Performance Improvement of Vapour Compression Refrigeration System using Air cum Evaporative Condensing Unit

Dr. V. R. Sivakumar
Head of the Department
Department of Mechanical Engineering
RVS College of Engineering and Technology,
Coimbatore – 641 402

C. Selva Kumar
PG Student
Department of Thermal Engineering
RVS College of Engineering and Technology,
Coimbatore – 641 402

Abstract

Normally air cooled and water cooled condensers are used separately according to their requirements. For small capacity refrigeration system air cooled condensers are used and for larger units water cooled condensers are used. In hot climatic condition the air cooled condensers does not provide the required output temperature. To get the required level, the power input for the system got increased. For that this air cum evaporative condensing unit is implemented. In this a wet pad arrangement is designed. There is a water flow provided in the wet pad. While passing the atmospheric air through the wet pad, the water present in that got vapourized and it mixes with the flowing air. While this moisture air is made to flow over the condenser tubes, the temperature of the condenser can be reduced to some extent. This result in the performance of the system. In the absence of water flow the system works normally as an air cooled condenser.

Keywords: Refrigeration, Evaporation, Condenser, Wetpad, Moisture, Saturation

I. INTRODUCTION

In refrigeration system heat transfer occurs at different places such as condenser, evaporator. In condenser the refrigerant flows through the coil, and cooler air is drawn across the coil, more and more of the gas condenses into a liquid until you achieve a solid column of liquid at the outlet of the coil. The latent heat required to condense this gas is rejected from the refrigerant into the outside air. This process is called condensation, thus the coil which this occurs is referred to as the condenser. The temperature that the condensation occurs is much higher than within the evaporator, as the pressures in the condenser are much higher. In evaporator Latent heat transfer is the main way mechanical refrigeration systems move heat. As the refrigerant flows through the coil, and more air comes in contact with the coil, more of the liquid refrigerant boils off until all that remains is a gas. The Latent heat required to boil off this refrigerant from a liquid to a gas is taken from the air as it passes through the coil, thus cooling the air. This boiling process is called evaporation, thus the coil in which this occurs is referred to as our Evaporator. The Evaporator is where we collect the heat we want to remove. The latent heat process happens at a low temperature because of the nature and properties of the refrigerant and the low pressure in this part of the refrigeration system.

II. EXISTING COOLING SYSTEM FOR CONDENSERS

In the existing vapour compression refrigeration system, most common used condensing systems are air cooled condensers and water cooled condensers. In air cooled condenser the atmospheric air is blown over the condenser with the help of fan. In that if the climatic condition is hot and humidity is low, it is difficult to achieve the condenser temperature.

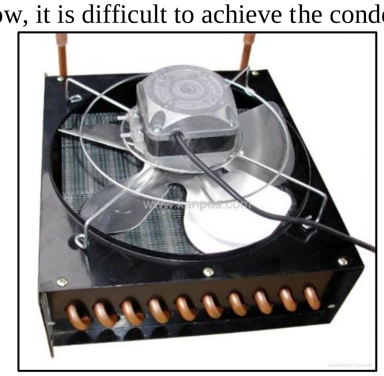

Fig. 1: Air Cooled Condenser

In water cooled condenser, there are different types of methods used. Such as, water spray, through heat exchanger and atomized spray of water etc., for making pressurized water additional amount of power is required. In water cooled condenser the required condenser temperature can be achieved.

