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Investigation and Optimization of Air Cooled Condenser of Chillers by Replacing Cu to Al Tubes

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ABSTRACT

Compact heat exchanger i.e. round tube plate heat exchangers are commonly employed in vapour compression refrigeration system to exchange heat between refrigerant to environment. A well designed, highly effective air cooled condenser can help to save energy and material cost. Now days, material cost is one of the important issues that should be consider during condenser design. The analytical study was carried out on air cooled condenser of a chiller by using R134a. This paper presents the improvement and development of heat transfer that occurs in the condenser by changing the coil material and also predicts the thermal performance of the condenser. Aluminium is chosen as our material due to cheap, corrosion resistant and good machinability. Use of low cost Aluminium material coil will increase the efficiency of the condenser due to factors such as the specific heat at constant pressure (Cp), overall heat transfer coefficient (U). The present study shows effect on condenser air outlet temperature, condensing temperature, heat rejection rate and on overall heat transfer coefficient and ultimately overall condenser cost.

Keywords: Air cooled condenser, Chiller, Condenser design, Cost, Overall Heat transfer Coefficient.

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I. INTRODUCTION

Compact heat exchanger i.e. Air cooled cross flow fin- tube heat exchanger is any device that transfers heat from hot fluid to environment. It includes condenser and evaporator coils are commonly used in industrial fields such as refrigeration, air conditioning and petrochemical industries. There are many different types of geometry for heat exchangers available and being used. The “plate-fin and tube” geometry is one of the most common configurations and consist of copper tube and aluminium fin is generally used. There are different types of plate-fin geometry, the most common being the plain fin, where the fins are parallel plates attached to a hot element in the form of tubes or some other shape. These fins act as a sink, absorbing the heat out of the hot element with the help of conductive heat transfer and dissipating this absorbed heat onto the outside environment which is at a lower temperature. These heat exchangers are commonly operated with a hot liquid inside the tubes and air on the outside. The heat from the fluid is transferred to the fin by conductive heat transfer. The fins then dissipate the heat onto the environment by convective heat transfer.

In order to design better heat exchangers and come up with efficient designs, a thorough understanding of the flow of air and refrigerant in these channels is required. Now days, HVAC&R industry is searching for ways to increase performance, energy efficiency and durability of HVAC&R equipment in a sustainable way, while reducing the cost of manufacturing these. This search has put the spotlight on

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substituting the copper tubes that have been in use for nearly a century with aluminium tubes. To estimate the heat transfer benefit in minimum cost, this study focuses on the heat transfer and overall heat transfer coefficient performance on these two types of heat exchangers of different material i.e. Cu and Al. Hence, in order to reduce cost. The performance is dependent on many factors such as the tubes length, type of tube surface, viz. smooth or enhanced, fin type, fin height, and fin width and density performance parameter such as air flow rate and velocity, fan power, the refrigerant inlet/outlet conditions etc. Economic parameters include material cost, manufacturing cost, cost of fan assembly etc. In order to reduce condenser cost, the experimental investigation and prediction of thermal performance of air cooled condenser is carried out by replacement of tube material having low cost. Some of researchers done their work on various above mention parameters to optimize the various constraints of air cooled condenser. Hassab et.al[1] present a simulation model of air cooled condenser of reciprocating water chillers using R134a as a refrigerant at steady state condition which present generalize thermal design at different cooling load which include mathematical equation for heat transfer and pressure drop. Flohr et.al [2] investigated the influence of aluminium brazing process operating on R407C and POE lubricant. It shows that the presence of brazing flux residues has no negative influence on apparent running condition and the stability of refrigeration system on R407C and POE lubricant, even under worst condition such as the absence filter dryer and with artificially high moisture content. Jannick et.al[3] theoretically investigated the simultaneous capacity measurement and comparison of mechanical produced and brazed heat exchanger with identical dimension and design. In average, capacity improvement of 1.5% were measured for the aluminum brazed heat exchanger. Aute et al[4] studied how genetic algorithm is powerful tool to develop optimal tool design for air cooled condenser. This study uses two different ranking schemes, the multiple solution thus obtained which are same quality, provide greater flexibility to designer, thereby leading to a better system. Jiang etal [5] introduced the genetic simulation and optimization tool for design of air cooled condenser, it shows the ratio of condenser capacity for the best performer i.e. R32 and the worst performer i.e. R600a, was 1.18.

