)\right]} \quad (3)$$

Three refrigerants (R134a, R290 and R600a) were selected and their performances in vapour compression refrigeration system (retrofitted domestic refrigerator) were investigated. The p – h diagram shown in Figure 1 is mostly used in the analysis of vapour compression refrigeration cycle. In the refrigeration system, the performance characteristics are refrigerating effect (Q_e, kW), compressor power (W_c kW) and Coefficient of Performance (COP).

Compressor

The compressor power input (*Wc*, kW) is shown as:

$$W_c = m_R(h_2 - h_1) \quad (4)$$

Where: h_2 = enthalpy of refrigerant at the outlet of compressor (kJ/kg), m_R = mass flow rate (kg/s)

Condenser

The heat rejected by the condenser (Q_{cond}, kJ/s) to the atmosphere is shown as:

$$Q_{cond} = m_R(h_2 – h_3) \quad (5)$$

Where: h_3 = enthalpy of refrigerant at the outlet of condenser (kJ/kg)

Capillary Tube

In the capillary tube the enthalpy remains constant, therefore, $h_3 = h_4$

Using first law of thermodynamic, the measure of performance of the refrigeration cycle is expressed as coefficient of performance (COP) and the refrigerating effect produced per unit of work required. It is expressed as:

$$COP = Q_{evap}/W_c \quad (6)$$

Compressor pressure ratio (P_R) is given as:

$$P_R = P_{dis}/ P_{suc} \quad (7)$$

Where, P_{dis} = refrigerant vapour pressure at the compressor discharge (kN/m^2).

P_{suc} = refrigerant vapour pressure at the compressor suction (kN/m^2).

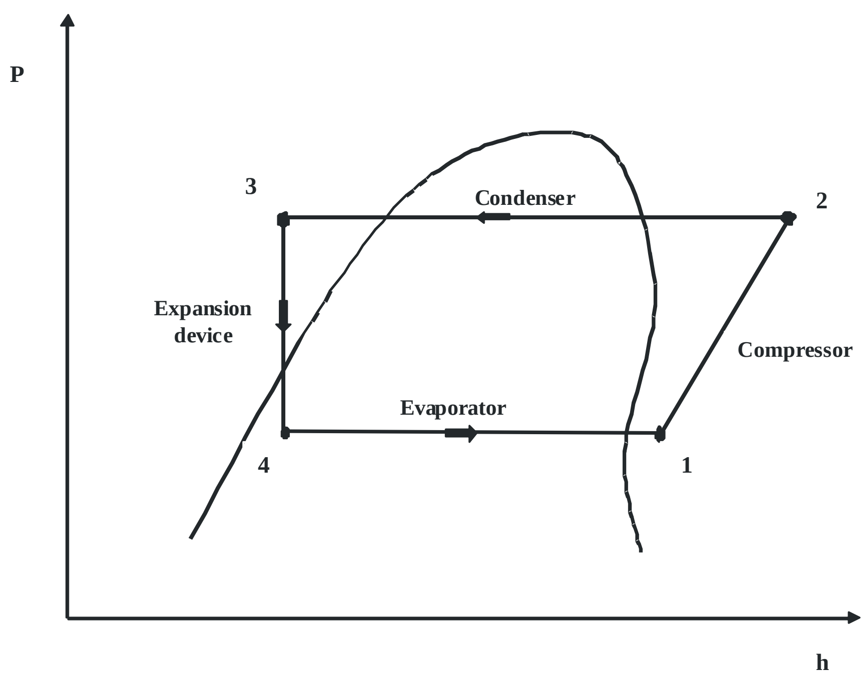

Figure 1: Vapour compression refrigeration system on p – h diagram

The Figure 2 is mostly used in the analysis of vapour compression refrigeration cycle. In the refrigeration system, the performance characteristics are refrigerating effect (Q_e, kW), compressor power (W_c kW) and Coefficient of Performance (COP).

