Performance Evaluation of VCR System by Using Shell and Tube LSHX

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Abstract *- This paper considers the influence of the heat exchangers to the efficiency of VCC cycle. The shell and tube type heat exchanger will be used to compare the coefficients of performance of vapour compression system with and without liquid suction heat exchanger .By using shell and tube type LSHX instead of tube type heat exchanger length of heat exchanger can be reduced by about 66% for same refrigeration effect. The approximate temperature range will be -50°c to 50°c. Initially performance of liquid suction heat exchanger will be evaluated for present refrigeration system and again the evaporator will be loaded at different flow rate of water across evaporator and with this change performance of LSHX will be studied. With this varying conditions the performance of LSHX will be evaluated with use of change in cop, operating condition, condenser and evaporator pressure and temperature. The expected results will be raise in COP with 10-15% and increase in cooling capacity by 7-9%.*

Keywords- VCC cycle, cop, refrigeration effect, shell and tube type LSHX, etc.

I. INTRODUCTION

The term refrigeration may be defined as the process of removing heat from a substance under controlled conditions. It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings. In other word, the refrigeration means a continued extraction of heat from a body whose temperature is already below the temperature of its surroundings.

According to second law of Thermodynamics, this process can only be performed with the aid of some external work. It is thus obvious that supply of power (i.e. electric motor) is regularly required to drive a refrigerator. Theoretically, a refrigerator is a reversed heat engine or a heat pump which pumps heat from a cold body and delivers it to a hot body. The substance which works in a heat pump to extract heat from a cold body and to deliver it to a hot body is called refrigerant. The refrigeration system is known to the man since the middle of nineteenth century.

1.1 Vapour Compression Cycle:

VCC is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. In this cycle refrigerant is forced to change its state from liquid to vapour in evaporator to absorb heat from surrounding. And it’s cooled again to condense at high pressure in condenser. A compressor is used as power source.

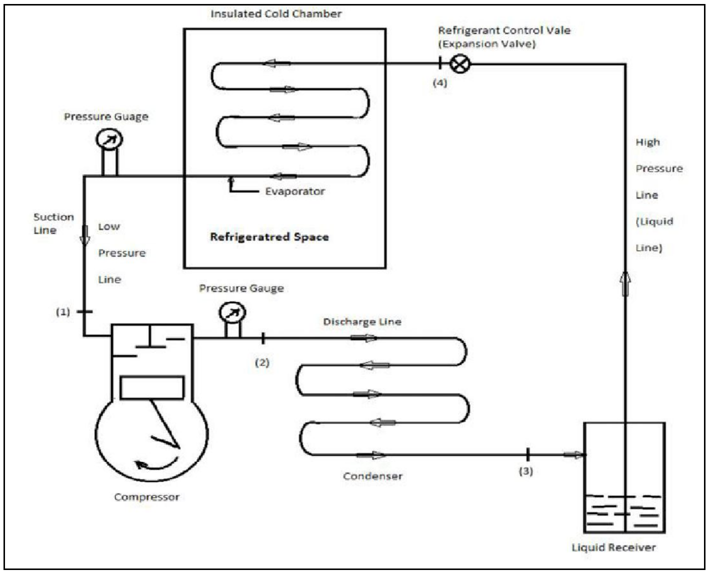

Fig1: Simple vapour compression cycle

1.2 Liquid Suction Heat Exchanger [LSHX]

‘‘Liquid Suction Heat Exchanger (LSHX)’’ is a counter or parallel flow heat exchanger in which the warm refrigerant liquid from the condenser exchanges heat with the cool refrigerant vapour from the evaporator. Since the temperature of the refrigerant liquid at the exit of condenser is considerably higher than the temperature of refrigerant vapour at the exit of the evaporator, it is possible to sub-cool the refrigerant liquid and superheat the refrigerant vapour by exchanging heat between them. It is used in few household refrigeration systems in order to ensure the necessary superheat at the compressor’s inlet section, while promoting certain subcooling before the capillary tube. A LSHX transfers energy from the refrigerant leaving the condenser to the suction gas, resulting in a lower inlet enthalpy at the evaporator, providing a higher cooling capacity.

