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# Evaluation of Vapour Compression Refrigeration System Using Different Refrigerants

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***Abstract*- The performance of heat transfer is one of the most important research areas in the field of thermal engineering. There are a large number of refrigerants, which are used to transfer heat from low temperature reservoir to high temperature reservoir by using vapour compression refrigeration system. There are various obstacles faced in working of different refrigerants due to their environmental impact (R11, R12), toxicity ($NH_3$), flammability (HC) and high pressure ($CO_2$); which makes them more hazardous than other working fluids according to safety and environmental issues. There experimental study was conducted to observe the performance of different environmental friendly refrigerant mixtures (HC mixture and R401a). It was also observed the effect of working parameters like diameter of capillary tube, working pressures and inlet water temperatures, which affect the coefficient of performance (COP) of vapour compression refrigeration system. It was observed that R134a is more efficient than HC mixture and R401a, but there is less mass quantity of HC mixture and R401a is required in the same system. So there is less effect in environment due to more mass of R134a.***

***Keywords*— Vapor compression refrigeration system, refrigerant, COP, ODP, GWP.**

## I. INTRODUCTION

Vapor compression refrigeration system is a system which is used to transfer heat from low temperature reservoir to high temperature reservoir with the help of working fluid, called refrigerant. There are different types of refrigerant, which were used as the working medium in vapour compression refrigeration system in the last few decades, but they cause of ozone layer depletion and green house effect.

### *A. Refrigeration system: working principle and construction*

Refrigeration system is based upon the Clausius statement of second law of thermodynamics. This statement shows, "It is impossible to construct a device which, operating in a cycle, will produce no affect other than the transfer of heat from a cooler to a hotter body. The construction of vapour compression refrigeration system is illustrated in figure 1. This system consists of four basic components, i.e. a compressor, an evaporator, a condenser and capillary tubes. Here the compressor delivery head, discharge line, condenser and liquid line form the high pressure side of the system. The expansion line, evaporator, suction line and compressor suction head form the low pressure side of the system. A drier is also installed in the liquid line which contains silica gel and absorbs traces of moisture presented in the liquid refrigerants so that it does not enter the narrow cross section of the expansion device causing moisture chocking by freezing.

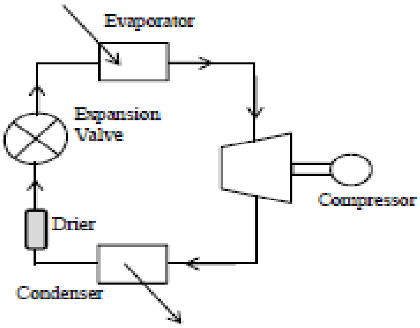


**Fig 1: Schematic of the Vapour Compression Refrigeration System.**

### *B. Processes Involved In Vapour Compression Refrigeration System:*

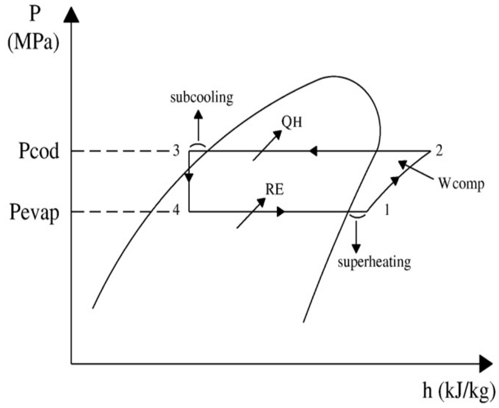


**Fig 2: Pressure-Enthalpy Graph for Vapour Compression Refrigeration System.**

Process 1 – 2: Isentropic compression in compressor.
Process 2 –3: Constant pressure heat rejection in condenser.
Process 3 – 4: Isenthalpic expansion in expansion device.
Process 4 – 1: Constant pressure heat absorption in evaporator.

