Performance Studies on Vapour Compression Refrigeration System

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ABSTRACT

This paper presents the effects of refrigeration system parameters namely, evaporating temperature (T_{eva}), condensing temperature (T_{con}) and mass of the refrigerant charge used (m), on the performance of the system using theoretical models. The direct effect of the system variables on the performance was calculated and plotted graphically for the hydrocarbon refrigerants R290/R600, R290/R600a and LPG. The graphs plotted with the help of mathematical models provide satisfactory explanations about the effect of system variables on the performance of a vapour compression refrigeration system.

Keyword: Refrigeration System Parameters, Theoretical Models, Hydrocarbon Refrigerants

1. INTRODUCTION

Refrigerators are one of the major energy consuming appliances in household environment [1]. R134a is the most widely used refrigerant in domestic refrigerators, due to its good thermodynamic and thermophysical properties. In India, about 80% of the domestic refrigerators use R134a as refrigerant [2]. But its GWP (Global Warming Potential) effect is 1300. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) asked for reduction in emission of six categories of greenhouse gases, including R134a, used as refrigerant in domestic refrigerators to prevent global warming [3]. Therefore, according to Kyoto protocol the consumption of R134a must be seriously reduced [4]. Halogenated refrigerants used in vapor compression based refrigeration, air conditioning and heat pump systems cause greenhouse gas emissions which, in turn, contribute significantly to the global warming. One effective solution to reduce this type of greenhouse gas emissions is using environment friendly and energy efficient refrigerants [5].

It is reported that, there is no single refrigerant or mixture available to satisfy both the Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) issues. The use of mixtures of refrigerant has proved to be an excellent substitute for the menacing refrigerant R134a.

Theoretical modelling is one of the most widely accepted practices to study the performance of vapour compression refrigeration system with environmental friendly refrigerants. This paper deals with the theoretical study and prediction of performance of the vapour compression refrigeration system with R134a and the selected hydrocarbon refrigerants R290/R600, R290/R600a and LPG.

2. THEORETICAL STUDY

The theoretical model used to compare the performance of the refrigerants is based on a one stage simple vapour compression refrigeration cycle consisting of compressor, condenser, expansion device and evaporator. The schematic line diagram of the vapour compression refrigeration cycle and corresponding P-h diagram are shown in Figure 1.

In this theoretical vapour compression cycle, the refrigerant enters the compressor at state 1 at low pressure, low temperature and saturated vapour state. From state 1 to 2, the refrigerant is compressed by the compressor and is discharged at state 2 as high pressure, high temperature and superheated vapour refrigerant. At the superheated state 2, it enters the condenser and releases heat to the environment. The superheated refrigerant vapour is cooled to saturation temperature (state 2).During condensation the refrigerant temperature decreases for mixtures (gliding temperature effect) while it remains constant for pure refrigerants if pressure drop is not considered. The refrigerant leaves the condenser at state 3 at high pressure and saturated liquid state. From state 3, the refrigerant enters the expansion valve where its pressure is reduced in a throttling process from high pressure (condenser pressure) to low pressure (evaporator pressure). After this it enters the evaporator (state 4) where it absorbs heat from the conditioned space and it leaves the evaporator at low pressure, low temperature and saturated vapour state. During evaporation the refrigerant temperature increases for mixtures while it remains constant for pure refrigerants if pressure drop is not considered. In the theoretical cycle, it is also assumed that there is no superheating in the suction line, no sub cooling in the liquid line and no pressure drop throughout the cycle.

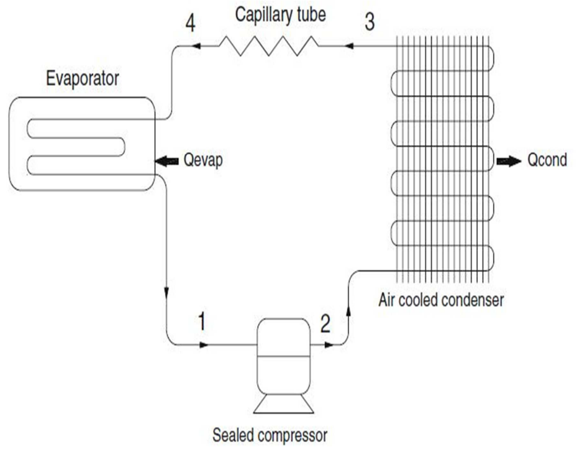

Fig.1 (a) Schematic Diagram of Vapour Compression refrigeration Cycle

It is also assumed that steady state and uniform flow conditions exist throughout the components of this simple vapour refrigeration cycle and changes in kinetic, potential energies and heat loss from the compressor are neglected. Therefore, specific compressor work w_{comp} can be written as

$$W_{comp} = h_2 - h_1$$

Where h_1 and h_2 are the specific enthalpies of refrigerant at the compressor inlet and exit respectively.

