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PROSPECT OF HYDROCARBON USES BASED ON EXERGY ANALYSIS IN THE VAPOR COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT
This paper emphasized on the possibilities of researches in the field of exergy analysis in various usable sectors where vapor compression refrigeration systems are used. Exergy losses, exergy efficiency, second law efficiency and irreversibility of the system components as well as of the whole system are measured. In the vapor compression system, R134a, R290 and R600a are considered as refrigerants. Exergy parameters in the compressor, evaporator, condenser and expansion devices are calculated and analyzed. Exergy losses depend on evaporator temperatures, condensing temperature, refrigerants and ambient temperature. Most of the exergy losses occur in the condenser. Expansion device has the lowest losses. Exergy parameters are compared for different operating temperatures. It is found that hydrocarbons (R600a) have 50% higher exergy efficiency than R134a. Mixture of hydrocarbons also shows the best performance based on the exergy analysis.

Keywords: Hydrocarbon, exergy loss, exergy efficiency, performance

1. INTRODUCTION

After the second half of the twentieth century, the industrialized rebellion increased the application of the new technological products in our daily life. This caused more uses of the energy and made it an inseparable part of the life. Moreover, the rate of energy uses per capita has become a criterion of success in the development for countries. Providing the growing society with the energy ceaselessly, safely and sufficiently needs to have an increasing amount of productivity and activity in this area. Thermodynamic processes in vapor compression refrigeration systems release large amounts of heat to the environment. Heat transfer between the system and the surrounding environment takes place at a finite temperature difference, which is a major source of irreversibility for the cycle. Irreversibility causes the system performance to degrade. The first law is concerned only with the conservation of energy, and it gives no information on how, where, and how much the system performance is degraded. Exergy analysis is a powerful tool in the design, optimization, and performance evaluation of energy systems. The principles and methodologies of exergy analysis are well-established (Gaggioli, 1998; Wark, 1995; Bejan, 1988, 1982; Moran, 1982). An exergy analysis is usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction. Generally, in the domestic purposes for refrigeration system, R134a is used as refrigerant. But this refrigerant has global warming potential and hygroscopic in nature. Polyol ester is used as lubricant for tis refrigerant. But hydrocarbon is cheaper and has high heat of vaporization compared to R134a. Many researchers fund it as a suitable substitute in cooling purposes.

In this paper, energy and exergy analysis is applied to the vapor compression refrigeration cycle using most energetic and environmental friendly refrigerants like R600 and R600a. The expressions for the exergy efficiency and exergy loses (lost works) and in the individual processes that make up the cycle as well as the coefficient of performance (COP) and second law efficiency for the entire cycle are analyzed. Effects of condensing and evaporating temperatures on the exergy losses, second law efficiency and COP are investigated. Different types of hydrocarbon mixtures are tested in the different experiments. Most of them are based on computational analysis. But still now there is no unique solution for that concern. More analysis is necessary to have a concluded decision for refrigeration system.

2. MATHMATICAL FORMULATION FOR EXERGY ANALYSIS

Vapor compression refrigeration system is one of the refrigeration systems available for refrigeration and air conditioning purposes. In the vapor compression refrigeration system, there are four components such as: evaporator, compressor, condenser and expansion valve/throttling valve. Mass, energy and exergy balances are to be employed to determine the heat input, the rate of exergy destruction, and energy and efficiencies. A general mass, energy and exergy balances can be expressed as (Rosen et al., 2008):

$$\sum E_{in} = \sum E_{out} \qquad (1)$$

$$\sum Ex_{in} - \sum Ex_{out} = \sum Ex_{dest} \qquad (2)$$

Exergy of refrigerant at any state can be measured using the reference point as follows:

$$ex_r = (h - h_0) - T_0(s - s_0) \qquad (3)$$

Where, h is enthalpy, s is entropy and the subscript 0zero indicates the properties at dead (reference) state. Generally the Reference state is atmospheric pressure and T_0 is the reference temperature 25^0 C. Exergy destruction in the heat exchanger i.e. evaporator or condenser and compressor pump are evaluated as follows:

$$\dot{E}x_{dest,HE} = \dot{E}x_{in} - \dot{E}x_{out} \quad (4)$$

$$\dot{E}x_{dest,pump} = \dot{W}_{comp} - (\dot{E}x_{out} - \dot{E}x_{in}) \quad (5)$$

Where, $\dot{W}_{comp}$ is the work rate of the compressor. The exergy efficiency can be expressed as the ratio of the exergy out put any state and the exergy input at that state.

$$\psi = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \quad (6)$$

In the evaporator, refrigerant is the cold fluid and the indoor foods/air in the chamber/room is the hot fluid. Whereas, in the case of condenser refrigerant is the hot fluid and outdoor air is the cold fluid. General vapor compression refrigeration cycle is described as shown in Fig.s1 (a) and 1(b).

