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ANALYTICAL INVESTIGATION OF DOMESTIC AIR-CONDITINOING SYSTEM USING DIFFERENT REFRIGERANTS

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Abstract- *In this research, considering the possibilities of research in various energy sectors and environment existence where Vapor compression refrigeration system are used, an analytical and comparative investigation based on second law of thermodynamics using different refrigerants and REFPROP 7 software in air-conditioning system is being evaluated. Thermodynamics analysis such as co-efficient of performance ,refrigerant effect and compressor work, exergy efficiency and exergy losses has been investigated at different operating condition. In this study, different refrigerants such as R22, R290, R410A, R22/R290 (4:1)(M1) and R22/R290(50:50)(M2) has been considered by keeping in mind GWP and ODP. It has been found that using blend of hydrocarbon R290 and Hydroflouro carbon R22 in about 20% and 80% by mass respectively i.e. R22/R290 (4:1)(M1) as an alternative refrigerant for the system provides best result than the other refrigerants. From this study, it has been observed that the mixture M1 shows the better co-efficient of performance and exergy efficiency than other refrigerants considered. It also has been found that the mixture M1 has lower compressor work and exergy destruction than the different refrigerants considered. So, mixture of hydrocarbons shows the best performance based on the energy and exergy analysis.*

Keywords: Alternative refrigerants, Thermodynamic performance, REFPROP 7, Exergy loss, Exergy efficiency.

1. INTRODUCTION

Vapor compression refrigeration system (VCRS) is the prime sector in energy area where most of the system continues to run on halogenated refrigerants due to its excellent thermodynamic and thermo-physical properties. But, halogenated refrigerants have adverse impacts such as ozone depletion potential and global warming potential. In the earlier date, the performance of this system is estimated based on only the energy performance of the system. Energy analysis has been dealt with 1st Law of Thermodynamics. But, nowadays with the increase of use of energy and creation of entropy it has become relevant to deal with the quality aspect of energy which is known as exergy analysis. Exergy is defined as the available energy which can be converted into a work. Since the world energy crisis in the early 1970s, scientists and researchers have focused to recover the energy usage, exploit renewable energy resources and diminish the impact of energy use on the environment [1].Chlorofluorocarbons (CFCs) and Hydro chlorofluorocarbons (HCFCs) were commonly used as refrigerants in the domestic refrigerator for the last few decades. In recent decades, the concept of global warming, greenhouse effect and sustainability has entered into the engineering world. HFC refrigerants are used as a refrigerant for their high thermodynamic performance. However, HFC showed high GWP on the environment. Due to rapid economic growth during the last few decades, it is accompanied with more offices, buildings in the world, which is causing the more energy consuming, more energy loss and environmental problems. In Bangladesh, more than 14% energy is consumed by air-conditioning system including refrigeration and cooling system which is really high as compared to different sectors. The last decade has seen radical changes in the selection and use of refrigerants, mainly in response to the environmental issues of 'holes in the ozone layer' and 'global warming or greenhouse effect'. High Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) and greenhouse effect from these refrigerants have led to the profound study for the alternative refrigerants. As per Montreal protocol 1987, developing countries are required to phase out all CFC by 2010 and all HCFCs by 2040.GWP is relative value, used to compare the impact of an emitted gas on the climate and its contribution to climate change. Comparable study on R22, R1270 and R290 has been found that R290 is the best alternative to R22. Their research was based on the small capacity system. But this hydrocarbon has flammable property. So, it is necessary to think about non-flammable refrigerant, having zero GWP, ODP with high efficiency [2]. Study based on R134a, R600 and R600a in the domestic refrigerator and found that R600a has the highest performance among the refrigerants [3].Studied about the mixture of R290 with R600a and found that 4% energy consumption is reduced compared to R134a [4].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 [5]. Investigation on the energy, exergy flow and 2nd law efficiency of vapor compression refrigeration cycle for refrigerants R22 and R436b. Exergy efficiency and COP of R436b (58% of R290, 42% of R600a) were found higher than those of R22 in all the ranges of temperatures with low GWP and zero ODP [6]. Study conducted on exergy analysis for a domestic refrigerator between the evaporation and condensation temperature ranges from -15°C and 40°C using R12 and R413a refrigerants has been found that the overall exergy performance of R413a was working better than R12. System working with R413a required less power and less irreversibility than the others [7]. Comparable study on the energy, exergy and heat transfer analysis of R290 and mixture of R22/R290 (3:1) has been found that better performance of mixture than R22 and low GWP [8]. In this study, I have studied about energy and 2nd law analysis of refrigerants R22, R290, R410A, R22/R290 (4:1) (M1) and R22/R290 (50:50) (M2) and compared their performance and selected the best alternative refrigerant and compare the energy and exergy performances and losses of the vapor compression system using different refrigerants. As per I know very few study based on this alternative refrigerants has been occurred in the literature.