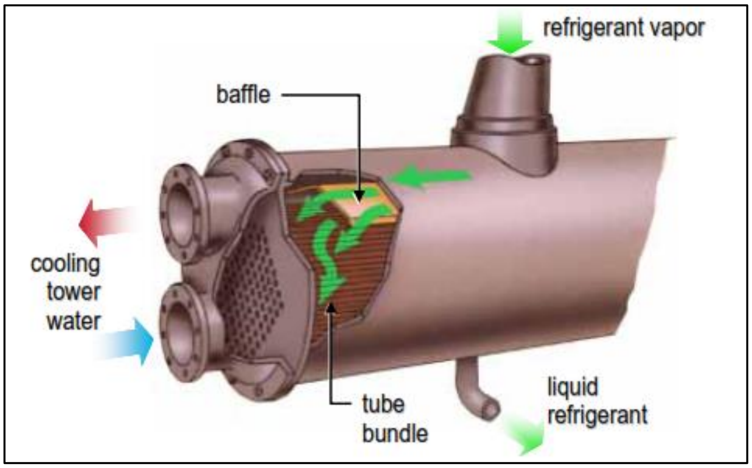

Fig. 2: Heat Exchanger type Condenser

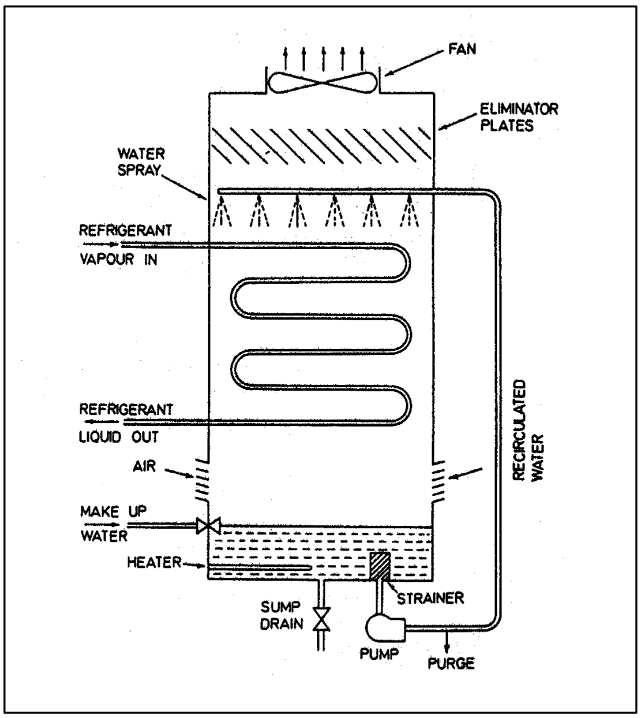

Fig. 3: Water Spray Type Condenser

III. EXPERIMENTAL SETUP

A. Modified Air cum Evaporative Condensing Unit:

This modified system consist of an evaporative system between the fan and condenser tubes. In that a wet pad is attached with that. Water is sprayed over the wet pad at the top surface, which flows down to the bottom of the wet pad. If the forced air is made to flow through the wet pad the water gets evaporated and it is mixed with the air. With that the humidity level rises and the temperature of the air gets reduced. With this air flow over the condenser the temperature can be reduced to some extent. For this there is no additional power is given. In some condition if water flow is not available the normal atmospheric air is continuously blowing in the system. This additional equipment or unit can be attached with the existing system and does not require major change in the existing system.