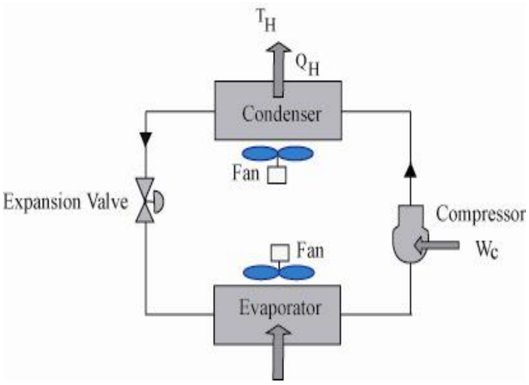

Fig. 1(a): A simple schematic of the vapor compression refrigeration system.

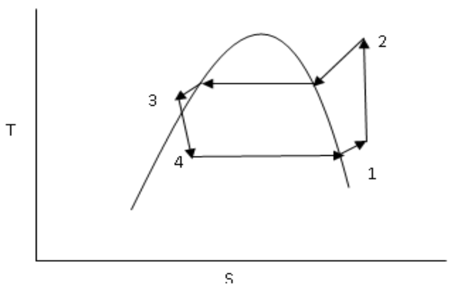

Fig. 1 (b): A simple T-S diagram of the vapor compression refrigeration system

3. EXPERIMENTAL METHODS AND FACILITY

In this experiment, a domestic refrigerator is used in the energy lab. Four thermocouples and three pressure transducers are set at different positions of the refrigeration system. Charging of refrigerant was done by using vacuum pump. R600, R600a and R134a are used to measure the performance of the vapor compression system. The temperature of the inlet/outlet of each component of the refrigerator was measured with copper-constantan thermocouples (T- type). The thermocouples or temperature sensors fitted at inlet and outlet of the compressor, condenser, and evaporator. Thermocouples or temperature sensors were interfaced with a HP data logger via a PC through the General Purpose Interface Bus (GPIB) cable for data storage. The pressure transducers were fitted at the inlet and outlet of the compressor and expansion valve. The pressure transducers made interfaced with a computer via a data logger to store data for further information. A service port was installed at the inlet of the expansion valve and compressor for charging and recovering the refrigerants. The evacuation has carried out through this service port.

4. RESULTS AND DISCUSSION

4.1 Variation of Coefficient of Performance with Evaporator Temperature

The COP of the domestic refrigerator using R-134a as a refrigerant was considered as baseline and the COP of butane, and iso-butane were compared with it. The effect of evaporator temperature on COP has been presented in Fig. 2.

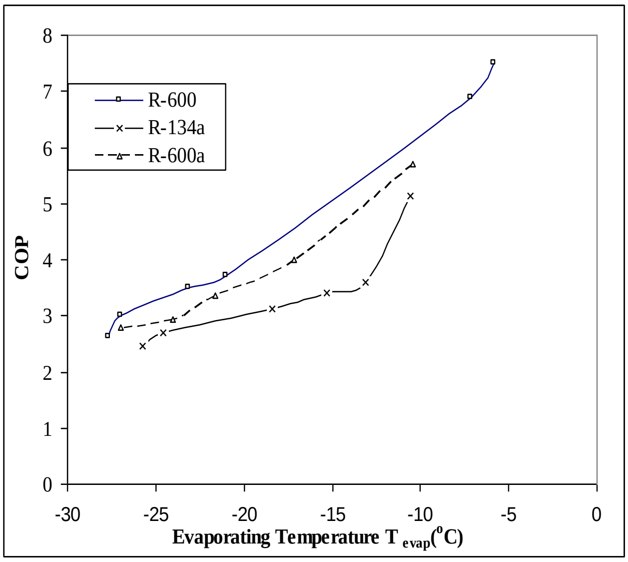

Fig. 2: Variation of coefficient of performance with evaporator temperature for different refrigerants.

The data represents a progressive increase in COP with the increase of evaporating temperatures. The reason is that the Refrigerating effect increase with the of evaporator temperature and work compression decreases with the increase of evaporating temperature. Hence the COP increases. The refrigerating is higher for R600 than R134a. So the CO of R600 is always higher than R134a.

