Performance analysis of Water Cooled Domestic Refrigerator

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Abstract: ***A large increase in the requirement of energy is the biggest problem faced by the world at present. This results in usage of more and more energy resources which is not a good sign. So there should be actions taken so as to reduce the energy losses from any system and an attempt should be made to develop an energy efficient device that utilizes maximum amount of the energy supplied. Keeping these things in mind a water cooled condenser refrigerator system is developed. In this paper the COP of the refrigerator by using water as the cooling medium instead of air for condenser system is calculated, which is the cooling medium in conventional refrigeration system otherwise. In this, experimental study performance of water cooled condenser is compared with the air cooled condenser in a domestic refrigeration system. It is observed that refrigerating effect increased and compressor work reduced hence COP increased.***

Keywords – Domestic refrigerator, air cooled condenser, water cooled condenser, COP, Refrigerating effect, compressor work, pressure ratio.

I. INTRODUCTION

A household refrigerator is a common household appliance that consists of a thermally insulated compartment and which when works, transfers heat from the inside of the compartment to its external environment so that the inside of the thermally insulated compartment is cooled to a temperature below the ambient temperature of the room. Heat rejection may occur directly to the air in the case of a conventional household refrigerator having air-cooled condenser or to water in the case of a water-cooled condenser. Tetrafluoroethane (HFC134a i.e.R-134a) refrigerant was now widely used in most of the domestic refrigerators. Heat can be recovered by using the water-cooled condenser and the system can work as a waste heat recovery unit. The recovered heat from the condenser can be used for bathing, cleaning, laundry, dish washing etc. Typical waste heat temperature for air conditioning and refrigeration condensers are 35 to 45^0C. Low temperature waste heat may be useful in a supplementary way for preheating purposes. Keeping this in mind, a technique for condensing heat of the refrigeration system is proposed in this paper. This new system provides not only the refrigeration effect, but also hot water. The hot water can also be stored in a tank for later use. The modified system results in energy saving due to non-usage of electricity for heating the water and cost saving by combining both utilities (refrigeration and heating) in one system. The hot water which was obtained from the water-cooled condenser can be utilised for household applications like cleaning, dish washing, laundry, bathing etc.

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components is concerned. However, differences exist as far as the heat transfer phenomena are concerned. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. Normally, the external fluid does not undergo any phase change, except in some special cases such as in cascade condensers, where the external fluid (another refrigerant) evaporates. In evaporators, the liquid refrigerant evaporates by extracting heat from an external fluid (low temperature heat source). The external fluid may not undergo phase change, for example if the system is used for sensibly cooling water, air or some other fluid. Earlier different types of condenser slides air cooled condenser, water cooled condenser is been used in a domestic refrigeration system. Air cooled condenser is most popular condenser for a refrigerator. Many researches done in a past ion the condenser, one of them is water cooled condenser. Heat transfer rate can be increased by using this condenser.

II. NOMENCLATURE

Time = Time span for taking reading in minutes,
T_1 = Temperature at compressor inlet in degree Celsius,
T_2 = Temperature at compressor outlet in degree Celsius,
T_3 = Temperature at condenser outlet in degree Celsius,
T_4 = Temperature at evaporator in degree Celsius,
T_5= Temperature of water in condenser in degree Celsius,
P1= Suction pressure in Psi
*P2=D*ischarge pressure in Psi
W_c= compressor work in kJ/kg
Q_c = heat removed in the condenser
R.E. = refrigerating effect in kJ/kg
h_4 = enthalpy of vapour entering evaporator in kJ/kg
h_1 = enthalpy of vapour leaving evaporator in kJ/kg
h_2 = enthalpy of vapour leaving evaporator in kJ/kg

III. Problem Statement and Objective

A large increase in the requirement of energy is the biggest problem faced by the world at present. This results in usage of more and more energy resources which is not a good sign. So there should be actions taken so as to reduce the energy losses from any system and an attempt should be made to develop an energy efficient device that utilizes maximum amount of the energy supplied.

To find out energy efficient domestic refrigerator with improvement in Coefficient of Performance by changing air cooled condenser into water cooled condenser.