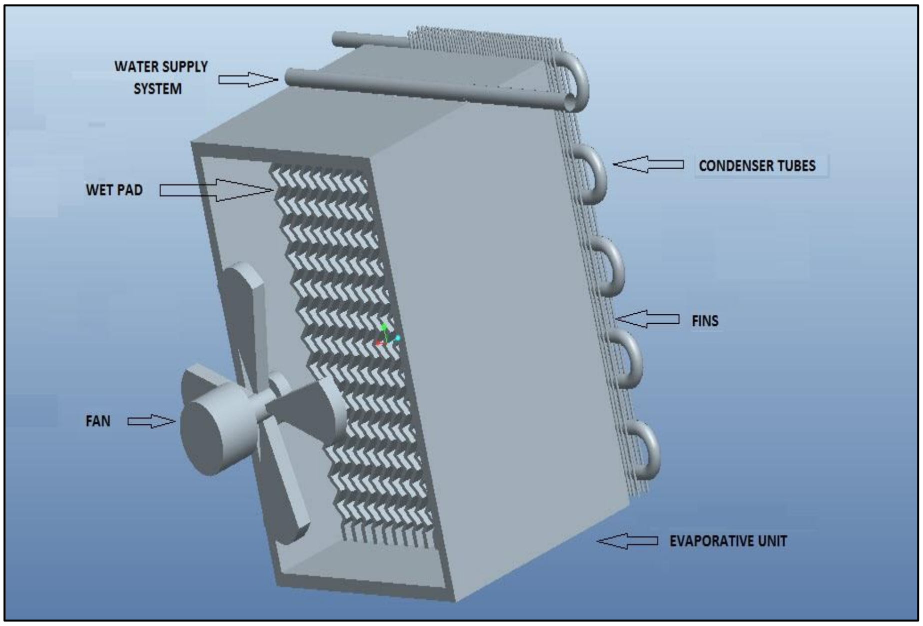

Fig. 4: Modified Air cum Evaporative Condensing Unit

IV. THEORETICAL ANALYSIS FOR VCRS SYSTEM

A theoretical analysis is performed at different condenser and evaporator temperatures. A sample calculation is given for compression system operating on R134a. The condenser is maintained at a temperature of 42˚C and evaporator at -12˚C. The properties of the refrigerant at 40˚C condenser temperature and -10˚C evaporator temperature are given in Table 1

Table – 1

T	*P*	*Vg*	h_f	h_g	S_f	*Sg*	*CpL*	*Cpg*
(˚C)	*bar*	*m³/kg*	*(kJ/kg)*	*(kJ/kg)*	*(kJ/kg.k)*	*(kJ/kg.k)*	*(kJ/kg.k)*	*(kJ/kg.k)*
-12	*1.85*	*0.10744*	*183.93*	*391.46*	*0.94066*	*1.7348*		
30	*7.7*	*-*	*241.07*	*414.82*	*1.1435*	*1.7145*	*1.4465*	*1.0655*
32	*8.15*	*-*	*243.93*	*415.78*	*1.1529*	*1.7138*	*1.4559*	*1.08*
34	*8.63*	*-*	*246.8*	*416.72*	*1.1623*	*1.7131*	*1.4658*	*1.095*
36	*9.12*	*-*	*249.69*	*417.65*	*1.1717*	*1.7124*	*1.4761*	*1.1108*
38	*9.63*	*-*	*252.6*	*418.55*	*1.1811*	*1.7118*	*1.487*	*1.1272*
40	*10.17*	*-*	*255.52*	*419.43*	*1.1905*	*1.7111*	*1.4984*	*1.1445*
42	*10.72*	*-*	*258.46*	*420.28*	*1.1999*	*1.7103*	*1.5105*	*1.1626*
44	*11.3*	*-*	*261.42*	*421.11*	*1.2092*	*1.7096*	*1.5232*	*1.1818*
46	*11.9*	*-*	*264.4*	*421.92*	*1.2186*	*1.7089*	*1.5367*	*1.2019*
48	*12.53*	*-*	*267.41*	*422.69*	*1.228*	*1.7081*	*1.5509*	*1.2233*
50	*13.18*	*-*	*270.43*	*423.44*	*1.2375*	*1.7072*	*1.5661*	*1.2461*

