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Experimental Analysis Of Vapour Compression Refrigeration System For Optimum Performance With Low Pressure Receiver

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Abstract

Refrigerator is a device used for chilling of food products for the both commercial and domestic appliances utilizing mechanical vapour compression Cycle in its process. Optimization for the better performance of the system becomes main issue and many researches are still ongoing to improve efficiency of the system.

The main objective of this work is to enhance the performance of the domestic refrigerator by flooding the evaporator with liquid refrigerant. To attain this objective a low pressure vessel is designed, developed, fabricated and incorporated between evaporator and compressor. The performance of refrigerator is evaluated with and without low pressure receiver. Also analysis is carried using two different refrigerants (R134a and R401C).

From the results it is found that COP, refrigeration of the system improves with the installation of low pressure receiver. Also the system gets benefited in the form of decrease in compressor work with the installation of low pressure receiver. Comparing the performance parameters of the refrigeration system with different refrigerants it is found that R401C gives optimum performance over the R134A.

Keywords: Receiver, Refrigerant, VCR system.

1. Introduction.

Refrigeration may be defined as the process to attain and keep an enclosed space at a temperature below than its surrounding temperature. This is done by continuous removal of heat from the enclosed space where as the temperature is lower than that of the surrounding temperature.

Refrigerator is a cooling appliance encompassing a thermally insulated compartment and a refrigeration system is a system to churn out cooling effect in the insulated compartment. Meanwhile, refrigeration is put into words as a process of removing heat from a space or substance and carries that heat to another space or substance. Nowadays, refrigerators are hugely used to store foods which decay at ambient temperatures; spoilage from bacterial growth and other processes is much slower in refrigerator that has low temperatures. In refrigeration process, the working fluid holding down a job as the heat absorber or cooling agent is called refrigerant. The refrigerant drawn up the heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure. As the heat is removed from the refrigerated space, the area appears to become cooler. The process of refrigeration occurs in a system which encompasses of a compressor, a condenser, a capillary and an evaporator.

Most of the domestic refrigerators today are functioning based on the vapour compression refrigeration system. It is somewhat relates to reverse Rankine cycle. The vapour compression refrigeration system consists of four main components which are compressor, condenser, expansion device, and evaporator.

Compressor is used to compress the low pressure and low temperature of refrigerant from the evaporator to high pressure and high temperature. After the compression process the refrigerant is then let out into condenser. In the condenser, the condensation process entails heat rejection to the surroundings. The refrigerant can be condensed at atmospheric temperature by increasing the refrigerant's pressure and temperature above the atmospheric temperature.

After the condensation process, the condensed refrigerant will flow into the expansion device, where the temperature of refrigerant will be dropped lower than the surrounding temperature caused by the reducing pressure inside the expansion device. When the pressure drops, the refrigerant vapour will expand. As the vapour expands, it pulls the energy from its surroundings or the medium in contact with it and thus brings out refrigeration effect to its surroundings. After this process, the refrigerant is ready to drawn up heat from the space to be refrigerated. The heat absorption process is to be done in the evaporator. The heat absorption process is normally being known as evaporation process. The cycle is finished when the refrigerant returns to the suction line of the compressor after evaporation process.

The performance of the domestic refrigerator is to be evaluated by using experimental method and attempt to upgrade and achieve the maximum performance for a unit of domestic refrigerator by incorporating low pressure receiver. In order to have more exact results for interpreting the performance of the domestic refrigerator, the suitable locations of parameters to be recorded down to determine the performance of the domestic refrigerator is crucial to be identified. The experiment is carried out by using the specially developed test rig (mini size domestic refrigerator). The test rig is upgraded and modified if required

This work explains some of the technical improvements of a novel refrigerator. The refrigeration system used to test the concept that had a low pressure receiver with single hermitic compressor.

2. Purpose of low pressure receiver Installation

Alternative refrigeration systems were therefore investigated. The use of low pressure receiver has been shown to enhance the effectiveness and reliability of large Chlorofluorocarbon (CFC) and ammonia refrigeration systems (Pearson, 1982, 1995). Capillary tube expansion is commonly used in domestic and small commercial applications. Capillary tubes are less expensive, authentic and requires no initial setting once correctly designed. Usually, capillary tubes are sized to offer excellent performance at a single operating condition and do not readily impart themselves to systems where both duty and operating pressures change. In most small capillary-based systems designers need to verify that the entire liquid refrigerant has boiled at the exit of the evaporator and there are few degrees of superheat to avert liquid returning to the compressor. In a low-pressure receiver system the aim is to over feed the evaporator and therefore control of superheat by the expansion device is not needed. Therefore the use of a capillary tube in conjunction with a low-pressure receiver had the potential to provide a less expensive and efficient system that could operate reliably over a range of duties.

