ASSESSMENT OF R430A REFRIGERANT AS A POSSIBLE SUBSTITUTE TO R134A REFRIGERANT IN LARGE CAPACITY FREEZER

S. Shodiya*, M.B. Oumarou and A.T. Abdulrahim
Department of Mechanical Engineering, University of Maiduguri,
Maiduguri, Nigeria.
sulaimonshodiya@yahoo.com

Abstract
R12 has been replaced with R134a due to its zero ozone depletion potential (ODP) in refrigeration system. The material compatibility and safety of R134a in refrigeration units as made it to be more attractive. However, R134a is to be phased out due to its high Global Warming Potential (GWP) and immiscible nature with conventional mineral oil. This paper presents the theoretical assessment of energy performance of a large capacity freezer using R134a and R430A as alternative refrigerant. In assessing the performance, three different condensing temperatures, that is, 40, 50 and 60°C and evaporator temperature between -30 and -18°C were chosen. The thermodynamic and thermophysical properties, namely, vapor pressure, latent heat, viscosity and density, using R134a and R430A refrigerants were compared. The performance parameters, such as coefficient of performance (COP), compressor power consumption (CPC) and Pressure ratio (Pr) were also compared. The results showed similarity in the vapor pressure in R134a and R420A refrigerants; as a result, R134a compressor can be used for R430A without modification. The results also showed that, at all operating temperatures, the COP of R430A was found to be higher than that of R134a by about 3.6–8.5% with about 10.5% lower CPC. It can be concluded that R430A is an energy efficient and environment-friendly alternative to R134a in large capacity freezer.
Keywords: R134a, R430A, Capacity, freezer, Global Warming, Ozone depletion

1.0 Introduction

The world is facing serious energy-related challenges that are further complicated by increasing concerns about Ozone depletion and global warming. Refrigerants such as R22, R502, R12, R404A, R134a used in the vapor compression refrigeration system has been identified to contribute to Ozone depletion and global warming. According to Montreal Protocol 1987, R502 and R12 have been eliminated because they are CFCs substances. Also, according to the Protocol, developing countries like Nigeria, with per capita consumption of some kg of ozone depleting substances have been categorized as article—5 countries. These countries are required to phase out all chlorofluorocarbons (CFC) by 2010 (Powell, 2002). R134a, due to its zero Ozone depleting potential (ODP) has replaced R12 (Riffat and Shankland, 1993). But R134a have two major problems, viz., its high GWP of 1430 (IPCC, 2012) and its immiscible nature with conventional mineral oil. To solve the immiscibility problem, polyol ester oil (POE) is recommended. However, POE is highly hygroscopic in nature, as a result, to avoid moisture absorption, strict service practices is required. Considering R134a limitations, it should be phased out soon

(Riffat and Shankland, 1993). The potential substitutes for R134a are pure hydrocarbons (HCs) such as R600a and R600, and their mixtures. However, as a result of operating pressure mismatched and volumetric displacement of R600a, it could not be used as a substitute for R134a systems. Hence, R600a is recommended only for new systems. Many researchers tested hydrocarbons (HCs) refrigerant mixtures in vapor compression refrigeration system due to its good thermodynamic and thermo-physical properties. Mohanraj et al. (2009) tested with binary HC mixture composed of R290 and 600a (in ratio of 45.2:54.8, by mass) as substitute to R134a in a domestic refrigerator. Similarly, Mohanraj et al. (2013) theoretically assessed R430A refrigerant as a possible substitute for R134a in a domestic refrigerator. They confirmed that R430A is an energy efficient alternative to R134a. Iwo et al. (2009) compared R134a and binary HC refrigerant mixture composed of R290 and R600a (in the ratio of 50:50, by mass) in domestic refrigerator and reported 4.4% lower energy consumption compared to R134a. The charge requirement of the HC mixture was also reduced by 40% compared to R134a due to its lower liquid density. Lee et al. (2008) investigated the performance of a small capacity directly cooled refrigerator using binary HC mixture composed of R290 and R600a (55:45, by mass) alternative to R134a. Shodiya et al. (2013) theoretically investigate different ratios of HC refrigerants HC290/HC600 mixtures flowing through adiabatic capillary tube in a split type Air-conditioner. They concluded that the mixture can be used to replace R22 in the system. Also, Mao-Gang et al. (2014) tested R290 and R600a and their mixture in large capacity chest freezer and concluded that the refrigerants are energy efficient.