### *C. Refrigerant:*

The working fluid used to transfer the heat from low temperature reservoir to high temperature reservoir is called refrigerant. There are different types of refrigerant which are described as followings.

*CFC:* They are molecules composed of carbon, chlorine and fluorine. They are stable, allowing them to reach the stratosphere without too many problems. It contributes to the destruction of the ozone layer. These are R11, R12, R113, R500, R502 etc.

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*HCFC*: They are molecules composed of carbon, chlorine, fluorine and hydrogen. They are less stable than CFCs, destroy ozone and to a lesser extent. These are R22, R123, R124, R401a etc.

*HFC:* They are molecules composed of carbon, fluorine and hydrogen. They do not contain chlorine and therefore do not participate in the destruction of the ozone layer. This is known as substitution substance. Restrictions on this family of gas are currently limited. Within the European Union, the HFC will be banned from air conditioners for cars from 2011.These are R134a.

*Mixture of refrigerants:*

They can be classified according to the type of fluorinated components they contain. They are also distinguished by the fact that some mixtures are:

- Zeotropic: in a state change (condensation, evaporation), the temperature varies. These are R404a, R407a and R410a etc.
- Azeotropes: they behave like pure, with no change in temperature during the change of state. These are R500, R502 and R507a etc.

*Ammonia ($NH_3$) or R717*

Fluid inorganic thermodynamically is an excellent refrigerant for evaporation temperatures between - 35 °C to 2 °C. But it is a fluid dangerous toxic and flammable, so it is generally used in industrial refrigeration.

*Hydrocarbons (HC) as R290, R600a*

This is primarily propane (R290), butane (R600) and isobutene (R600a). These fluids have good thermodynamic properties, but are dangerous because of their flammability. The world of the cold has always been wary of these fluids, even if they have reappeared recently in refrigerators and insulating foams. Their future use in air conditioning seems unlikely, given the cost of setting both mechanical and electrical safety.

*Carbon dioxide ($CO_2$) or R744*

This is inorganic, non-toxic, non flammable, but inefficient in thermodynamics. Its use would involve high pressure and special compressors. Currently, specialists in air conditioning and refrigeration are interested again by:

- Its low environmental impact (ODP = 0, GWP = 1);
- The low specific volume resulting in facilities with low volume (small leak);
- It has the distinction of having a low critical temperature at 31 °C at a pressure of 73.6 bars.