3.Objective

The main objective of this work is to enhance the performance of the domestic refrigerator by flooding the evaporator with liquid refrigerant. To attain this objective a low pressure vessel is designed, developed, Fabricated and incorporated between evaporator and compressor to evaluate the performance of the refrigerator with and without low pressure receiver (with and without sub-cooling the liquid refrigerant). In this present work two different refrigerants (R134a and R401C) are used in the test rig. In order to avoid any notable pressure drop and heat transfer to and from the system for complete vapour compression refrigeration cycle and the effect of charge quantity of the refrigerant based on the refrigerant gauge pressure temperature charts are used.

To obtain the optimum $COP_{R,}$ Refrigeration effect, Power consumption, and better refrigerant choice using the data collected from the experiment from where the exact location of points of interest at where the data (temperature and pressure) should be collected and identified perfectly.

For conducting the above experiment the same test rig is used for different refrigerants (R134a and R401C) by using the same compressor and changing the compactable oil for the refrigerant to the compressor and performance test has been done.

4. Low Pressure Receiver (or) Vessel

4.1 Introduction

A low-pressure receiver is a vessel placed in the refrigeration suction line. Its function is to allow refrigerant from the evaporator to separate into liquid and gas and store the liquid. The high pressure liquid line from the condenser passes through the foot of the receiver where the low pressure liquid is collected. The heat from the high pressure line causes the liquid in the foot of the receiver to boil whilst sub cooling the liquid line. The vapour at the peak of the receiver is drawn back to the compressor over the high-pressure liquid line, superheating it and verifying no liquid returns to the compressor.

The advantage of using a low-pressure receiver is that the evaporator can be over fed without any chance of liquid returns back to the compressor. Therefore, control of the expansion device is less difficult as it only needs to feed required liquid to the evaporator whilst maintaining a pressure difference across the device. Thus capillary expansion in combination with a low-pressure receiver was used.

Generally the usage of vessels is much more common in industrial refrigeration systems than in domestic refrigeration & air conditioning. A fundamental principle in choosing the size of liquid vessels is to choose them large enough that during operation they never become completely full of liquid nor completely vacant, there must always be some vapour space above the highest liquid level to be faced.

Figure 3.1 Low pressure receiver final views

4.2 Vessel Design Analysis

The main objective of this project is to design the suitable low pressure receiver to domestic refrigerator. To achieve the above objective a 205 Liter Godrge refrigerator is used.

The design of low pressure receiver corresponds to approximately to a 1 ton refrigeration load in evaporator. The vapour volume flow rate is the sum of the evaporated refrigerant from the load and the vapour from the LPR to maintain a constant liquid level in the vessel.

Input necessary conditions for a vessel sizing:

INPUT	English	SI
Vapor/liquid temperature	20^0F	-6.1^0C
Liquid volume flow rate	$2.5x10^{-3}$gpm	0.0015 L/s
Vapour volume flow rate	0.15 cfm	0.070 L/s
Liquid reserve volume(5 min)	$0.0168ft^3$	0.47L
Surge volume	1.1×10^{-3} ft^3	0.03L

The following vertical vessel design recommendations are considered.

4.3 According to ASHRAE (1998) recommendations

(a) Vessel diameter:

According to ASHRAE 1998 standards for droplet size of 25 µm

Vapour velocity is 3.77 ft / min (0.019 m/ sec).

$D_{vessel} = (4v / \pi u_{xy})^{0.5}$

$= (4 \times 0.15/\pi \times 3.77)^{0.5}$

$= 0.225ft = 0.068m$

$= 6.8cm (=7cm)$

(b) length of the liquid section corresponds to surge and ballast;

$L\ liquid = (v_{surge} + v_{ballast}) / ((\pi/4) x D^2_{vessel})$

$= (1.11 \times 10^{-3} + 0.0168)/(3.14 \times 0.25 \times 0.225^2)$

= 0.4504ft = 0.1372m = 13.7cm (=14cm)

(c) Height of nozzle above maximum liquid level

$H = D_{vessel}/5 = 0.225 / 5$

= 0.045 ft = 0.0137 m = 1.37 cm (=2 cm)

(d) To determine the total length

$L_{vessel} = L_{liquid} + H$ +allowance(i.e. vertical separation distance VSD)