Exit temperature of the condenser can be found using this formula

$$S_2 = S_3 + \frac{C_{pg}\ln(T_2 + 273)}{T_3 + 273}$$

$$T_2 = \frac{\exp(s2 - s3)}{c_{pg}} \times (ts + 273)\text{-}273$$

$$= \frac{\exp(0.02)}{1.1626} \times (42 + 273) - 273$$

$$= 48.71^{\circ}C$$

$$h_1 = h_g \text{at -12˚C}$$

$$= 391.46 \text{ kJ/kg}$$

$$h_2 = h_g + c_{pg}(T_2 - T_3)$$

$$= 420.28 + 1.1626(48.32 - 42)$$

$$= 428.0794 \text{ kJ/kg}$$

$$h_3 = h_{f4} - c_{pl} \times T_3$$

$$= 259.41 \text{ kJ/kg}$$

$$h_4 = h_3$$

$$= 259.41 \text{ kJ/kg}$$

$$\eta_{vol} = 1 + C + C(\frac{P_2}{P_1})^{1/n}$$
$$= 1 + 0.03 + 0.03 \times \frac{10.72^{(\frac{1}{1.12})}}{1.85}$$
$$\eta_{vol} = 0.89$$
$$P_r = \frac{P_3}{P_4}$$
$$= \frac{10.72}{1.85}$$
$$P_r = 5..79$$
$$m = \frac{Q_E}{h_1 - h_4}$$
$$= \frac{6.13e - 6 \times 2600 \times 0.89}{0.10744}$$
$$= 0.1340 \text{ kg/s}$$
$$VCC = \frac{(h_1 - h_4)\eta_{vol}}{v_g}$$
$$= \frac{(391.46 - 259.41) \times 0.89}{0.10744}$$
$$VCC = 1096.94 \text{ kJ/m}^3$$
$$Q_3 = m(h_2 - h_3)$$
$$= 0.1340(428.0794 - 259.41)$$
$$= 22.601 \text{ kW}$$
$$Q_4 = m(h_1 - h_4)$$
$$= 0.1340(391.46 - 259.41)$$
$$= 17.6497 \text{ kW}$$
$$W_{Comp} = m(h_2 - h_1)$$
$$= 0.1340(428.0794 - 391.46)$$
$$= 4.90 \text{ kW}$$
$$COP = \frac{Q_4}{W_{comp}}$$
$$= \frac{17.6497}{4.90}$$
$$= 3.63$$

V. RESULTS AND DISCUSSION

A. Analysis for Different Condenser Temperature:

The analysis of the vapour compression refrigeration system has been done theoretically for different condenser temperatures (T_3) by maintaining evaporator temperature (T_4) as -10˚C. The properties of the refrigerants at different temperatures are taken from the Refprop software. Various parameters are calculated.
The following table 2. shows the properties at different condenser temperatures

Table – 2

T2	*h2*	*h1*	*h3*	*η vol*	*m*	*COP*	*Pr ratio*	*VCC*
(˚C)	*(kJ/kg)*	*(kJ/kg)*	*(kJ/kg)*	*(%)*	*(kg/s)*			*(kJ/m³)*
35.83	*421.0299*	*391.46*	*241.07*	*0.92*	*0.1395*	*5.09*	*4.16*	*1291.73*
37.99	*422.2477*	*391.46*	*243.93*	*0.92*	*0.1387*	*4.79*	*4.40*	*1259.51*
40.14	*423.4483*	*391.46*	*246.8*	*0.91*	*0.1378*	*4.52*	*4.66*	*1227.05*
42.29	*424.6419*	*391.46*	*249.69*	*0.91*	*0.1369*	*4.27*	*4.92*	*1194.63*
44.41	*425.7765*	*391.46*	*252.6*	*0.90*	*0.1359*	*4.05*	*5.20*	*1162.08*
46.55	*426.9254*	*391.46*	*255.52*	*0.89*	*0.1350*	*3.83*	*5.49*	*1129.38*
48.71	*428.0794*	*391.46*	*258.46*	*0.89*	*0.1340*	*3.63*	*5.79*	*1096.77*
50.83	*429.1842*	*391.46*	*261.42*	*0.88*	*0.1329*	*3.45*	*6.10*	*1063.96*
52.95	*430.2718*	*391.46*	*264.4*	*0.87*	*0.1318*	*3.27*	*6.42*	*1031.14*
55.08	*431.3549*	*391.46*	*267.41*	*0.86*	*0.1307*	*3.11*	*6.76*	*998.11*
57.23	*432.4543*	*391.46*	*270.43*	*0.86*	*0.1295*	*2.95*	*7.12*	*965.20*

1) Pressure Ratio (P_r):

The Pressure ratio of the compression system at different condenser temperatures. shows that, when the condenser temperature increases, the pressure ratio of the system increases. Figure 5 shows the plot between the condenser temperature and pressure ratio for different refrigerants.

It is observed from the Figure 5, when the condenser temperature increases, the pressure ratio of the compression system increases gradually. For air cooled condenser, the temperatures 30˚C, 35˚C are difficult to maintain as these require additional source which increases power consumption and the temperatures 45˚C, 50˚C have larger value of pressure ratio which gives lesser effect.