### D. *Mathematical Relations:*

a. Heat abstraction in evaporator -

$$Q_a = m_{ew} \times C_{pw} \times \Delta T_{ew}$$

b. Work input in compressor -

$W_{in}$ = Energy meter reading

Coefficient of performance-

$$COP = \frac{Q_a}{Win}$$

## II. LITERATURE REVIEW

James M. Calm [1], has studied the emission and environmental impacts of the different refrigerants (R11, R123, R134a) due to leakage from centrifugal chiller system. He also investigated the total impact in form of TEWI by analyzing the direct and indirect $CO_2$ emission equivalent due to leakage and energy consumption by the system. He studied the change in system efficiency or performance due to charge loss. He also summarized the methods to reduce the refrigerant losses by the system like design modifications, improvement in preventive maintenance techniques, use of purge system for refrigerant vapour recovery, servicing and lubricant changing in system. Samira Benhadid-Dib and Ahmed Benzaoui [2], have showed that the refrigerants are widely used in both industrial and domestic equipments. These fluids, which are banned due to their environmental toxicity, are expected to be replaced. Replacing them is a difficult task considering that the only solutions currently, called "natural" refrigerants, such as ammonia, hydrocarbons and $CO_2$. The disadvantages of these products are mainly toxicity ($NH_3$), flammability (HC) and high pressures ($CO_2$). However, with least skills and observance with safety rules, they do not finally prove to be more dangerous than other fluids. They proposed as a contribution to the protection of our environment. Samira Benhadid-Dib and Ahmed Benzaoui [3], have showed that the uses of halogenated refrigerants are harmful for environment and the use of "natural" refrigerants become a possible solution. Here natural refrigerants are used as an alternative solution to replace halogenated refrigerants. The solution to the environmental impacts of refrigerant gases by a gas which contains no chlorine no fluorine and does not reject any $CO_2$ emissions in the atmosphere. The researchers showed that emissions have bad effects on our environment. They also concerned by a contribution to the reduction of greenhouse gases and by the replacement of the polluting cooling fluids (HCFC). Eric Granryd [4], has enlisted the different hydrocarbons as working medium in refrigeration system. He studied the different safety standards related to these refrigerants. He showed the properties of hydrocarbons (i.e. no ODP and negligible GWP) that make them interesting refrigerating alternatives for energy efficient and environmentally friendly. But safety precautions due to flammability must be seriously taken into account. Y. S. Lee and C. C. Su [5], have studied the performance of domestic vapour compression refrigeration system with isobutene (R600a) as refrigerant and compare the results with R12 and R22. They used R600a about 150 g and set the refrigeration temperature about 4 °C and -10 °C to maintain the situation of cold storage and freezing applications. They used 0.7 mm internal diameter and 4 to 4.5 m length of capillary tube for cold storage applications and 0.6 mm internal diameter and 4.5 to 5 m length of capillary tube for freezing applications. They observed that the COP lies between 1.2 and 4.5 in cold storage applications and between 0.8 and 3.5 in freezing applications. They also observed that the system with two capillary tubes in parallel performs better in the cold storage

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and air conditioning applications, whereas that with a single tube is suitable in the freezing applications. R. Cabello, E. Torrella and J. Navarro-Esbri [6], have analyzed the performance of a vapour compression refrigeration system using three different working fluids (R134a, R407c and R22). The operating variables are the evaporating pressure, condensing pressure and degree of superheating at the compressor inlet. They analyzed that the power consumption decreases when compression ratio increases with R22 than using the other working fluids. Mao-Gang He, Tie-Chen Li, Zhi-Gang Liu and Ying Zhang [7], have analyzed that the R152a/R125 mixture in the composition of 0.85 mass fraction of R152a has a similar refrigeration performance with the existing refrigerant R12. Experimental research on the main refrigeration performances of domestic refrigerators was conducted, under the different proportions and charge amounts, when R152a/R125 is used to substitute R12 as a ‘‘drop-in’’ refrigerant. The experimental results indicate that R152a/R125 can be used to replace R12 as a new generation refrigerant of domestic refrigerators, because of its well environmentally acceptable properties and its favorable refrigeration performances. Ki-Jung Park, Taebeom Seo and Dongsoo Jung [8], have analyzed performances of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a, and dimethylether were measured to substitute for R22 in residential air-conditioners and heat pumps at the evaporation and condensation temperatures of 7 °C and 45 °C, respectively. Test results show that the coefficient of performance of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had a similar capacity to that of R22. For these fluids, compressor-discharge temperatures were reduced by 11–17 °C. For all fluids tested, the amount of charge was reduced by up to 55% as compared to R22. Overall, these fluids provide good performances with reasonable energy savings without any environmental problem and thus can be used as long-term alternatives for residential air-conditioning and heat-pumping applications. Ki-Jung Park and Dongsoo Jung [9], have analyzed thermodynamic performance of two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a, and dimethylether (R170) was measured in an attempt to substitute R22 in residential air-conditioners. The pure and mixed refrigerants tested have GWP of 3–58 as compared to that of $CO_2$ at the evaporation and condensation temperatures of 7 and 45 °C, respectively. Test results show that the COP of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had the similar capacity to that of R22. Compressor discharge temperatures were reduced by 11–17 °C with these fluids. There was no problem found with mineral oil since the mixtures were mainly composed of hydrocarbons. The amount of charge was reduced up to 55% as compared to R22. K. Mani and V. Selladurai [10], have analyzed a vapour compression refrigeration system with the new R290/R600a refrigerant mixture as drop-in replacement was conducted and compared with R12 and R134a. The vapour compression refrigeration system was initially designed to operate with R12.The results showed that the refrigerant R134a showed slightly lower COP than R12. The discharge temperature and discharge pressure of the R290/R600a mixture was very close to R12. The R290/R600a (68/32 by wt %) mixture can be considered as a drop-in replacement refrigerant for R12 and R134a. A.S. Dalkilic and S. Wong wises [11], have studied the performance on a vapour compression refrigeration system with refrigerant mixtures based on R134a, R152a, R32, R290, R1270, R600 and R600a was done for various ratios and their results are compared with R12, R22 and R134a as possible alternative replacements. The results showed that all of the alternative refrigerants investigated in the analysis have a slightly lower COP than R12, R22, and R134a for the condensation temperature of 50 °C and evaporating temperatures ranging between −30 °C and 10 °C. Refrigerant blends of R290/R600a (40/60 by wt. %) instead of R12 and R290/R1270 (20/80 by wt. %) instead of R22 are found to be replacement refrigerants among other alternatives. Vincenzo La Rocca and Giuseppe Panno [12], have analyzed and compared the performance of a vapour compression refrigerating unit operating with R22, and with three new HFC fluids, substituting the former according to Regulation No 2037/2000. Here the plant working efficiency was first tested with R22 and then with three new HFC fluids: R417a, R422a and R422d. It is analyzed that the performance with the new tested fluids did not result as efficient as when using R22.