= 14 +2 + 2 = 18 cm

5. Experimental Procedure

Schematic diagram of the experimental apparatus is shown in Figure. After the integration of the components, the valves V 1 and V 2 was opened to make the system work only with the low pressure receiver. The system was run at no load and load conditions respectively. For every test condition, temperature and pressure at salient points were noted down. The temperature of the refrigerant at inlet and exit of low pressure receiver was also measured. The experiment was done until steady state conditions were attained in the evaporator. The energy consumption of the system is measured using a digital energy meter. The performance of the refrigerator with low pressure receiver measured using HFC134a/POE oil as the working fluid. Finally the test results of domestic refrigerator with and without low pressure receiver were compared.

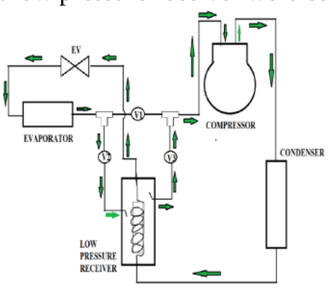


Fig 7.2 Basic line diagram of VCR system with LPR

Figure 7.3 Front and side views of test rig

5.1 Experimental Testing Procedure:

1. First the refrigerator test rig is checked properly for any refrigerant leakage, all component line connections and electrical connections etc.
2. The main power switch is switched on.
3. The hand shut valve V1 should be opened and hand shut valves V2 and V3 should be closed before starting the unit and for running the unit without LPR.
4. The hand shut valves V2 and V3 should be opened and hand shut valve V1 should be closed before starting the unit and for running the unit with LPR.
5. The readings of suction, discharge pressure gauge, readings of energy meter for the compressor are noted.
6. Temperature readings should be noted at respective locations by using infrared thermometer.
7. The readings of various pressure gauges are noted and absence of any reading indicates the leakage of pipe line or leakage of gas.
8. The unit is run for 30 minutes and the following readings are taken once in twenty minutes.
    a. Discharge pressure gauge (P1)
    b. Suction pressure gauge (P2)
    c. Discharge pressure gauge at compressor outlet (T2)
    d. Discharge temperature at condenser outlet (T3)
    e. Suction temperature at compressor inlet (T1)
    f. Ambient temperature (Ta)
    g. LPR liquid in temperature(T3)
    h. LPR liquid out temperature (T_3^l)
    i. LPR suction out temperature(T1)
    j. LPR suction in temperature (T_1^l)
    k. Refrigerant inlet temperature into evaporator (T_4)
9. The P-h chart is drawn accordingly and the C.O.P and cooling capacity are found with the help of formulae. Also the readings of current and final energy meter are noted down.
10. C.O.P = Refrigerating effect / work done

    $= h_1 - h_4 / h_2 - h_1$
11. Cooling capacity = $m (h_1 - h_4)$

    Where m =mass flow rate in kg per minute

    h_1=enthalpy of refrigerant in KJ per kg

    h_2=enthalpy of superheated vapor refrigerant at the end of compression in KJ per kg.

    h_3=enthalpy of refrigerant at the end of cooling of refrigerant or condenser outlet in KJ per kg

    h_4=enthalpy of refrigerant at end of expansion in Kj per kg.

5.2 Performance Tests:

(a) **No load test**:

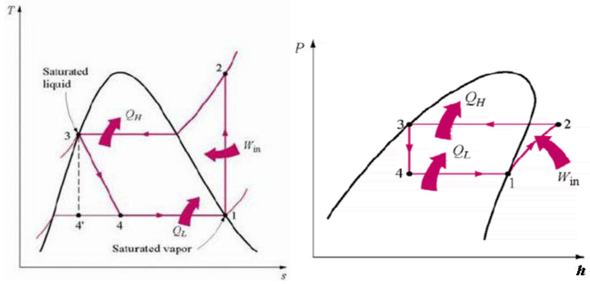
It is one of the fundamental tests to be performed. In this test, the compressor will be running continuously by bypassing the thermostat. The thermocouples are placed at different locations as specified above. For every 30 minutes the temperatures are noted till steady state is reached. Significance of this test is to find out how much time is required to attain specified temperature at the air center. This test helps us to know how the system is running. In no load cycling test, the system is run keeping the thermostat in cycling mode in the refrigeration system. As the temperature reaches specified highest set freezing temperature, the compressor stops which is called the cut-off time, and as the temperature inside the cabinet reaches lowest set freezing temperature, the compressor starts which is called the cut-in time, taking the power and maintaining the temperature inside the cabinet at stabilized condition. The compressor on/off can be noted down directly from the digital temperature control unit, which records the temperatures. Significance made through this is to find the time required to attain the specified temperature near the air center when freezer is in unloaded condition. And other is the compressor run percentage should be equal to or less than 80%.