Work Objective

- The objective of this project is to determine the energy savings associated with improved heat transfer rate in domestic refrigerator.
- To analyze performance of water cooled condenser.
- Result analysis of various parameters like, Refrigeration effect, Work input & COP.

IV. METHODOLOGY

The methodology of the system design is evaluated by following procedure.

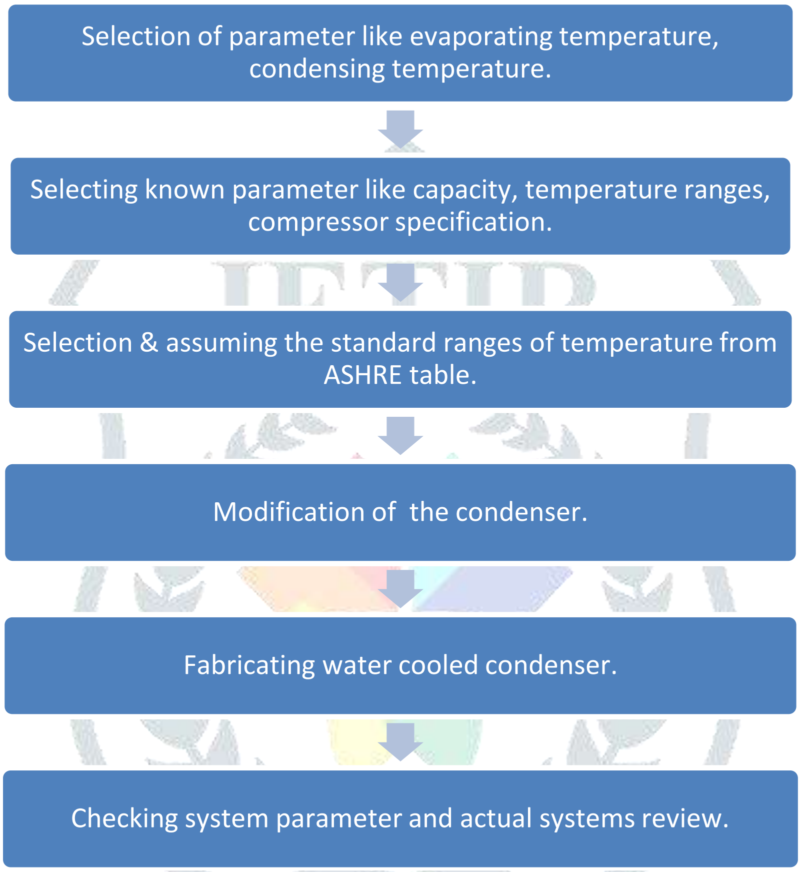


Fig I. Flow Chart

V. EXPERIMENTAL SETUP

Experimental setup consists of 165 L capacity. The system was retrofitted with a water tank having capacity of 20 L. A tank made-up of MS is fitted at the beginning of the condenser line. A portion of the condenser line is immersed in the tank in which heating occurs. The volume of water used for testing is 14.4 L. Water in tank was kept stationery till water get temperature more than 40^0C. An instrument panel made-up of MS is used for mounting gauges. Pressure gauges indicating suction pressure of compressor and pressure after condensation. A digital temperature indicator set has been used to monitor various temperatures encountered in the system. Symbols used for indicating temperatures are below:

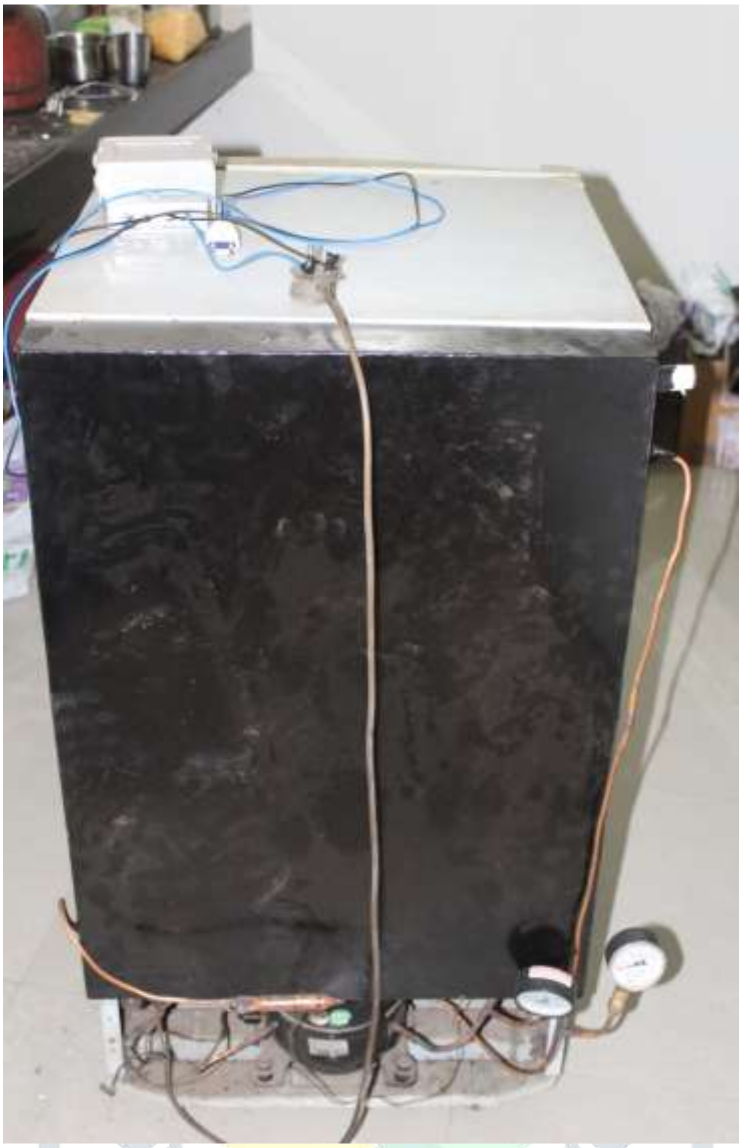


Fig-II Experimental setup

VI. Test Procedure

The objective of the study is to compare the refrigeration performance of R-134a and R-600a refrigerants. Digital Temperature was used to measure the temperatures and pressures were measured using calibrated pressure gauges. The ranges of equipment used in the experimental test setup are showed in Table. The temperatures and pressures of the refrigerant and initial water temperatures are measured at various locations in the experimental setup as shown in Figure 6.1. Put main switch 'ON'. Start the refrigerator to keep the water temperature in evaporator uniform. Wait 150 minutes to achieve steady state condition. Note down all readings in observation table at following test conditions as given below. The test is performed at 32^0C ambient temperature and inlet water temperature 28^0C.

From above figure analysis of vapour compression refrigeration cycle is done with following assumptions

I. Each component of cycle is analyzing as a control value as a steady state.
II. Except for the expansion through the capillary valve which is throttling process (Irreversible). All processes of the refrigerant are internally reversible.
III. The compressor operates adiabatically.
IV. The pressure losses in the flow line of evaporator and condenser are neglected.
V. The compression process is an isentropic Process.
VI. Kinetic and potential energies are negligible.
VII. Evaporation and Condensation occur only at Constant Temperature.

A) Compressor

Compressor is a steady flow machine. For reversible adiabatic or isentropic compression of vapour, the shaft work/kg input is given by,

$$Wc = (h_2 - h_1) \text{ kJ/kg}$$

Where W_c is compressor work; h_2 and h_1 are enthalpies at suction and delivery of the compressor respectively. On the p-h chart the values of h_2 and h_1 can be read out. Condenser steady flow process

Dry saturated vapour refrigerant rejects heat at constant pressure to cooling medium during process 2-3. Cooling at constant pressure, the heat removed is given by,

$$Q_c = (h_2 - h_3) \text{ kJ/kg}$$

Where, Q_c is the heat removed in the condenser

h_3 is the enthalpy of liquid/kg leaving the condenser

On the P-h chart, the values of h_3 and h_2 can be read out direct from the chart.