During the throttling process in the expansion valve, it is assumed that there is no heat transfer to the environment, which results in

$$h_3 = h_4$$

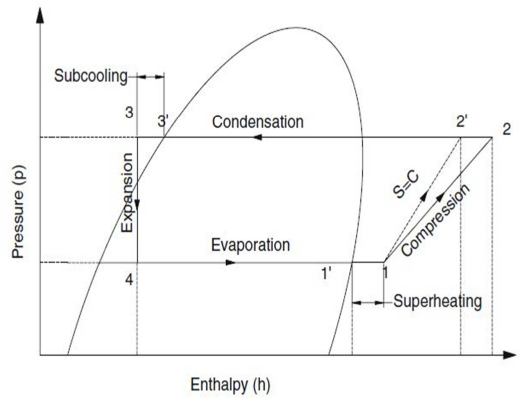

Fig.1 (b) Pressure – enthalpy (P-h) diagram of Vapour Compression refrigeration cycle.

The refrigerating effect of the cycle calculated from the rate of enthalpy change in the evaporator is

$$q_{ref} = (h_1 - h_4)$$

Where q_{ref} is the refrigerating effect of the refrigeration cycle. The coefficient of performance (COP) of the theoretical refrigeration cycle is then calculated by

$$COP_{th} = \frac{q_{ref}}{W_{comp}}$$

The parameters such as pressure ratio, refrigerating effect, compressor work and coefficient of performance are studied for the refrigerants R134a, R290/R600, R290/R600a and LPG.

3. STUDIES ON THE PERFORMANCE PARAMETERS

The system performance parameters such as pressure ratio, refrigerating effect, compressor work and coefficient of performance are calculated with evaporating temperature varying from 248 K to 288K and condensing temperature of 308 K using the following correlations.

1) Pressure ratio ,
   $PR = P_{con} / P_{eva}$
2) Refrigerating effect,
   $q_{ref} = h_1 - h_4$
3) Compressor work,
   $W_{comp} = h_2 - h_1$

4) Coefficient of performance, $COP_{th} = q_{ref} / W_{comp}$

3.1 Pressure Ratio

Figure 2 shows the variation of Pressure Ratio (PR) with varying evaporating temperature. The pressure ratio values of hydrocarbon (HC) refrigerant mixtures are lower than that of R134a. LPG mixture has the lowest pressure ratio values among the HC mixtures. At the rating conditions, the descending order of pressure ratios for the selected refrigerants are R134a, R290/R600a, R290/R600 and LPG.

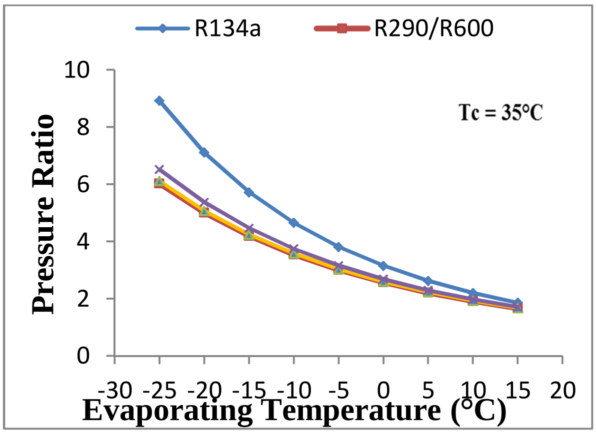

Fig.2 Variation of Pressure Ratio (PR) with varying Evaporating Temperature.

3.2 Refrigerating Effect

Figure 3 shows the variation of Refrigerating effect (RE) with varying evaporating temperature. From the figure it is observed that the hydrocarbon (HC) refrigerant mixtures have higher refrigerating effect than that of R134a. This is due to higher enthalpy values of the saturated vapour of HC mixtures with higher evaporating temperatures. The refrigerant mixtures R290/R600a, R290/R600 and LPG have higher refrigerating effect than that of R134a in the ascending order of refrigerating effect.