(b**) Load Test**:

In this test, the freezer is fully loaded, and the thermostat is by-passed. The thermocouples are placed at different locations as specified before except at the air Center and some thermocouples are noted till steady state is reached by the digital temperature control unit. Significance of this test is to find out how much time is required by the loaded product to attain the specified temperature. The system performance is tested according to center temperature of cabinet and time, which shows how the system runs at full load condition and how much time is required to pull down the load.

In load cycling test, the thermostat is connected to the circuit at full load condition. As The temperature reaches highest set freezing temperature the compressor stops which is called the cut-off time, and as the temperature inside the cabinet reaches the lowest set freezing temperature, the compressor starts which is called the cut-in- time, taking the power maintaining the temperature inside the cabinet at stabilized condition. The compressor on or off can be noted down directly from the digital temperature control unit, which records the temperatures. Significance of this test is to find out how much time is required by the loaded product to attain the specified temperature at full load condition also shows how power is required by the compressor at cut-in and cut-off positions. From the experimental procedure in order to find the Refrigeration effect, C.O.P, and work done on the system the above can be obtained by using P-h chart. The following Experimental values are plotted on the P-h to know the behavior of the simple vapor compression cycle with and without low receiver.

The following is the procedure to find performance of the system. The unit is run for 30 minutes and the following readings are taken once in twenty minutes.



A. Discharge pressure gauge (P1)

b. suction pressure gauge (P2)

a. Discharge pressure gauge at compressor outlet (T2)
b. Discharge temperature at condenser outlet (T3)
c. Suction temperature at compressor inlet (T1)
d. Ambient temperature (Ta)
e. LPR liquid in temperature(T3)
f. LPR liquid out temperature (T_3^l)
g. LPR suction out temperature(T1)
h. LPR suction in temperature (T_1^l)
i. Refrigerant inlet temperature into evaporator (T_4)

The P-h chart is drawn accordingly and the C.O.P and cooling capacity are found with the help of formulae. Also the readings of current and final energy meter are noted down.

C.O.P = Refrigerating effect / work done

$= h_1\text{-}h_4 / h_2\text{-}h_1$

Cooling capacity = m (h_1-h_4)

Where m =mass flow rate in kg per minute

h_1=enthalpy of refrigerant in KJ per kg

h_2=enthalpy of superheated vapor refrigerant at the end of compression in KJ per kg.

h_3=enthalpy of refrigerant at the end of cooling of refrigerant or condenser outlet in KJ per kg

h_4=enthalpy of refrigerant at end of expansion in Kj / kg.

The P-h chart for the two refrigerants are plotted for the refrigerants R401C and R134a by varying the load and performance is evaluated with and without low pressure receiver

6. Results and Discussions

6.1 Performance of Low Pressure Receiver

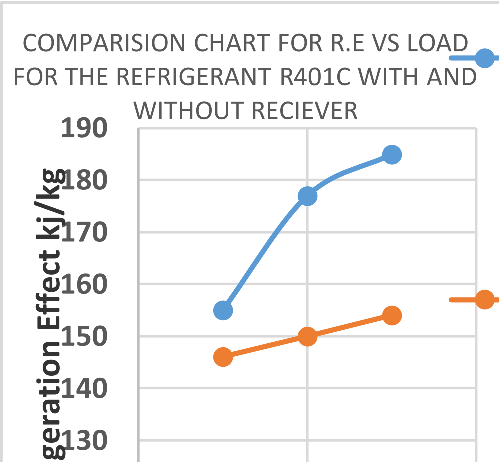
To understand the operation of LPR when test rig run continuously there was no temperature control and the heat load was only that being conducted through the insulation, and due to infiltration. Under these conditions liquid backed up in the lower part of the condenser. The liquid line through the entrance to the capillary tubes was completely filled with liquid refrigerant. As the liquid flowed through the capillary tube, the pressure was lowered to the evaporating pressure and a mixture of liquid and vapor entered to evaporator.