The one used in household refrigerators is the shell and tube liquid heat exchanger with liquid line (from condenser) placed concentrically inside the suction tube. Another widespread design is the capillary tube heat exchanger. With a capillary tube welded to outer surface of suction line or capillary tube is placed in suction line i.e. concentric heat exchanger.

Liquid-suction heat exchangers are effective in:
i) Increasing the system performance;
ii) Sub-cooling liquid refrigerant to prevent flash gas formation at the inlet of expansion device;
iii) Fully evaporating any residual liquid that may remain in the liquid-suction prior to reaching compressor.

1.3 Problem Statement

With the rapid development of the economics and the improvement living standard of ordinary people worldwide, the use of refrigerating equipment has been increasing quickly in recent years. The investigation report shows that of the total energy consumption in buildings, the amount of energy used by refrigeration system is 24% in restaurants, 28% in Commercial buildings, 18% in office buildings and 30% in hospitals. The ever increasing energy requirement puts a great burden on the further economic development of developing nations as India.

To reduce the energy consumption, by using new energy saving technologies and equipment's is an important task now-a-days, in order to reduce the energy consumption in refrigeration systems. Required degree of sub-cooling and superheating may not be possible if one will to rely only on heat transfer between the refrigerant and external heat source and sink respectively.

Also, if the temperature of refrigerant at the exit of the evaporator is not sufficiently superheated, then it may get superheated by exchanging heat with the surroundings as it flows through the connecting pipelines (useless superheating), which is detrimental to system performance. One way of achieving the required amount of sub-cooling and superheating is by the use of a liquid-suction heat exchanger (LSHX).

II. LITERATURE SURVEY

Bjork et.al.(2006) have studied performance of a domestic refrigerator under influence of varied expansion device capacity, refrigerant charge and ambient temperature and they energy consumption is insensitive to varied EDC and charge within a wide range of settings. For the charge this is explained by the low side accumulator, which buffers over- and undercharge. It was also found that the optimum charge increased at lower ambient temperature. The paper describes an experimental procedure on how to determine the capillary tube length and the quantity of charge for a domestic refrigerator/freezer. This procedure is recommended since it takes different thermal masses and loads into consideration and since the potential for energy saving with a more sophisticated method appears to be limited.

Mastrulloet.al. (2007) have studied a chart for predicting the possible advantage of adopting a suction/liquid heat exchanger in refrigerating system and he found that evidencing that, its use can improve or decrease the system performance depending on the operating conditions. Attention is focused on developing an easy operating method in order to predict the behavior of the system introducing the heat exchanger, changing the operating conditions and/or the refrigerant fluids. To this aim, 19 different ozone friendly fluids (R-22, R-32, R-152a, R-125, R-134a, R-236a, R-227a, RC-318, R-410A, R-413A, R-407C, R-417, R-502, R-507A, R-717, R-290, R-600, R-600a and R-1270) have been considered, varying evaporating and condensation temperatures, respectively in the range 40 ^{0} C to 10 ^{0} C and 25 ^{0} C to 50^{0} C Furthermore, a simple chart allowing to verify the effectiveness of installation of heat exchanger has been developed for each refrigerating fluids and for the specified operating conditions.

Upadhya et.al.(2012) have studied the effect of sub-cooling and diffuser on the coefficient of performance of vapour compression refrigeration system mainly carried out to improve the coefficient of performance of system. He found that to improve the coefficient of performance, it is required that compressor work should decrease and refrigerating effect should increase. The purpose of a compressor in vapour compression system is to elevate the pressure of the refrigerant, but refrigerant leaves the compressor with comparatively high velocity which may cause splashing of liquid refrigerant in the condenser, liquid hump and damage to .condenser by erosion. It is needed to convert this kinetic energy to pressure energy for this purpose diffuser can be used. By using diffuser , power consumption is less for same refrigerating effect so performance is improved. The size of the condenser can also be reduced due to more heat transfer. So cost of the condenser will be reduced.