B) Throttling in capillary tube

Steady flow process throttle expansion is a constant enthalpy process. There is no work or heat transfer. The pressure of refrigerant is reduced to evaporator pressure as it passes through capillary tubes. The condition of vapour at the end of expansion is wet, therefore $h_3 = h_4$

C) Evaporator

Steady Flow Process. No work done, heating at constant pressure where the heat absorbed/kg is given by

$$Q_e = (h_1 - h_4)\ \text{kJ/kg}$$

Where Q_e is the refrigerating effect

h_4 is the enthalpy of vapour entering evaporator/kg

h_1 is the enthalpy of vapour leaving evaporator/kg

D) Theoretical COP

The coefficient of performance of refrigerant is given by,

$$\frac{\text{Refrigerating effect, RE}}{\text{Work of compression, Wc}} = \frac{h1 - h4}{h2 - h1}$$

E) Compressor Pressure Ratio

$P.R = P_d / P_s$

Where,

P_2 = Refrigerant vapour pressure at the compressor discharge (kN/m^2);

P_1= Refrigerant vapour pressure at the compressor suction (kN/m^2).

VI. EXPERIMENTAL RESULT

We have conducted experiment on our vapour compression refrigeration test rig. Totally eight temperature readings were taken one after another with a gap of 15 minutes. Suction pressure and discharge pressure were also noted down. In this experiment, we are studying two different parameters. Firstly readings were taken for systems with air cooled condenser & water cooled condenser.

Table no. I : Observations for R600a with air cooled condenser

Sr. No	Time (min.)	T_1(°c)	T_2(°c)	T_3(°c)	T_4(°c)	*P1*	*P2*	*Time for* 10 blinks
1	0	30.1	30.3	30.1	30.2	0	0	0
2	15	27.3	52.1	44.0	20.3	10	160	64
3	30	26.1	53.4	45.8	16.6	10	175	69
4	45	25.4	55.1	47.8	13.8	10	195	71
5	60	24.3	58.3	48.6	11.9	12	200	76
6	75	22.9	61.4	49.9	10.6	15	210	81
7	90	21.7	65.3	51.3	9.2	15	210	83
8	105	20.8	67.5	52.7	8.1	15	210	87
9	150	19.6	68.4	54.2	7.3	15	210	91

TABLE NO. II :OBSERVATIONS FOR R600A WITH WATER COOLED CONDENSER

Sr. No	Time (min.)	T_1(°c)	T_2(°c)	T_3(°c)	T_4(°c)	T_5(°c)	*P1*	*P2*	*Time for* 10 blinks
1	0	30.1	30.3	30.1	30.2	1	0	0	0
2	15	27.4	52.3	40.1	20.6	28.1	10	160	66
3	30	26.2	53.3	41.9	16.1	30.2	10	170	69
4	45	25.3	55.2	43.3	12.9	32.9	10	180	73
5	60	24.1	57.8	45.2	10.8	34.8	12	190	78
6	75	22.6	60.2	46.9	8.9	37.4	13	190	84
7	90	21.3	63.4	48.1	6.8	39.6	15	190	89
8	105	20.2	65.6	49.7	5.1	41.8	15	190	96
9	150	19.1	67.1	51.1	3.2	44.2	15	190	102

Table no. III Observations for R134a with air cooled condenser:

Sr. No	Time (min.)	T_1(°c)	T_2(°c)	T_3(°c)	T_4(°c)	*P1*	*P2*	*Time for* 10 blinks
1	0	30.1	30.3	30.1	30.2	0	0	0
2	15	27.9	53.1	41.7	28	10	160	54
3	30	27.3	55.3	44.8	26.7	10	180	57
4	45	26.6	57.0	47.8	23.3	10	200	59
5	60	25.8	59.6	49.6	20.5	12	215	61
6	75	24.9	61.7	51.4	17.6	13	230	64
7	90	24.1	63.4	53.7	14.1	13	240	66
8	105	23.2	65.8	55.6	12.3	15	240	69
9	120	22.4	67.6	57.7	10.4	15	250	73
10	135	21.1	69.7	59.4	8.1	15	250	74
11	150	19.8	71.5	61.6	6.8	15	250	76