Another possible alternative to R134a in these systems is R152a, with low GWP of 124 (IPCC, 2012). In an experimental study with domestic refrigerator, it was concluded that R152a has 4.7% higher COP compared to R134a (Bolaji, 2010). R152a is a HFC refrigerant, which is not miscible with conventional mineral oil. Hence POE lubricant is preferred. Mohanraj, et al. (2011) in their studies confirmed that the low volatile component (R600a) can be used as a possible additive with HFC refrigerants to tackle the miscibility issue with mineral oil and also to reduce the environmental impact of HFC refrigerants. The mixture composed of R152a and R600a in the ratio of 76:24, by mass has been developed and designated as R430A by ASHRAE. Previous studies have confirmed that there is no specific work reported on the performance of R430A as an alternative to R134a in large capacity freezer. The main objective of this paper is to explore the use of R430A as a potential alternative to R134a in large capacity freezer.

2.0 Methodology

The important properties and performance parameters for the two refrigerants were compared. To determine the performance parameters, their connecting equations were used. All thermophysical and thermodynamics properties data were taken from the REFPROP (2007) computer program.

2.1 Properties of R134a and R430A

2.1.1 Vapor Pressure

Fig. 1 depicts the variation of vapor pressure of R134a and R430A against temperature. It was observed that R134a has approximately the same vapor pressure at lower temperatures. However, the vapor pressure of R430Awas found to be 8.5–12.3% lower than that of R134a at higher temperatures. Hence the compressors can operate relatively at lower pressures.

.

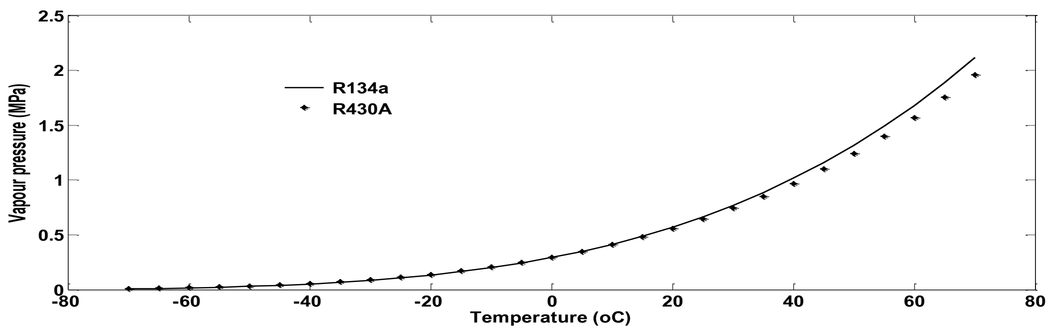

Figure 1: Vapor pressure against Temperature

2.1.2 Latent Heat

The variation of latent heat of two investigated refrigerants is shown in Fig. 2. It was observed that R430A has about 34–40% higher latent heat compared to R134a. The higher latent heat of R430A yields an increase in refrigeration capacity of the system, which reduces the compressor running time.

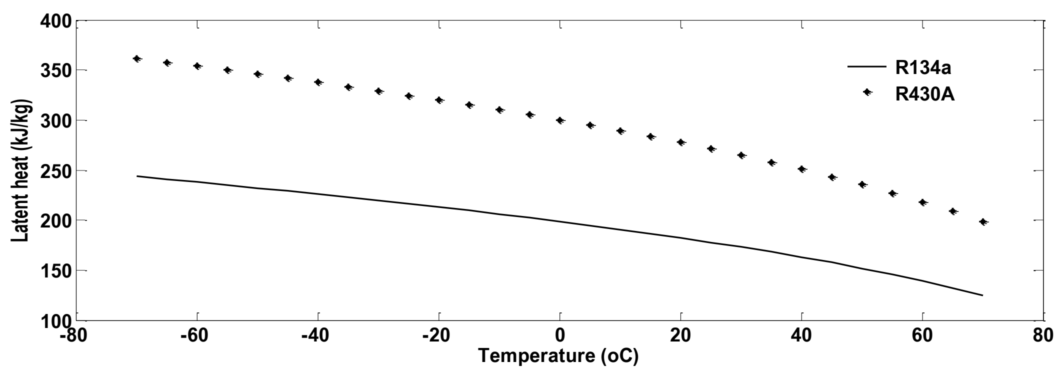

Figure 2: Latent heat against Temperature

2.1.3 Viscosity

The variation of viscosity of R134a and R430A against temperature is illustrated in Fig. 3. It was observed that liquid viscosity of R430A was found to be lower than that of R134a over the wide range of temperature resulting in low friction (low irreversibility). Hence less power consumption can be expected with the use of R430A.