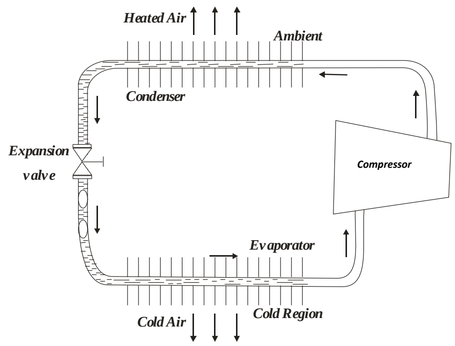

Figure 2: Vapour Compression Refrigeration System

Experimental Apparatus and Procedure

R134a refrigerant was charged into the system with the help of charging system. Mercury in glass thermometer was used in confirming the set ambient temperature by the air conditioner thermometer was used. The ambient temperature of the thermodynamics laboratory was controlled using an air conditioner, setting the range from 17°C to 32 °C. A k-type thermocouple with an intelligent multimeter was used in taking the temperatures at the condenser compressor and dryer/filter. An intelligent multimeter was used. A pressure guage device was used in taking pressures at both inlet and outlet of the compressor, the pressure gauge was used. A special temperature gauge called Athermeter, was used in taking the evaporator readings, with the probe protruding through the door of the cooling compartment of the refrigerator to the evaporator. This research work was carried out under a controlled environment, whereby the ambient temperature of the room was strictly maintained and monitored. The temperature of the evaporator was recorded using the athermeter.

The temperature and pressure readings were taken at an interval of a 1 hour at the inlet-arid outlet, of various units, three times daily on the basis of the five days. An elepaq 13.5hp petrol generator was used to achieve uninterrupted power supply. The temperatures from the readings were used to determine the enthalpy of the refrigerant. Simsci/PROII software was used to find the enthalpy of the refrigerant, the readings were then used to calculate the needed parameters. The test unit was observed under different ambient temperature.

Figure 3: Shows the complete experimental set up of 60 litres domestic refrigerator. The ambient temperatures range from 17.0°C to 32.0 °C. The same procedure was carried out for R290 and R600a.

Figure. 4: Experimental Setup of Different Capillary Tube Length of 1.5m, 2m and 3m

RESULT

Important performance parameters such as compressor power (W_c), refrigeration capacity (Q_e), coefficient of performance (COP) and pressure ratio (Pr) were calculated using equations (1-6). SIMSCI/PROII, a computer simulation system for process engineers was used in obtaining thermodynamic properties (like the enthalpy and entropy) of R290, R600a and R134a at steady state. SIMSCI/PROII includes a chemical component library, thermodynamic property prediction methods and unit operations such as distillation columns, heat exchangers, compressors, and reactors as found in the chemical processing industries. It can perform steady state mass and energy balance calculations for modelling continuous processes. Therefore SIMSCI/PROII simulator was used to obtain thermodynamic properties of R290, R600a and R134a.

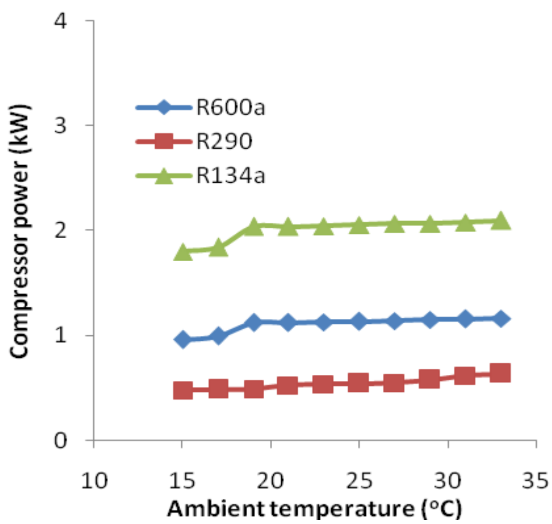

Figure 5: Variation of Compressor Power (Wc) with Ambient Temperature

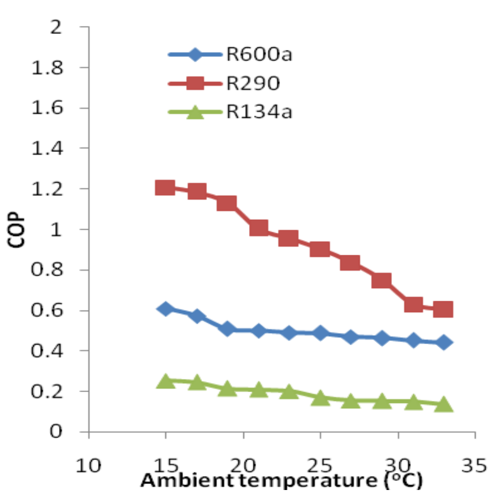

Figure 6: Variation of Coefficient of Performance (COP) with Ambient Temperature

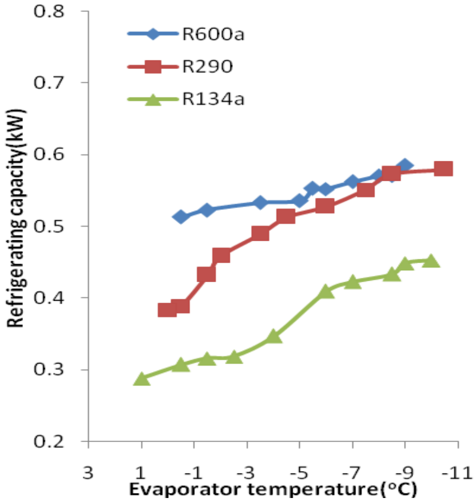

Figure 7: Variation of Refrigeration Capacity (Qe) with Evaporator Temperature (Te)

