Experimental investigation on VCRS by using R-134a and R-410a of air and evaporative cooled condenser

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Abstract. In this study, experimental research is carried out on two different class of refrigerants at three varied ambient conditions viz. (30°C, 35°C and 40°C) and three different air velocities viz. (1.25, 1.00, 0.75 m/s) in air cooled and evaporative cooled condenser. The first class is of low temperature refrigerant (R-134a) and the second is of high temperature refrigerant (R-410a). The results described that COP of high temperature refrigerant is greater than that of low temperature refrigerant. The COP increased with increasing air speed in air cooled and evaporative cooled condenser and decreased with increasing the ambient temperatures. For a fixed ambient temperature and air velocity, the COP of R-410a turned out to be greater than the COP of R-134a. Thus proving that high temperature refrigerant is better in performance than low temperature refrigerant.

1. Introduction

Refrigeration is a process of maintaining temperatures lower than that of surroundings that is attained by removing the heat from the space to be cooled. It is a mechanism to take out the heat liberated from a region at a lesser temperature to space at a greater temperature with input of few work. Among all refrigeration systems the vapour compression refrigeration system (VCRS) from viewpoint of commercial and household utility, is the most effective form owing to its high value of COP and low maintenance as compared to another form of refrigeration (VARS) [1,2].

Wang and Hihara[3] proposed an Equivalent DBT technique to analyze the cooling and dehumidification performance of refrigeration and air conditioning systems. This method could predict the fully dry, wet and little wet cooling modes. The simulation model was validated by experimental data and the deviation was found to be within 10%. Riffat & Shankland [4] conducted the experiments and developed a method to analyse the mass flow coefficient for the flow of refrigerants R22, R410a and R407c through EEVs of different separate geometries consists of copper material. By choosing the parameters such as EEV (outlet conditions, inlet conditions and head geometry), refrigerant properties and using Buckingham pi Theorem, the correlations for the refrigerant mass flow coefficient (CD) for EEV was predicted. The behaviour of EEVs with different half tapers and inside diameter arrangements for R22 and its alternatives R407c and R410a were experimentally determined. R410a showed highest flow coefficient (CD) 30 for given temperatures of condenser mainly due to its greater saturation pressure as compare to other fluids. Zhang et al. [5] developed a dimensionless correlation using experimental data to analyse flow rate of mass of R22 and its alternative R407C with the help of an EEV. The mass flow rate was detected at various temperatures of condenser and evaporator and degree of subcooling at the EEV entry. By analyzing the experimental data, this was reported that operating conditions, area of flow and thermophysical properties of refrigerant affected the flow rate of mass with the help of EEV. The predicted correlations through the Buckingham pi Theorem were used to analyse flow rate of mass through EEV.
whose highest flow area was less than 2.544 mm$^2$. Y Kim et al. [6] determined the in-tube evaporation heat transfer features of R-410a and examined them as a function of the temperature of evaporator, geometry of tube, heat and mass flux. Experimental results described that coefficients of evaporation of heat transfer improved with mass flux and heat flux for all tubes tested. C Park et al. [7] described mass flow features of R22 and R410a through EEVs. They showed that the flow rates of mass passing through EEVs increased with the increase in EEV opening, inlet pressure and sub-cooling. R Cabello et al. [8] carried out experimental tests on a single-stage vapour compression refrigeration system using three different working fluids R134a, R22 and R407c. They analyzed the refrigerating capacity and concluded that flow rate of mass evolution becomes most influencing on behaviour of refrigerating capacity. Considering the consumption of electrical power and working with R22, it showed more decrease with increasing compression ratios as compare to other working fluids. A lower value of COP was obtained by using R22 as compare to R407c. V Havelsky [9] presented experimental investigations on the effect of refrigerants R409a, R22, R134a, R401a and a mixture of R12 with R134a on values of COP and TEWI in comparison to that of R12. It was found that use of R401a, R134a and R409a refrigerants increases COP and then notably reduced the value of the TEWI in comparison to that of R12.

In the current work, we are trying to evaluate the performance of VCRS by using R-134a and R-410a by varying ambient temperatures and air velocities in air cooled and evaporative cooled condenser. Our main objective is to reduce the power consumption by finding optimal air speed that gives higher COP. The performance of the VCRS has also been analyzed by keeping the fixed ambient temperature and varying the air velocity. Hence to obtain the optimal cooling effect at higher ambient temperatures, power consumption will be increased. Moderate ambient temperatures and higher air speed are the most favourable conditions for improving the COP of the VCRS.