II. THEORETICAL ANALYSIS

A heat exchanger is a device that is used for transfer of thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid or between solid particulates and a fluid at differing temperatures and in thermal contact, usually without external heat and work interactions. The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger. The current design objectives were based on the requirement specified by manufacture of coil of comprised of both economic and performance related parameter. The mathematically expression and correlation for design of air-cooled condenser are presented heat transfer between refrigerant and ambient air as well as for pressure drop in refrigerant and air sides. In addition, different condenser coil areas are expressed in terms of coil geometry and layout.

A. Heat Transfer Areas in Finned Tube Condensers: A condenser or a cooling coil consists of tubes and fins. The air flows through the passages formed by the fins. Fig.(a) shows a section of the plate fin-and-tube condenser and its side view.

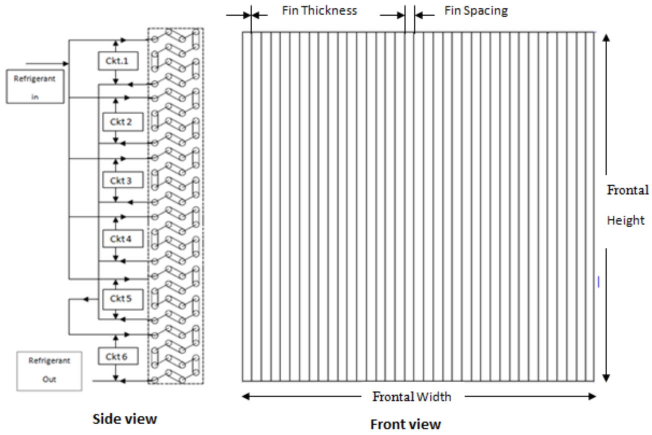

Fig 1: Crossectional View of Air Cooled Condenser

B: Vertical spacing between the tubes in row, mm
C: Spacing between the tube in different rows, mm
D: Centre to centre spacing between the fins, mm
t: Thickness of the fins, mm
d_o: Outer diameter of tube, mm
d_i: Inner diameter of tube, mm.
From the above condenser geometry, the various heat transfer areas are calculated as follow.

1. Bare tube area (A_b): m^2 / unit area/ number of rows

$$Ab = \left[\frac{D-t}{DB}\right]\pi do$$

(1)

2. Fin area (A_f): m^2 / unit area/ number of rows:

$$Af = \frac{2}{D}\left[C - \frac{\pi do}{4B}\right]$$

(2)

3. Minimum flow area (A_c): m^2 / unit area/ number of rows:

$$Ac = \frac{D-t}{D}\left[1 - \frac{do}{B}\right]$$

(3)

4. Total area (A_o): m^2 / unit area/ number of rows:

$$Ao = Ab + Af$$

(4)

5. Inside heat transfer area (A_i): m^2 / unit area / number of rows:

$$Ai = \frac{\pi do}{B}$$

(5)

B. Condenser Analysis:

The amount of heat rejected from refrigerant can be expressed as the difference between the refrigerant enthalpy at the inlet and at the outlet of the condenser. The total heat rejected in the condenser, Qc is given by

$$Qc = maCpa\Delta T$$

(6)

C. Air-Side Heat Transfer Coefficient (h_o)

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Kays and London (1955) have carried out extensive measurements on different types of fin and tube arrangements. They have presented the data in the forms of plot of Colburn j-factor (St.Pr2/3) vs. Reynolds number (Re) for various geometries. On the average, following correlation is a good fit to their data for various geometries.

$$Nu = C R_e^n P_r^{1/3}$$

(7)

where,

N_u= Nusselt number
P_r= Prandlt number
R_e= Reynold number, $R_e = \frac{\rho V_{max} D_h}{\mu}$

In which,

D_h=Hydraulic diameter, $D_h = \frac{4A_c}{P}$

where,

P = Wetted perimeter, $P = \frac{Ao}{C/1000}$

From this correlation, the Nusselt number is calculated which is used to estimate the air side heat transfer coefficient and is given by

$$N_u = \frac{h_o D_h}{k}$$

(8)

where,

h_o- Air side heat transfer coefficient
D_h- Hydraulic Diameter
k - Thermal conductivity of Air.