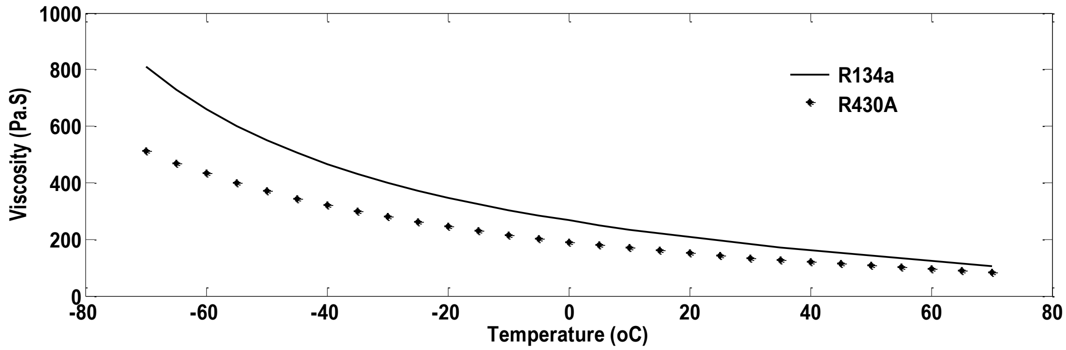

Figure 3: Vapor pressure against Temperature

2.1.4 Liquid Density

The liquid densities of R134a and R430A are compared in Fig. 4. The liquid density of R430A was found to be lower than that of R134a by about 35%, which will significantly reduce the refrigerant charge requirement.

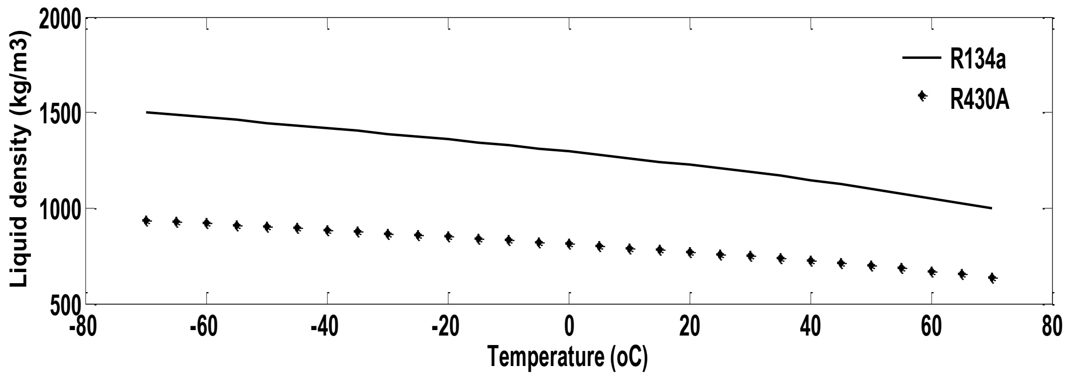

Figure 4: Vapor pressure against Temperature

The other properties such as critical temperature, critical pressure, boiling point, molecular weight, ODP and GWP of R134a and R430A are compared in Table 1. R430A has zero ODP with low GWP of 107. The critical temperature and critical pressure of R430A were found to be higher than those of R134a.

Table 1: Characteristics of R134a and R430A

Refrigerant	Reference	Boiling point (°C)	Molecular weight	Critical temperature (°C)	Critical Pressure (bar)	Ozone depleting potential	Global warming potential
R134a	IPCC (2012)	-26.4	102.03	101.1	4.06	0	1430
R430A	Park and Jung (2009)	-21.4	64.14	118.43	4.3	0	107

2.2 Thermodynamic Analysis of the performance prarameters

2.2.1 Vapor compression Refrigeration System

Vapor compression refrigeration system is made up of four major mechanical components – condenser, compressor, evaporator and an expansion device. In vapor compression refrigeration system, capillary tube is often used as an expansion device because of it low cost and simplicity. Fig. 5 shows vapor compression refrigeration system with capillary tube as expansion device and the p-h diagram.

