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PROPANE MIXTURE WITH R22 AS AN ALTERNATIVE REFRIGERANT FOR AIR-CONDITIONING SYSTEM BASED ON EXERGY ANALYSIS

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Abstract-*First law and Second law analysis are now essential for energy-related fields, especially in the domestic air conditioner system. This paper emphasized on the second law efficiency and exergy performance of the domestic air conditioner. Exergy efficiency of the system and exergy lossesin components are measured. Mixture of R22 with R290 is used as an alternative to pure R22. Exergy parameters in the different components are calculated and analyzed. Exergy losses depend on evaporator temperatures, condensing temperature, refrigerants and ambient temperatures. Most of the exergy losses are occurred in the condenser. Expansion device has shown the lowest losses. Exergy parameters are compared for different operating temperatures. It is found that hydrocarbon mixture with R22 (M1) have 20% higher exergy efficiency than R22. In the air conditioner, mixture of R290 and R22 also shows best performance compared to R22.*

Keywords: Hydrocarbon mixture, exergy efficiency, R22, exergy loss.

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[1-3]. 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 [4-8]. An exergy analysis is usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction.

Along with the energy performance parameters, scientists are searching environmental benign refrigerants. Being an environment benign refrigerant, hydrocarbon draws an important attention among the scientists and researchers. Considering the thermodynamic properties of different hydrocarbons, it should be chosen as a refrigerant. Latent heat of vaporization of the refrigeration should have as large as possible. As from the literature, R290 and its mixture with R22 are the candidates for analysis with R22. Pressure ratio of the refrigerant should be small with high volumetric efficiency and low power consumption.

Hydrocarbons are cheaper than R-134a and R22. These are easily available. Most of the hydrocarbons offer good miscibility with mineral oils and good compatibility with common materials employed in the refrigeration equipment. The thermo-physical properties of hydrocarbons are very similar to those of CFC refrigerants and also non-toxic and environmentally safe. Tashtoush*et al.[9]*and Sekharet *al.*[10]reported that ODPs of hydrocarbons are very low ($<5x10^{-4}$), but the GWPs is quite high (1300). It is found that HCs have greater advantages based on energy and other environmental impacts.

In this paper, mixture of propane R290 with R22 was used as alternative refrigerant to R22 based on exergy performance in the domestic air conditioner. The expressions for the exergy efficiency and exergy loses (lost works) and pressure losses for 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, pressure losses, second law efficiency and COP are investigated. Different hydrocarbons mixtures are tested in the different experiments. But still now there is no unique solution for that concern. More analysis is necessary to have a concluded decision for refrigeration system.

2. Global Warming Potential

GWP is a relative value, used to compare the impact of an emitted gas on the climate and its contribution to climate change. The standard equation for GWP (100) is derived based on the ratio of time integrated radioactive forcing of one kg of a substance, relative to that of one kg of carbon di oxide over a 100 year time period[11-12]. Within the Montreal Protocol[13], the production, distribution and use of CFCs, HCFCs, halogens, methyl bromide is described and the developed countries have phased out the production and uses of these substances [14]. R22 is used as a refrigerant in the domestic refrigerant which has 0 ODP but GWP value is 1700. So, it is a common announcement in the Europe and all over te world that R22 should be phased out by 2030 [13]. R290 has less GWP (3) and zero ODP. The mixture of R22 and R290 can be a candiate in replace of R22 for air conditioner with less GWP. If the proposed mixture is R290:R22 (25:75), the GWP will be changed. For the mixture M1, GWP can be calculated as follows:

$$GWP(M1) = 0.75 \times GWP(R22) + 0.25 \times GWP(R290)$$

$$\Rightarrow GWP(M1) = 0.75 \times 1400 + 0.25 \times 0$$
$$\Rightarrow GWP(M1) = 1050 + 0$$
$$\Rightarrow GWP(M1) = 1050.0 \tag{1}$$

So, the mixture reduces the GWP compared to that of R22. When the ratio of R290 increases, the GWP will be reduced. If the mass ratio incurs 50:50, then the GWP will be 851.5. However, this mixture will cause flammable and safety concern.

3. Mathematical Modeling

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 [15]:

$$\sum E_{in} = \sum E_{out} \tag{2}$$
$$\sum Ex_{in} - \sum Ex_{out} = \sum Ex_{dest} \tag{3}$$

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

$$ex_r = (h - h_0) - T_0(s - s_0) \tag{4}$$

Where, h is enthalpy, s is entropy and the subscript zero indicates the properties at dead (reference) state. Generally the Reference state is atmospheric pressure and T_0 is the reference temperature 25° C.