Waykoleet.al.(2014) have studied performance evaluation of water cooler with modification of Liquid Suction Heat Exchanger and they found that ,The effects of different flow rates of refrigerant and initial temperature of water on COP, work of compression, refrigeration effect of the system, heat exchange capacity of the LSHX, effectiveness of the LSHX & refrigeration capacity of the evaporator are calculated and analyzed. On the basis of experimentation and analysis, it is found that, use of liquid suction heat exchanger in the VCRS, increases the COP of the refrigeration unit for different initial temperatures of water. The power consumption by the compressor gets reduced by using the liquid suction heat exchanger. The optimum effect of the LSHX is seen at different flow rates of the refrigerant for lower initial temperature of water (30 to 35 °C).

Klein et.al.(2000) have studied refrigeration system using liquid-suction heat exchangers in the year 2000 and found that a new dimensionless group to correlate performance impacts attributable to liquid-suction heat exchangers. Second, the paper extends previous analyses to include new refrigerants. Third, the analysis includes the impact of pressure drops through the liquid- suction heat exchanger on system performance. It is shown that reliance on simplified analysis techniques can lead to inaccurate conclusions regarding the impact of liquid-suction heat exchangers on refrigeration system performance.

From detailed analyses, it can be concluded that liquid-suction heat exchangers that have a minimal pressure loss on the low pressure side are useful for systems using R507A, R134a, R12, R404A, R290, R407C, R600, and R410A. The liquid-suction heat exchanger is detrimental to system performance in systems usingR22, R32, and R717.

Cutler et.al.(2000) have studied Suction Line Heat exchanger for R134a Automotive Air-Conditioning System and found that Depending on the operating conditions and design, a suction line heat exchanger can improve the performance of an automotive system_ At higher air temperatures of 40°C at the condenser and with a low air velocity of 1.0 m/s, which typically occurs in idling conditions, a suction line heat exchanger can improve the capacity as well as the COP by about 5 to 10 % .At higher air velocities and lower temperatures, the benefit nearly vanishes

Patel et.al.(2013) have studied Experimental Investigation of Sub Cooling Effect on Simple Vapour Compression System by Domestic and they found that In refrigeration systems, system performance increases with subcooling. A thermoelectric cooling device, placed at the outlet of the condenser to subcool the liquid refrigerant in a vapour compression refrigeration system. It increases of cop of vapour compression system in domestic refrigerator. The result obtained showed that cop of vapour compression system with thermoelectric module is higher than vapour compression system without module. An increase in subcooling reduces the compressor work input and increases the system refrigeration capacity. Thermoelectric module are not position dependent & required lower space so easily applicable in domestic refrigerator for sub cooling purpose

Rashed et.at.(2011) have studied effect of the evaporator temperature on vapour compression refrigeration system and he found that The results of a refrigeration system simulation software to an increase in the amount of oil flowing with the refrigerant show that there are optimal values of the apparent overheat, for which either the exchanged heat or the refrigeration COP is maximized. It is not possible to optimize both the refrigeration COP and the evaporator energy. However, in most of the cases the optima values of the apparent overheat are below the values that the expansion valves usually impose. It would be possible to improve the refrigeration COP by increasing the apparent overheat above 6 K when the oil mass fraction is greater than 1%, but at the expense of the evaporator energy. In this study, we evaluated the performance of R600a, R134a, R290, R22, R410A, and R32.

dagilis et.al.(2004) have studied Liquid–gas heat exchanger for household refrigerator. They performed experiment with different types of LSHX, mostly common in household refrigerators.

Tube-in-tube heat exchanger with a capillary tube placed concentrically inside the suction tube. Another widespread design is the heat exchanger with a capillary tube welded to the outer surface of the suction tube. They found that any decrease in flow area of suction line will cause pressure drop at compressor suction, this will increase compressor work and consequently will decrease in COP of the system. Therefore LSHX should be designed such that flow area of suction line should be kept constant, and if outer tube is not available as design then a tube of higher diameter should be used.

