EXERGY ANALYSIS OF DOMESTIC REFRIGERATOR WITH DIFFERENT REFRIGERANTS

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Abstract — "Electricity saved is electricity generated". In today's scenario, our country is facing various challenges of saving electricity. Various gadgets, tools and equipments are flooded into the market, which work upon non-conventional sources of energy. Hence requirement of energy efficient devices is of utmost importance in view of the futuristic energy requirements. The uses of electricity in house hold appliances like air conditioner, water pump, refrigerator is obvious and if these devices can be made more energy efficient, handsome amount of electricity can be saved. Work has already been carried out in the field of energy economics, thermo economics.

It has been observed that refrigerators are the devices which work almost 365 days round the clock, hence our scope of energy efficiency improvement initiates with the coining of new term "exergy analysis" of the refrigerator. The new term introduced for refrigerator will be solely based on the properties of refrigerants used in this paper.

The performance of domestic refrigerator depends upon various different parameters. As the basic domestic refrigerators have condenser, evaporator, compressors, expansion valve and refrigerant. A lot of work has been done to improve the performance of refrigerator. The heat transfer and the pressure drop are the two major factors governing the systemperformance. Therefore, selection of refrigerant becomes very important in ascertaining the overall system efficiency.

Earlier, the domestic refrigerator working fluid was (CFC's) chlorofluorocarbons. In 1930 it was used as an alternative to ammonia and sulphur dioxide refrigerants. Because CFC's were found non-flammable, non explosive and non corrosive. However, the discovery of hole in the ozone layer over Antarctica in 1985 lead to a movement to replace the (CFC's) due to their high ozone depleting potential which lead to found different refrigerant.

In present scenario, no of refrigerants available for fulfilling the different needs are R-134a ,R-12,R-141b,R-22 and Hydrocarbon blend. This paper is proposed with an attempt to select the right refrigerant for domestic refrigerator with specified refrigeration capacity to optimize the performance of a domestic refrigerator. For this purpose analysis based on work is proposed which would be compared with the theoretically computed results using any computer software. Exergy analysis of the system is also proposed which will help in studying the heat distribution through the system

Keywords — Exergy, second law efficiency, VCR system, R-12, R-134A, Carnot cycle, Exergy destruction .

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1. INTRODUCTION

Vapour compression refrigeration systems are the most commonly used among all refrigeration systems. As the name implies, these systems belong to the general class of vapour cycles, where in working fluid (refrigerant) undergoes phase change at least during one process. In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. The input to the system is in form of mechanical energy required to run the compressor.

Hence these systems are also called as mechanical refrigeration system. Vapour compression refrigeration system are available to suit almost all applications with refrigeration capacities ranging from Watts to Megawatts. A wide variety of refrigerants can be used in these system to suit different applications, capacities etc. The actual vapour compression cycle is based on Carnot cycle. Thermodynamic process in refrigeration system releases large amount of heat to the environment. Heat transfers between the system and surroundings takes place at finite temperature difference, which is the major source of irreversibility for the process.

To evaluated the performance of Vapour compression refrigeration system many investigation have been conducted in research into search of optimization of system I.L. Maclaine Cross, E. Leonardi [1] investigated comparative performance of hydrocarbon refrigerants using energy analysis they work out the performance vapour compression refrigeration systems for hydrocarbon. Vaibhav Jain, S.S kachhwha [2] study Vapour compression refrigeration system with R22/R410A using exergy analysis. The conventional view expressed by Strobridge [3] that the exergetic efficiency of the refrigeration cycles does not depend on the refrigeration temperature was questioned by Bejan [4] he showed that the exergetic efficiencies decrease as the refrigeration temperature decreases.

In this paper, exergy analysis is applied to the vapour compression refrigeration systems. For R22 and R143A using this to refrigerate and evaluate the cooling load as well as the second law efficiency, and investigating the COP. Considering the evaporator temperature range (-10 to -15) and the envi-

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ronment condition as in summer.

LITERATURE SURVEY

Miguel Padilla [5] studied the exergy analysis of the impact of direct replacement R12 with the R143A on the performance of a domestic vapour-compression refrigeration system originally designed to work with R12. In a contorted condition at the condenser and evaporator.