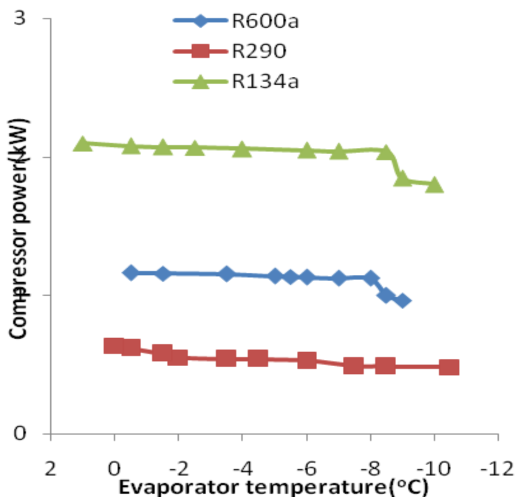

Figure 8: Variation of Compressor Power (Wc) with Evaporator Temperature (Te)

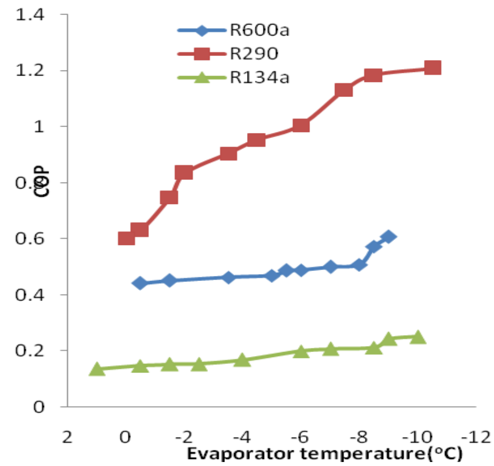

Figure 9: Variation of Coefficient of Performance (COP) with Evaporator Temperature (Te)

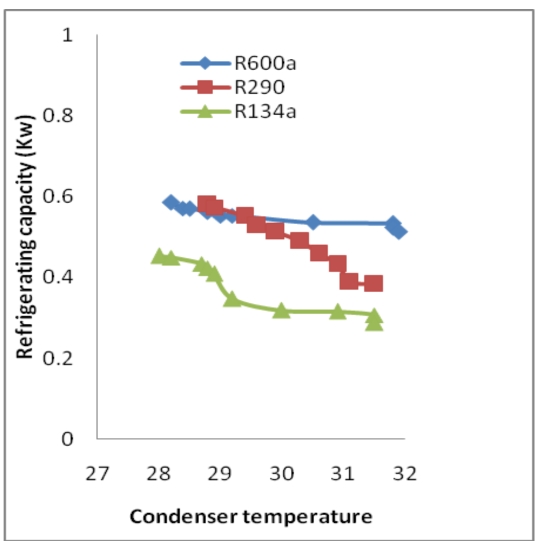

Figure 10: Variation of Refrigeration Capacity (Qe) with Condenser Temperature (Tc)

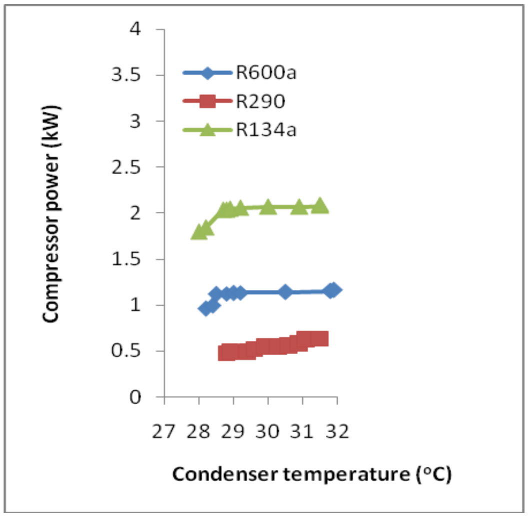

Figure 11: Variation of Compressor Power (Wc) with Condenser Temperature (Tc)