## III. LIMITATIONS FOR USE OF REFRIGERANTS

Some refrigerants are expelled due to their environmental impact, are expected to be replaced. Replacing them is a difficult task considering that the only solutions currently available are the so-called "natural" refrigerants, such as ammonia, hydrocarbons and $CO_2$. The disadvantages of these products are mainly toxicity ($NH_3$), flammability (HC) and high pressures ($CO_2$). Some refrigerants are banned due to their high ozone depletion potential (ODP) and global warming potential (GWP), these are followings.

- Production of R11 was halted by the clean air act on January 1, 1996.
- Production of R12 was halted by the clean air act on January 1, 1996.
- Production of R113 was halted by the clean air act on January 1, 1996.
- Production of R500 was halted by the clean air act on January 1, 1996.
- Refrigerant R134a is a commercially available hydro fluorocarbon (HFC) refrigerant long-term replacement for R12 in new equipment and for retrofitting medium temperature CFC.

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## IV. FACTORS AFFECTING THE PERFORMANCE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

The following factors affect the performance of vapour compression refrigeration system.

- Properties of working fluid.
- Amount of charge filled and system pressure.
- Diameter of capillary tubes.
- Inlet water temperature.

## V. EXPERIMENTAL SETUP OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

The main loop of the system under study was composed of five basic components, i.e., a compressor, an evaporator, a condenser, capillary tubes and a liquid line filter–drier, as shown in Fig. 3. A three-phase, 220 V, reciprocating compressor originally designed for R134a systems was used. The input power of the compressor within the system varied between 230 and 300 W. The major ingredient of the compressor lubricant was mineral oils. A silica gel drier filter was used to absorb the moisture. Compact forced air cooled type condenser was used for their good heat transfer performances. Capillary tubes of different internal diameters were used to find the optimum operating points of the system. Evaporator section was made by shell and tube type by copper tubes and stainless steel tank. For minimizing the heat loss, the evaporator tank was well insulated by puff. The refrigerants used were R134a, HC mixture (R290+R600a) and R401a. Some other measuring and controlling components were used in the system, that were, an electrical switch, an energy meter, a voltmeter, an ampere meter, a digital thermostat for controlling the evaporator temperature, bourdon tube type low pressure gauge and high pressure gauge, 'J' type thermocouples and indicator and gas flow control valves.

