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Experimental Investigation of the Performance of Vapour Compression Refrigeration System Using Various Refrigerants

Ali Mubarak Al-Qahtani[1], Jebaraj S.[2]

[1,2]Department of Mechanical and Manufacturing Engineering Technology, Jubail Industrial College, Al-Jubail, Kingdom of Saudi Arabia.

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Corresponding Author: **Ali Mubarak Al-Qahtani1**

ABSTRACT

Refrigeration and air conditioning plays a major role in modern era. Every year the energy consumption for the refrigeration is also increasing globally. This study comparatively analysis the thermodynamic performance of refrigerants in a vapour compression refrigeration system. The designed experiments were performed and results were analysed using a modified commercial split air conditioning system of capacity 1.5 tons. The refrigerant used in the study are R12 and R22. Results showed that the actual COP and tonnage capacities of R22 is considerably better than that of R12. It is found that the actual COP of R22 is higher by 15%. The tonnage capacity of R22 is higher by 7.36%. This analysis was performed at condenser temperatures ranging from 30 °C and 40 °C and evaporator temperature ranging from 6 °C to 0.6 °C. It is also found that the power input for the compressor was lower for R22 by 35%. Hence, the lower energy consumption, which makes it, had better option than R12 for industrial applications and domestic applications as well. It is concluded that refrigerant R22 is better in all aspects considered in this study when compared with R12.

KEYWORDS: Vapour compression system, COP, expansion valve, tonnage capacity, refrigeration.

1. INTRODUCTION

Refrigeration has become an essential part in the modern developing era. Household utilities that make use of the refrigeration concept are very popular nowadays. The vapor compression refrigeration cycle has four main devices: evaporator, compressor, condenser, and expansion (or throttle) valve. The most widely used refrigeration cycle is the vapor-compression refrigeration cycle. In an ideal vapor compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor and is cooled to the saturated liquid state in the condenser. It is then expanded to the evaporating pressure and vaporizes as it absorbs heat from the refrigerated region.

A refrigeration system utilizes work delivered by an electric motor to release the heat from a region to be cooled to a high temperature sink. Low temperature boiling fluids called refrigerant absorb thermal energy to get vaporized in the evaporator resulting a cooling effect in the space being cooled. While comparing the advantages and disadvantages of various refrigeration systems, two major parameters; the operating temperature and the coefficient of performance are of vital importance. These systems can be investigated using energy and energy analyses which are based on first and second law of thermodynamics. The ideal vapor-compression cycle is shown in figure 1.

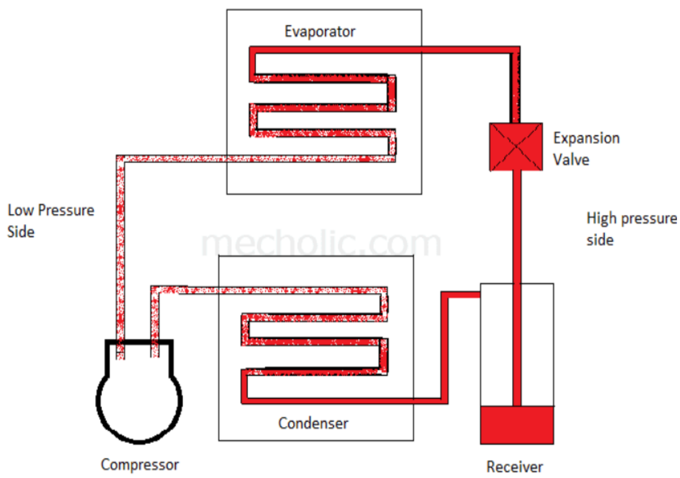

Figure 1. Schematic of Vapour Compression Refrigeration System

Vapour compression refrigeration system are the most widely used among all refrigeration systems. These systems works on the basis of reversed heat engine cycles. Vapour compression refrigeration systems are available to suit almost all applications with the refrigeration capacities ranging from few watts to megawatts. A wide variety of refrigerants can be used in these systems to suit different applications, capacities. It can be seen that there is a reduction in refrigeration effect when the isentropic expansion process of Carnot cycle is replaced by isenthalpic throttling process of VCRS cycle.