E. Bilgen [6] exergy analysis of heat pump-air conditioner system has been carried out. The irreversibility's due to heat transfer and friction have been considered. The coefficient of performance based on the first law of thermodynamics as a function of various parameters, their optimum values, and the efficiency and coefficient of performance based on exergy analysis have been derived. Based on the exergy analysis, a simulation program has been developed to simulate and evaluate experimental systems.

ReepYumrutas [7] computational model based on the exergy analysis is presented for the investigation of the effects of the evaporating and condensing temperatures on the pressure losses, the exergy losses, the second law of efficiency, and the coefficient of performance (COP) of a vapor compression refrigeration cycle.

CE Vincent [8] He fined that the Energy Efficiency Rating (EER) of compressor has most effect on system performance and economics, and similar to previous studies, he fined that cost of refrigerating is driven by compressor costs. Finally, he noted that future efforts to reduce compressor cost should be accompanied by a corresponding effort to improve compressor thermodynamic performance. (The studied for South Africa and United States.)

EXERGY ANALYSIS

An effective method using the conservation of mass & conservation of energy principles together with the second law for the design and analysis of vapour compression refrigeration system. It gives a way to study how we can make system and process more efficient and a key tool for determining the locations, types, & true magnitudes of wastes & loss.

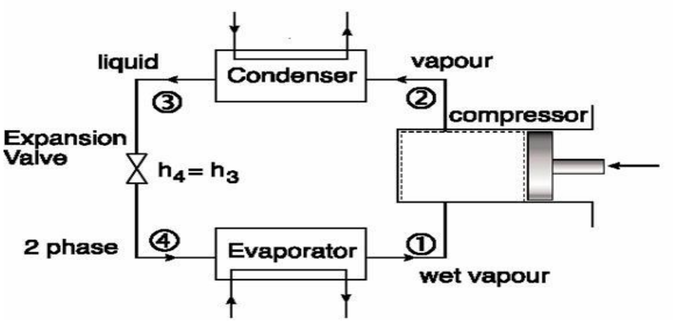

Figure:- 1 An ideal vapour-compression refrigeration system for analysis.

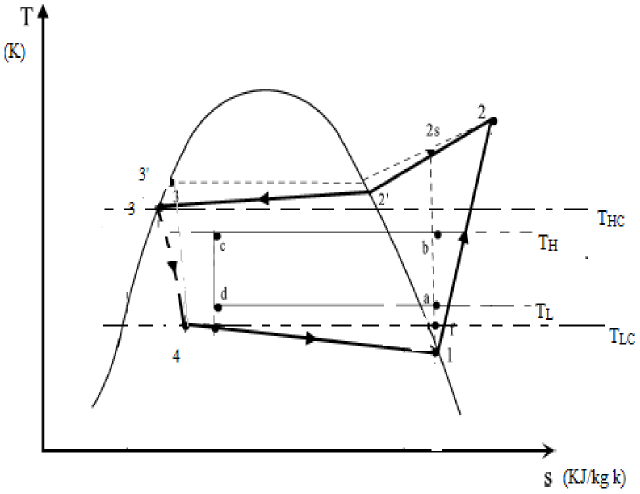

Figure:- 2 T-s diagram of the vapour compression system studies.

Figure 2 is a schematic of a vapour-compression refrigeration cycle operating between a low-temperature medium (T_L) and a high-temperature medium (T_H). The maximum COP of a refrigeration cycle operating between temperature limits of T_L and T_H based on the based on the Carnot refrigeration cycle was given as

$$\mathrm{COP}_{\mathrm{Carnot}} = \frac{T_L}{T_H - T_L} = \frac{1}{\frac{T_H}{T_L} - 1} \tag{1}$$

Practical refrigeration systems are not as efficient as ideal models like the Carnot cycle, because of the lower COP due to irreversibility in the system. As a result of Equation 1 a smaller temperature difference between the heat sink and heat source (T_H - T_L) provides greater refrigeration system efficiency (i.e., COP). The Carnot cycle has certain limitations, because it represents the cycle of the maximum theoretical performance.