For the mixture M1, GWP can be calculated as follows:

GWP (M1) = 0.80×GWP (R22) + 0.20×GWP (R290)
» GWP (M1) = 0.80×1400+0.20×0
» GWP (M1) = 1120.0

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

2. MATHMATICAL FORMULATION FOR ENERGY AND 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. In this study, the following assumptions are made:

1. Steady state conditions are remaining in all the components.
2. Pressure loses in the pipelines are neglected.
3. Heat gains and heat loses from the system or to the system are not considered.
4. Kinetic and potential energy and exergy losses are not considered.
5. Same cooling load is considered here.

This study is an analytical type study. So, REFPROP 7 software is used to find the thermal properties of single refrigerant as well as the mixture of refrigerants. This software can calculate the enthalpy and entropy of refrigerants. Thermo-physical properties obtained by using REFPROP 7 software used in calculation to find out the thermodynamic performance of used different refrigerants. Generally the Reference state is atmospheric pressure and T_0 is the reference temperature 25°C.General vapor compression refrigeration cycle is described as shown in Figure 1 (a) and 1(b).

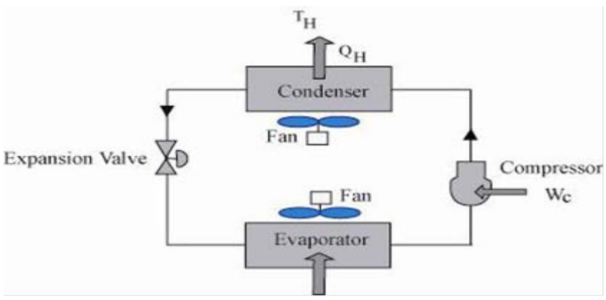

Fig.1(a): A simple schematic of the vapor compression refrigeration system.

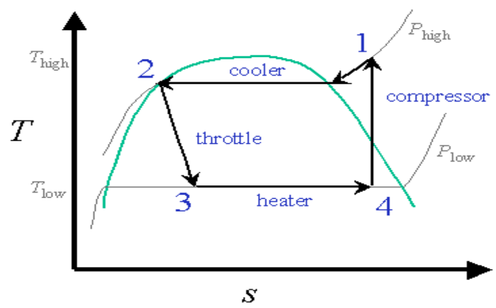

Fig.1(b): T-S diagram of ideal vapor compression refrigeration and air-conditioning system.

2.1 Energy analysis

Mathematical formulae for energy analysis are analyzed below according to the components of vapor compression refrigeration system:

Refrigeration capacity, $Qev = mr\ (h_1 - h_4)$ (1)

Compressor work, $COP = \frac{m_r(h_1-h_4)}{W_c}$ (2)

Condenser duty, $Qc = mr\ (h_2 - h_3)$ (3)

Coefficient of performance, COP = $\frac{m_r\,(h_1-h_4)}{W_c}$ (4)

Cooling capacity, $Qcool = mr\ (h_1 - h_4)$ (5)

2.2 Exergy analysis

Mathematical formulation for exergy analysis in different components can be arranged in the following way:

Specific Exergy in any state,

$\Psi = (h_i - h_0) - T_0(s_i - s_0)$ (6)

For Evaporator:

Heat addition in evaporator, $Q_{ev} = \dot{m}(h_1 - h_4)$

Exergy losses, $I_{ev} = \dot{m}(\Psi_4 - \Psi_1) + Q\left(1 - \frac{T0}{Tev}\right)$

$= \dot{m}[(h_4 - h_1) - T0(s_4 - s1)] + Q\left(1 - \frac{T_0}{T_{ev}}\right)$ (7)

For Compressor:

Compressor work, $W_C = \dot{m}(h_2 - h_1)$

For non-isentropic compressor, $h_c = \frac{h_{2s} - h_2}{\eta_c}$

Electrical power,

$W_{el} \quad \frac{W_c}{\eta_{mech} \times \eta_{el}}$ (8)

So, exergy loss, $I_{comp} = \dot{m}(\Psi_1 - \Psi_2) + W_{el}$

$= \dot{m}[(h_1 - h_2) - T_0(s_1 - s_2)] + W_{el}$ (9)