It is easy to show that the loss in refrigeration effect increases as the evaporator temperature decreases and/or condenser temperature increases. A practical consequence of this is a requirement of higher refrigerant mass flow rate. The heat rejection in case of VCRS cycle also increases when compared to Carnot cycle. Since the heat rejection increases and refrigeration effect reduces when the Carnot cycle is modified to standard VCRS cycle, the network input to the VCRS increases compared to Carnot cycle.

2. LITERATURE REVIEW

A very broad literature review has been conducted in vapour compression refrigeration system and is presented below. Baakeemetal (2018) had presented theoretical investigation of the performance of a multistage vapour-compression refrigeration system using energy, exergy and economic analysis. The system was modeled using Engineering Equation Solver (EES) software and the model was validated against published data with maximum error of 1.14%. Eight refrigerants were used in the investigation. They are R717, R22, R134a, R1234yf, R1234ze (E), R410A, R404A, and R407C. Results show that COP increases with increasing the sub-cooling parameter. The maximum COP of 6.17 was achieved with ammonia while minimum COP of 4.95 was achieved with R407C [1]. A novel methodology for modelling a simple compression refrigeration system was described. Starting from three input parameters, i.e. the ambient air temperature, the cold room air temperature, and the degree of superheating, a calculation algorithm based on iterative loops was used in the model to determine the operating point of the system. An experimental set-up consisting of a walk-in freezer unit was used for the development and validation of the model (Gabriel Zsembinszk et al., 2017) [2]. Optimal control of vapour-compression refrigeration systems, where only the compressor speed and the expansion valve opening were considered as manipulable inputs. A suboptimal hierarchical control strategy is proposed, where an online optimizer explores the two-dimensional controllable subspace to generate the reference on the degree of superheating, which, along with the cooling demand set point and the uncontrolled state, defines the cycle in steady state (Guillermo Bejarano et al., 2017) [3].

The performance of an integrated organic Rankine cycle-vapor compression refrigeration (ORC-VCR) system was investigated from the viewpoint of energy and exergy analysis. The system performance was represented by system coefficient of performance (COP_S), system exergy efficiency ($\eta_{e,sys}$), turbine pressure ratio (TPR), and total mass flow rate of the working fluid for each kW cooling capacity ($\dot{m}$total). Many common and new hydrocarbons, hydrofluorocarbons, fluorocarbons, hydrofluoroethers, and hydrofluoroolefins were suggested as working fluids. The highest COP_S, $\eta_{e,sys}$, TPR, and the corresponding $\dot{m}$total using R602 are 0.99, 53.8%, 12.2, and 0.005 $kg\,s^{-1}\,kW^{-1}$, respectively at a condenser temperature of 25 °C and the typical values for the rest parameters (Saleh, 2018) [4]. A novel meso-scale vapor compression refrigeration system (mVCRS) consisting of an evaporator, a compressor, a condenser and an expansion nozzle had been presented. The meso-scale vapour compression refrigeration system was successfully constructed, whose overall size is 60 × 60 × 100 mm^3 (width × length × height).

Through extensive experiments, it was validated that the proposed mVCRS can keep the temperature of heat source around 46 °C with the maximum cooling capacity of 80 W, and that the average coefficient of performance (COP) is up to 2.15 (Taijong Sung et al., 2014) [5].A comprehensive review on energy-efficient and -economic technologies for air conditioning with vapour compression refrigeration was described. The review was summarized in terms of the technology classification, basic ideas, advantages/ disadvantages, current research status and efforts to be made in the future (Xiaohui She et al., 2018) [6]. An experimental investigation into the effects, in terms of energy, of employing a dedicated mechanical subcooling cycle with a residential 1.5 ton simple vapour compression refrigeration system was presented. A comparative analysis of the experimental cycle performance was conducted with and without the dedicated subcooler cycle when the room temperature was kept between 18 and 22 °C. R22 was employed as the refrigerant in the main cycle whereas R12 was flowing in the dedicated subcooling cycle. The experimental outcomes indicate that the load carrying capacity of the evaporator increased by approximately 0.5 kW when R22 was subcooled, in the main cycle, by 5–8 °C (Bilal A.Qureshi et al., 2013) [7]. Interactive computer routines had been composed, in BASIC language, in order to permit the prediction of the performances of simple, multi-evaporator multi-stage compressor vapour-compression refrigerators when employing refrigerant R-11, R-12, R-22 or R-502. Listings of the composed programs and samples of the predictions obtained were presented (O.Badr et al., 1990) [8].