4.2 Effect of Evaporating Temperature on Exergy Losses for Different Refrigerants

The exergy destructions were measured for the vapor compression refrigeration system. Exergy loss increases as the temperature of the evaporator decreases as shown in Fig. 3. This can be explained that if the evaporating temperature increases the heat transfer between the refrigerant entered into the evaporator tubes and the medium being cooled also increases which ultimately increase the refrigerating effect thus the exergy loss decreases. Among the three refrigerants, isobutene exhibits minimum exergy loss.

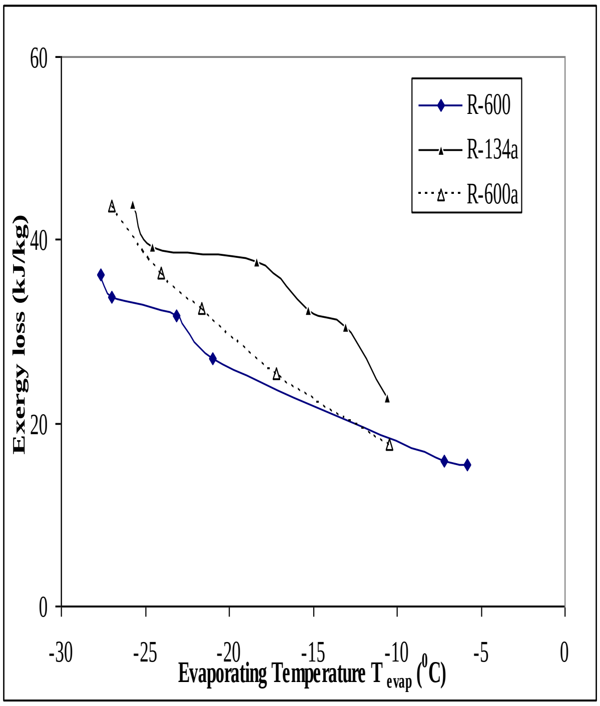

Fig. 3: Variation of exergy losses for different refrigerants at different evaporative temperatures.

At higher evaporating temperature, exergy loss is lower compared to that of at lower evaporating temperature. Vincent and Heun (2006) found that higher exergy destruction occurred in the compressor compared to condenser and other parts. They found that compressor has greater effect on the total exer*gy* destruction.

4.3 Effect of Evaporating Temperature on Exergy Losses in Different Components

Exergy losses in the individual components for Refrigerant R-134a are shown in Fig. 4 with the variation of evaporating temperatures. The trends of exergy losses in the different components of the vapor compression system for other refrigerants are also found similar. Greater portion of exergy losses take place in the compressor. Evaporator has lower exergy losses compared to the other components. Experimental results with other refrigerants also show the similar results i.e. compressor has the highest exergy losses compared to that of other components. The exergy losses in the components decrease with the increase of evaporating temperature. The higher the temperature differences in any component with the surroundings, the higher the exergy loss. Bayrakci and Ozgur (2009) studied about four different pure hydrocarbons (R290), butane (R600), isobutene (R600a) and iso-pentane (R1270) and also R22 and R134a. He found that R600 can be assumed as appropriate alternative to R22 and R134a.

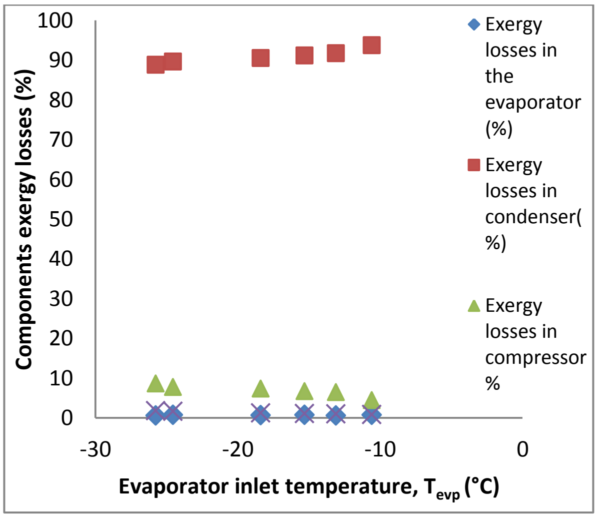

Fig. 4: Variation of Exergy losses in the different components at different evaporating temperatures using refrigerant R-134a.

4.4 Effect of Refrigerant on Exergy Efficiency and Losses

Some literatures are found about exergy analysis for different refrigerant. Chee (2007) found that the second law efficiency (exergy efficiency), η_{II} of the refrigeration cycle will decrease for high of condensing temperature and increase at high evaporating temperature.