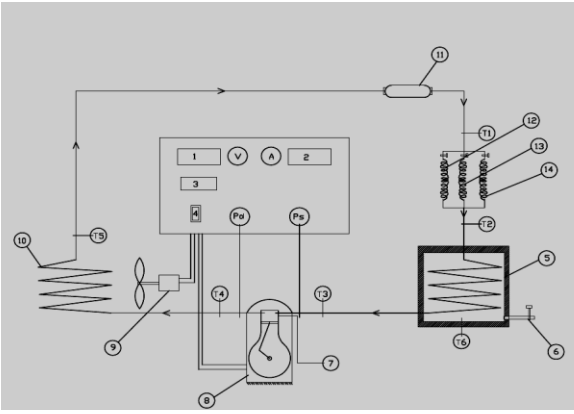

**Fig 3: Schematic Diagram of Experimental Setup.**

**Table 1: Description of Setup Components**

| Notation | Component | Description |
|---|---|---|
| V | Voltmeter | Range 0-300 v |
| A | Ampere meter | Range 0-10 A |
| $P_d$ | Discharge pressure gauge | Range 0-300 Lb/in$^2$ |
| $P_s$ | Suction pressure gauge | Range 0-150 Lb/in$^2$ |
| $T_x$ | Thermocouple | 'J' Type and 'T' type thermocouple |
| 1 | Energy meter | Electronic, range 0-20 A |
| 2 | Temperature indicator | 'J' Type, Range 0-750°C (iron–constantan) |
| 3 | Thermostat | Digital controller |
| 4 | Switch | 15 A switch |
| 5 | Evaporator tank | Inner stainless steel tank insulated by puff |
| 6 | Water drainage Valve | Brass Valve |
| 7 | Gas charging line | 1/4 inch diameter line with brass valve |
| 8 | Compressor | KCE444HAG, Hermatically sealed, Reciprocating type |
| 9 | Condenser fan motor | 1/83 HP |
| 10 | Condenser | 10 inch * 11 inch * 3 row |
| 11 | Filter drier | DM 50 type containing silica gel |
| 12 | Expansion Device | Capillary tube of ID 0.036 inch |
| 13 | Expansion Device | Capillary tube of ID 0.040 inch |
| 14 | Expansion Device | Capillary tube of ID 0.050 inch |

## VI. EXPERIMENTAL PROCEDURE

The objective of the study was to compare the refrigeration performance of different refrigerants in terms of COP. 'J' and 'T' type thermocouples were used to measure the temperatures and pressures were measured using calibrated pressure gauges. The thermocouples were located in the pockets on the surface of the tubes and sensor was calibrated to reduce experimental uncertainties. The ranges of equipment used in the experimental test setup are showed in Table 1. The temperatures and pressures of the refrigerant and initial water temperatures were measured at various locations in the experimental setup as shown in Fig. 3. The compressor energy consumption was measured using an energy meter. Three manual type expansion devices were used to regulate the mass flow rate of refrigerant and to set pressure difference. The refrigerant was charged after the system had been evacuated. The working fluids were R134a, R290/R600a (50/50 by wt %) and R401a. The refrigerant R290/R600a is a zeotropic blend, which is charged in the liquid phase due to its composition shift and temperature glide. Drop-in experiments were carried out without any modifications to the experimental apparatus. The experiment was started with R134a to set up the base reference for further comparisons with the other two refrigerants. The thermal load of the system was changed with an external electrically heated unit.

## VII. RESULTS AND DISCUSSION

The experimental results obtained from the performance analysis of R134a, HC mixture (R290/R600A) and R401a are discussed with respect to COP. Figure 4, 5 and 6 shows the experimental results of the parameters affecting the COP of system. At initial refrigerant pressure 70 lb/in$^2$ in the system,