Performance characteristics due to fouling in a vapour compression cycle with integrated mechanical sub-cooling were investigated for various applications. Considering the first set of refrigerants i.e. R134a, R410A and R407C, from a first law standpoint, the COP indicated that R134a always performs better unless only the evaporator was being fouled. From a second law standpoint, the second-law efficiency indicates that R134a performed the best in all cases. Considering the second set of refrigerants i.e. R717, R404A and R290, the COP indicated that R717 always performs better unless only the evaporator was being fouled; however, the second-law efficiency indicated that R717 performs the best in all cases (Bilal and Syed M.Zubair, 2012) [9]. The concept of the air blast-cryogenic freezing method (ABCF) was based on an innovative hybrid refrigeration system with one common cooling space. The hybrid cooling system consists of a vapour compression refrigeration system and a cryogenic refrigeration system. The prototype experimental setup for this method on the laboratory scale was discussed. The energetic analysis had been carried out for the operating modes of the refrigerating systems for the required temperatures inside the cooling chamber of −5 °C, −10 °C and −15 °C. A comparison of these coefficients for the vapour compression refrigeration and the cryogenic refrigeration system had also been presented (Wiesław and Joachim, 2013) [10].

3. EXPERIMENTAL ANALYSIS

In real applications, energy consumption of the cycle is different from compressor power and is equal to energy consumption of the driving motor. The actual compressor power input, W_A, can be measured from the electrical power input.

$$W_A = V_L I_c \tag{1}$$

Where V_L and I_C are supply voltage (Volt) and current of the compressor motor (Ampere).

Then, the actual COP is the ratio of heat absorbed by refrigerant when passing through the evaporator to the actual work input for the compressor, and is given by:

$$COP_A = \frac{m_a C_p (T_5 - T_6)}{W_{actual}} \tag{2}$$

Where m_a is mass of air flowing through the evaporator, C_p is the specific heat of air (1.005 kJ/kg K), and (T_5-T_6) is the difference between the inlet and outlet air temperatures through evaporator. The capacity of a refrigeration machine is the refrigeration effect in a given time from a body. A common term that has been used in refrigeration work to define and measure the capacity or refrigeration effect is called ton of refrigeration. It is the amount of heat absorbed in melting a ton of ice over a 24-hour period at 0°C, which is 3.88 kJ/sec, thus given by:

$$TR = \frac{m_a C_p (T_5 - T_6)}{3.88} \tag{3}$$

A review was made from the above-mentioned research papers and it was found that construction of vapour compression refrigeration test rig is a viable option and is more efficient in terms of performance analysis in comparison of refrigerants R12 and R22. Based on this review, a VCRS test rig was constructed. The refrigerants to be used has been selected to be Dichlorodifluoromethane (R12) and Difluoromonochloromethane (R22). The tests were conducted on three separate days across three weeks.

In developing a reliable test rig, consideration is highly addressed especially in the development method, measurement locations of pressure and temperature. These are very important to ensure that the test rig can produce reliable data. To accomplish this, the authors referred to the several technical papers related to the study. Discussions was held about the locations of temperature and pressure measurement points, measurement devices and measurement methods. There are seven points of temperature measurement, four points of pressure measurement and one point of flow rate measurement. From the seven points of temperature measurement, three points have been placed inside the refrigeration circuit to measure refrigerant temperature and another four points have been placed externally on other compartments.

In addition, four points of pressure were modified and made on pipes connecting all main components. Bourdon Tube pressure gauges were used for each pressure measurement in this test rig. A copper tube was used to connect the refrigerant tube to each pressure gauge. A metal tube flow meter was assembled between condenser and expansion to measure the refrigerant flow rate in liquid form.

