Analysis of vapor compression refrigeration system employing tetrafluoroethane and difluoroethane as refrigerants

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Abstract: The axiomatic effects of ozone layer depletion have caused additional damage in the last few decades. The accretion in greenhouse gases has transformed to take cardinal steps immediately. The concoct blend of 1,1,1,2 Tetrafluoroethane (R134a) and 1,1, Difluoroethane (R152a) was tested in a vapour compression refrigeration system as these are non-toxic, eco-friendly, non-flammable and non-corrosive. Experimental performance analysis of vapor compression refrigeration system using R134a and blends of R152a and R134a is done for different dimensions of expansion valves. Various parameters like coefficient of performance (COP), refrigerating effect and compressor work were analyzed. Refrigeration effect and compressor work of R134a was higher than R152a. COP value was reliable for 60/40 ratio of R152a and R134a and maximum COP was achieved with the blend of 90/10 ratio in the first expansive coil. These aberrant results could be overcome by amalgamation of R134a and R152a as the discharge temperature of R152a is effectively controlled by blending.

Keywords – Alternative Refrigerants, Eco-friendly Refrigerants, COP, Compressor work, discharge temperature.

1. INTRODUCTION:

Refrigeration is a process of extracting heat from a space to be cooled in controlled conditions. The test was carried out in vapor-compression machine consisting of the compressor, condenser, capillary tube device, and evaporator. Out of all these components of the system the compressor is the only moving part in the system and its functions is to raise the pressure of the vapor refrigerant coming from the evaporator, high enough so that the temperature of the leaving gas is higher than that of the condensing medium. Hence, the same refrigerant can be liquefied back and expanded to the evaporator suction conditions in a cycle. This work was done to Investigate the performance characteristics of R134a and blends of R152a and R134a in a vapor compression refrigeration system with various sizes of expansion coils and to find which vapor compression refrigeration system serves best in terms of non-toxic, eco-friendly, non-flammable and non-corrosive. From the previous work it was found that the experiment was carried only on R134a and R152a where, R134a has a global warming potential (GWP) of 1300 whereas, R152a has a significant reduced value of GWP of 140 only, but R152a is not as efficient as R134a. So, blends of R152a and R134a with (60/40) and (90/10) proportions are considered to find out which refrigeration serves better in terms of refrigeration effect, compressor work, COP and low GWP.
2. EXPERIMENTAL DETAILS:

2.1 PROPERTIES OF REFRIGERANT:

R134a also known as 1,1,1,2-Tetrafluoroethane. It is a halo-alkane refrigerant with thermodynamic properties similar to R-12(dichlorodifluoromethane) but with insignificant ozone depletion potential, where R152a is known as 1,1-Difluoroethane. This colorless gas is used as a refrigerant, where it is often listed as R152a (refrigerant-152a). As an alternative to chlorofluorocarbons, it has an ozone layer depletion potential of zero, and a shorter atmospheric lifetime (1.4 years). It has recently been approved for use in automobile applications as an alternative to R-134a.

Table 1. Properties of Refrigerants

| Properties                          | R134a | R152a |
|-------------------------------------|-------|-------|
| Molecular Weight (kg/kmol)          | 102.0 | 66    |
| Boiling Point at 1.013 bar (°C)     | –26.1 | -25   |
| Critical Temperature (°C)           | 101.1 | 72.07 |
| Critical Pressure (bar)             | 40.6  | 37.32 |
| Critical Density (kg/m³)            | 515   | 485   |
| Critical Volume (m³/kg)             | 1.94 x 10⁻³ | 2.06 x 10⁻³ |
| Density Liquid (kg/m³)              | 1208  | 1045  |
| Density Saturated Vapor (kg/m³)     | 32.609 | 64.033 |
| Heat of Vaporization (kJ/kg)        | 175.5 | 143.68 |
| Specific Heat Capacity (Liquid) (kJ/kgK) | 1.423 | 1.64  |
| Specific Heat Capacity (Vapor) (kJ/kgK) | 0.876 | 1.03  |

2.2 METHODOLOGY:

The experimental setup comprises of a reciprocating compressor, 60 liters of closed cabinet, a stainless-steel container of 16.5 liter’s inside the cabinet to store water as shown in fig 1, evaporator coil, condenser with fan, expansion coil of various dimensions as shown in table 2, energy meter, two pressure gauges, one after evaporator and another after condenser, five thermocouples attached to digital display device for recording temperature at every stage of the system.