D. Refrigerant – Side Heat Transfer Coefficient (h_i)

Akers, Dean and Crosser have proposed following correlation when the rate of condensation or the length is very large. This is very similar to Dittus-Boelter correlation for turbulent heat transfer in tubes, except the constant is different.

$$\frac{h_i d_i}{k_f} = 5.03 R_{e_m}^{1/3} P_r^{1/3} \dots\dots\dots\dots\dots\dots\dots R_{e_g} < 5 \times 10^4$$
$$= 0.0265 R_{e_m}^{1/3} P_r^{1/3} \dots\dots\dots\dots\dots\dots\dots R_{e_g} > 5 \times 10^4$$

(9)

Where,

$$R_{e_m} = R_{e_f}\left[1 + \left(\frac{\rho_f}{\rho_g}\right)^{0.5}\right]$$

$$R_{e_m} = \frac{U d_i}{\gamma_f}$$

$$P_{r_f} = \frac{C_{pf}\mu_f}{k_f}$$

Where, k, ρ, Cp and μ are thermal conductivity, density, specific heat and viscosity of refrigerant respectively. Subscripts 'f' and 'g' denotes saturated liquid and dry saturated refrigerant respectively.

E. Log Mean Temperature Difference (LMTD)

If we assume condensation throughout the length of the condenser and also assume the pressure drop to be negligible, then the mean temperature difference is given by the Log Mean Temperature Difference (LMTD):

$$LMTD = \frac{T_o - T_i}{\ln\left[\frac{T_c - T_i}{T_c - T_o}\right]}$$

(10)

where

T_i= Air inlet temperature
T_o= Air outlet temperature
T_c= Condensing Temperature

F. Overall Heat Transfer Coefficient (U_o)

The overall heat transfer coefficient can be based on either internal area (Ai) or external area (Ao) of the condenser. In general we can write:

$$\frac{1}{U_o A_o} = \frac{1}{h_o A_o} + \frac{t_m}{A_m k_m} + \frac{1}{h_i A_i}$$

(11)

where

t_m= Thickness of material
A_m= Mean area of condenser
k_m= Thermal conductivity of material

The fouling due to deposition of scale on the fin side of an air cooled condenser usually has little effect since $1/h_{co}$ is rather large. In some cases an allowance may be made for imperfect contact between the fins and the tubes; however it is difficult to evaluate. It is negligible for good construction. The fouling resistance for the inside of the tube is not negligible and must be included.

G. Heat transfer area (A)

Required condenser area is the area is required to reject the heat from condenser of given capacity. The required condenser area is then given by,

$$Q_c = U_o A \Delta T_m$$

(12)

where, U_o is the overall heat transfer coefficient
A is the heat transfer area of the condenser, and
ΔT is mean temperature difference between refrigerant and external fluid

III. DISCRIPTION OF CONDENSER TEST FACILITY

In this chapter brief description of experimental test setup facility and experimental procedure for the dissertation work is explained. Most of the researcher carried out investigation and optimization of air cooled condenser by varying the various effecting parameters such as fin spacing, fin thickness, diameter of tubes number of tube circuit etc. the current study proposed to predict the thermal performance of air cooled condenser by replacing the condenser coil tube material by Cu to Al. for that purpose vapor compression refrigeration chiller was installed which consist of refrigeration system components and water tank with circulating pump and data acquisition system. The condenser model is used for testing with the specification and prescribed along with vapor compression refrigeration system setup.

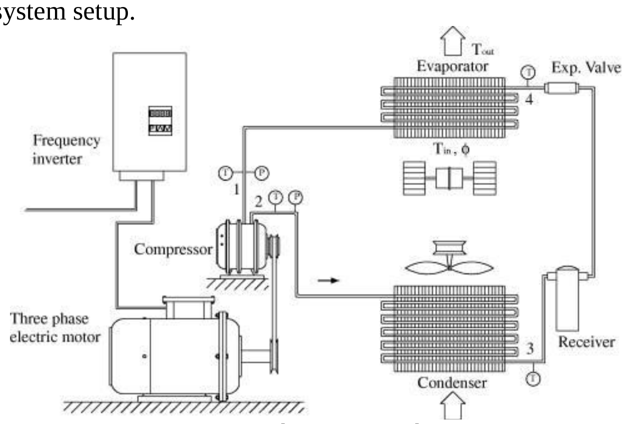

Fig 2: Condenser Test Facility

Experiments were carried out on two models of chiller having different material of condenser tubes i.e. copper tube condenser and aluminium tube condenser of 5 TR capacities. Heat exchangers laboratory directly under incorporation, consist of an unattached air, water, R134a refrigerant and vapor compression refrigeration system with required accessories. The setup was equipped with automatic control devices and high precision metrical instruments, as per standards. Thermocouples are fixed at appropriate location to measure temperature of compressor inlet-outlet, condenser. Pressure gauges are attached at the inlet and outlet of the compressor to measure the suction and discharge pressure of compressor and other recording parameters was measured by separate instrumentation panel (Data Acquition System) which consists of multipoint temperature, pressure indicator, voltmeter, ammeter, and thermostat.