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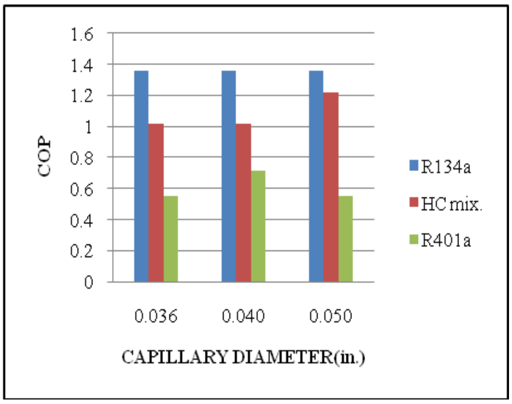
figure 4, (a, b and c) indicates that COP of R134a is more than other two refrigerants at 23°C and 30°C initial water temperature. Figure 4 also shows that HC mixture having approximately same performance as R134a at 0.050 inch capillary diameter. At other refrigerant pressure 75 lb/in$^2$ in the system, figure 5, (a, b and c) indicates that COP of R134a is approximately same as HC mixture but more than R401a at all initial water temperature and capillary diameter conditions. Figure 5 also shows that HC mixture having approximately same performance as R134a at all temperature and capillary diameter conditions. At last refrigerant pressure 80 lb/in$^2$ in the system, figure 6, (a, b and c) indicates that COP of HC mixture is greater than R134a and R401a. By all graphs it is indicated that generally R134a has more performance than other two refrigerants but HC mixture shows better performance at capillary diameter 0.050 inch.The COP of R401a is very much less than others.

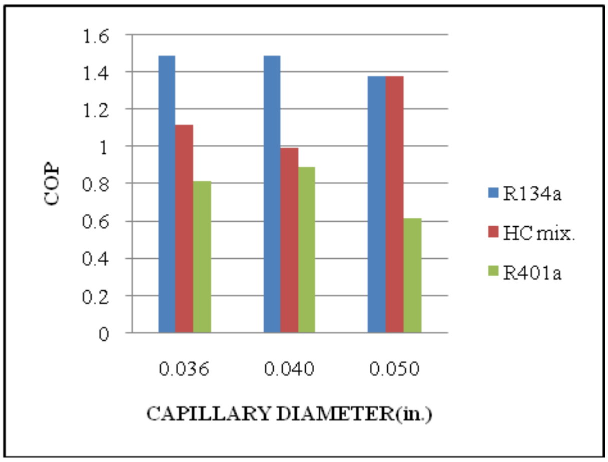
1. Capillary diameter v/s COP at pressure 70 lb/in$^2$

**a. Inlet water temperature- 23°C**



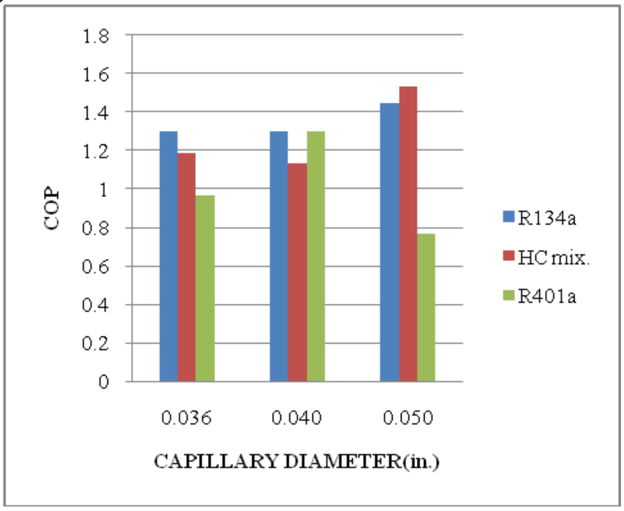

(a)

**b. Inlet water temperature- 30°C**




(b)