Exergy destruction in the heat exchanger i.e. evaporator or condenser and compressor pump are evaluated as follows:

$$\dot{E}x_{dest} = \dot{E}x_{in} - \dot{E}x_{out} \tag{5}$$
$$\dot{E}x_{dest,pump} = \dot{W}_{comp} - (\dot{E}x_{out} - \dot{E}x_{in}) \tag{6}$$

Where, $\dot{W}_{comp}$ is the work rate in 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.

$$\Psi = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \tag{7}$$

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).

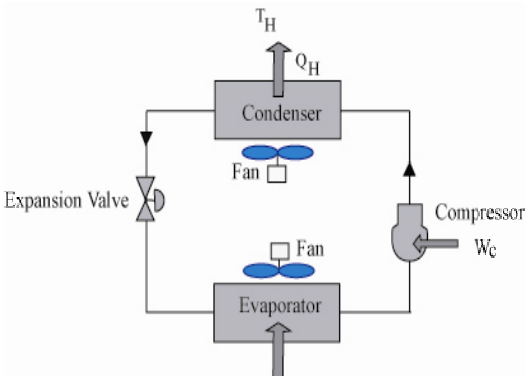

Fig. 1(a): A simple schematic of the vapor compression refrigeration system.

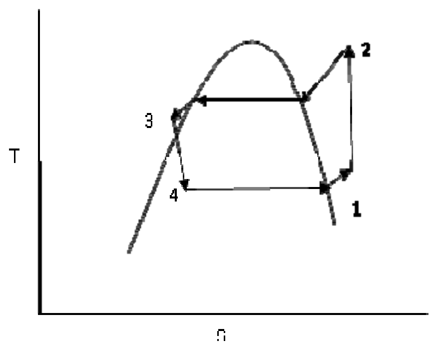

Fig. 1 (b): A simple T-S diagram of the vapor compression refrigeration system.

4. Experimental Procedure

In this experiment, a domestic air conditioner is used in the energy lab. Four thermocouples and three pressure transducers are set at different positions of the air conditioning system. Charging of refrigerant is done by using vacuum pump. R22 and mixture of R290 with R22 (25:75 by mass) are used to measure the performance of the system. The temperature of the inlet/outlet of each component of the air conditioner is measured with copper-constantan thermocouples (T- type). The thermocouples or temperature sensors is fitted at inlet and outlet of the compressor, condenser, and evaporator. Thermocouples or temperature sensors are 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.

5. Results and Discussion

5.1 Effect of operating temperatures and refrigerants on exergy losses

The nature of the exergy losses in the system are decreasing with the evaporating temperature and it can be explained by Yumrutas et al. [16]. The main cause is that the average temperature difference between the evaporator chamber and the control room decreases with increasing evaporating temperature. The higher the temperature difference the higher the exergy loss. Hence the total exergy losses with the increase of evaporator temperature are decreased.

Exergy losses for different evaporating temperature for both the refrigerants at ambient temepature T_a = 29 $^{\circ}$C are described in the Fig.2. For the refrigerant R22, the exergy losses are higher at every evaporating temperature than that of the refrigerant mixture M1. The trend also shows that the exergy losses are decreased with the increase of evapoarator temeprature. This Fig. shows that the mixture M1 is more efficient than R22. Thermodynamic performance of the mmixture is higher than R22. It also indicates that the evaporator temperature has great effect on exergy losses for both refrigerants.

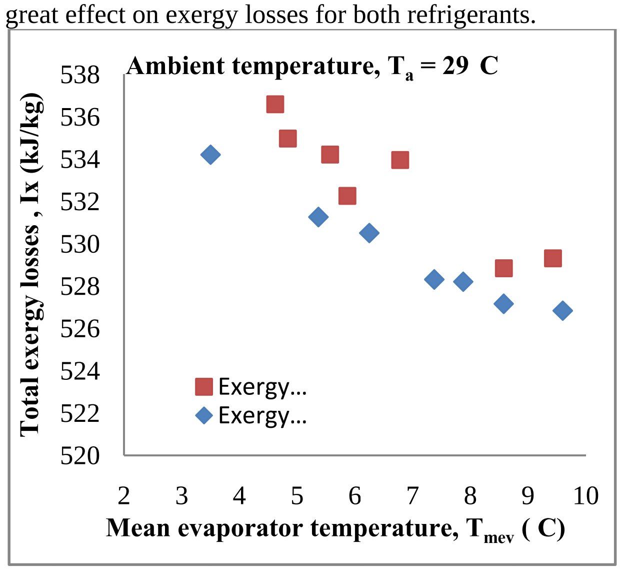

Fig.2: Variation of exergy losses of the refrigerants with evaporator temperatures at ambient temperature, T_a= 29 $^{\circ}$C.