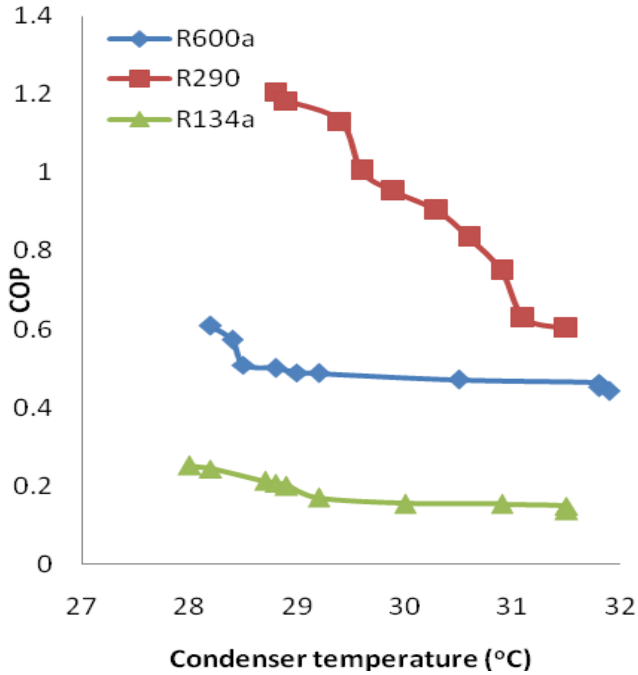

Figure 12: Variation of coefficient of performance (COP) with Condenser Temperature (Tc)

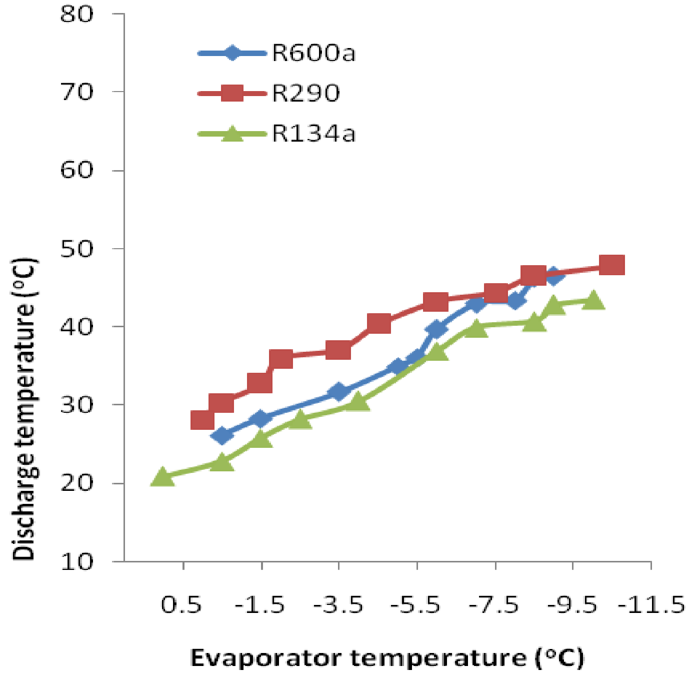

Figure 13: Variation of Discharge Temperature (Td) with Evaporator Temperature (Te)

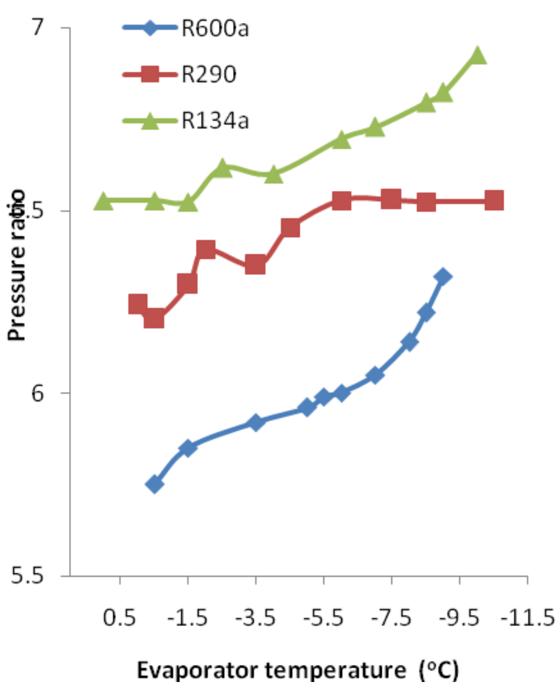

Figure 14: Variation of pressure ratio (Pr) with evaporator temperature (Te)

Conclusions

The results of the compressor power at different ambient temperature intervals showed that the compressor power increases with increase in ambient temperature. Compressor power inputs for both R290 and R600a were almost the same within the range of ambient temperature considered, while that of R134a was lower. At the same range of ambient temperature (15 to 33^{o}C), the compressor power inputs of R600a is higher than those obtained for R134a and R290 by while R290 is higher than R134a by 23.25%. Average compressor power of 1.112kW, 0.55kW 2.002kW were obtained during test using R600a, R290 and R134a respectively.
The coefficient of performance decreases with increase in ambient temperature in the variation of coefficient of performance (COP) with different ambient temperature.. Average COP of 0.499, 0.919 and 2.00 were obtained during the test using R600a, R290 and R134a respectively.