Peixoto and Bullard et.al.(2012) have found that application of capillary tube in the liquid suction heat exchanger will give better results with R134a rather than R22,due to its lower specific volume. The compressor volumetric efficiency is higher for R134a than R22 as the density of R134a is more than R22; also the mass flow rate required for R134a is less than R22 because of its higher latent heat than R22 at same saturation evaporator temperature.

Guo-yan Zhou et.al.(2012) have studied that Prediction of temperature distribution in shell-and-tube heat exchangers and they found that On the basis of the differential theory, an accurate and simplified model for predicting temperature distribution in the shell-and-tube heat exchanger is proposed. According to the baffle arrangement and tube passes, the heat exchanger is divided into a number of elements with tube side current in series and shell side current in parallel. Two examples of BEU and AES heat exchangers with single-phase fluid are analyzed to demonstrate the application and accuracy of the proposed model in temperature distribution prediction, compared with the Cell model and HTRI method. The results show that the proposed model reproduces the temperature distribution given by the HTRI solution on the tube side flow with 0.19% accuracy for the BEU heat exchanger and 0.35% for the AES heat exchanger.

III. DESIGN AND SLECTION OF REFRIGERATION COMPONENT

3.1 Compressor Selection

Cooling capacity calculations:

Let, suppose we want to cool 10 kg of water in ½ hr. from 30℃to 5℃. Therefore cooling load will be,

$$Q = \frac{m * Cp * \Delta T}{1800} kw$$

$$Q = \frac{10 * 4.2 * 25}{1800}$$

But,

1 kW cooling = 3418.80 BTU/hr cooling.

Therefore,

0.6 kW cooling=2051 BTU/hr at 5 ^{0}C

This is the desired cooling capacity

Selection of compressor from catalogue of “emerson compressors”

The function of compressor is to suck the vapour (suction line) from evaporator through liquid suction heat exchanger and to compress it upto the condenser pressure.

Model- KCE444HAG
Cooling capacity- 1690 BTU/hr at -6.7 ^{0}C

3.2 Condenser Selection:

A Water Cooled Condenser may be located either adjacent to or remote from the compressor. Also, a condenser may be designed for either indoor or outdoor operation and the discharge of air may be either vertical or horizontal. In a Water Cooled Condenser, heat is transferred in three phases:

i) De-superheating
ii) Condensing and
iii) Sub-cooling

Condenser capacity calculations:

Heat rejection through condenser is addition of heat supplied through evaporator and compressor input power.

Qc = Qe + Pc
= 0.6 + 0.45 kW
Qc = 1.05 kW

Therefore, selecting a condenser of **1.5 kW**capacities, which is suitable for system.

Water cooled condenser design calculation:

Logarithmic mean temperature difference:

$$\text{LMTD} = \Delta T_{\text{LM}} = \frac{\Delta T_{\text{in}} - \Delta T_{\text{out}}}{\ln(\frac{\Delta T_{\text{in}}}{\Delta T_{\text{out}}})}$$

Where,

$$\Delta T_{\text{in}} = (\Delta T_{\text{in hot}} - \Delta T_{\text{out cold}}) = 26℃$$
$$\Delta T_{\text{out}} = (\Delta T_{\text{out hot}} - \Delta T_{\text{in cold}}) = 3℃$$

So LMTD equation becomes,

$$\text{LMTD} = \Delta T_{\text{LM}} = \frac{26 - 3}{\ln(\frac{26}{3})}$$
$$\Delta T_{\text{LM}} = 10.65℃ \cong 11℃$$

We have,

$$Q_c = h_c \times A_c \times \Delta T$$
$$1500 = 200 \times A_c \times 11$$

(∵he = 200 W/ m^2K)

$$A_c = 0.6818\ m^2$$

Now area of condenser coil is given by,

$$A_c = \pi \times D_c \times L_c$$
$$\because L_c = 23.50\ \text{m} \cong 24\ \text{m}$$

So new present area of condenser coil for 24 m of coil length is $A_c = 0.6974\ m^2$

Capacity of condenser water tank:

Dimensions of cylinder

Tank Diameter D = 0.350 m
Tank height L = 0.450 m

Therefore, volume of tank

Tank volume (V) =cylinder volume - condenser coil volume

$$V = \frac{(\pi \times D^2 \times L)}{4} - \frac{(\pi \times D^2 \times L_c)}{4}$$

So nearly 30 ltr of tank is required for the condenser.