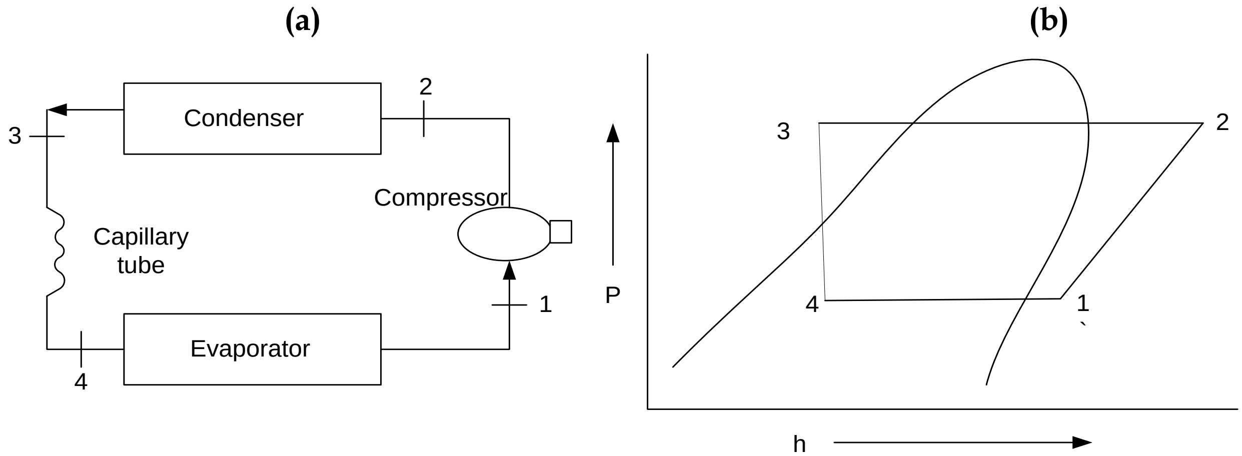

Figure 5: (a) Schematic diagram of vapor compression refrigeration system (b) the p-h diagram

In Fig. 5b, processes, 1-2, 2-3, 3-4 and 4-1 represent the various processes such as compression, condensation, expansion and evaporation, respectively. Points 1, 2, 3 and 4 represent the thermodynamic state of the refrigerant at compressor inlet (superheated vapor at evaporator pressure), compressor outlet (superheated vapor at condenser pressure), condenser outlet (sub cooled liquid at condenser pressure) and two phase fluid at evaporator pressure. The performance of large capacity freezer is theoretically assessed in terms of energy aspects based on the first law of thermodynamics. The freezer evaporating temperature varies from -30^{o}C to -18^{o}C.

The following general equations are used for the study:

- Variation of refrigerant mass flow rate ($\dot{m}$)

$\dot{m} = Q/(h_1 - h_2)$ ……………………… 1

- Variation of pressure ratio (Pr)

$Pr = Pc/Pe$ ………………………….. 2

- Variation of Coefficient of performance (COP)

$COP = (h_1 - h_4) / (h_2 - h_1)$ ………….. 3

- Variation of compressor power consumption (CPC)

$CPC = \dot{m}(h_2 - h_1)$ …………………… 4

Where Q is the refrigerating capacity taken to be 500 W for large capacity freezer, h_1, h_2, h_3 and h_4 are enthalpies at points 1, 2, 3, and 4 respectively.

3.0 Results and Discussions

The results obtained in the theoretical assessment of the large capacity freezer using R134a and R430A at three different condensing temperatures (40, 50 and 60 °C, which covers normal, subtropical and tropical climatic conditions) against the evaporator temperatures (range between−30 and -18°C,which covers different thermostat settings in the freezer) are presented in this section.

3.1 Refrigerant Mass Flow Rate

The mass flow rate of two assessed refrigerants is depicted in Fig. 6. The mass flow rate of R430A was lower than that of R134a by about 36–40% due to its lower liquid density. Hence lower compressor power can be expected with R430A.