A gauge set was then used to connect to the system on both high and low side pressure ports and it will also be used to vacuum down and recharge the system. The red colored gauge and connector valve represents the high pressure side of the system while the blue color represents the low pressure side. A vacuum pump was then used to connect to the unit. This step is used to remove any moisture and static air from inside the system. Slowly the low side gauge valve was turned on and the pump started pulling vacuum throughout the system as the gauge needle slowly moves into vacuum. The vacuum pump was left for 30 minutes until gauge indicted vacuum pressure and then removed.

Charging the system takes place after disconnecting the vacuum pump, the Freon cylinder was connected. The valve on the manifold gauge was turned over to allow the refrigerant to be present in the system. The unit was charged until low pressure side gauge reads 60 psi and in some trials an extra 10% to overcompensate for the losses and leaks which was fixed later.

The system was first tested with R22 in order to obtain the baseline data. After the completion of all tests with R22, the air conditioner was retrofitted with R12. The compressor unit uses mineral oils that fits both refrigerants as per manufacturer. After each charge, according to the set up used in this study, the unit was allowed to run for 15-20 minutes to reach the steady state condition, then an operation of 40 minutes taking the readings at an interval of 10 minutes.

4. RESULTS AND DISCUSSION

The test used two refrigerants, R12 and R22, and was conducted on the same day, after few trials to make sure system was working satisfactory. The test duration for each refrigerant was 40 minutes and the readings were taken at an interval of 10 minutes. All analysis, except when otherwise listed, is based on final readings which is after 40 minutes. Table 1and table 2 shows the observations for refrigerants R12 and R22 taken at an interval of 10 minutes for a duration of 40 minutes. This is to study the system as it reaches steady state condition.

Table 1. Experimental Observations of Refrigerant R12

Time	t	min	10	20	30	40
Room Temperature	T_a	°C	21.2	21.1	21.3	21.5
Evaporating Pressure	P_e	psi	37.1	37.2	37.8	37.8
Condensing Pressure	P_c	psi	130	131	130	130
Evaporating Temperature	T_1	°C	5.7	5.7	5.9	6
Condensing Temperature	T_2	°C	37.9	37.8	38	38
Refrigerant Mass Flow Rate	m_r	g/s	21.2	21.3	21.1	21.2
Evaporator Air Outlet Velocity	v	m/s	3.3	3.5	3.5	3.6
Evaporator Air Inlet Temperature	T_5	°C	19.5	19.6	19.5	19.8
Evaporator Air Outlet Temperature	T_6	°C	8.7	8.8	8.8	8.6
Voltage	V	V	218	219	218	219
Current	I	A	9.7	9.9	9.8	10.5
Power	W	W	1917	1997	2051	2208
Energy	E	kW·h	0.548	0.576	0.564	0.603

Table 2. Experimental Observations of Refrigerant R22

Time	t	min	10	20	30	40
Room Temperature	T_a	°C	21.3	21.4	21.4	21.6
Evaporating Pressure	P_e	psi	61.3	61.2	61.7	61.5
Condensing Pressure	P_c	psi	159.1	159.3	159.4	161.1
Evaporating Temperature	T_1	°C	0.5	0.5	0.5	0.6
Condensing Temperature	T_2	°C	31.5	31.4	31.3	31.3
Refrigerant Mass Flow Rate	m_r	g/s	21.3	21.4	21.3	21.1
Evaporator Air Outlet Velocity	v	m/s	3.4	3.4	3.5	3.5
Evaporator Air Inlet Temperature	T_5	°C	20.4	20.3	20.3	20.3
Evaporator Air Outlet Temperature	T_6	°C	8.6	8.6	8.5	8.4
Voltage	V	V	218	219	218	218
Current	I	A	9.1	8.6	9.3	9.2
Power	W	W	1885	1789	1926	1905
Energy	E	kW·h	0.529	0.523	0.535	0.527

The experiment was conducted and the results are summerised in table 3 and table 4 for the refrigerants R12 and R22, respectively