A proportion of the liquid has evaporated but the vapor leaving the exit of the evaporator was wet and it returned through the suction line to the low-pressure receiver. The low-pressure receiver separated the liquid refrigerant from the vapor and the liquid accumulated in the bottom of the receiver. The warm liquid from the condenser passed through a heat exchanger in the lower part of the receiver. This ensured that the high-pressure liquid was substantially sub cooled by the low temperature, low pressure liquid which was vaporized. Refrigerant vapor was drawn from the top of the receiver back to the compressors. When evaporating at -5ºC this vapor was superheated by 5.5ºC. The refrigerant charge in the circuit was chosen so that under these conditions there was liquid backed up in the lower part of the condenser and held in the lower part of the low-pressure receiver. In this steady-state condition, there was a balance between the liquid vaporized and the amount of sub cooling plus the heat ingress through the walls of the receiver. A small bleed hole in the vapor exit pipe in the lower part of the low pressure receiver allowed oil to return to the compressor. When the heat load in the evaporator increased, more of the refrigerant evaporated in the evaporator. There was relatively little change in the mass flow rate of refrigerant entering the evaporator as the condensing and evaporating pressures only changed by a small amount so the mass flow through the capillary tubes only changed by a small amount. The refrigerant therefore left the evaporator in a dryer state, and the level of liquid in the low-pressure receiver fell, reducing the amount of sub cooling of the liquid refrigerant. When the added heat load in evaporator increased to more than 250W, the refrigerant leaving the evaporator was superheated and there was no liquid in the low pressure receiver. The excess liquid was now backed up in the lower part of the condenser. This caused an increase in the condenser pressure, due to the smaller surface area available for condensation. However, the increase in condensing pressure was small and there was only a small increase in the refrigerant flow rate through the capillary tube. When the surplus heat load in the evaporator (over and above heat ingress through the insulation and by infiltration) increased from 0 to 250W the condensing temperature increased from 47 to 52ºC (ambient 43ºC). When one evaporator was switched off the refrigerant in that evaporator drained down by gravity and evaporation, leaving the evaporator dry. The surplus liquid was transferred to the low-pressure receiver, increasing the level in the bottom of the receiver. As the flow rate of refrigerant round the circuit decreased, the evaporating pressure decreased. If this state were to continue for long enough, the surplus liquid would eventually be transferred to the condenser, backing up in its lower part. In practice, before steady state conditions can be achieved the solenoid valve opened and the refrigerant flow rate from the condenser increased. Also, when the unit was operating normally, the suction pressure was controlled, the pressure being chosen to suit the set temperatures in evaporator. Thus, the evaporator was not reduced to very cold temperatures if these were not necessary. If the heat load in the

drawers was very small for long periods, the surplus liquid was held in the lower part of the condenser.
The results obtained from the P-h chart for the domestic refrigerator with and without low pressure receiver are as above.

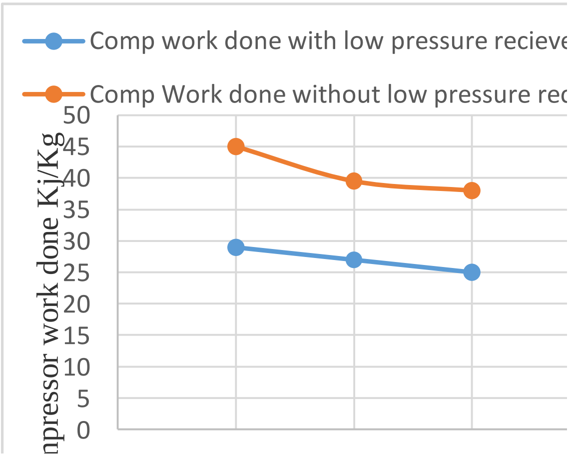
6.2 Performance of VCR system with and without low pressure receiver and also with different Refrigerants

From the graph 1 it is observed that as load of water increases the refrigeration effect increases using R401C refrigerant either with low pressure receiver or without low pressure receiver. Also it is observed that in case of using low pressure receiver the refrigeration effect increases rapidly with increases of load than that of in the case of without low pressure receiver. The maximum refrigeration effect of 185KJ/Kg is obtained with low pressure receiver where as it is 152KJ/Kg in case of without low pressure receiver.



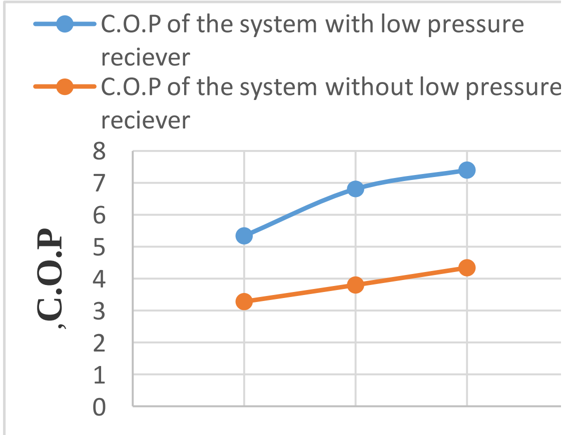
Graph: 1 Load Vs Refrigeration Effectfor the refrigerant R401C with and without low pressure receiver.