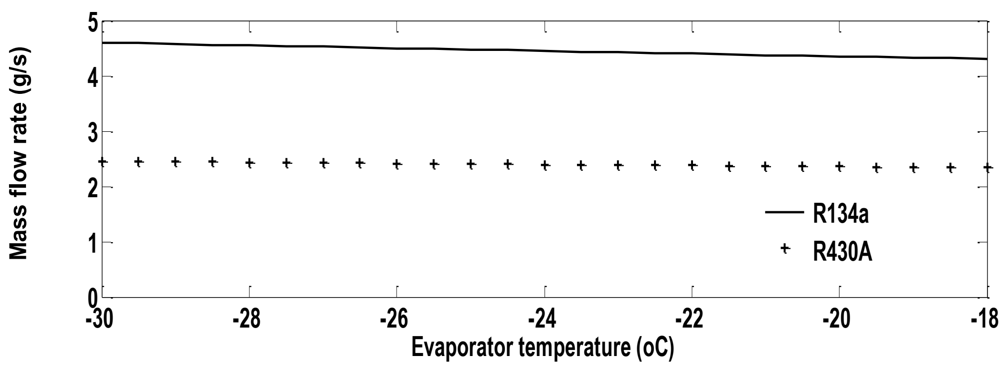

Figure 6: Mass flow rate versus Evaporator temperature

3.2 Pressure Ratio

The pressure ratio of the refrigerant influences the volumetric efficiency of the compressor. The variations of pressure ratio against evaporator temperature are compared in Fig. 7. The pressure ratio of R430A was observed to be lower than that of R134a by 4.7–10%, 6.9–11%, and 6.8–12% at 40, 50 and 60 °C, respectively. Hence, better volumetric efficiency can be expected with R430A.

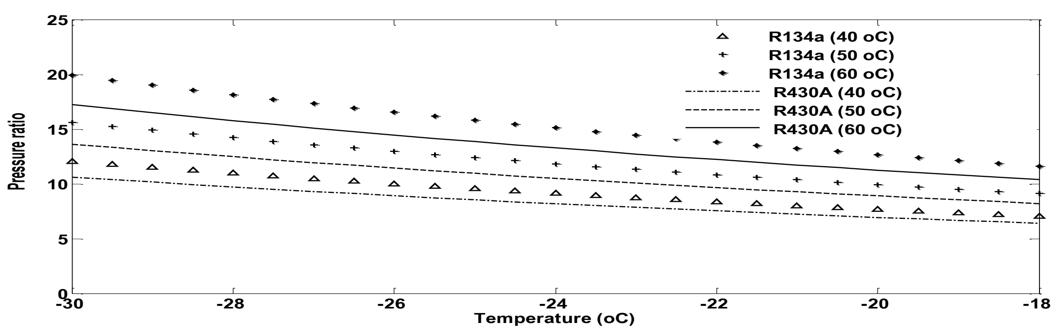

Figure 7: Pressure ratio versus Evaporator temperature

3.3 Coefficient of Performance

The COPs of the two refrigerants are compared in Fig. 8. The COP of R430A is higher than that of R134a by about 2.6%, 4.3% and 7.5% at 40, 50 and 60 °C, respectively due to its lower compressor power consumption and higher evaporator capacity. The COP of both R134a and R430A increases by about 5.5% with an increase in evaporator temperature from −30 to -18 °C.

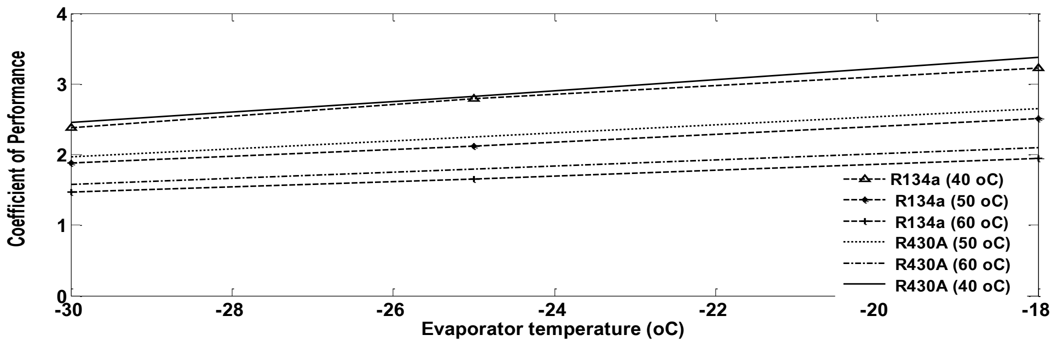

Figure 8: Coefficient of Performance versus Evaporator temperature

3.4 Compressor Power Consumption

Power consumptions of using the two refrigerants are compared and reflected in Fig. 9. The power consumption of R430A was found to be lower than that of R134a by 5.2–8.2%, at 50 °C condensing temperatures, for range of evaporator temperatures between −30 and -18°C. The variation of power consumption with condensing temperature was observed to be very small as a result neglected.