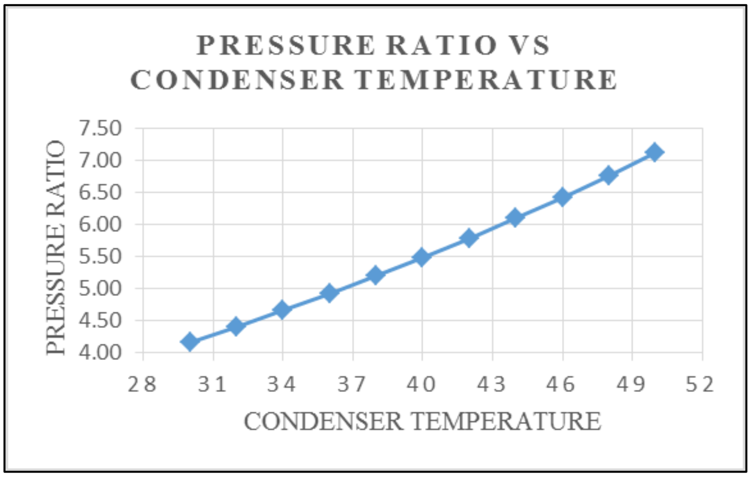

Fig. 5: Pressure Ratio Vs Condenser Temperature at Constant Evaporator Temperature

2) Volumetric Efficiency:

The volumetric efficiency of the compression system at different condenser temperatures shows that, when the condenser temperature increases, the volumetric efficiency of the system decreases. Figure 6 shows the plot between the condenser temperature and volumetric efficiency for different refrigerants.

From the Figure 6, it is observed that, when the condenser temperature increases, the volumetric efficiency of the compression system reduces by considerable amount. . For air cooled condenser, the temperatures 30˚C, 35˚C are difficult to maintain as these require additional source which increases power consumption and the temperatures 45˚C, 50˚C have lesser value of volumetric efficiency which decreases COP.

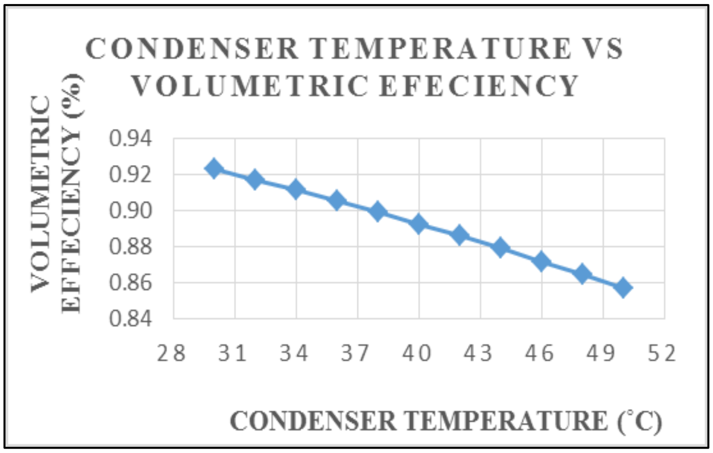

Fig. 6: ηvolumetric Vs Condenser Temperature At Constant Evaporator Temperature

3) Mass Flow Rate:

The mass flow rate of the compression system at different condenser temperatures shows that, when the condenser temperature increases, the mass flow rate of the system decreases. Figure 7 shows the plot between the condenser temperature and mass flow rate for different refrigerants