Table 3. Experimental Results of Refrigerant R12

Time	t	min	10	20	30	40
Mass of Air Flow	m_a	kg/s	0.2774	0.2942	0.2942	0.3026
Actual Coefficient of Performance	COP_A	-	5.49	5.54	5.61	5.65
Relative Coefficient of Performance	COP_R	-	0.74	0.75	0.76	0.76
Tonnage Capacity	TR	Ton	0.78	0.82	0.82	0.88

Table 4. Experimental Results of Refrigerant R22

Time	t	min	10	20	30	40
Mass of Air Flow	m_a	kg/s	0.2858	0.2858	0.2942	0.2942
Actual Coefficient of Performance	COP_A	-	6.41	6.43	6.52	6.68
Relative Coefficient of Performance	COP_R	-	0.85	0.85	0.85	0.87
Tonnage Capacity	TR	Ton	0.87	0.87	0.90	0.91

Throughout the test for both refrigerants, the value of room temperature, refrigerant mass flow rate, and evaporator air outlet velocity remain persistent. Figure 2, figure 3 and figure 4 shows that these parameters are reserved at the same level to a satisfactory state.

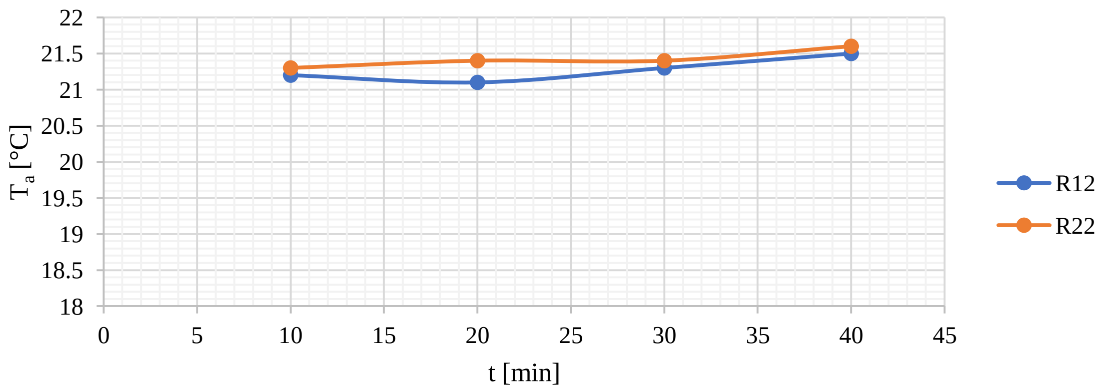

Figure 2. Relationship between Time and Room Temperature

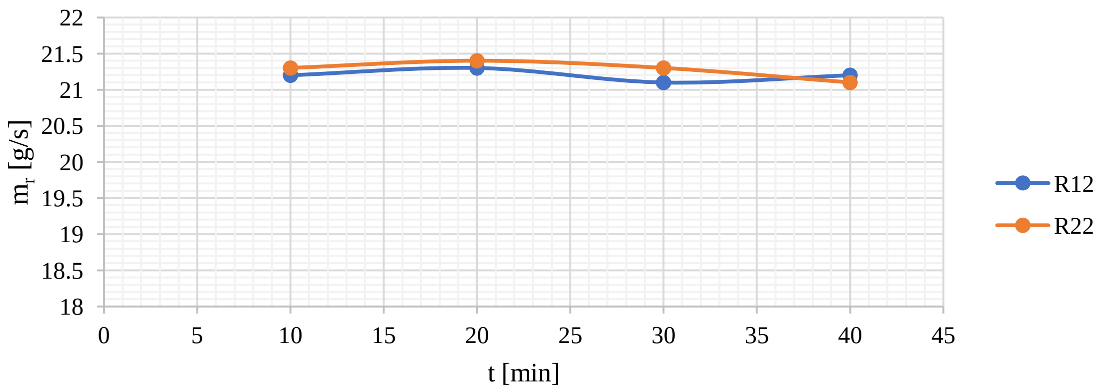

Figure 3. Relationship between Time and Refrigerant Mass Flow Rate

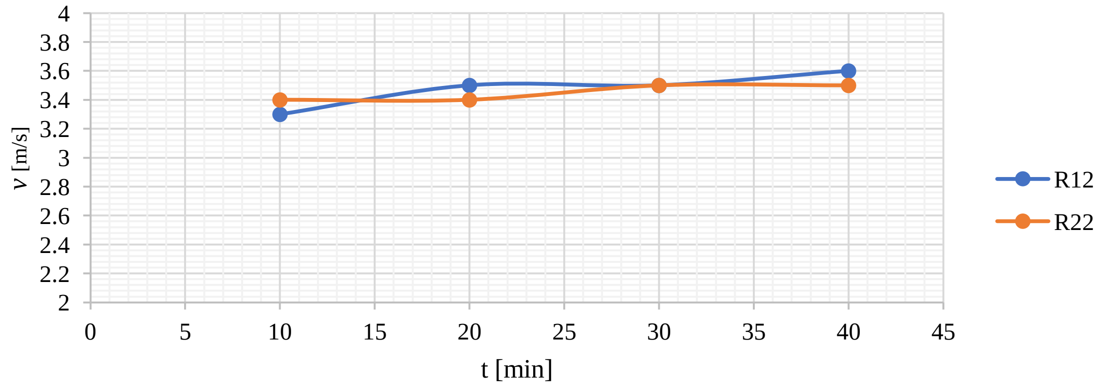

Figure 4. Relationship between Time and Evaporator Air Outlet Velocity