Table no. IV Observations for R134a with water cooled condenser:

Sr. No	Time (min.)	T_1(°c)	T_2(°c)	T_3(°c)	T_4(°c)	T_5(°c)	*P1*	*P2*	*Time for* 10 blinks
1	0	30.1	30.3	30.1	30.2	28.0	0	0	0
2	15	28.1	53.2	39	28.1	28.2	10	160	55
3	30	27.5	54.8	42.1	26.2	30.3	10	180	59
4	45	26.4	56.9	44.3	22.9	32.5	10	195	63
5	60	25.3	58.6	46.6	19.6	34.9	12	205	65
6	75	24.0	60.4	48.7	16.3	37.0	12	215	67
7	90	23.6	62.3	50.5	13.1	40.1	13	215	69
8	105	22.4	64.1	52.4	10.3	42.8	15	220	72
9	120	21.1	65.9	54.3	7.6	44.5	15	220	76
10	135	19.9	67.4	56.4	5.4	46.1	15	220	80
11	150	18.6	69.3	57.1	4.1	47.3	15	220	83

VI.1. Calculations for R600a with air cooled condenser :

I. Theoretical Reading :

Pressure readings:

P1= 15psi = 1.03421 bar
P2= 210 psi = 14.479 bar
Where *P1*= Suction pressure at compressor inlet.
P2= Discharge pressure at compressor outlet

From P-h Chart:

h_1 = 535 KJ/Kg
h_2 = 660 KJ/Kg
$h_3 = h_4$ = 400 KJ/Kg

Specific heat absorption in the evaporator (RE) (kJ/kg):

RE = h_1 - h_4

= 535-400

= **135 kJ/kg**

Specific heat rejection in condenser (KJ/Kg):

Q_R = h_2 - h_3

= 660-400

= **260 kJ/kg**

Compression work (kJ/kg):

W_c = h_2 - h_1

= 660-535 = **125 kJ/kg**

Coefficient of performance of this refrigerating system:

$$COP = \frac{RE}{W_c} = \frac{h_1-h_4}{h_2-h_1} = \frac{535-400}{660-535} = \frac{135}{125}$$

= **1.08**

Pressure ratio of the system:

$$P.R = \frac{P_2}{P_1} = \frac{210}{15}$$

= **14**

II. Actual Reading:

Actual Refrigerating effect

$$R.E. = \frac{m.cp.dt}{t}$$

$$R.E.1 = \frac{10*4.187*(20.3-16.6)}{15*60} = 0.17$$

Similarly,

R.E.2 =0.13

R.E.3 =0.080

R.E.4 =0.060

R.E.5 =0.060

R.E.6 =0.050

R.E.7 =0.030

$$(R.E.)_{Actual} = \frac{R.E.1+R.E.2+R.E.3+R.E.4+R.E.5+R.E.6+R.E.7}{7}$$

(R.E.)Actual = 0.08285

Actual compressor work

$$W.C. = \frac{\text{no.of pulses}*3600}{\text{time for 10 blinks}*3200}$$

$$W.C.1 = \frac{10*3600}{64*3200}$$

W.C.1 = 0.1757

Similarly,

W.C.2= 0.1630

W.C.3= 0.1584

W.C.4= 0.1480

W.C.5= 0.1388

W.C.6= 0.1355

W.C.7= 0.1293

W.C.8= 0.1236

$$(W.C.)_{Actual} = \frac{W.C.1+W.C.2+W.C.3+W.C.4+W.C.5+W.C.6+W.C.7+W.C.8}{8}$$

(W.C.) Actual = 0.1465

$$\textbf{Actual COP} = \frac{RE}{W_c} = \frac{0.08285}{0.1465}$$

Actual COP =0.5655

Calculations for R600a with water cooled condenser :

I. Theoretical Reading :

Pressure readings:

P1= 15psi = 1.03421 bar

P2= 190 psi = 13.1 bar

Where *P1*= Suction pressure at compressor inlet.
P2= Discharge pressure at compressor outlet