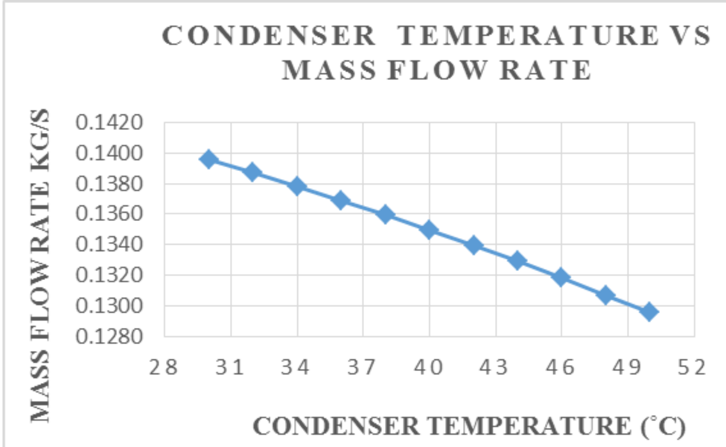

Fig. 7: Mass flow rate Vs Condenser Temperature At Constant Evaporator Temperature

As seen from the Figure 3, when the condenser temperature increases, the mass flow rate of the compression system remains almost constant. . For air cooled condenser, the temperatures 30˚C, 35˚C are difficult to maintain as these require additional source which increases power consumption and the temperatures 45˚C, 50˚C have larger value of mass flow rate which increases compressor work.

4) Volumetric Cooling Capacity (VCC):

The volumetric cooling capacity of the compression system at different condenser temperatures shows that, when the condenser temperature increases, the volumetric cooling capacity of the system decreases. Figure 8 shows the plot between the condenser temperature and volumetric cooling capacity for different refrigerants.

It is inferred from the Figure 8, when the condenser temperature increases, the volumetric cooling capacity of the compression system decreases by considerable amount. For air cooled condenser, the temperatures 30˚C, 35˚C are difficult to maintain as these require additional source which increases power consumption and the temperatures 45˚C, 50˚C have lesser value of VCC which gives lesser effect.

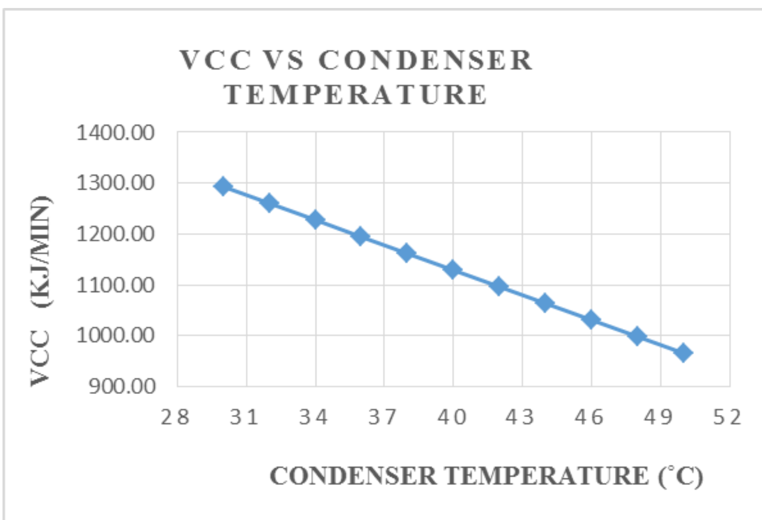

Fig. 8. VCC Vs Condenser Temperature at Constant Evaporator Temperature

5) Co-efficient of Performance:

The COP of the compression system at different condenser temperatures shows that, when the condenser temperature increases, the COP of the system decreases. Figure 9 shows the plot between the condenser temperature and COP for different refrigerants.

As seen from the Figure 9, when the condenser temperature increases, the COP of the compression system decreases gradually. For air cooled condenser, the temperatures 30˚C, 35˚C are difficult to maintain as these require additional source which increases power consumption and the temperatures 45˚C, 50˚C have lesser value of COP.