**c. Inlet water temperature- 40°C**

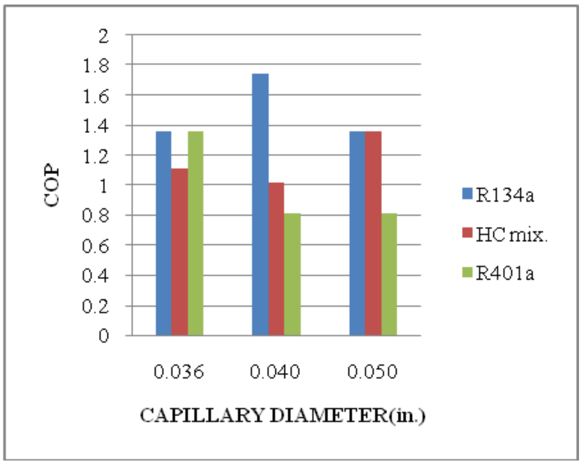



(c)

**Fig 4: COP at pressure 70 lb/in$^2$.**

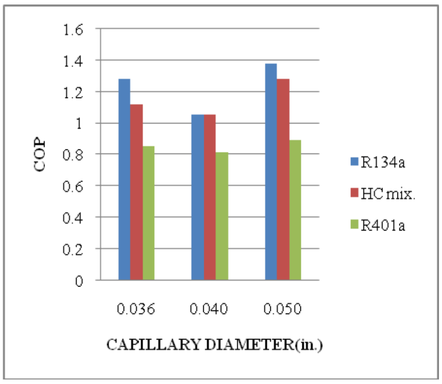
2. Capillary diameter v/s COP at pressure 75 lb/in$^2$

**a. Inlet water temperature- 23°C**




(a)

**b. Inlet water temperature- 30°C**




(b)

**c. Inlet water temperature- 40°C**

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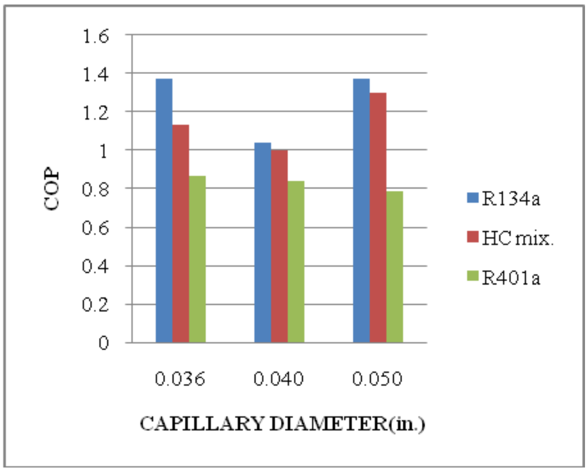
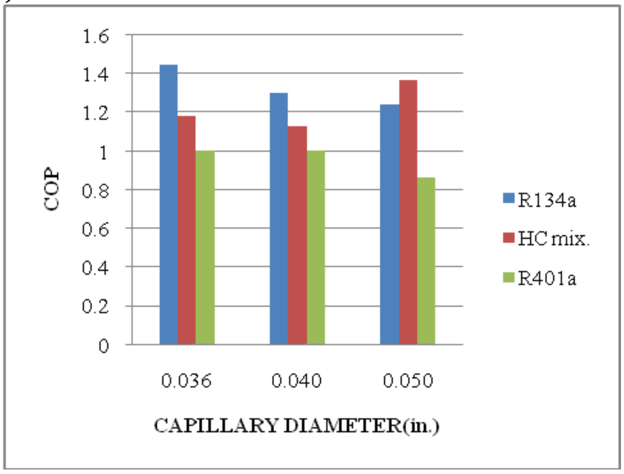



(c)

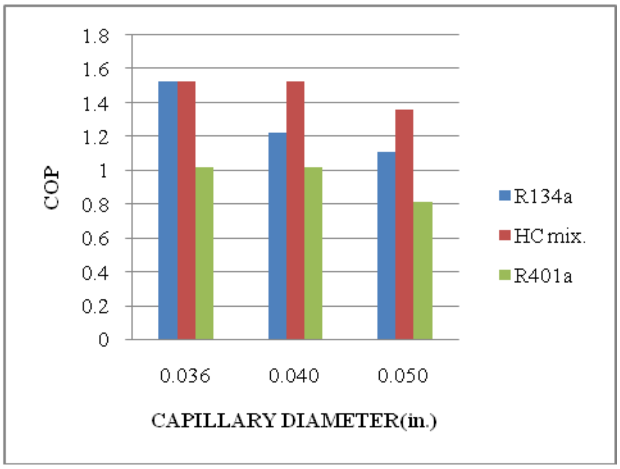
**Fig 5: COP at pressure 75 lb/in$^2$.**




