Performance Consideration and Result Analysis Using Various Alternative Refrigerants in a Vapour-Compression Refrigeration System

R P Dhivakar Raviram¹*, D Vijayaganapathy¹, V Dhinakaran²

¹Department of Mechanical Engineering, Chennai Institute of Technology, Chennai, Tamilnadu, India.
²Centre for Applied Research, Department of Mechanical Engineering, Chennai Institute of Technology, Chennai, Tamilnadu, India.

* Corresponding author: 9494dhivakar@gmail.com

Abstract. The performance consideration of various refrigerants such as R22, R134a, R410a and R290 are considered and the various properties of the refrigerant are considered. The experiments are conducted in Vapour compression refrigeration system based AC test rig with the selected refrigerants. The power consumption is calculated with no loads and various load conditions such as 100W, 200W, 300W & 400W are monitored and recorded and the graph is plotted to attain the selection of refrigerant. The theoretical and actual COP is calculated using the standard formula and it is plotted with various load conditions. The selection of refrigerants R22 is selected based on the results.

1. Introduction
Refrigeration may be characterised as the process of, under controlled conditions, removing heat from a product. It also requires the process of reducing and sustaining a body's temperature below its environment’s temperature. In other words, cooling implies the continuous extraction of heat from a body whose temperature is already below its surrounding temperature. It is also commonly used to cool storage chambers where perishable foods, beverages and medicinal products are processed. Of all other types of cooling systems, the Vapour Compression Refrigeration System is widely used.

1.1. Desirable Properties of an Ideal Refrigerant
The important and desirable properties of suitable refrigerant are,

- Low boiling and freezing point.
- High critical pressure and temperature.
- High thermal conductivity.
- Non-corrosive to the material of construction of the flow circuit and related components.
- Ozone friendly

2. Literature review
Shubham Srivastava et al (2015) have reported that the refrigerant the environment is also influenced by CFC very quickly. In order to prevent such damage, it is therefore important to work on these systems. Therefore, a lot of research has recently been found to develop those structures that have the least impact on the environment and humanity, but work very efficiently for the same reason. Radhouane Ben Jemaa et al (2016) conducted energy and energy studies with an alternative working fluid R1234ze to R134a for an air-cooled vapour compression chilled water. Using the Engineering
Equation Solver (EES), a thermodynamic model was created. No major variations were found between the energy & exergy efficiencies for both refrigerants. The compressor, accompanied by the condenser, the expansion valve and the evaporator, posed the highest energy destruction among the components. In order to be lower than R134a, the irreversibility obtained in the unit using R1234ze was obtained. R1234ze has been found in the VCCW systems to be a good alternative to R134a. The high efficiency 2-stage vapour compression cycles have been recorded by Mina Yang et al (2015); these were designed for the application of the domestic refrigerator-freezer. The freezing load ratio (RQ- F 1/4 Q- F = Q- total) was found to be the most significant parameter for performance improvement. The degree of sub-cooling by the heat exchanger (DTsub 1/4 T2-T3) was also found to have the most important impact on total m. However, some difficulties in operating the newly established cycle have occurred, such as challenging individual evaporator operations. "This research therefore suggested an innovative new cycle with parallel and without the separator linked evaporators, which was referred to as the" two-circuit evaporating sub cooler cycle. Finally, it was concluded that the (R / F) 1/4 (R152a / R600a) refrigerant pair is the best candidate for the two-circuit evaporating sub-cooler cycle with the highest COP of 3.758. [3].

The linear compressors were designed on the basis of a free piston system by Jong Kwon Kim et al (2011), which required stroke controllers because the movement of the piston is responsive to ambient temperature. A novel design method for an inherent power modulated linear compressor using R600a for use in household refrigerators was described in this paper. The compressor was able to independently modulate its power, and this feature ensured stable and efficient operation without stroke requirements. In accordance with the cooling demand heterogeneity, the electrical parameters were configured to offer inherent power modulation. To create the effective resonance system, the mechanical parameters were tuned. A numerical model was developed and a compressor prototype was designed. The prototype compressor has been tested over a condensing temperature range of between 15 and 50 °C, corresponding to an ambient temperature range of between 5 and 43 °C. The simulation results showed that the cooling power was implicitly modulated over the ambient temperature range from 55 to 90 percent, and the inherent modulation was verified by the experiment to be 70 to 90 percent. Initially, the vapour compression refrigeration method was designed to work with R12. Experimental findings showed that the coolant R290 / R600a had 19.9% to 50.1% higher cooling power compared to R12 and 28.6% to 87.2% compared to R134a. The coolant R134a displayed a significantly lower cooling power than that of R12. 6.8% to 17.4% more energy than R12 was absorbed by the R290 / R600a mixture. At lower evaporating temperatures, the coefficient efficiency of the R290 / R600a mixture increases from 3.9 percent to 25.1 percent compared to R12 and 11.8 percent to 17.6 percent at higher evaporating temperatures. The system's cooling performance has also been investigated.[4].