Table 2. Expansion Coil Specifications

| COILS | INTERNAL DIAMETER (mm) | COIL DIAMETER (mm) | AXIAL PITCH (mm) | LENGTH (mm) |
|-------|------------------------|-------------------|------------------|-------------|
| Coil 1 | 0.5                    | 6.5               | 2                | 135         |
| Coil 2 | 0.36                   | 6.5               | 2                | 135         |
The single stage VCRS system was run on R134a for 15 minutes and five readings of temperature and pressure were taken and tabulated at a regular interval of 15 minutes. Time taken for five revolutions of energy meter disc is noted down after particular intervals to determine the compressor work. The temperature drop of water is noted to calculate the refrigerating effect.

The energy meter reading is used to find out the compressor work and thus COP is calculated from these two values. After completion of the experiment the system is switched off and the water in the container is replaced with fresh water at room temperature. The above procedure is then repeated for all the expansion valves in turn and with different coil size.

At the end of experiment analysis of R134a, the system was recharged with blend of R152a and R134a (in 90/10 ratio) and R152a and R134a (in 60/40 ratio) as shown in fig 2. A technician was called to assist with the recharging process. The R134a refrigerant was evacuated using a vacuum pump and a release valve. The blend was filled in the liquid state to prevent any change in the composition of refrigerant as it is an azeotropic blend. The container was held in inverted state while filling the refrigerant as it was in liquid state. Finally, the values for both the refrigerants were tabulated and the inferences was drawn to compare the results.
The refrigerating effect is given by the relation,

\[ \text{RE} = \frac{mC_p(\Delta T)}{t} \text{ (kW)} \]  

(1)

where \( m \) is the mass of water in tank in kg, \( C_p \) is specific heat of water in kJ/kgK, \( \Delta T \) is the change in temperature of water in °C and \( t \) is the time interval in seconds.

Compressor work is given by

\[ \text{W}_c = \frac{n \times 3600}{\text{Ec} \times t_c} \text{ (kW)} \]  

(2)

where \( n \) is the no. of revolutions and \( \text{Ec} \) is the energy meter constant and \( t_c \) is the time taken for ‘n’ revolution in seconds.

The coefficient of performance can be estimated from the relation,

\[ \text{COP} = \frac{E}{\text{W}_c} \]  

(3)

3. RESULTS AND DISCUSSION:

The values have been tabulated and inference has been drawn for R134a and blends of R152a and R134a with the proportion (60/40) for expansion coil 1&2.

3.1 Refrigerant R134a:

| T1 | T2 | T3 | T4 | P1 | P2 | Time for 5 revolutions of energy meter disc | Mass of water | Initial temperature of water | Final temperature of water | CP | Time of refrigeration effect | Compressor work | Actual COP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | (°C) | (°C) | bar | bar | s | (kJ/kgK) | (s) | (kW) | (kW) |
| 12.3 | 30.7 | 36.6 | 12.4 | 15.17 | 22.0 | 6 | 40.9 | 16.57 | 31.1 | 25 | 4.187 | 900 | 0.470 | 0.366 | 1.28 |
| 11 | 49.7 | 36.4 | 11.3 | 15.17 | 20.6 | 8 | 42.5 | 16.57 | 31.1 | 21.7 | 4.187 | 1800 | 0.362 | 0.352 | 1.02 |
| 9.3 | 47.5 | 36.1 | 10 | 5.17 | 19.3 | 45 | 45 | 16.57 | 31.1 | 18.6 | 4.187 | 2700 | 0.321 | 0.333 | 0.96 |
| 7.9 | 46.6 | 35.5 | 8.4 | 4.27 | 18.9 | 6 | 46.6 | 16.57 | 31.1 | 15.4 | 4.187 | 3600 | 0.302 | 0.321 | 0.93 |
Table 4. Readings of expansion coil-2 (R134a)