For Condenser:

$Q_{cond} = \dot{m}(h_2 - h_3)$

Exergy loss, $I_{cond} = \dot{m}(\Psi_2 - \Psi_3) - Q_{cond}\left(1 - \frac{T_0}{T_{cond}}\right)$

$= \dot{m}[(h_2 - h_3) - T_0(s_2 - s_3)] - Q_{cond}\left(1 - \frac{T_0}{T_{cond}}\right)$ (10)

For Expansion Valve:

Exergy destruction, $I_{exp} = \dot{m}(\Psi_4 - \Psi_3)$

$= \dot{m}\ T_0\ (s_4 - s_3)$[In throttling process, $h_4 = h_1$] (11)

Total destruction,

$I_{total} = I_{cond} + I_{exp} + I_{comp} + I_{evap}$ (12)

Exergy efficiency, $\eta_x = \frac{\Psi_1 - \Psi_4}{W_{el}}$ (13)

With reference to cited literatures, it is assumed that mechanical efficiency of the compressor is 90% and the electrical efficiency of the motor is 90%.

3. RESULTS AND DISCUSSIONS

3.1 Variation of Coefficient of Performance with Evaporator Temperature

From Figure 2, it can be seen that mixture (M1) R22/R290 (4:1) has higher COP than that of R22 at different evaporator temperatures. The mixture M1 has higher latent heat of vaporization than that of R22.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.

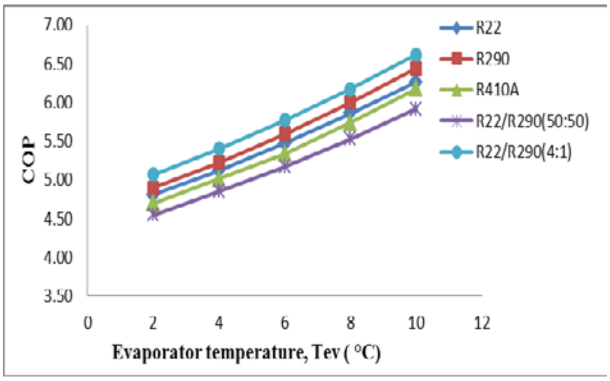

Fig.2: Variation of COP on mean evaporator temperature at T_{cond}=45°C for different refrigerants.

3.2 Variation of Coefficient of Performance with Condenser Temperature

From Figure 3, it is found that COP decreases with the increases of condenser temperature. At higher condenser temperature, the system needs more power to do more work by the compressor. The compression work has to be increased. Thus the COP is decreased.

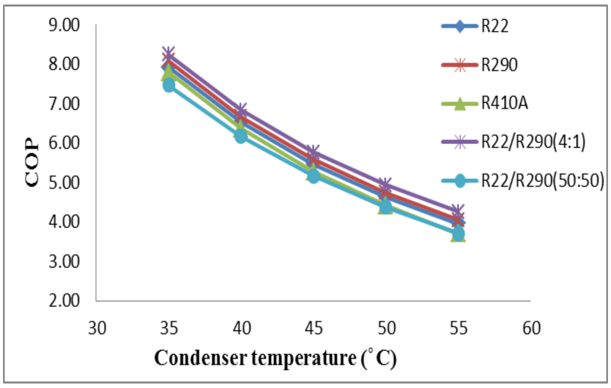

Fig.3: Variation of COP on condenser temperature at T_{evp}=6°C for different refrigerants.

3.3 Variation of Compressor Work with Evaporator Temperature

From Figure 4, it is observed that compressor work decreases with the increase of evaporator temperature for different refrigerants. So, power consumption is also decreased by the compressor. It has been seen that mixture (M1) R22/R290 (4:1) has lower compressor work than that of R22 at different evaporator temperatures. So, less power is consumed by the mixture M1.

3.4 Variation of Compressor Work with Condenser Temperature

From Figure 5, it has observed that, at higher condenser temperature, outlet temperature of the compressor is higher and thus the work of compression is increased. Hence irreversibility of the compressor is also increased and performance is decreased.