3. Problem Identification

It is observed from the review of the available literature that the following knowledge gaps are identified. The earlier works have been done on the theoretical and experimental performance of a vapour compression system with different types of refrigerant and its mixture used in several refrigeration applications. In this work it is planned to establish vapour compression refrigeration system (VCRS) based air conditioning test setup and the same is to be tested with different refrigerants and its mixture to study the performance of the VCRS based air conditioning system.
4. Experimental Setup
It is observed that in earlier days most of the domestic air conditioners are working on vapour compression refrigeration system (VCRS) with R22 as conventional refrigerant. Presently the R22 is replaced with R134a for the upcoming VCRS based air conditioning systems. Hence in this work, a VCRS based air conditioning test rig is tested for its performance with four different alternate refrigerants. As a first step a VCRS based air conditioning test rig is fabricated with proper instrumentation facility to observe necessary data.

4.1. VCRS based air conditioning test rig
The VCRS based air conditioner test rig is equipped with 0.8 TR vapour compression system. The photographic view of VCRS based air conditioner test setup is shown in Figure 1.1. The VCRS based Air Conditioning Test Rig includes compressor, evaporator, condenser, expansion valve and control cooling chamber. The test setup is used to test the performance of the VCRS based Air Conditioner system working with different alternate refrigerants.

4.2. Control Cooling Chamber
A closed control cooling chamber is fabricated by using wood (for frame) and plywood (for walls). It is thermal coated with thermocol sheets. The cooling chamber is made for 58x58x58 inch size. The photographic view of the Control Cooling Chamber is shown in Figure 1.2.
5. Selection of Refrigerants

A refrigerant is a heat transfer medium in the vapour compression-based air conditioning system. In this work, various alternate refrigerants such as R22, R134a, R410a and R290 are used for the VCRS based Air Conditioning test rig for testing its performance.

5.1. HCFC Refrigerant (R22)

HCFC-22, or R-22, is best known as this colourless gas. It is widely used as a propellant and refrigerant. Due to its comparatively low ozone depletion potential (ODP) of 0.055, R-22 is reliable as an alternative to extremely ozone-depleting CFC-11 and CFC-12. R-22 is a vibrant greenhouse gas with a GWP equal to 1810 as an additional environmental risk (indicating 1810 times as powerful as carbon dioxide).

5.2. Zeotropic Refrigerant Mixture (R410)

The zeotropic mixtures, however similar to the azeotropic mixture of Di Fluoro Methane (CH2F2 called R-32) and Penta Fluoro Ethane R-125, R410A were sold under the brand names Suva 410A, Forane 410A, Puron, EcoFluor R410, Genetron R410A and AZ-20. It has the components CH2F2 (50 percent) and CHF2CF3 (50 percent) at atmospheric pressure with a boiling point of −48.5 °C.

5.3. HC Refrigerant (R290)

Natural gas processing and petroleum refining is the place were propane is made. In traditional stationary refrigeration and air conditioning systems, propane has a negligible ODP and very low GWP (having a value of 3.3 times the GWP of CO2) and can act as a practical substitute for R-12, R-22, R-134a and other CFC or HFC refrigerants. At air pressure, it has a −42.06 °C boiling point.

6. Measurement of Basic Parameters

In this project, the performance of the VCRS based Air Conditioning Test Rig with different refrigerants is being evaluated at various load conditions. After running the VCRS based air conditioning test setup for 10 minutes, the temperature and pressure at various points such as compressor inlet etc. and the energy consumption are observed & recorded for the calculation of various other performance parameters including COP.

To measure the temperature at the required points such as compressor inlet etc. the thermocouples are used. The temperature indicator is used to display the readings. Pressure is measured by using the pressure gauges, which are fixed at required points. The energy consumption readings are also measured by using energy meter. These readings are observed and recorded.

The above process is followed to observe, record and tabulate the parameters by running the VCRS based air conditioning test rig at no load and various loading (100W, 200W, 300W, and 400W) conditions. For loading, the lamps with different wattages (100W, 200W, 300W, and 400W) are being used by switching ON the corresponding lamps during testing.

By switching ON the lamps (100W, 200W, 300W and 400W) fitted inside the cooling chamber and running it for 60 minutes, the cooling chamber temperature has been noted before and after running the air conditioning setup for 10 minutes at each load conditions. The temperature and pressure readings at various points have been noted. The energy meter reading is also been noted.
By following the same procedure, the necessary parameters are observed, predicted and recorded corresponding to all the load conditions (100W, 200W, 300W and 400W). The similar experimental procedure has been followed to predict the power consumption and theoretical & actual COP of the VCRS based Air Conditioning Test Rig with all the refrigerants R22, R134a, R410a and R 290.