Fig 2 shows the effect of load of water on the compressor work done and is observed that as load increases the compressor work decreases either by using low pressure receiver or without it. The minimum compressor work is 25KJ/Kg and 35KJ/Kg with and without low pressure receiver.



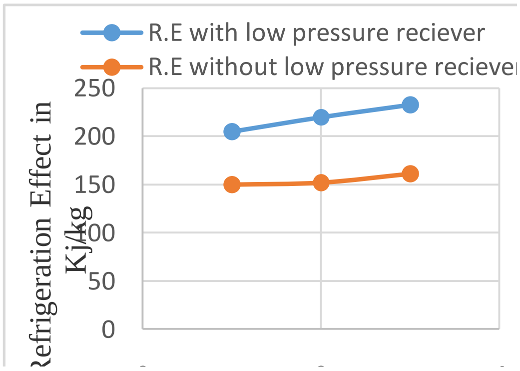
Graph: 2 Compressor work Vs Load for the refrigerant R401C with and without low pressure receiver.

Graph 3 shows the effect of load of water on the COP of the system with and without low pressure receiver. It is observed from the graph that COP increases with increase of load of water in both the cases either by using low pressure receiver or without using it. Also it is observed that the increase of COP is rapid with incorporation of receiver than that of the system without receiver. The maximum COP obtained with receiver is 7.4 and it is 4.34 without receiver.



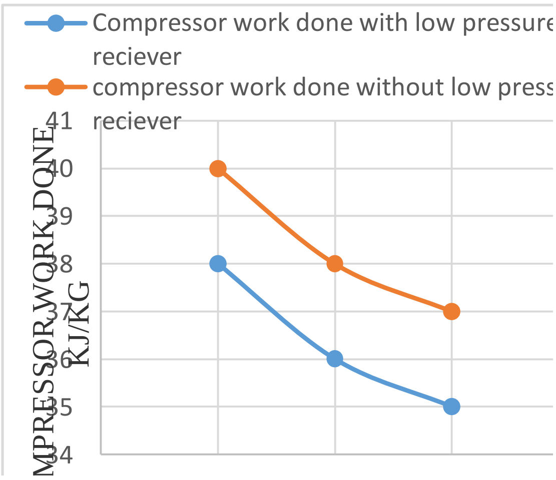
Graph: 3 C.O.P Vs Load for the refrigerant R401C with and without low pressure receiver.

From the graph 4 it is observed that as load of water increases the refrigeration effect increases using R134A refrigerant either with low pressure receiver or without low pressure receiver. Also it is observed that in case of using low pressure receiver the refrigeration effect increases rapidly with increases of load than that of in the case of without low pressure receiver. The maximum refrigeration effect of 235KJ/Kg is obtained with low pressure receiver where as it is 161KJ/Kg in case of without low pressure receiver. Also it is observed that with increase of load the refrigeration effect increases rapidly in case of system with receiver where as it increases only slightly without receiver.



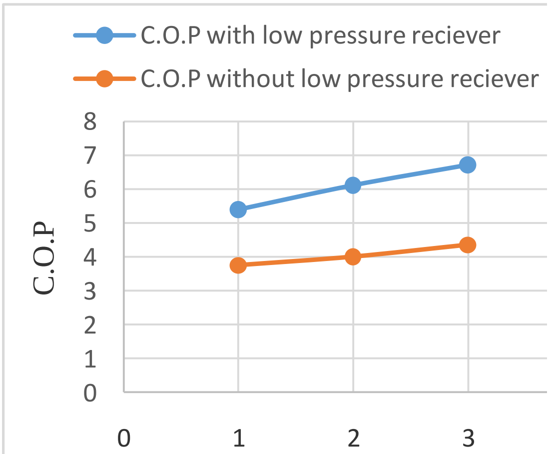
Graph: 4 Refrigeration effect Vs Load for the refrigerant R134a with and without low pressure receiver.

Fig 5 shows the effect of load of water on the compressor work done and is observed that as load increases the compressor work decreases either by using low pressure receiver or without it. The minimum compressor work is 35KJ/Kg and 37KJ/Kg with and without low pressure receiver. So compressor work with or without receiver is not much difference using R134a refrigerant.