IV. RESULT AND DISCUSSION

Air cooled water Chiller test is conducted to determine the condenser performance parameters by replacing condenser coil material Cu to Al. The experiment is conducted on two models of condenser of Cu and Al tube condenser at same input parameters to study the variation in the performance parameters.

Figure 3 shows the variation in condenser air outlet temperature. When the refrigerant flows through the circuit and the air flow over the tube, then heat is transferred from refrigerant to air, ultimately the air temperature increases. The heat transfer rate from refrigerant to air is same for both condensers. It seems that, air outlet temperature of copper as well as aluminium tube condenser is same. As the time increases the air outlet temperature decreases because the load (water temperature) on the system decreases.

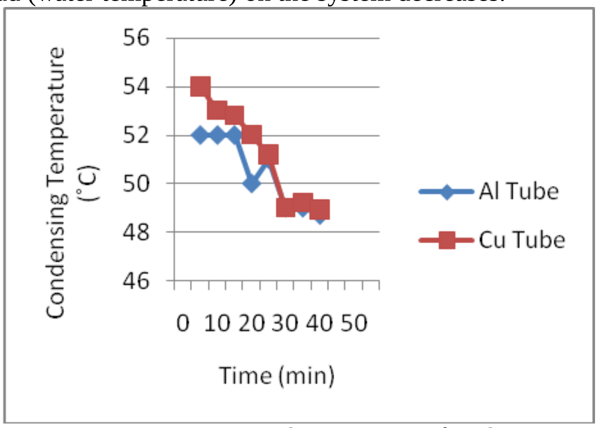

Fig 3: Variation in Air Outlet Temperature of condenser

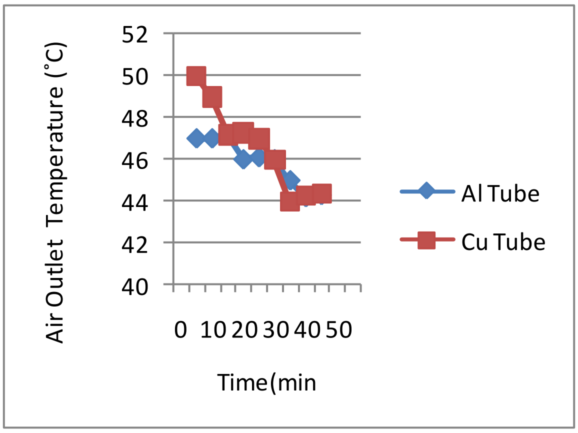

Fig 4: Variation in condensers condensing temperature

Figure 4 Variation in condensing temperature. Condensing outlet temperature is depends on temperature of compressor and its given at the end of the condenser circuit. When the heat is transferred from refrigerant where the vapor refrigerant gets condensed up to saturation temperature which is relevant to the compressor pressure and also degree of sub-cooled below the saturation temperature to get more refrigerating effect to improve efficiency. It is observed that the condensing outlet temperature of condenser is same for Cu as well as Al. it means the heat rejection capacity of both the condenser is same.