Exergy losses have an effect on ambient temperature also. Fig.3 shows the variation in total exergy losses at ambient temperature T_a= 27°C. Exergy loss decreases with the increase of mean evaporator temperature. This trend is similar to that is shown in Fig.2. But it is also clear from the Fig.s2 and 3 that exergy losses at ambient temperature 27°C are higher than that at 29°C.

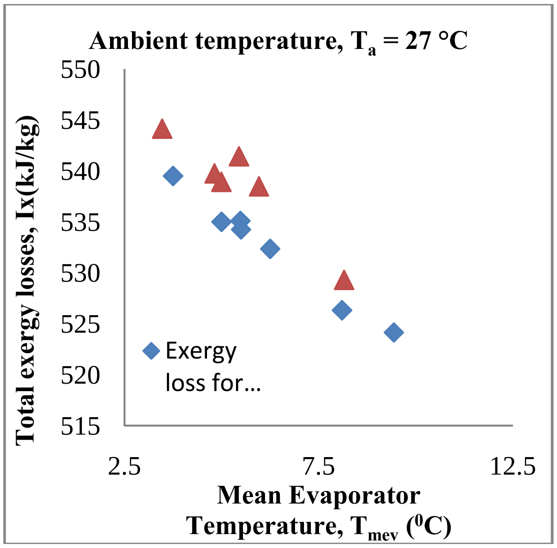

Fig.3: Variation of total exergy losses of the refrigerants with evaporator temperatures at ambient temperature, T_a= 27 $^{\circ}$C.

Fig.4 shows that exergy losses increase with the increase of condensing temperature for a given evaporator and ambient temperature. Total irreversibility rate is increased with the increase of condensing temperature for any kind of refrigerant. It is obvious. When the temperature difference between the ambient and respective component become higher, the exergy losses is higher i.e. availability of work is reduced. Chances or possibility of irreversibility increases. Fig.4 shows the total exergy losses for refrigerant R22 and mixture M1 at different condenser temperature. But the ambient temperature was remained within the range of 27.0 °C to 28.5°C and the evaporator temperature was remained within the range of 4.5 °C to 8.5 °C. The variation of the evaporator and ambient temperatures are very small. So, the variations in exergy losses shown in Fig. 4.30 are only depended on condensing temperatures. Bayrakci and Ozgur[17] found also similar results for R134a, R600a, R600, R22, R290 and R1270. Kalaiselvam and Saravanan [18]also found that with the increase in condensing temperature, exergy losses increases and exergy efficiency decreased in the case of all the refrigerants.

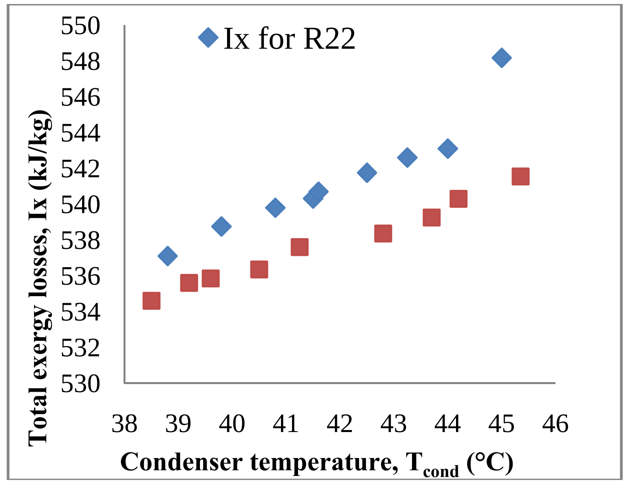

Fig.4: Variation of exergy losses for different condensing temperatures.

5.2 Exergy losses in the different components

Exergy losses depend on evaporator temperature of the air conditioner. It also depends on the temperature and process in the components. There are four components in the vapor compression system. In the condenser, the inlet temperature is higher than compared to other components. So, exergy losses in the condenser are higher than the other components. Due to the irreversibility in the condenser and friction, exergy losses are high compared to that in other components. Author observed that due to friction pressure there are pressure losses in the condenser and evaporator. So, higher exergy losses are occurred in these two parts compared to the others (Shown in Fig. 5).