From P-h Chart:
$h_1 = 535$ KJ/Kg
$h_2 = 642$ KJ/Kg
$h_3 = h_4 = 380$ KJ/Kg

Specific heat absorption in the evaporator (RE) (kJ/kg):

$$RE = h_1 - h_4 = 535-380 = \mathbf{155\ kJ/kg}$$

Specific heat rejection in condenser (KJ/Kg):

$$Q_R = h_2 - h_3 = 642-380 = \mathbf{262\ kJ/kg}$$

Compression work (kJ/kg):

$$W_c = h_2 - h_1 = 642-535 = \mathbf{107\ kJ/kg}$$

Coefficient of performance of this refrigerating system:

$$COP = \frac{RE}{W_c} = \frac{h_1-h_4}{h_2-h_1} = \frac{535-380}{642-535} = \frac{155}{107} = \mathbf{1.44}$$

Pressure ratio of the system:

$$P.R = \frac{P_2}{P_1} = \frac{190}{15} = \mathbf{12.66}$$

II. Actual Reading:

Actual Refrigerating effect

$$R.E. = \frac{m.cp.dt}{t}$$

$$R.E.1 = \frac{10*4.187*(20.6-16.1)}{15*60} = 0.2093$$

Similarly,
R.E.2 =0.1488
R.E.3 =0.097
R.E.4 =0.088
R.E.5 =0.09769
R.E.6 =0.079
R.E.7 =0.0883

$$\textbf{(R.E.)Actual} = \frac{R.E.1+R.E.2+R.E.3+R.E.4+R.E.5+R.E.6+R.E.7}{7}$$

(R.E.)Actual = 0.1154

Actual compressor work

$$W.C. = \frac{\text{no.of pulses}*3600}{\text{time for 10 blinks}*3200}$$

$$W.C.1 = \frac{10*3600}{66*3200}$$

W.C.1 = 0.1704

Similarly,
W.C.2= 0.1630
W.C.3= 0.1541
W.C.4= 0.1442
W.C.5= 0.1339
W.C.6= 0.1264
W.C.7= 0.1271
W.C.8= 0.1102