| T1  | T2  | T3  | T4  | P1  | P2  | Time for 5 revolutions of energy disc | Mass of water | Initial temperature of water | Final temperature of water | CP | Time of run | Refrigeration effect | Compressor work | Actual COP |
|-----|-----|-----|-----|-----|-----|---------------------------------------|---------------|-----------------------------|----------------------------|----|-------------|---------------------|---------------|-----------|
| °C  | °C  | °C  | °C  | bar | bar |                                      | (kg)          | (°C)                        | (°C)                      | (kJ/kgK) | (s)         | (kW)                | (kW)          |           |
| 13.7 | 49.8 | 39.9 | 14.3 | 5.51 | 20.6 | 8                                      | 40.6          | 16.57                       | 29.3                      | 23.4 | 4.187       | 900                 | 0.457         | 0.369     | 1.23     |
| 12.6 | 49.3 | 39.4 | 13.4 | 5.51 | 20.6 | 8                                      | 42.3          | 16.57                       | 29.3                      | 19.9 | 4.187       | 1800                | 0.362         | 0.354     | 1.02     |
| 11.1 | 48   | 39.3 | 11.9 | 4.82 | 6   | 19.6                                   | 44.6          | 16.57                       | 29.3                      | 17.6 | 4.187       | 2700                | 0.300         | 0.336     | 0.89     |
| 10   | 47.2 | 38.7 | 10.9 | 4.82 | 6   | 19.3                                   | 46.9          | 16.57                       | 29.3                      | 15.1 | 4.187       | 3600                | 0.273         | 0.319     | 0.85     |

Table 3 and Table 4 represents the readings of expansion coil 1&2 for refrigerant R134a at various temperature and pressure, the refrigeration effect, compressor work and Actual COP is found.

Figure 3. (R134a) Expansion coil 1&2 Vs Refrigeration effect, Compressor work & COP

The figure 3 indicate the variation of various parameters such as refrigeration effect, compressor work & cop for different expansion coil with respect to time for R134a based on VCRS. From the graph it is found that the expansion coil 1 having larger diameter than coil 2 gave the maximum efficiency considering all the parameters.
3.2 Refrigerant R152a (60/40):
Here refrigerant R152a is considered with proportion 60:40 where 60% of R152a and 40% of R134a is considered and the refrigerator is run and the values are tabulated.

Table 5. Readings of expansion coil-1 (R152a (60/40))

| T₁ | T₂ | T₃ | T₄ | P₁ | P₂ | Time for 5 revolutions of energy meter disc | Mass of water | Initial temperature of water | Final temperature of water | Cₚ | Time of run | Refrigeration effect | Compressor work | Actual COP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | (°C) | (°C) | bar | bar | (s) | (kg) | (°C) | (°C) | (kJ/kgK) | (s) | (kW) | (kW) |
| 17.9 | 44.6 | 35.9 | 18.7 | 3.79 | 12.06 | 60 | 16.57 | 31.1 | 25.7 | 4.187 | 900 | 0.416 | 0.250 | 1.66 |
| 16.8 | 43.8 | 35.5 | 18 | 3.79 | 11.72 | 63 | 16.57 | 31.1 | 23.6 | 4.187 | 1800 | 0.289 | 0.238 | 1.21 |
| 15.8 | 43 | 35.9 | 17 | 3.79 | 11.03 | 70 | 16.57 | 31.1 | 21.5 | 4.187 | 2700 | 0.246 | 0.214 | 1.15 |
| 15.2 | 42.4 | 35.9 | 16.2 | 3.79 | 10.61 | 72 | 16.57 | 31.1 | 19.7 | 4.187 | 3600 | 0.219 | 0.208 | 1.05 |