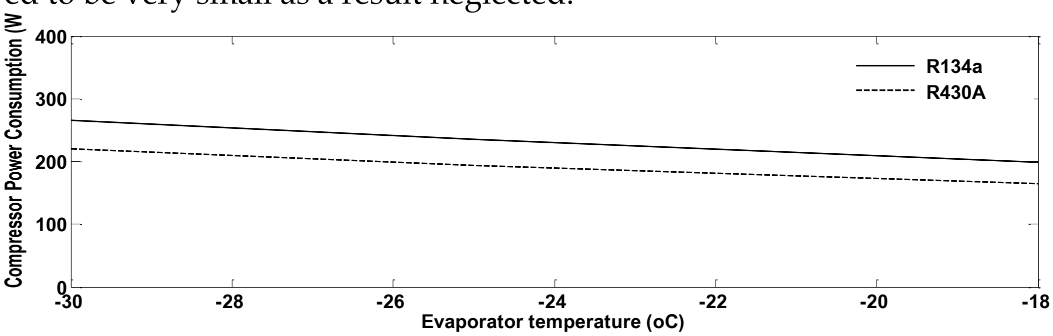

Figure 9: Compressor Power Consumption versus Evaporator temperature

4.0 Conclusions

The energy performance assessment has been made for a large capacity freezer working with R134a and R430A refrigerants. The results obtained from the theoretical study confirmed that R134a refrigerant can be replaced with R430A refrigerant without changing the system compressor in a large capacity freezer.

References

Bolaji, B. O., 2010. Experimental study of R152a and R32 to replace R134a in a domestic refrigerator. Energy, 35: 3793–3798.

IPCC. (2012). Climate change 2007: the physical science basis. The working group I contribution to the IPCC fourth assessment report; . Retrieved 4 May 2013:

Iwo, C. S., C. C. Ting and W. R. Wang, 2009. Efficiency analysis of home refrigerators by replacing with hydrocarbon refrigerants. Meas, 42: 697–701.

Lee, M. Y., D. Y. Lee and Y. Kim, 2008. Performance characteristics of a small-capacity directly cooled refrigerator using R290/R600a (55/45). Int. J. Refrig., 31: 734–741.

Mao-Gang, H., S. Xin-Zhou, L. Huan and Z. Ying, 2014. Application of natural refrigerant propane and propane/isobutane in large capacity chest freezer. Applied Thermal Engineering, 70: 732-736.

Mohanraj, M., 2013. Energy performance assessment of R430A as a possible alternative refrigerant to R134a in domestic refrigerators. Energy for Sustainable Development, 17(5): 632-637.

Mohanraj, M., C. Muraleedharan and S. Jayaraj, 2011. A review on recent developments in new refrigerant mixtures for vapour compression based refrigeration, air conditioning and heat pump units. Int. J. Energy Res., 35(8): 647–669.

Park, K. J. and D. S. Jung, 2009. Performance of alternative refrigerant R430A on domestic water purifiers. Energy Convers. Manag., 50: 3045–3050.

Powell, R. L., 2002. CFC Phase out; have we met the challenge. J. Fluor. Chem., 114: 237–250.

REFPROP, 2007. Thermodynamic properties of refrigerants and refrigerants mixtures version 8.0. Gathersburg, M.D. national institute of standards and technology, USA.

Riffat, S. B. and N. J. Shankland, 1993. Comparison of R 134a and R 12 refrigerants in a vapourcompression system. Int J Energy Res, 17: 439–442.

Shodiya, S., A. A. Azhar, N. Henry and N. D. Amer, 2013. Investigation of Various Mixtures of HC290/HC600 Refrigerants in Adiabatic Capillary tube used in Split-type Air-conditioner. Applied Mechanics and Materials, 388 71-75.