The results of the refrigeration capacity of a domestic vapour compression refrigeration system using propane (R290) and iso-butane (R600a) as alternatives to current refrigerant (R134a) at different ambient temperature showed that it increases with increase in ambient temperature. At the same range of ambient temperature (15 to 33^{o}C), the refrigeration capacity obtained from R600a is higher than that of R134a by 40.18%, and R290 is higher than R600a by 41.10% and then R134a by 64.76%. Average refrigeration capacities with their standard deviations of 6.62kW, 1.483; 11.23kW, 1.132; and 3.96kW, 0.102 were obtained during the test using R600a, R290 and R134a respectively.

The results of the compressor power at different ambient temperature intervals showed that the compressor power increases with increase in ambient temperature. Compressor power inputs for both R290 and R600a were almost the same within the range of ambient temperature considered, while that of R134a was lower. At the same range of ambient temperature (15 to 33^{o}C), the compressor power inputs of R600a is higher than those obtained for R134a and R290 by while R290 is higher than R134a by 23.25%. Average compressor power of 1.112kW, 0.55kW 2.002kW were obtained during test using R600a, R290 and R134a respectively.

The variation of the compressor power with condenser temperature for R600a, R290 and R134a shows that the compressor power of R134a and R600a was very close for the two refrigerants. The compressor power inputs of R600a is higher than that obtained for R134a by 31.15% and R600a is higher than R290 by 10.29% while R290 is higher than R134a by 23.25%.

For the three refrigerants, the variation of pressure ratio with evaporator temperature showed that the pressure ratio increases with increase in evaporator temperature. The three refrigerants have close value of pressure ratio. High pressure ratio in refrigeration will affect the system reliability and performance negatively. The refrigerants used exhibit moderately low pressure ratio in the order of R600a, R290 and R134a therefore showing good system reliability and performance.

This research work evaluated the performance of R134a domestic refrigerator retrofitted with R290 and R600a. Both R290 and R600a are ozone friendly, energy efficient, safe and cost-effective alternative refrigerant. The performances of R290 and R600a refrigerants in terms of refrigeration capacity, compressor power input, pressure ratio and coefficient of performance (COP) were evaluated and compared with those of R134a, the current alternative refrigerant.

REFERENCES

Akash, B.A. and Said S.A. 2003. Assessment of LPG as a possible alternative to R12 in domestic refrigerators. Energy Conversion and Management, 44(3):381-388.

Bolaji, B.O. 2010. Effect of Sub – Cooling on the Performance of R12 Alternatives in a Domestic Refrigeration System. Tuammasat Journal, 15(1):12-19.

Brown, D.R., Fernandes, N., Dirks, J.A. and Stout, T.B. 2010. The Prospects of Alternatives to Vapour Compression Technology for Space Cooling and Food Refrigeration Application. Energy Conversion and Management, 12: 15-35

Kim, S.G., Kim, M.S. and Ro, S.T. 2002. Experimental investigation of the performance of R-22, R-407C, and R-404a in several capillary tubes for air conditioners Journal of Refrigeration, 25(5): 521-531.

Maclaine – Cross, I.L. and Leonardi, E. 1997. Why Hydrocarbons Save Energy, AIRAH journal, 51(6): 33-37.

Middlebrook, A.M. and Tolbert, M.A. 2000. stratospheric Ozone Depletion. University Science Books Sausalito, California.

Mohanraj, M., Jayray, S. and Miraleedharan, C. 2009. Environmental friendly alternatives to halogenated refrigerants- a review, International Journal of Green House gas control, (3): 108-119

Nazeer, M.A., Quraishi, A. and Wankehede, U.S. 2013. Use of Hydrocarbons and other Blends as Refrigerants. International Journal of Refrigeration, 3(1): 250-253.

Satar, M.A., Saidu, R. and Masjuki, H.H. 2007. Performance investigation of Domestic Refrigeration using Pure Hydrocarbons and Blends of Hydrocarbons as Refrigerants. International Journal of Refrigeration, 5: 1-6.

Sudipta, P., Achinta, S. and Bijan, K.M. 2013. Environmental impacts of Halogenated Refrigerants and their Alternatives. International Journal of Refrigeration, 3(3); 400-4009