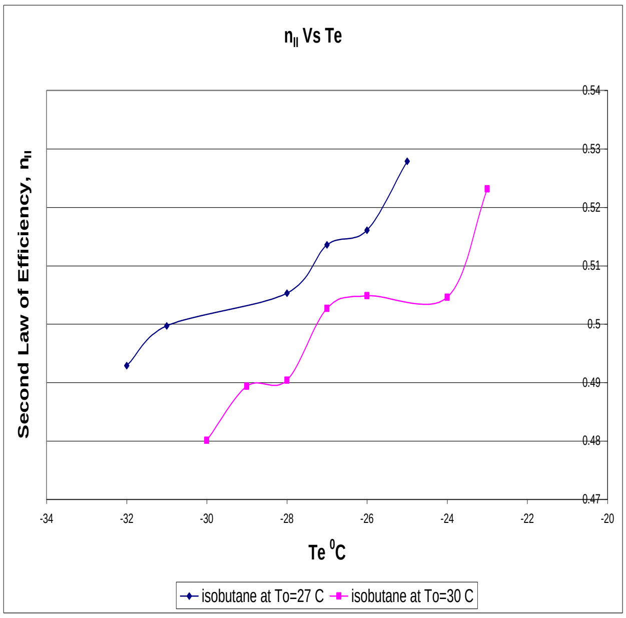

Fig. 5: Variation of second law efficiency with evaporator temperature.

Butane has the highest η_{II}, followed by isobutane and R134a. At constant condensing temperature, η_{II} will increase when increase of ambient temperature. From the graphs, we can conclude butane has the highest exergy loss and highest efficiency, following by isobutane and R134a shown in Fig.s 5 and 6.

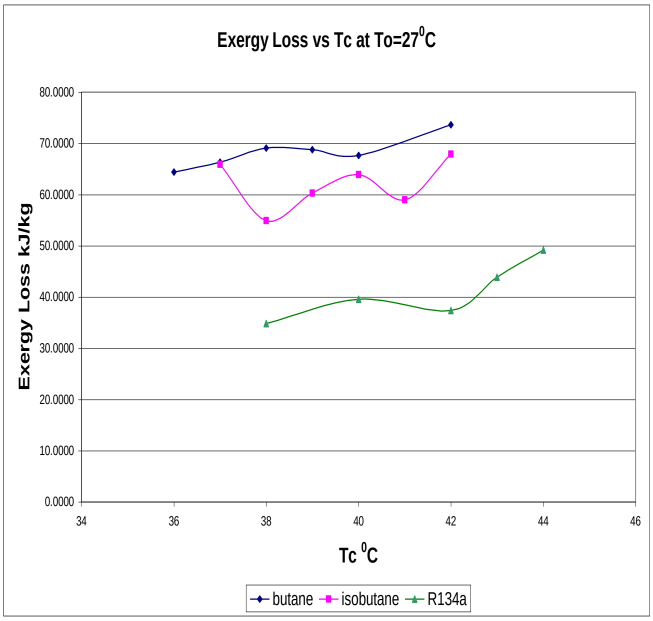

Fig. 6: Variation of Exergy loss with different condensing temperature at ambient temperature 27^{0}C.

5.0 SYSTEM DEVELOPMENT

From the analysis of Arora and Kaushik (2008), it is found that exergy efficiency for 10^0 C sub-cooling is 14.9% for R404 and 14.8% for R507 at 407C condenser temperature. Using the computer program for any refrigerant, Adegike et *al.* (2007) found that sub-cooling up to 2 to 5^{0}C is advantageous for energy and exergy performance of a refrigeration system but superheating is not advantageous. Second law efficiency and the coefficient of performance (COP) were increased and the total exergy losses were decreased with the decrease in a temperature difference between the evaporator and the refrigerated space and between the condenser and outside air (Yumrutas et *al.*, 2002; Ahamed et *al*, 2011).

6.0 CONCLUSION

After the successful investigation of the HC as a refrigerant on the basis of performance, the following conclusions can be drawn based on the results obtained:

- Exergy loss for butane and isobutene are less than that of the refrigerant R134a in the present test unit. In the higher evaporating temperature exergy loss is decreased for all refrigerants.
- Exergy efficiency is also higher for butane compared to that of isobutene and R-134a as refrigerants.
- Exergy loss in the compressor is higher than that in the other parts of the system i.e. upto 69% of the total exergy loss occurs in the compressor.
- The co-efficient of performances for butane and isobutene are comparable with that of R134a.
- Exergy loss increases with the increase of condenser temperature. Its higher foor butane compared that of R134a and iso butane.

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