The aim in an exergy analysis is usually to determine the exergy destructions in each component of the system and to determine exergy efficiencies. The components with greater exergy destructions are also those with more potential for improvements. Exergy destruction in a component can be determined from an exergy balance on the component. It can also be determined by first calculating the entropy generation and using

$$\dot{E}_{xdest} = T_0 \dot{S}_{gen} \tag{2}$$

Where T_O is the dead-state temperature or environment temperature. In a refrigerator, T_O is usually equal to the temperature of the high-temperature medium T_H. Exergy destructions and exergy efficiencies for major components of the cycle of the cycle are as follows (state numbers refer to Figure 3.2):

Compressor:

$$\dot{E}_{x,in} - \dot{E}_{x,out} - \dot{E}_{x,dest,1-2} = 0$$

$$\dot{E}_{x,dest,1-2} = \dot{E}_{x,in} - \dot{E}_{x,out}$$

$$\dot{E}_{x,dest,1-2} = \dot{W} + \dot{E}_{x,1} - \dot{E}_{x,2}$$

$$\dot{E}_{x,dest,1-2} = \dot{W} - \Delta\dot{E}_{x,12}$$

$$= \dot{W} - \dot{m}[h_2 - h_1 - T_o(s_2 - s_1)]$$

$$= \dot{W} - \dot{W}_{rev}$$

$$\dot{E}_{x,dest,1-2} = T_o\dot{s}_{gen,1-2} = \dot{m}T_o(s_2 - s_1)$$

$$\eta_{ex,Comp} = \frac{\dot{W}_{rev}}{\dot{W}} = 1 - \frac{\dot{E}_{x,dest,1-2}}{\dot{W}} \qquad (3)$$

Condenser:

$$\dot{E}_{x,dest,2-3} = \dot{E}_{x,in} - \dot{E}_{x,out}$$

$$\dot{E}_{x,dest,2-3} = (\dot{E}_{x,2} - \dot{E}_{x,3}) - \dot{E}_{xQ_H}$$

$$= \dot{m}[h_2 - h_3 - T_o(s_2 - s_3)] - \dot{Q}_H\left(1 - \frac{T_o}{T_H}\right)$$

$$\dot{E}_{x,dest,2-3} = T_o\dot{s}_{gen,2-3} = \dot{m}T_o\left(s_2 - s_1 + \frac{q_H}{T_H}\right)$$

$$\eta_{ex,Cond} = \frac{\dot{E}_{x,Q_H}}{\dot{E}_{x,2} - \dot{E}_{x,3}} = \frac{\dot{Q}_H\left(1 - \frac{T_o}{T_H}\right)}{\dot{m}[h_2 - h_3 - T_o(s_2 - s_3)]}$$

$$= 1 - \frac{\dot{E}_{x,dest,1-2}}{\dot{E}_{x,2} - \dot{E}_{x,3}} \qquad (4)$$

Expansion valve:

$$\dot{E}_{x,dest,3-4} = \dot{E}_{x,in} - \dot{E}_{x,out}$$

$$\dot{E}_{x,dest,1-2} = (\dot{E}_{x,3} - \dot{E}_{x,4})$$

$$= \dot{m}[h_3 - h_4 - T_o(s_3 - s_4)]$$

$$\dot{E}_{x,dest,3-4} = T_o\dot{s}_{gen,3-4} = \dot{m}T_o(s_4 - s_3)$$

$$\eta_{ex,ExpValve} = 1 - \frac{\dot{E}_{x,dest,3-4}}{\dot{E}_{x,3} - \dot{E}_{x,4}} = 1 - \frac{\dot{E}_{x,3} - \dot{E}_{x,4}}{\dot{E}_{x,3} - \dot{E}_{x,4}} \qquad (5)$$