3.3 Selection Of Capillary Tube:

A capillary tube is a long, narrow tube of constant diameter. Typical tube diameters of refrigerant capillary tubes range from 0.3 mm to 3 mm and the length ranges from 1.0 m to 6 m. The pressure reduction in a capillary tube occurs due to the following two factors:

i) The refrigerant has to overcome the frictional resistance offered by tube walls. This leads to some pressure drop.
ii) The liquid refrigerant flashes (evaporates) into mixture of liquid and vapour as its pressure reduces. The density of vapour is less than that of the liquid. Hence, the average density of refrigerant decreases as it flows in the tube. The Mass flow rate and tube diameter (hence area) being constant, the velocity of refrigerant increases since $\dot{m}_r = \rho VA$. The increase in velocity or acceleration of the refrigerant also requires pressure drop.

Fig.2:Capillary tube

3.4 Evaporator Design:

Function of evaporator is to provide required heat transfer surface area through which heat will be absorbed by the vapour refrigerant from cold chamber or refrigerated space. Evaporators are being heat exchangers, are also classified as per the medium they cool like air cooling evaporator and liquid chilling evaporators.

Coil Evaporator:

This is similar to the shell and coil condenser. Normally liquid is chilled in the shell with refrigerant in coil. A lowering of liquid temperature below normal during partial loads allows storage of cooling capacity. This becomes useful during peaks and result in lesser capacity of plant. In some cases like instant water cooler, water may be circulated through coil to give instant cooling. We have coil type evaporator with following specifications

Diameter of evaporator tube De=9.25mm

Design calculations:

We have heat transfer rate for evaporator coil 660 W (∵1690 BTU/hr compressor Capacity).

Therefore, designing evaporator for 660 W capacity
We have,

$$Q_e = h_e \times A_e \times \Delta T$$
$$660 = 200 \times A_e \times 8$$
$$(\because h_e = 200\ W/\ m2\ K)[11]$$
$$A_e = 0.4125\ m^2$$

Now area of evaporator coil is given by,

$$A_e = \pi \times D_e \times L_e$$
$$\because \quad L_e = 14.19\ m \cong 15\ m$$

Therefore the evaporator coil length is 15 m
Therefore present area of evaporator coil is,

$$A_e = \pi \times D_e \times L_e$$
$$A_e = 0.4358\ m^2$$

Capacity of water tank required

Dimensions of tank
Tank Diameter D = 0.300 m
Tank height L = 0.300 m
Therefore, volume of tank

V= cylinder volume- evaporator coil volume
= 0.02019 ≈ 0.020

Therefore volume of tank is V= 0.020 m^3
Then water will store capacity of the tank is = 20 liter of water

IV. DESIGN AND MODEL DEVELOPMENT OF LIQUID SUCTION HEAT EXCHANGER [LSHX]

The proper design, operation and maintenance of heat exchangers will make the process energy efficient and minimize energy losses. A LSHX transfers energy from the refrigerant leaving the condenser to the suction gas, resulting in a lower enthalpy at the inlet of evaporator, providing more cooling capacity. The competing effects with respect to performance are a larger enthalpy change across the compressor, condenser and evaporator with a lower mass flow rate. Now for designing of LSHX we are having a reading set of ordinary water chiller which is having same specifications as our selected design. From these reading we can estimate the amount of heat transfer that can be possible through LSHX.