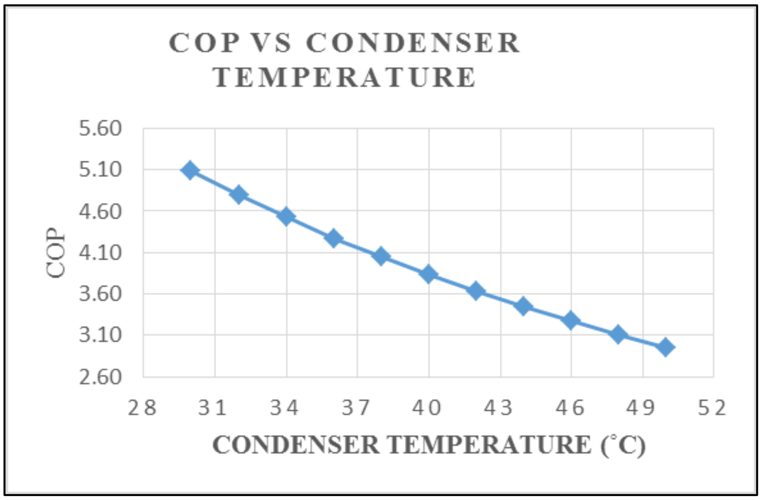

Fig. 9: COP Vs Condenser Temperature At Constant Evaporator Temperature

VI. CONCLUSION

The thermodynamic analysis of the system had been performed. With that this air cum evaporative condensing unit can be installed in any climatic conditions. Since it includes a smaller change in the system and with an easier replacement.

With this implementation of this unit in the refrigeration system, the overall performance of the system got increased. At the same time there is no additional power is used for that unit.

By using direct water spray or water cooling method the power input for the system got increased. The wet pad used in this are easily available. This system helps in getting the required cooling capacity with the actual power input.

REFERENCES

[1] Dr.C.R.Patel, K.G.Hirde, Badnera (2013) 'The concept of Indirect Evaporative Cooling' International Journal of Engineering Science and Innovative Technology Volume 2, Issue 5 pp 391 – 396.
[2] Sreejith.k, Sushmitha.S, Vipin Das (2014) 'Experimental Investigation of a House Hold Refrigerator using Air-Cooled and Water-Cooled Condenser' International journal of Engineering and science, Volume 4 Issue 6 pp 13 – 17.
[3] Xun Zhu, Jun-jun Wu, Bin Lin, YU Tan, Cheng-cheng Huang, Hua Li, Lei Cao, Ze-jun Liu 'Air Conditioning Condenser Integrated with a Spray System utilizing Condensate Water' , UDC : 621.5.
[4] Mayuri M.Choundikar, J.M.Patil (2015) 'Comfort air cooler' International journal of Advanced Engineering Research and Technology, Volume 3 Issue 5 pp 190 – 192.
[5] Mohammed H.Alhamdo, Maathe A.Theeb, Jaafar J.Abdulhameed (2015) 'Using Evaporative Cooling Methods for Improving Performance of an Air-Cooled Condenser' Universal Journal Of Mechanical Engineering, Volume3 Issue 3 pp 94 – 106.
[6] P.Thangavel, Dr.P.Somasundaram, T.Sivakumar (2013) 'Simulation Analysis of Compression Refrigeration Cycle with Different Refrigerants' International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 10 pp 127 – 131.
[7] Ramin Faramarzi, John Lutton, Sean Gouw (2010) 'Performance Comparison of Evaporatively-Cooled Condenser versus Air-Cooled Condenser Air conditioners' ACEEE Summer Study on Energy Efficiency in Buildings pp 117 – 127 .
[8] Abdullah Alotaibi, Momoud Awad, Ahmed Hamed (2015) 'Performance Of Air Conditioning System using Air Cooled Condenser with Water Atomization' International journal of Engineering research and science & Technolgy, Volume 4, No 1 pp 127 – 135 .
[9] P.Balashanmugam, G.Balasubramanian (2014) 'Experimental Study on the Design of a Cooling Tower for a Central Air-Conditioning Plant' International journal of Engineering and Technical Research, Volume 2 Issue 3 pp 1 – 12 .
[10] Gourav Roy, Taliv Hussain, Rahul Wandra 'Experimental Investigation of Enhancing the COP of VCRS system by using Cooling Tower' ELK Asia pacific journals - Special Issue.
[11] Rajput.R.K (2008) 'Refrigeration and Air Conditioning', S.K.Kataria and Sons, New Delhi.
[12] Arora.C.P (1988) 'Refrigeration and Air Conditioning', Tata McGraw Hill, New Delhi.