(c)

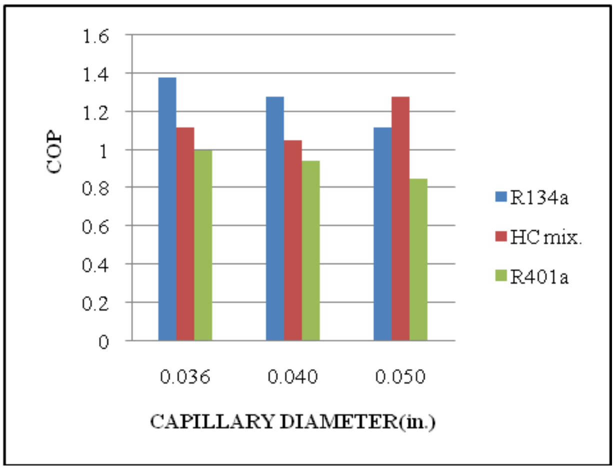
**Fig 6: COP At Pressure 80 Lb/In$^2$.**

3. Capillary diameter v/s COP at pressure 80 lb/in$^2$
   a. Inlet water temperature- 23°C




(a)

**b. Inlet water temperature- 30°C**




(b)

**c. Inlet water temperature- 40°C**

## VIII. CONCLUSION

Performance analysis on a vapour compression refrigeration system with the new refrigerant blend as substitute for R134a was made and the following conclusions were drawn.

- COP of HC mixture (R290/R600a) was higher than other two refrigerants at all working pressure and inlet water temperature at capillary diameter 0.050 inch. So it can be used as working medium in air conditioning system.
- COP of R401a is always lower than other two refrigerants, so it is not efficient in use in general purpose.

During the experimental test HC mixture was found to be safe. However care should be taken when using HC mixture in a vapour compression refrigeration system. From the two major environmental impact (ozone layer depletion and global warming) point of view this HC mixture (R290/R600a) can be used as a drop-in replacement refrigerant for R134a.

## IX. NOMENCLATURE

| Symbol | Meaning |
|---|---|
| COP | Coefficient of performance |
| GWP | Global warming potential |
| ODP | Ozone depletion potential |
| GHG | Green house gas |
| TEWI | Total equivalent warming impact |
| CFC | Chlorofluorocarbon |
| HCFC | Hydro Chlorofluorocarbon |
| HFC | Hydrofluorocarbon |
| HC mixture | 50% of R290 and 50% of R600a |
| R11 | Trichlorofluoromethane |
| R12 | Dichlorodifluoromethane |
| R22 | Monochlorodifluoromethane |
| R32 | Methylene Fluoride |
| R125 | Pentafluoroethane |
| R134a | Tetrafluoroethane |
| R152a | Difluoroethane |
| R290 | Propane |

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| | |
|---|---|
| R401a | 53% of R22, 34% of R124a and 13% of R152a |
| R407c | 23% of R32, 25% of R125 and 52% of R134a |
| R410a | 50% of R32 and 50% of R125 |
| R600 | Butane |
| R600a | Isobutane |
| R717 | Ammonia |
| R744 | Carbon Dioxide |
| R1270 | Propylene |
| $m_{ew}$ | Mass of water in evaporator (Kg) |
| $\Delta T_{ew}$ | Temperature difference in evaporator water (K ) |
| $C_{pw}$ | Specific heat of water (KJ/Kg.K) |
| ID | Inner diameter |

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