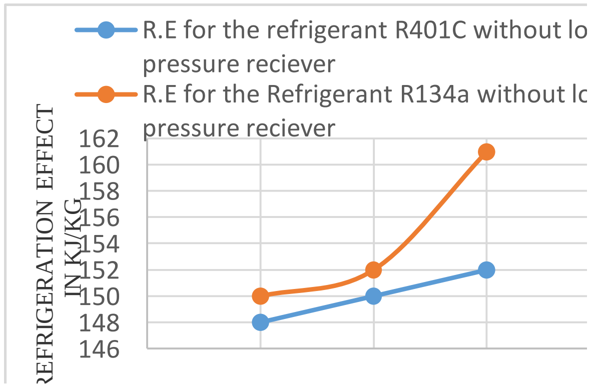
Graph: 5 Compressor work Vs Load for the refrigerant R134a with and without low pressure receiver

Graph 6 shows the effect of load of water on the COP of the system with and without low pressure receiver. It is observed from the graph that COP increases with increase of load of water in both the cases either by using low pressure receiver or without using it. Also it is observed that the increase of COP is rapid with incorporation of receiver than that of the system without receiver. The maximum COP obtained with receiver is 6.714 and it is 4.35 without receiver.



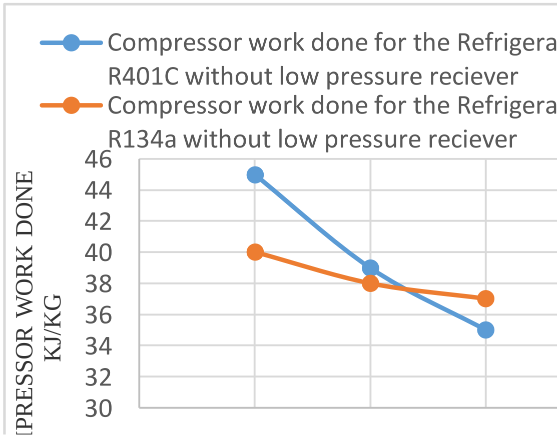
Graph: 6 C.O.P Vs Load for the refrigerant R134a with and without low pressure receiver.

From the graph 7 it is observed that increase of load increases the refrigeration effect and it is observed that increase of refrigeration effect is slightly from load 1 to 2 liters and thereafter it increases rapidly beyond that for refrigerant R401C. But for R134A increase of refrigeration effect is slightly and is uniform throughout the load from 1 to 3 liters.



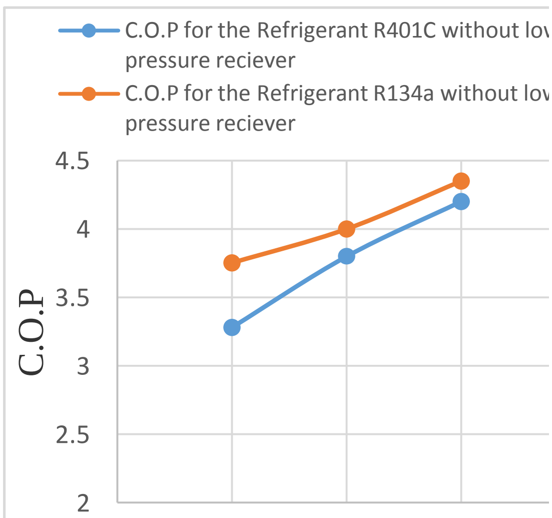
Graph: 7 Refrigeration effect Vs Load for refrigerants R401C& R134a without low pressure receiver.

From the graph 8 it is observed that compressor work decreases with increase of load of water. It is found that compressor work is high for R401C than that of R134A at low load where as at higher load compressor work is higher for R134A than that of R401C.



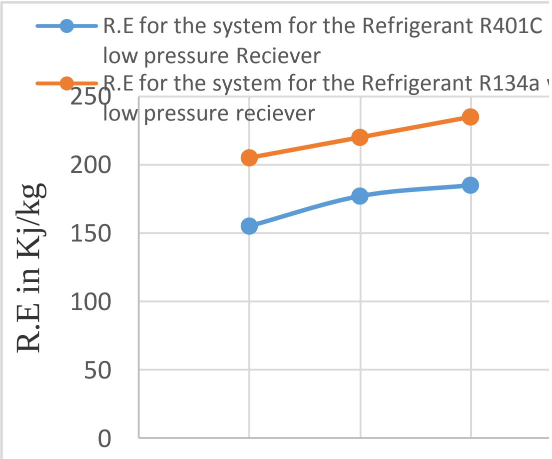
Graph: 8 Compressor work done Vs Load for the refrigerants R401C and R134a without low pressure receiver.