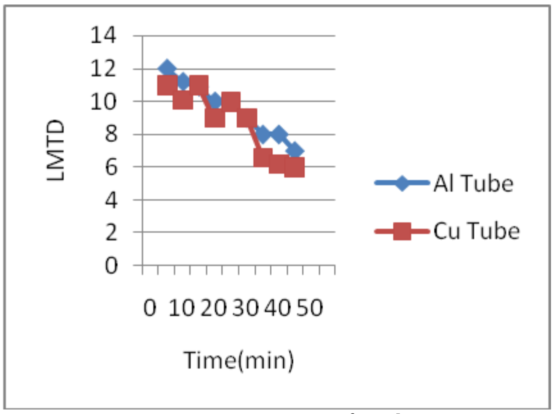

Fig 5: Variation in LMTD of condenser

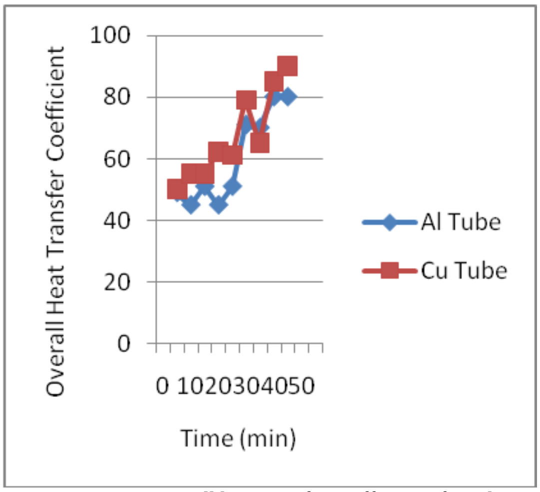

Fig 6: Variation in overall heat transfer coefficient of condensers

Figure 5 and 6 shows the variation in LMTD and overall heat transfer coefficient. LMTD and overall heat transfer coefficient is main important performance parameter to check the performance and to design of air cooled condenser. Figure5 shows that LMTD Aluminium tube condenser more than the copper tube condenser and the figure6 shows that the overall heat transfer coefficient of the Aluminium tube condenser is less than copper tube condenser which is approximately considered as same. Therefore for same capacity of condenser, area requirement for both copper as well as aluminium tube condenser is same.

Figure5 shows that the C.O.P variation of the refrigeration system. The coefficient of performance of the system is depends on refrigeration effect and work done by the compressor and its shows that the C.O.P. of the refrigeration system is approximate same of both the condenser. At 20 minutes the C.O.P. of Cu as well as Al tubes is same.

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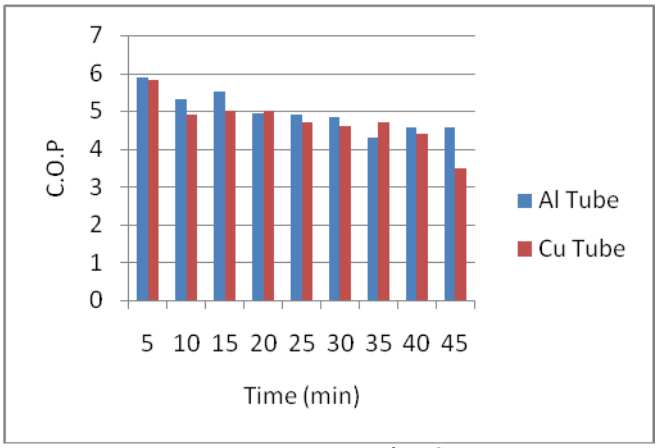

Fig 7: Variation in COP of condenser

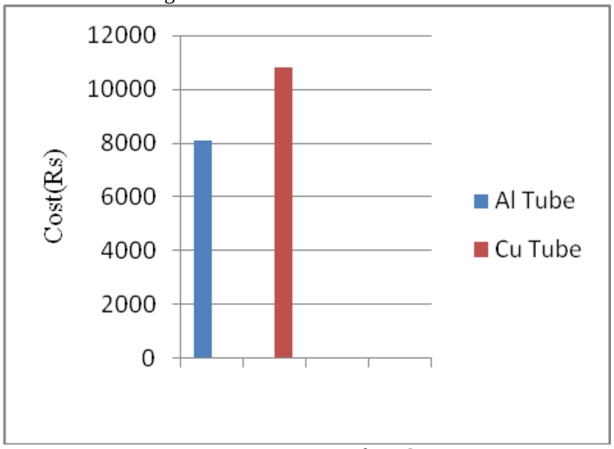

Fig 8: Variation in cost of condensers

Figure 8 shows the cost variation of Cu and Al tube condenser. By keeping in mind regarding the issue of cost of condenser and performance comparison of Cu and Al tube condenser, the cost of copper is three times higher than the aluminum. So at same C.O.P. it is possible to replace the Cu to Al tubes. By this tube replacement, the total cost of condenser is reduced.

V. CONCLUSION

The mathematical and experimental study has been carried out to design the air cooled condenser of a chiller by replacing Cu. To Al tubes for heat rejection capacity of 5TR.The main objective of this study is cost reduction with same performance which is based on performance parameter and economic parameters. The main performance parameters is overall heat transfer coefficient, and it seems that the air side coefficient is more dominant than the refrigerant side coefficient, therefore the overall heat transfer coefficient which is summation of air side and refrigerant side performance coefficient is approximate same by replacing Cu to Al tubes. The theoretical investigation promises the cost benefit of air cooled condenser is up to 24% and other benefits for stationary refrigeration and air-conditioning systems which follow from the use of aluminium heat exchanger are lower material costs and weight, better resistance against environmental influences, and minimized recycling.

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