2. Experimental setup

![Figure 1. VCRS system (R-410a)](image1)

![Figure 2. VCRS system (R-134a)](image2)
Figure 1 and 2 shows the experimental set-up of an VCRS system using R-410a and R-134a refrigerants respectively. It consists of four major components viz. compressor, condenser, throttling device and evaporator. The system executes a VCR cycle. The vapour at low temperature and pressure enters into the compressor side where the working fluid (refrigerant) is compressed isentropically and subsequently its pressure and temperature increases. The vapour going out of the compressor then enters the condenser side where it is condensed into high pressure liquid form. External work is done on the compressor (known as compressor work) and it is one of the factors affecting the COP. From condenser it goes to the expansion valve where it is throttled down to a lower temperature and pressure. Through expansion valve it lastly enters into evaporator where it takes out the heat from surrounding to be cooled. Evaporator is most important part as the refrigeration effect is obtained here which is one of the fundamental parameters in determining the COP of a system.

INSTRUMENTS USED

- Hygrometer is used for measuring air humidity.
- Blower is used to maintain air flow rate.
- Anemometer is used for measuring the velocity of air.
- Temperature sensing device is used for measuring temperatures.
- Pressure gauges are used for measuring the pressure at different points.

FORMULAE USED

- Compressor work \( (W_c) = V*I = m_{ref}*(h_2-h_1) \)
- Refrigeration effect generated \( (Q_r) = m_{ref}*(h_1-h_4) \)
- Coefficient of performance \( = Q_r / W_c \)

Here,
- \( h_1 \) = Enthalpy at entry point of compressor in kJ/kg.
- \( h_2 \) = Enthalpy at exit point of compressor in kJ/kg.
- \( h_4 \) = Enthalpy at entry point of evaporator in kJ/kg.
- \( m_{ref} \) = mass flow rate of refrigerant (R-410a and R-134a).

3. Experimental data and results

The experiment is performed once with using R-134a and then R-410a refrigerant by varying three ambient temperatures i.e (30°C, 35°C and 40°C) and by varying three different air flow rates i.e (1.25, 1.00, 0.75 m/s) in air cooled condenser and the evaporative cooled condenser.

Table (1-6) shows experimental readings and results using R-134a refrigerant.
Table 1. The following experimental readings are obtained for R-134a using air cooled condenser after steady state condition is achieved at 30°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 132        | 138        | 142        |
| Evaporator pressure (psi)   | 13         | 14         | 15         |
| Condenser inlet temp(°C)    | 60         | 64         | 67         |
| Condenser exit temp(°C)     | 40         | 42         | 43.5       |
| Evaporator inlet temp(°C)   | -6         | -4         | -3         |
| Evaporator outlet temp(°C)  | 24         | 26.5       | 28.5       |
| COP                         | 2.09       | 2.06       | 2.03       |

Table 2. The following experimental data is obtained for R-134a using air cooled condenser after steady state condition is achieved at 35°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 143        | 146        | 150        |
| Evaporator pressure (psi)   | 14         | 15         | 16.5       |
| Condenser inlet temp(°C)    | 68         | 74         | 76.5       |
| Condenser exit temp(°C)     | 49.5       | 53         | 54.5       |
| Evaporator inlet temp(°C)   | -4.5       | -3.0       | -2         |
| Evaporator outlet temp(°C)  | 28         | 29.5       | 33         |
| COP                         | 1.96       | 1.88       | 1.84       |

Table 3. The following experimental data is obtained for R-134a using air cooled condenser after steady state condition is achieved at 40°C for different air flow velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 152        | 155.5      | 160        |
| Evaporator pressure (psi)   | 15.5       | 16         | 17.5       |
| Condenser inlet temp(°C)    | 76.5       | 81         | 83         |
| Condenser exit temp(°C)     | 60         | 62         | 64.5       |
| Evaporator inlet temp(°C)   | -3         | -2         | -1         |
| Evaporator outlet temp(°C)  | 33         | 34.5       | 36         |
| COP                         | 1.85       | 1.82       | 1.80       |