From the graph 9 it is observed that COP increases with increase of load of water in liters. It is observed that with increase of load COP increases drastically with increase of load for R401C, whereas increase in COP is smooth and slightly for R134A.



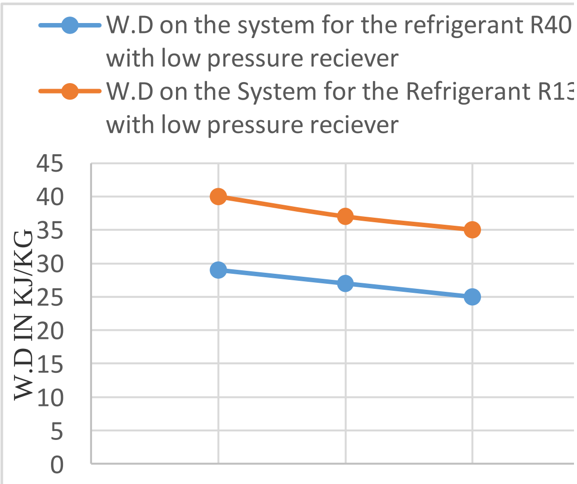
Grapph:9 C.O.P Vs Load for the refrigerants R401C and R134a without low pressure receiver.

From the graph 10 it is observed that increase of load increases the refrigeration effect and it is observed that increase of refrigeration effect is uniform throughout the increase of load from 1 liter to 3 liters.



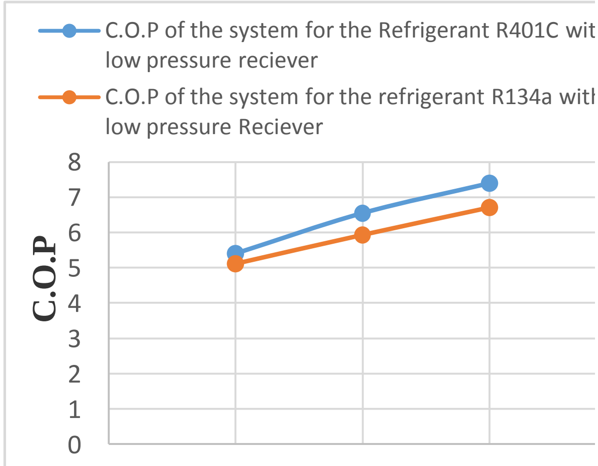
Graph: 10 Refrigeration effect Vs Load for the refrigerants R401C and R134a with low pressure receiver

From the graph 11 it is seen that compressor work decreases with increase of load of water for both the refrigerants R401C and R134A with low pressure receiver.



Graph: 11 Compressor work done Vs Load for the refrigerants R401C and R134a with low pressure receiver.

From the graph 12 it is observed that COP increases with increase of load of water. Also it is observed that at low load COP for both the refrigerants is closer to each other whereas at higher load COP for R401C is much higher than the COP for R134A.



Graph: 12 C.O.P Vs Load for the refrigerants R401C and R134a with low pressure receiver.

7. Conclusions

The results are obtained for the two different refrigerants R134a and R401C by incorporating the low pressure receiver for the experimental test rig. The water is considered as the load. The load varies from 1 to 3 liters and the performance analysis is carried with and without receiver.

Compressor work for R401C is 28.57% lower by using receiver than that of work without receiver.

Compressor work for R134A is 5.4% lower by using receiver than that of work without receiver.

The refrigeration effect by incorporating receiver is 21.71% higher than the refrigeration effect without receiver for R401C.

The refrigeration effect by incorporating receiver is 45.96% higher than the refrigeration effect without receiver for R134a.

The maximum COP of the system without receiver for refrigerant R401C is 70.5 % higher by using receiver compared to the COP without using receiver.

The maximum COP of the system without receiver for refrigerant R134a is 54.3 % higher by using receiver compared to the COP without using receiver.

Again by comparing the above performance parameters for R401C and R134a it is observed that COP is higher for R401C than that of R134a where as refrigeration effect is higher for R134a than that of R401C. But the compressor work is lower for R401C than that of R134A.

So finally from the results it is concluded that incorporating low pressure receiver improves the COP, refrigeration effect and simultaneously decreases the compressor work and also the performance is optimum by using R401C refrigerant.

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