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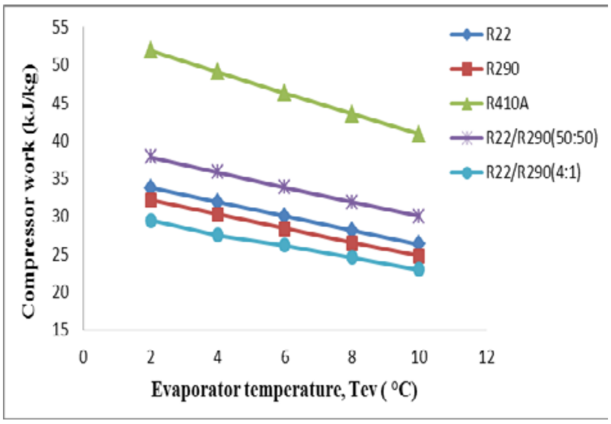

Fig. 4: Variation of compressor work on mean evaporator temperature at T_{cond}=45°C for different refrigerants.

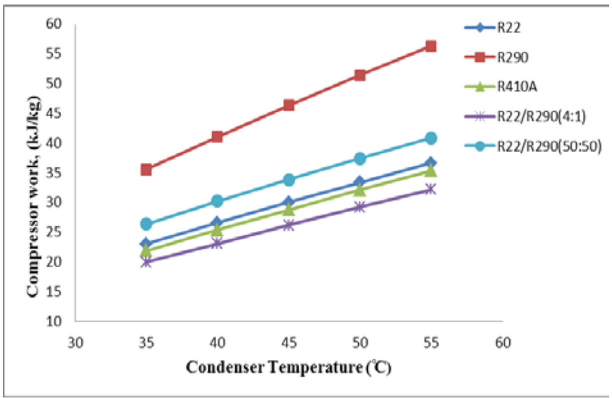

Fig.5: Variation of compressor work on condenser temperature at T_{evp}=6°C for different refrigerants.

3.5 Effects of Evaporator Temperature on Total Exergy Losses

Figure 6 shows that the exergy losses are reduced with the increase of evaporator temperature. The higher the temperature difference the higher the exergy loss. Hence, the total exergy losses with the increase of evaporator temperature are decreased.

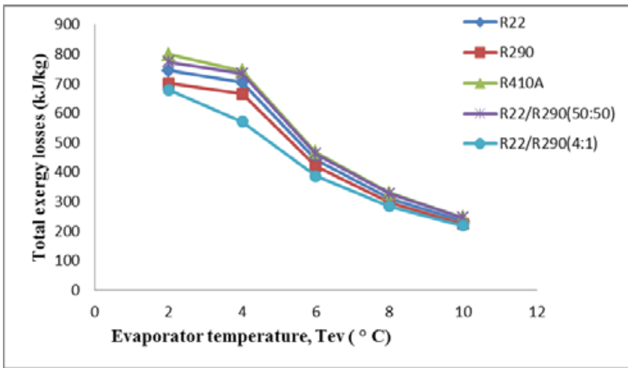

Fig.6: Variation of total exergy losses on mean evaporator temperature at T_{cond}=45°C for different refrigerants.

This figure also shows that M1 is more efficient than that of R22 based on 2nd law of analysis. Thermodynamic performance of M1 is also higher than that of R22. It also indicates that the evaporator temperature has a great effect on exergy losses for all refrigerants. Pure R290 has lower exergy losses than R22.

3.6 Effects of Condenser Temperature on Total Exergy Losses

From Figure 7, it has been found that total irreversibility rate i.e. total exergy losses increased with the increase of condensing temperature for any kind of refrigerant used for a given evaporator and ambient temperature. For the refrigerant R22, the exergy losses are higher at every condenser temperature than that of the refrigerant R22/R290 (4:1) (M1).

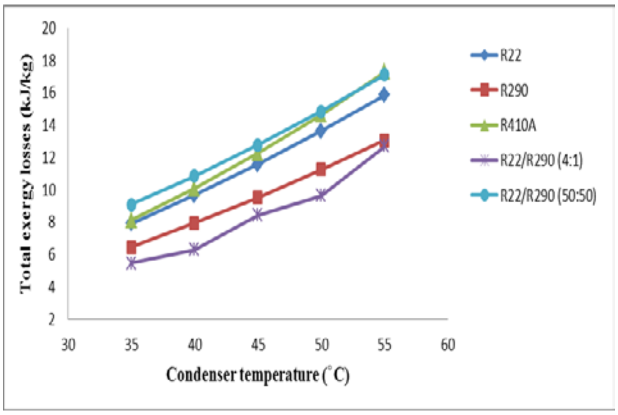

Fig.7: Variation of total exergy losses on condenser temperature at T_{eva}=6°C and T_{amb}=25℃ for different refrigerants.