The COP of refrigeration is another important parameter that gives the ratio of the desired output and the required work input. It is observed from figure 5, that R22 is the refrigerant with higher actual COP of 6.5 followed by R12 is having the actual COP of 5.6 respectively. The low actual COP of R12 is reasonable considering the fact that the compressor unit is designed to work mainly with R22. The difference in condensing pressure of R22 at any given temperature is higher than that of R12 and volumetric cooling capacity greater than R12 so smaller swept volume beside their needs of different lubricant oil requirements.

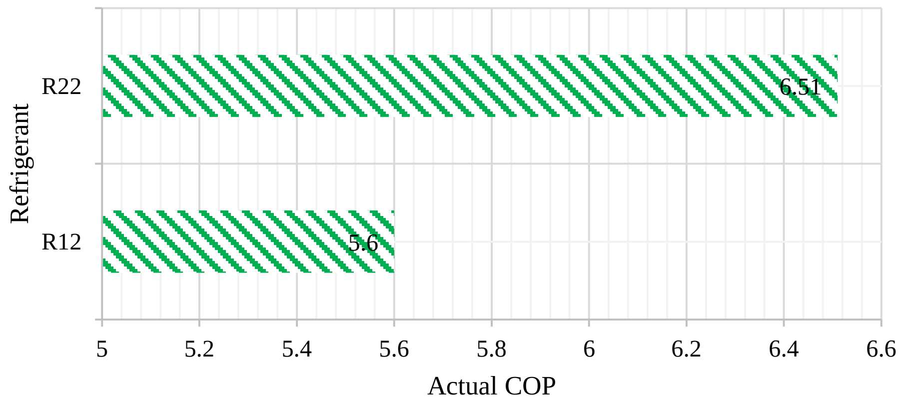

Figure 5. Actual COP comparision of R12 and R22

5. CONCLUSION

An experimental test rig of vapour compression air conditioning system was fabricated and analysed by conducting the experiments using R12 and R22. The investigation mainly included the effects of the relationship between time and room temperature, refrigerant mass flow rate and evaporator air outlet velocity. It was observed that the actual COP of R22 is considerably higher than that of R12. The actual COP for R22 is higher by 15%. The tonnage capacity of R22 is higher by 7.36%. This analysis was performed at condenser temperatures ranging from 30 °C and 40 °C and evaporator temperature ranging from 6 °C to 0.6 °C. It is concluded that the performance of vapour compression refrigeration system using the refrigerant R22 is superior than the system using R12 as refrigerant.

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