Table 4. The following experimental data is obtained for R-134a using evaporative cooled condenser after steady state condition is achieved at 30°C for different air flow velocities.
Table 5. The following experimental data is obtained for R-134a using evaporative cooled condenser after steady state condition is achieved at 35°C for different air flow rates.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 116        | 121        | 124        |
| Evaporator pressure (psi)   | 9.5        | 11         | 11.5       |
| Condenser inlet temp(°C)    | 53         | 57         | 61         |
| Condenser exit temp(°C)     | 35         | 36.5       | 37.5       |
| Evaporator inlet temp(°C)   | -10        | -9.5       | -8.5       |
| Evaporator outlet temp(°C)  | 18         | 21         | 22.5       |
| COP                         | 2.23       | 2.19       | 2.15       |

Table 6. The following experimental data is obtained for R-134a using evaporative cooled condenser after steady state condition is achieved at 40°C for different air flow rates.

| Parameters                      | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|---------------------------------|------------|------------|------------|
| Condenser pressure (psi)        | 123        | 130        | 134        |
| Evaporator pressure (psi)       | 10.5       | 11.5       | 12.5       |
| Condenser inlet temp(°C)        | 63         | 68         | 71         |
| Condenser exit temp(°C)         | 42         | 45.5       | 48         |
| Evaporator inlet temp(°C)       | -9         | -8.5       | -7         |
| Evaporator outlet temp(°C)      | 22         | 23.5       | 25         |
| COP                             | 2.04       | 2.01       | 1.99       |

Table (7-12) shows the experimental data and results using R-410a refrigerant.
Table 7. The following experimental data is obtained for R-410a using air cooled condenser after steady state condition is achieved at 30°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 215        | 260        | 300        |
| Evaporator pressure (psi)   | 62         | 65         | 70         |
| Condenser inlet temp(°C)    | 53         | 58         | 63         |
| Condenser exit temp(°C)     | 38         | 44         | 48         |
| Evaporator inlet temp(°C)   | 2          | 4          | 6          |
| Evaporator outlet temp(°C)  | 6          | 9          | 11         |
| COP                         | 3.19       | 2.92       | 2.63       |

Table 8. The following experimental data is obtained for R-410a using air cooled condenser after steady state condition is achieved at 35°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 220        | 266        | 310        |
| Evaporator pressure (psi)   | 65         | 71         | 75         |
| Condenser inlet temp(°C)    | 55         | 60         | 66         |
| Condenser exit temp(°C)     | 40         | 45         | 50         |
| Evaporator inlet temp(°C)   | 3          | 5          | 7          |
| Evaporator outlet temp(°C)  | 7          | 10         | 12         |
| COP                         | 3.01       | 2.75       | 2.30       |

Table 9. The following experimental data is obtained for R-410a using air cooled condenser after steady state condition is achieved at 40°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 235        | 275        | 320        |
| Evaporator pressure (psi)   | 70         | 76         | 80         |
| Condenser inlet temp(°C)    | 62         | 67         | 70         |
| Condenser exit temp(°C)     | 46         | 51         | 56         |
| Evaporator inlet temp(°C)   | 4          | 6          | 8          |
| Evaporator outlet temp(°C)  | 8          | 11         | 13         |
| COP                         | 2.80       | 2.5        | 2.01       |

Table 10. The following experimental data is obtained for R-410a using evaporative cooled condenser after steady state condition is achieved at 30°C for different air velocities.
Table 11. The following experimental data is obtained for R-410a using evaporative cooled condenser after steady state condition is achieved at 35°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 170        | 200        | 230        |
| Evaporator pressure (psi)   | 55         | 60         | 65         |
| Condenser inlet temp(°C)    | 47         | 52         | 57         |
| Condenser exit temp(°C)     | 32         | 36         | 41         |
| Evaporator inlet temp(°C)   | -1         | 2          | 4          |
| Evaporator outlet temp(°C)  | 4          | 7          | 9          |
| COP                         | 3.51       | 3.23       | 2.91       |

Table 12. The following experimental data is obtained for R-410a using evaporative cooled condenser after steady state condition is achieved at 40°C for different air velocities.

| Parameters                  | (1.25 m/s) | (1.00 m/s) | (0.75 m/s) |
|-----------------------------|------------|------------|------------|
| Condenser pressure (psi)    | 175        | 215        | 240        |
| Evaporator pressure (psi)   | 60         | 65         | 70         |
| Condenser inlet temp(°C)    | 50         | 56         | 63         |
| Condenser exit temp(°C)     | 35         | 40         | 45         |
| Evaporator inlet temp(°C)   | 1          | 3          | 5          |
| Evaporator outlet temp(°C)  | 5          | 8          | 10         |
| COP                         | 3.30       | 3.00       | 2.60       |

4. Graphs and discussion

4.1 Effect of varying ambient temperature on COP at fixed air velocity
For both air and evaporative cooled condenser COP of the system continuously decreases with increase in temperature as shown in figures (3-5). But the COP is greater for evaporatively cooled condenser as compare to air cooled condenser. This is due the reason, evaporative cooling reduces temperature at exit side of condenser and therefore enhances the refrigeration effect at evaporator, thus more refrigeration effect is obtained and at the evaporator it also increases the heat transfer rate.