Now effectiveness is the ratio of the actual heat transfer to the heat that could be transferred by a heat exchanger of infinite size. Effectiveness is the best way to compare different types of heat exchangers. The product of the mass flow rate and the specific heat of thehot stream is less than that of the cold stream, because of the required heat transfer rate balance.

$$(mCp\Delta T)\ \text{cold} = (mCp\Delta T)\ \text{hot}$$

Therefore,

$$(\Delta T)\ \text{cold} > (\Delta T)\ \text{hot} \because (mCp)\ \text{cold} < (mCp)\ \text{hot}$$

Effectiveness,

$$\epsilon = \frac{(mc_p)_{cold}}{(mc_p)_{min}} \times \frac{Tout_{clod} - Tin_{cold}}{Tin_{hot} - Tin_{cold}}$$

Where,

$Tout_{cold}$= suction line outlet temperature;
Tin_{cold}= suction line inlet temperature
Tin_{hot} = liquid line inlet temperature;
$Tout_{hot}$= liquid line outlet temperature

We have,

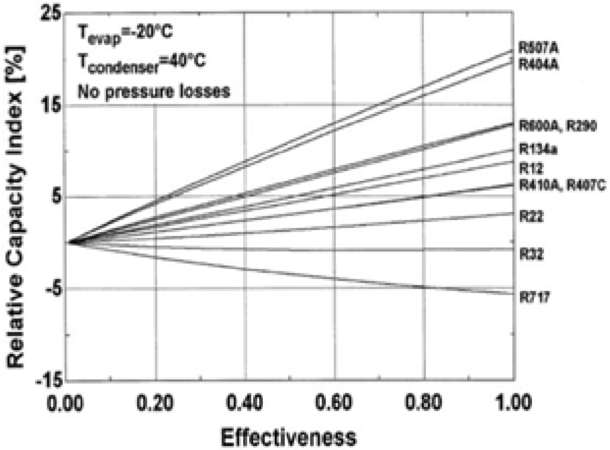

Fig3: Effectiveness of LSHX vs. Relative capacity index for different refrigerants [4]

Form Fig we can see that 65% effective heat exchanger can give 8% relative capacity index. Therefore we are considering a LSHX which is having ε=0.65. Where, relative capacity index means percentage rise in *COP* value with LSHX.

Now, we have reading,

$$T_{in\ cold} = 23℃$$

$$T_{in\ hot} = 41℃$$

Therefore using the effectiveness formula we get,

$$T_{out\ cold} = 35℃$$

Energy balance equation for heat exchanger:

$$m_{lr} \times Cp_{lr} \times \Delta T_{hot} = m_{vr} \times Cp_{vr} \times \Delta T_{cold}$$

Where,

Cplr=1.5(kJ/kg K) Specific heat of liquid refrigerant at 41℃ (at 314K)
Cpv=1(kJ/kg K) Specific heat of vapour refrigerant at 23 ℃ (at 296K)

The above equations become

$$Cp_{lr} \times (T_{in} - T_{out})_{hot} = Cp_{lr} \times (T_{out} - T_{in})_{cold}$$

By putting the values

$$(T_{out})_{hot} = 33℃ = 306K$$

$$LMTD = \Delta T_{lm} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln \frac{\Delta T_{in}}{\Delta T_{out}}}$$

$$\Delta Tln = 7.83 \cong 8°C = 281K$$

Heat exchange through LSHX

$$Q = m_{vr} \times Cp_{vr} \times \Delta T_{cold} \quad KW$$

Where,

Q=Heat transfer rate in kW
Mvr=5.5× 10^{-3}kg/sec (as per specification of compressor).
Cpvr=Specific heat of superheated vapour of R134a
ColdΔT = Temperature difference for vapour (suction) line $= 35 - 23 = 12℃$

Substituting values we get

$$Q_{LSHX} = 66W$$

4.1 heat exchanging area for LSHX:

We have,

$$Q_{LSHX} = h_r \times A \times \Delta T_{lmtd}$$

Where,

h_r= overall heat transfer coefficient for R134a
h_r= 490 W/m²K (experimentally determined value)
A= Area required for heat exchanger.

By putting the values and solving above equation we get

$$A = 0.01683 m^2$$

This is final area required of heat exchanger A = 0.01683 m².