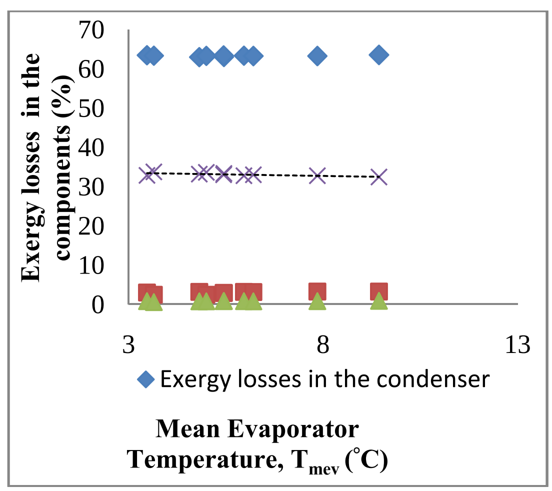

Fig.5: Variation of exergy losses in the different components at different evaporator temperature (T_a= 27 $^{\circ}$C).

5.3 Variation of exergy efficiency with refrigerants and evaporation temperature

In the Fig.6, variation of exergy efficiency with mean evaporator temperature at ambient temperature T_a= 29°C for refrigerant R22 and M1is shown. It is observed that exergy efficiency increases with the increase of mean evaporator temperature for both the refrigerants. As exergy losses are decreased at higher evaporator temperatures, thus the exergetic efficiency also increases. But for refrigerant mixture, the exergy efficiency shows higher values at all of the mean evaporator temperatures. This is due to lower exergy losses and higher refrigerant effect of the mixture than those of R22.

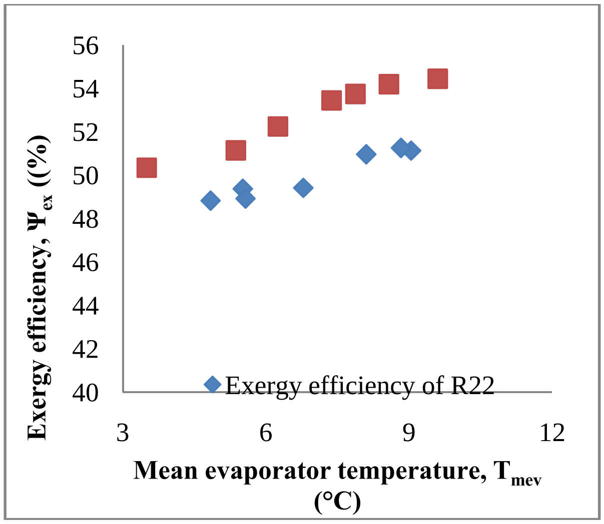

Fig.6: Exergy efficiency of refrigerant R22 and the mixture, M1 for different mean evaporating temperature at T_a= 29°C.

The trend exergy efficiency is similar to that of studied by Yumrutas et al. [16]. Bejan [6]found that exergy efficiency depends on refrigeration temperature. Exergy efficiency deceases with the increase of evaporator temperature.

6. Conclusion

Though hydrocarbons and its mixtures have some flammability problems, it is the most suitable refrigerant for the air conditioner because it has zero ODP and less GWP. It has a better exergy efficiency compared to the existing refrigerants. In this experiment, the amount of hydrocarbons (R290) was 25% of the total mixture by mass whereas, R22 was about 75%. Small amounts of hydrocarbons are necessary for the room air conditioner. For this reason, this amount does not create any harmful or dangerous effect for the people though it is flammable. Many researchers and manufacturers suggest that it should be used with care and properly i.e. without any leakage. Results obtained based on thermal performance at various operating conditions for pure R22 and mixture M1 are summarized here and has been taken for comparison. The findings are as follows:

- Exergy losses or destruction depends on evaporator temperature. Exergy losses per kg of refrigerant flow are increased with the increase of mean evaporator temperature. It is also observed that for both ambient temperatures, the exergy losses are decreased with the increase of mean evaporator temperature. It is also observed that exergy losses are lower at T_a=31 °C than that at T_a= 27 °C for every mean evaporator temperature.
- Exergy losses in the condenser are found to be higher than that in other components. Due to the irreversibility and friction in the condenser, exergy losses are higher compared to that in other components. Condenser is to work at a higher temperature compared to evaporator.
- Exergy efficiency of air conditioner system as well as vapor compression refrigeration system increases with the increase of evaporator temperature. It indicates that the second law performance of the system increases with the evaporator temperature.
- Exergy efficiency for the mixture has 20% higher than that of R22.
- Exergy efficiency of the system for the mixture, M1 is 10-15% higher than that for the R22. Exergy efficiency of the system can be increased up to 10% by lowering the atmospheric temperature.
- Exergy loss in the condenser is about 64% of the total losses. Lowest exergy loss is occurred in the expansion device.

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