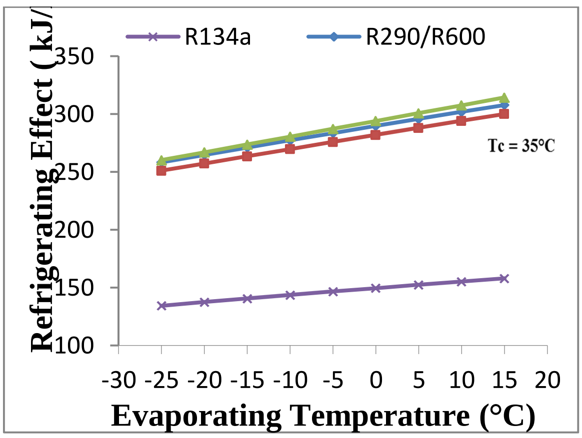

Fig.3 Variation of Refrigerating effect (RE) with varying Evaporating Temperature.

3.3 Compressor Work

Figure 4 shows the variation of compressor work with varying evaporating temperature. The compressor work of all the refrigerants increases, with decreasing evaporator temperature. This is due to constant entropy of refrigerants in the superheated region. All the hydrocarbon refrigerant mixtures require more compressor work than R134a. The descending order of compressor work for the selected refrigerant is R290/R600, R290/R600a and LPG.

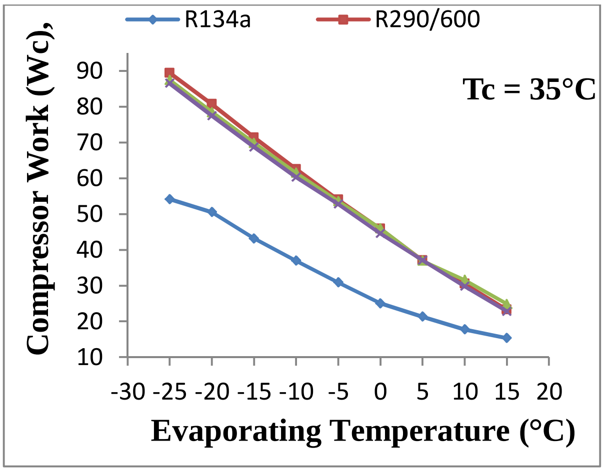

Fig.3 Variation of Compressor Work (W_C) with varying Evaporating Temperature

3.4 Coefficient of Performance

Figure 4.4 shows the Coefficient of Performance (COP) for R134a and selected hydrocarbon refrigerant mixtures for varying evaporating temperature. The COP of HC refrigerant mixtures is higher than that of R134a.LPG refrigerant has the highest COP. R290/R600a and R290/R600 has a higher COP than that of R134a for a range of temperatures taken for this study. The descending order of the selected refrigerants for COP is LPG, R290/R600 and R290/R600a

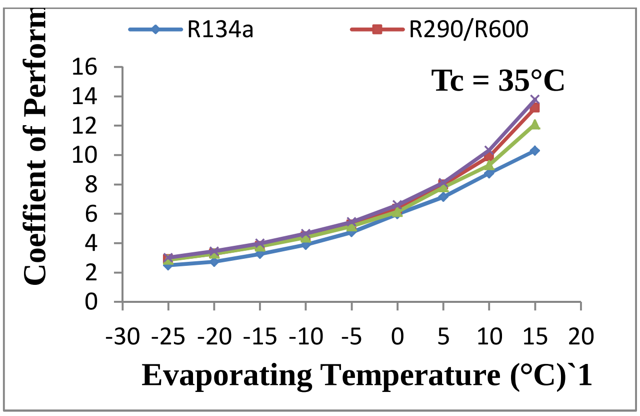

Fig.4 Variation of Coefficient of Performance (COP) with varying evaporating temperature

4. CONCLUSION

The characteristics and behavior of the selected hydrocarbon refrigerant mixtures are analyzed theoretically by considering various parameters like pressure ratio, refrigerating capacity, compressor work and COP. From the theoretical analysis the following conclusions are made:

1. The pressure ratios of the hydrocarbon mixtures are lower than that of R134a.
2. The refrigerating effect of the selected refrigerant mixtures of R290/R600, R290/R600a and LPG are higher than that of R134a.
3. The compressor work of all the selected HC refrigerant mixtures is higher than that of R134a. The compressor work of all the refrigerants increases with the decreasing evaporating temperature.
4. The coefficient of performance of the hydrocarbon mixtures is higher than that of R134a due to higher refrigerating capacity.
5. The hydrocarbon refrigerant mixtures of R290/R600, R290/R600a and LPG have been identified as suitable alternatives toR134a.

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