Table 6. Readings of expansion coil-2 (R152a (60/40))

| T₁ | T₂ | T₃ | T₄ | P₁ | P₂ | Time for 5 revolutions of energy meter disc | Mass of water | Initial temperature of water | Final temperature of water | Cₚ | Time of run | Refrigeration effect | Compressor work | Actual COP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | (°C) | (°C) | bar | bar | (s) | (kg) | (°C) | (°C) | (kJ/kgK) | (s) | (kW) | (kW) |
| 17.4 | 43.2 | 37.3 | 18.7 | 3.58 | 10.68 | 68 | 16.57 | 29 | 25.3 | 4.187 | 900 | 0.285 | 0.220 | 1.29 |
| 16.6 | 42 | 37.3 | 18.2 | 3.79 | 10.68 | 72 | 16.57 | 29 | 22.9 | 4.187 | 1800 | 0.235 | 0.208 | 1.12 |
| 15.9 | 41 | 37.2 | 17.2 | 3.79 | 10.68 | 74 | 16.57 | 29 | 20.9 | 4.187 | 2700 | 0.208 | 0.202 | 1.02 |
| 15.3 | 41 | 37.7 | 16.7 | 3.86 | 10.82 | 86 | 16.57 | 29 | 19.4 | 4.187 | 3600 | 0.184 | 0.174 | 1.06 |

Table 5 and Table 6 represents the readings of expansion coil 1&2 for refrigerant R152a (60/40) at various temperature and pressure, the refrigeration effect, compressor work and Actual cop is found.
Figure 4. (R152a (60/40)) Expansion coil 1&2 Vs Refrigeration effect, Compressor work & COP

The figure 4 indicate the variation of various parameters such as refrigeration effect, compressor work & COP for different expansion coil with respect to time for R152a (60/40) based on VCRS. From the graph it is found that the expansion coil 1 having larger diameter than coil 2 gave the maximum efficiency considering all the parameters.

3.3 Refrigerant R152a (90/10):

Here refrigerant R152a is considered with proportion 90:10 where 90% of R152a and 10% of R134a is considered and the refrigerator is run and the values are tabulated.

Table 7. Readings of expansion coil-1 (R152a (90/10))

| T₁  | T₂  | T₃  | T₄  | P₁  | P₂  | Time for 5 revolutions of energy meter disc (s) | Mass of water (kg) | Initial temperature of water (°C) | Final temperature of water (°C) | Cᵢ | Time of run (s) | Refrigeration effect (kJ/kgK) | Compressor work (kW) | Actual COP |
|-----|-----|-----|-----|-----|-----|----------------------------------------------|-------------------|-----------------------------------|-----------------------------------|----|----------------|-------------------------------|----------------------|------------|
| 22.5 | 44.4 | 35.2 | 23.4 | 10.48 | 22.4 | 58.1                                           | 16.57             | 31.1                              | 24.4                             | 4.187 | 900            | 0.516                         | 0.258                | 2.00       |
| 21.4 | 45.3 | 35.1 | 22.9 | 12.06 | 25.85 | 59.1                                           | 16.57             | 31.1                              | 23.3                             | 4.187 | 1800           | 0.300                         | 0.253                | 1.18       |
| 20.1 | 43.8 | 34.8 | 22  | 12.06 | 25.85 | 61                                             | 16.57             | 31.1                              | 22.5                             | 4.187 | 2700           | 0.220                         | 0.245                | 0.89       |
| 20.1 | 46.9 | 33.7 | 21.8 | 12.41 | 25.85 | 62                                             | 16.57             | 31.1                              | 21.6                             | 4.187 | 3600           | 0.183                         | 0.241                | 0.75       |