$$(W.C.)\ Actual = \frac{W.C.1+W.C.2+W.C.3+W.C.4+W.C.5+W.C.6+W.C.7+W.C.8}{8}$$

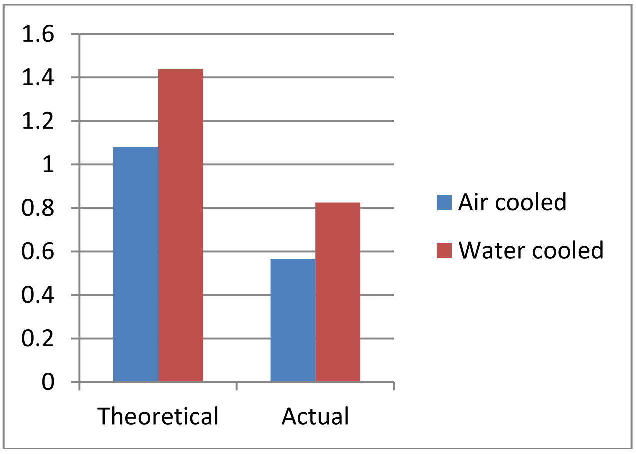
(W.C.) Actual = 0.1399

$$\textbf{Actual COP} = \frac{RE}{W_c} = \frac{0.1154}{0.1399}$$

Actual COP =0.8248

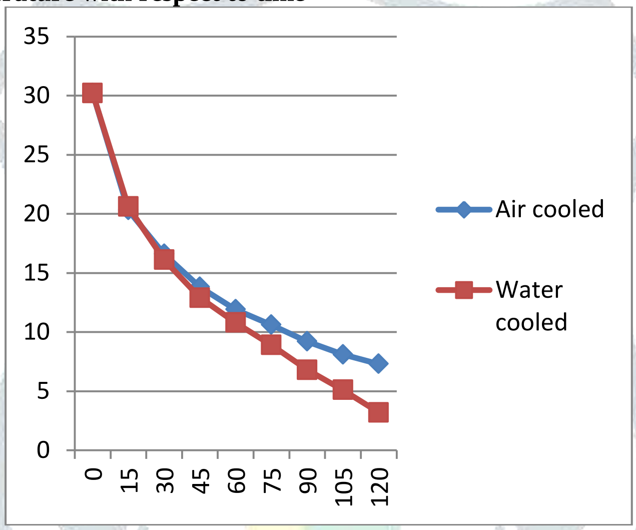
Result and Discussion

Graph of R-600a for comparing theoretical and actual COP



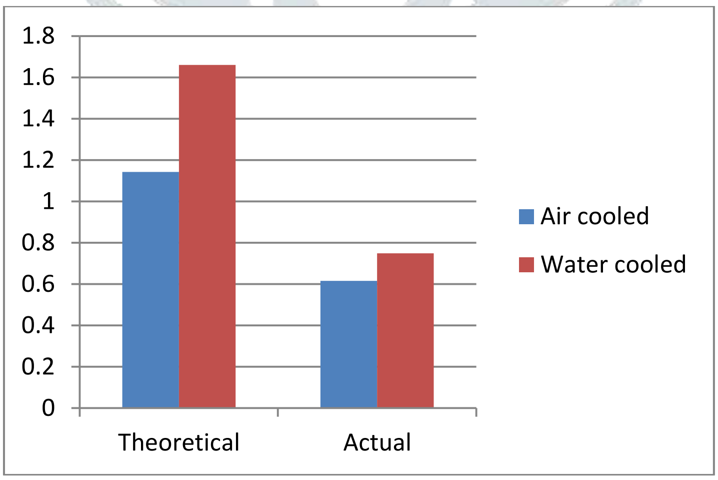
Graph-1: Theoretical VS Actual COP for R-600a

Graph of R-600a for comparing temperature with respect to time



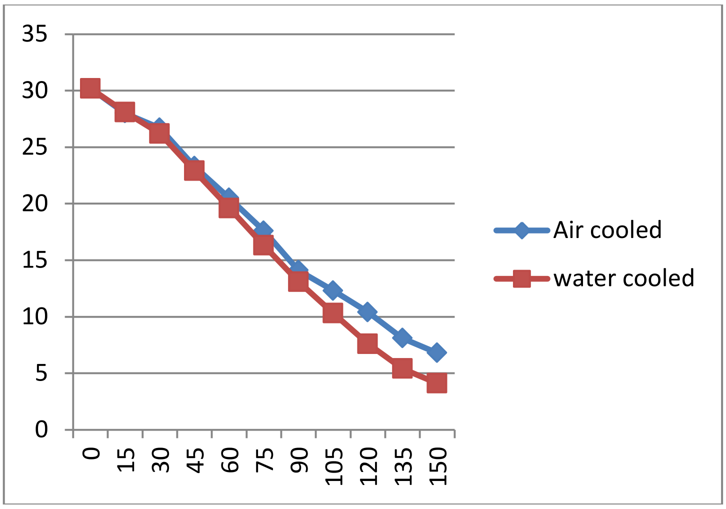
Graph-2: Temperature VS time for R-600a

Graph of R-134a for comparing theoretical and actual COP



Graph-4: Theoretical Vs actual COP for R-134a

Graph of R-134a for comparing temperature with respect to time



Graph-5: Temperature VS time for R-134a

VII. CONCLUSION

- With the incorporation of water cooled Condenser, the Refrigeration Effect increases which in turn increase the COP by 31.43% for R-600a & 17.69% for R-134a.
- With the incorporation of water cooled Condenser, the Compressor work reduces which in turn increases the COP. Time for cooling in the Freezer is reduced drastically. Hence, time required to reach the required temperature is less and the compressor can shut off quickly saving electrical power.
- With the incorporation of water cooled Condenser, the net weight of the system increases.
- Since the specific heat of water is 4.187kJ/kg/°C which is higher than any other common substance and because air is having its specific heat as 1.005kJ/kg/°C which is lower than water, hence the heat carrying capacity by water is more than air which leads to lower condenser temperature in water cooled condenser than that of air cooled condenser.

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