In design of LSHX we have area as 0.01683 m², and diameter as 5 mm, From that we can calculate length as

$$A = N \times \pi \times D \times L_{tube}$$

Where

N= numbers of tubes=4
D_0 = dia of tube
L =Length of tube

$$\because \quad 0.01683 = 4 \times \pi \times 0.005 \times L$$
$$L = 0.2678 \text{ m} \cong 27 \text{ cm}$$

Shell side design

From standard, length of tube should be 5 to 10 times of diameter of shell, so selecting the ratio 9, we get diameter of shell as 3 cm

$$D_{shell} = 0.030 \text{ m}$$
$$\text{clearance} = 0.900 \text{ cm}$$
$$\text{Pitch} = d_0 + c$$
$$\text{Pitch} = 1.4 \text{ cm}$$

Final Dimensions of heat exchanger:

Numbers of tubes = 4
Diameter of tube = 0.5 cm
Lengthof tube = 27 cm
Pitch of tube = 1.4 cm
Clearance of tube = 0.9 cm
Shell diameter = 3 cm

V. VCR SYSTEM WITH WATER COOLED CONDENSER & LSHX:

Working:

Working of this system is same as that vapor compression cycle. After starting of the compressor, the hot refrigerant leaving the compressor under pressure is discharged into the condenser. Here condenser is water cooled condenser, consisting copper coil made in coil type & around circumference of coil there is continuous supply water. Here high temperature, high pressure refrigerant condensed at constant pressure, rejecting heat to water; And then high pressure liquid line is passed through the liquid suction heat exchanger (LSHX).

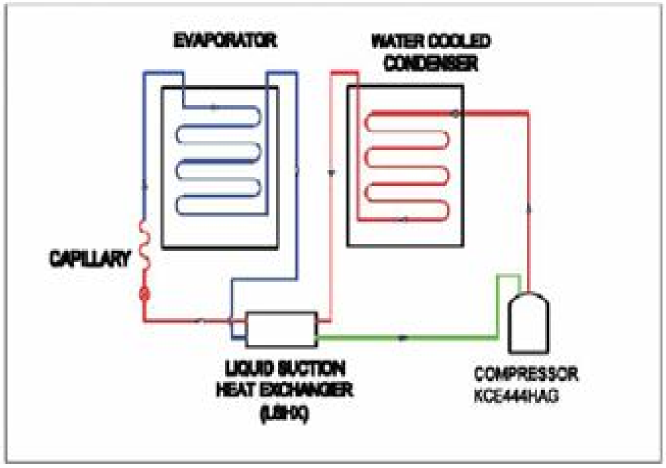

Fig 4: Schematic diagram of experimental setup with LSHX using water cooled condenser.

The suction line heat exchanger transfers heat to the suction gas, providing more cooling capacity and improving the cycle COP. Refrigerant after passing through Liquid Suction Heat Exchanger (LSHX) goes into Capillary tube. It reduces the high pressure liquid refrigerant into low pressure liquid refrigerant before being fed to the evaporator. Low pressure, low temperature refrigerant then goes into evaporator. Evaporator is made up of coil shape, around circumference of which water is present. Refrigerant absorbs latent heatat constant pressure to this water. Water gets cooled refrigerant converts into vapor form. Low pressure, high temperature refrigerant passes through LSHE gets further heat. The refrigerant loop is equipped with thermocouples on tubing at different places and pressure gauges at the inlet and outlet of the main components.

IV. CONCLUSION

Performance of VCR cycle with and without heat exchanger was evaluated by varying different flow rate of water across evaporator a suction line heat exchanger can improve the performance of VCR system by 10-15% and increase in cooling capacity by 7-9%. By using shell and tube type LSHX instead of tube type heat exchanger length of heat exchanger can be reduced by about 66% for same refrigeration effect. Also it as observed that. As the system running time increases the COP system reduces to some amount and becomes constant after some time. At the starting of the system, maximum heat transfer through LSHX, heat transfer reduces as time progresses and becomes constant. Compressor work reduces as time progresses. We will get constant heat transfer water cooled system which is not possible in case air cooled system.

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