Figure 5. (R152a (90/10)) Expansion coil 1&2 Vs Refrigeration effect, Compressor work & COP
Table 8. Readings of expansion coil-2 (R152a (90/10))

| T1 (°C) | T2 (°C) | T3 (°C) | T4 (°C) | P1 (bar) | P2 (bar) | Time for 5 revolutions of energy meter disc (s) | Mass of water (kg) | Initial temperature of water (°C) | Final temperature of water (°C) | C_P (°C) | Time of run (s) | Refrigeration effect (kW) | Compressor work (kW) | Actual COP |
|---------|---------|---------|---------|----------|----------|-----------------------------------------------|-------------------|-----------------------------------|-----------------------------------|---------|----------------|--------------------------|----------------------|-----------|
| 21.3    | 43.2    | 37.2    | 22.9    | 10.48    | 25.85    | 59.2                                          | 16.57             | 31.6                              | 26.6                              | 4.187   | 900            | 0.385                    | 0.253                | 1.52      |
| 20.9    | 42.6    | 37.1    | 22.4    | 10.48    | 25.85    | 60.8                                          | 16.57             | 31.6                              | 25.1                              | 4.187   | 1800          | 0.250                    | 0.246                | 1.01      |
| 20.1    | 43.6    | 35.9    | 21.5    | 10.61    | 26.2     | 61.6                                          | 16.57             | 31.6                              | 23.4                              | 4.187   | 2700          | 0.210                    | 0.243                | 0.86      |
| 19.8    | 44.2    | 31.8    | 21.1    | 10.61    | 26.2     | 62.5                                          | 16.57             | 31.6                              | 22.1                              | 4.187   | 3600          | 0.183                    | 0.240                | 0.76      |

Table 7 and Table 8 represents the readings of expansion coil 1 & 2 for refrigerant R152a (90/10) at various temperature and pressure, the refrigeration effect, compressor work and Actual cop is found. The figure 5 indicate the variation of various parameters such as refrigeration effect, compressor work & cop for different expansion coil with respect to time for R152a (90/10) based on VCRS. From the graph it is found that the expansion coil 1 having larger diameter than coil 2 gave the maximum efficiency considering all the parameters.

4. CONCLUSION

This study investigated the performance of different expansion coil geometries in a vapour compression refrigeration system having R134a and R152a blends as the refrigerants. The experiment work were conducted on two expansion coils of different dimensions and the following conclusions are drawn:

- The expansion coil 1 having internal diameter 0.5 mm gave the maximum COP as well as refrigerating effect for both the refrigerants. In the expansion coil 2 having an internal diameter of 0.36mm, the COP was observed to decrease where the internal diameter was reduced keeping other dimensions constant. Hence it can be concluded that to obtain maximum COP the internal diameter of the expansion coil should be greater.
- From the graph plotted it is found that the refrigerating effect of R134a was better than R152a but the compressor work of R134a is greater, such that the overall COP decreases as compared to the blends of R152a and R134a.
- The evaporator temperature of blend (R152a and R134a) is greater than pure R134a, so greater the evaporator temperature lesser work is needed by the compressor to increase its temperature and pressure which results in higher COP.
- Pressure ratio of R134a is found to be greater than blend of R152a and R134a, so blend is better in terms of pressure ratio since low pressure ratio leads to high volumetric efficiency and lower power consumption.
- Heat rejection from condenser is greater for R134a compared to other two blends.
- COP at specific time intervals is far more consistent for 60/40 ratio of R152a and R134a compared to 90/10 ratio of the above two refrigerants but maximum COP is obtained for 90/10 ratio in first expansion coil.
- From various comparisons of parameters carried out between the two refrigerants R134a and R152a blends it can be concluded that R152a (60/40) is a better choice of refrigerant because it has the lowest GWP compared with other two refrigerant and can be used for lower temperature applications and where high cooling rate is required whereas R134a is a better option for medium temperature applications and where higher performance is desired.
- Hence from the above inferences we can conclude that if the discharge temperature of R152a is effectively controlled which here is done by blending with R134a then R152a as a blend can be used in domestic refrigerators for better performance.
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