7. Results and Discussion

The experiments are conducted on the VCRS based Air Conditioning Test Rig with various alternate refrigerants. The performance was calculated with no load and various load conditions (100W, 200W, 300W &400W) and the obtained results are tabulated. The results are presented and discussed in this section.

| Table 1. Power Consumption for Different Refrigerant |
|---|---|---|---|---|
| Refrigerant | Power Consumption (W) |
|   | R134a | R22 | R290 | R410a |
| No load | 0.397 | 0.525 | 0.377 | 0.507 |
| 100W | 0.397 | 0.525 | 0.377 | 0.507 |
| 200W | 0.397 | 0.525 | 0.377 | 0.507 |
| 300W | 0.397 | 0.525 | 0.377 | 0.507 |
| 400W | 0.397 | 0.525 | 0.377 | 0.507 |

| Table 2. COP$_T$ of VCRS based Air Conditioning Test Rig |
|---|---|---|---|---|
| Refrigerant | COP$_T$ |
| R134a | R22 | R290 | R410a |
| No load | 1.43 | 1.75 | 1.38 | 1.38 |
| 100 W | 1.67 | 1.75 | 1.25 | 1.5 |
| 200 W | 1.6 | 1.75 | 1.21 | 1.57 |
| 300 W | 1.8 | 1.75 | 1.24 | 1.44 |
| 400 W | 1.6 | 1.75 | 1.41 | 1.63 |

| Table 3. COP$_A$ of VCRS based Air Conditioning Test Rig |
|---|---|---|---|---|
| Refrigerant | COP$_A$ |
| R134a | R22 | R290 | R410a |
| No load | 1.078 | 1.5 | 1.035 | 1.024 |
| 100 W | 1.078 | 1.59 | 1.002 | 1.024 |
| 200 W | 1.078 | 1.63 | 1.067 | 1.035 |
| 300 W | 1.34 | 1.68 | 1.089 | 1.056 |
| 400 W | 1.26 | 1.72 | 1.153 | 1.132 |
8. Discussion on the Results

Figure 1.3 shows the Power Consumption of VCRS based Air Conditioning Test Rig with various refrigerants at no-load condition and different load conditions (100W, 200W, 300W and 400W). However, R22 has the higher power consumption, whereas R290 has a low power consumption. These trends of variation are due to the amount of refrigerant charge used by the system (more for R22 & less for R290). Figure 1.4 shows the COP_T of VCRS based Air Conditioning Test Rig with various refrigerants at no-load condition & different load (100W, 200W, 300W and 400W) conditions. Figure 1.5 shows the COP_A of VCRS based Air Conditioning Test Rig with various different alternate refrigerants at no-load condition and different load condition (100W, 200W, 300W and 400W). The changes in COPA with load are in the increasing trend upon the increase of load for all the alternate refrigerants considered in this study. However the COPA for the R22 seems to be higher than that of other refrigerants considered.

![Figure 4. Power Consumptions of Refrigerants](image)

![Figure 5. Theoretical COP of VCRS based Air Conditioning Test Rig](image)
Figure 6. Actual COP of VCRS based Air Conditioning Test Rig

9. Conclusion
The experiments were conducted on the conventional VCRS based Air Condition Test Rig with different refrigerants like, R22, R134a, R410a and R290 as refrigerant. R22 is found to perform well than that of other refrigerants considered in this study. The properties of R22 have revealed the high GWP and ODP since it is affecting the environment. The properties of R290 have revealed that zero GWP & ODP and hence, the R290 has witnessed the low power consumption with environmental advantages. In summary, it is concluded that the R22 has better COP but has very bad effect on the environment. The refrigerant R290 has been suitable for the VCRS based Air Conditioning system, since it has lower power consumption with better environmental benefits.

10. References
[1] Shubham Srivastava, Ravi Kumar Sen, Arpit Thakur, Manish Kumar T 2015 Review Paper on Analysis of Vapour Absorption Refrigeration System, International Journal of Research in Engineering and Technology Volume: 04 Issue: 06.
[2] Radhouane Ben Jemaa, Rami Mansouri, Ahmed Bellagi, 2016 Energy and exergy investigation of R1234ze as R134a replacement in vapor compression chillers, International Journal of Hydrogen Energy 17 42
[3] M Yang, CW Jung, YT Kang 2015 Development of high efficiency cycles for domestic refrigerator-freezer application, Energy 93 2258-2266
[4] K.Mani, V.Selladurai, 2008 Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a, International Journal of Thermal Sciences 47(11) 1490-1495