3.7 Effects of Evaporator Temperature on Exergy Efficiency

It is shown in the Figure 8 that the exergy efficiency of the system increases with the increase of mean evaporator temperature. It indicates that the 2nd law performance of the system increases with the evaporator temperature. With the increase in evaporator temperature, COP also increases, exergy losses decreases. Hence, the exergy performance increases and system sustainability increases. For refrigerant mixture R22/R290 (4:1) (M1), the exergy efficiency shows higher value at all of the mean evaporator temperature than R22due to lower exergy losses and higher refrigerating effect of M1 than those of R22.

3.8 Effects of Condenser Temperature on Exergy Efficiency

Exergy efficiency also varies with respect to condenser temperature. It is shown in the Figure 9 that the exergy efficiency of an air-conditioning system decreases with the increase of condenser temperature.

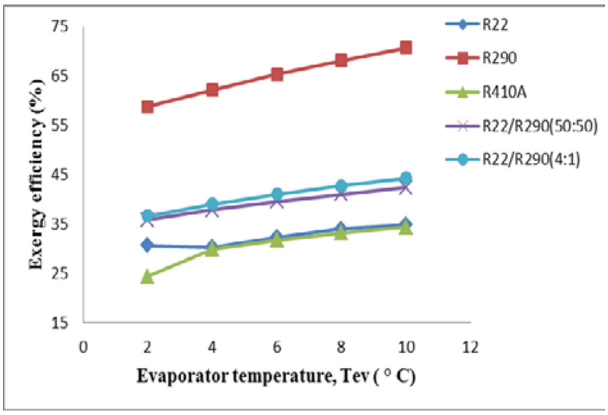

Fig.8: Variation of exergy efficiency on mean evaporator temperature at T_{cond}=45°C for different refrigerants.

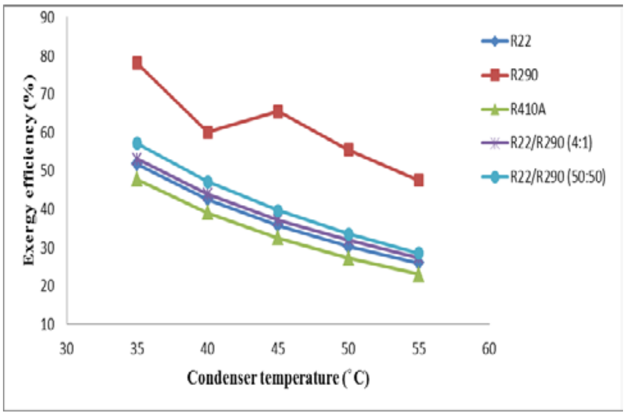

Fig.9: Variation of exergy efficiency on condenser temperature at T_{eva}=6°C and T_{amb}=25°C for different refrigerants.

4. CONCLUSIONS

In this study, it has been found that mixture of R22/R290 (4:1) (M1) showed best performance than the refrigerants considered.M1 has high potentiality to sustain as a refrigerant in the domestic air-conditioner system as it has low viscosity, high thermal conductivity, low surface tension, low pressure ratio, high COP and refrigerant effect, low exergy losses, high exergy efficiency, zero ODP and low GWP with low power consumption. After the successful investigation the following conclusions can be drawn based on the results obtained:

- Average COP of M1 is about 5.36% higher than R22, about 3.10% higher than R290, about 7.23% higher than R410A and about 10.50% higher than R22/R290(50:50) (M2) due to its high latent heat of vaporization for the given operating condition.
- Average compression work of M1 is about 12.97% lower than R22, about 2.48% lower than R290, about 9.61% lower than R410A and about 14.09% lower than M2 for different operating condition.
- Average value of total exergy loss for M1 is about 12.14% lower than R22, about 7.21% lower than R290, about 17.18% lower than R410A and about 15.80% lower than M2 for the given operating condition.
- Exergy efficiency for M1 is about 20.47% greater than R22, about 37.33% greater than R290, about 24.56% greater than R410A and about 3.44% greater than M2 for different operating condition.

That's why R22/R290 (4:1) M1 can be said as an alternative refrigerant of conventional refrigerants.

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7. NOMENCLATURE

Symbol	Meaning	Unit
h	Specific enthalpy of the refrigerant	(kJ/kg)
I	Exergy losses or destruction	(kJ/kg)
m	Mass flow rate	(kg/sec)
T	Temperature	(°C)
P	Pressure	(kN/m^2)
Q	Condenser duty	(kJ/kg)
q	Heat removal rate	(kJ/kg)
s	Entropy of the refrigerants	(kJ/K)
W_c	Compressor work	(kJ/kg)
Ψ	Specific Energy	Dimension-less

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