Evaporator:

$$\dot{E}_{x,dest,4-1} = \dot{E}_{x,in} - \dot{E}_{x,out}$$

$$\dot{E}_{x,dest,4-1} = -\dot{E}_{xQ_L} + \dot{E}_{x,4} - \dot{E}_{x,1}$$

$$\dot{E}_{x,dest,4-1} = (\dot{E}_{x,4} - \dot{E}_{x,1}) - \dot{E}_{xQ_L}$$

$$= \dot{m}[h_4 - h_1 - T_o(s_4 - s_1)] - \left[-\dot{Q}_L\left(1 - \frac{T_o}{T_L}\right)\right]$$

$$\dot{E}_{x,dest,4-1} = T_o\dot{s}_{gen,4-1} = \dot{m}T_o\left(s_1 - s_4 - \frac{q_L}{T_L}\right)$$

$$\eta_{ex,Evap} = \frac{\dot{E}_{x,Q_L}}{\dot{E}_{x,1} - \dot{E}_{x,4}} = \frac{-\dot{Q}_L\left(1 - \frac{T_o}{T_L}\right)}{\dot{m}[h_1 - h_4 - T_o(s_1 - s_4)]}$$

$$= 1 - \frac{\dot{E}_{x,dest,4-1}}{\dot{E}_{x,1} - \dot{E}_{x,4}} \qquad (6)$$

The total exergy destruction in the cycle can be determined by adding exergy destruction in each component:

$$\dot{E}_{dest,total} = \dot{E}_{dest,1-2} + \dot{E}_{dest,2-3} + \dot{E}_{dest,3-4} + \dot{E}_{dest,4-1} \qquad (7)$$

It can be shown that the total exergy destruction in the cycle can also be expressed as the difference between the exergy supplied (power input) and the exergy recovered (the exergy of the heat transferred from the low temperature medium)

$$\dot{E}_{dest,total} = \dot{W} - \dot{E}_{x,Q_L} \qquad (8)$$

Where the exergy of the heat transferred from the low temperature medium is given by

$$\dot{E}_{xQ_L} = -\dot{Q}_L\left(1 - \frac{T_o}{T_L}\right) \qquad (9)$$

The minus sign is needed to make the result positive. Note that the exergy of the heat transferred from the low-temperature medium is in fact the minimum power input to accomplish the required refrigeration load $\dot{Q}_L$:

$$\dot{W}_{min} = \dot{E}_{x,Q_L} \qquad (10)$$

The second –law efficiency (or exergy efficiency) of the cycle is defined as;

$$\eta_{II} = \frac{\dot{E}_{x,Q_L}}{\dot{W}}$$

$$\eta_{II} = 1 - \frac{\dot{E}_{x,dest,total}}{\dot{W}} \qquad (11)$$

RESULTS AND DISCUSSIONS

A computational model is developed for carrying out the exegertic analysis of the system using Matlab (7.8.0(R2009a)). The comparative performance is evaluated for refrigerant flow rate 1Kg/s for the condenser temperature varying 298 K to 307 K with an increment of 1k the evaporator temperature is varying between 264 K to 255 K with a decrement of 1K.

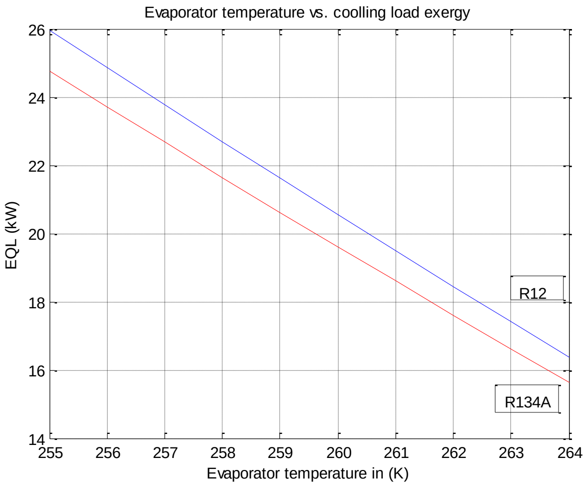

Figure 3 Comparison of exergy of cooling load with evaporator temperature

Figure 3 shows the variation of cooling load exergy with evaporation temperature. For the matching input parameters, R12 has exergy of cooling load higher compared to R134A. In other words for the same work input the exergy cooling load is more in case of R12. There is a linear relationship between exergy cooling load and evaporator temperature as the evaporator temperature decrease, the exergy cooling load increases.