**Figure 3.** Variation of COP with the ambient temperature at fixed air velocity (0.75 m/s)

![Figure 3](image-url)

**Figure 4.** Variation of COP with the ambient temperature at fixed air velocity (1.00 m/s)

![Figure 4](image-url)
Figure 5. Variation of COP with ambient temperature at fixed air velocity (1.25 m/s)

4.2 Effect of varying ambient temperature on COP at different air velocities

Figure 6. Variation of COP with ambient temperature at different air velocities
Figures (6,7) shows variation of COP with the ambient temperatures at different air velocities for the air cooled and evaporative cooled condenser. In both cases, the COP is decreasing as the temperature increases. This is due to reason that as the ambient temperature increases compressor work is increased which ultimately decreases COP. With the increase in temperature, experimental tests proved that the performance of evaporatively cooled condenser is increased significantly as compared to the air-cooled condenser. It was also noted that the increasing ambient temperature decreases COP of air-cooled condenser considerably but it has fewer adverse effect on the performance of evaporatively cooled condenser.

5. Conclusion

A Vapour Compression Refrigeration System (VCRS) is experimentally investigated using R-134a and R-410a refrigerants. There is a noticeable change in COP of the VCRS when we vary the air flow rates using air cooled and evaporative cooled condenser and then the ambient conditions. On comparing the COP of R-410a and R-134a at the same air flow rate and same ambient temperature, the COP of R-410a was greater than that of R-134a. The COP was high at air flow rate (1.25 m/s) for both the refrigerants. For both of these refrigerants, the COP was less at the low air flow rate (0.75 m/s) and increases with increment in flow rate of air. The performance of both the refrigerants was better at lower ambient temperature of 30°C. The performance of both refrigerants was also better for evaporative cooled condenser as compare to air cooled condenser. The COP increases with an increment in flow rate of air and decreases as ambient temperatures increases. The performance of the high temperature refrigerants was better than low temperature refrigerants. We further conclude that refrigerant R-410a is better than R-134a.
References

[1] Ansari, A. A., Goyal, V., Yahya, S. M., & Hussain, T. 2018 Experimental investigation for performance enhancement of a vapor compression refrigeration system by employing several types of water-cooled condenser Science and Technology for the Built Environment 24(7) 793-802.
[2] Ansari, A. A., Khan, F., Chaturvedi, P., Goyal, V., Raj, A., & Hussain, T. 2018 Theoretical and Experimental Performance Evaluation of Vapour Compression Refrigeration System Using Organic and Inorganic Pads in Evaporative Cooled Condenser Advanced Science, Engineering and Medicine 10(3) 374-378.
[3] Wang, J., & Hihara, E. 2003 Prediction of air coil performance under partially wet and totally wet cooling conditions using equivalent dry-bulb temperature method International Journal of Refrigeration 26(3) 293-301.
[4] Riffat, S. B., & Shankland, N. J. 1993 Comparison of R 134a and R 12 refrigerants in a vapour-compression system International journal of energy research 17(5) 439-442.
[5] Zhang, C., Ma, S., Chen, J., & Chen, Z. 2006 Experimental analysis of R22 and R407c flow through electronic expansion valve Energy Conversion and Management 47(5) 529-544.
[6] Kim, Y., Seo, K., & Chung, J. T. 2002 Evaporation heat transfer characteristics of R-410A in 7 and 9.52 mm smooth/micro-fin tubes International journal of refrigeration 25(6) 716-730.
[7] Park, C., Cho, H., Lee, Y., & Kim, Y. 2007 Mass flow characteristics and empirical modeling of R22 and R410A flowing through electronic expansion valves International Journal of Refrigeration 30(8) 1401-1407.
[8] Cabello, R., Torrella, E., & Navarro-Esbri, J. 2004 Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids Applied thermal engineering 24(13) 1905-1917.
[9] Havelský, V. 2000 Investigation of refrigerating system with R12 refrigerant replacements Applied Thermal Engineering 20(2) 133-140.