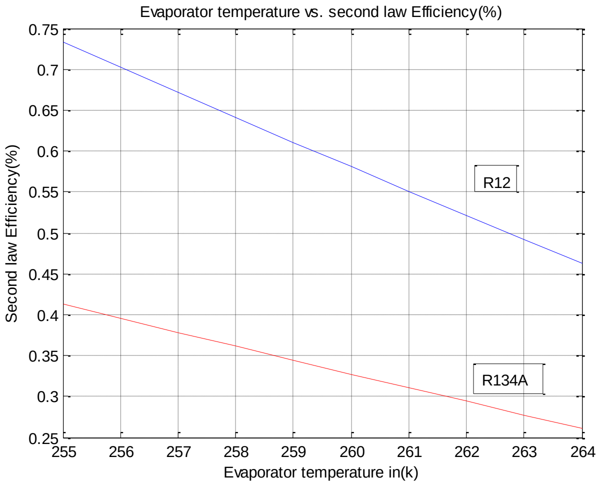

Figure 4 comparison of second law efficiency with evaporator temperatures

Figure 4 shows the effect of varying evaporator temperature on second law efficiency for R12 and R134A, as the second law efficiency of R12 lies between 0.75% to 0.45% for the same evaporator temperature the second law efficiency of R134A lies between 0.25% to 0.4%.

Increase in evaporator temperature results increase in exergy cooling load for both refrigerants, where as the mass flow rate has been constant for the system.

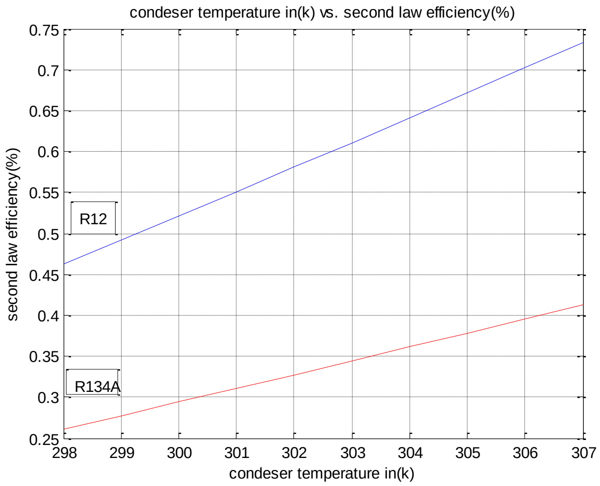

Figure 5 Comparison of second law efficiency with condenser temperature

It can be seen from Figure 5 that, at high condenser temperature the second law efficiency is also higher which shows that at higher temperature the exergy of the system is higher.

CONCLUSION

The exergy analysis of cooling load, second law efficiency along with variation in evaporator temperature and condenser temperature is presented in this paper. The results shows that exergy of cooling load and second law efficiency are affected by change in evaporator and condenser temperature. The effect of dead-state temperature, which keeps on varying, depending upon the particular geological location of the system since it affects second law efficiency. This analysis shows that the second law efficiency of R134A is lower then R12.

REFERENCES

[1] I.L Maclaine, E. Leonardi, Comparative Performance of hydrocarbon Refrigerants, School of Mechanical & manufacturing engineering., The University of New South Wales Sydney NSW, Australia., I.I.F-I.I.R- commissions E2,E1,B1,B2 Melbourne (Australia)-1996 11th to 14th February.

[2] Vaibhav Jain, S.S. Kachhwaha, R.S. Mishra, International Journal of Energy and Environments. Volume 2, issue 2, 2011 pp.297-310.

[3] T.R. Strobridge, Cryogenic Refrigerators—An Updated Survey, in: National Bureau of Standards Technical Note, Vol. 655, Washington, DC, 1974.

[4] A. Bejan, G. Tsatsaronis, M.Moran, Thermal Design & optimization, wiley, New York 1995.

[5] Miguel Padilla,Exergy analysis of R143a as replacement of R12 in domestic refrigeration system.(2010)2198-2201.

[6] E. Bilgen, H. Takahashi Exergy analysis and experimental study of heat pump systems.(2002) 259-265,

[7] Recep Yumrutas,Exergy analysis of vapour compression refrigeration systems.(2002)266-272

[8] CE Vincent & MK Heun,Thermoeconomic analysis & design of domestic refrigeration systems.(2006)

[9] V.P Venkatarmanmurthy et al, experimental comparative energy, exergy flow and second low of efficiency analysis of R22,R436b on VCR system. Vol2(5),2010,1399-1416