Optimization of Fin Density of Air Cooled Condenser

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Abstract— In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. The primary component of a condenser is typically the condenser coil, through which the refrigerant flows and fins are provided for better transfer and rejection of heat. In this work heat transfer by convection in air cooled condensers is studied and improved along with study of heat distribution over fins. The assessment has been carried out on an air-cooled finned-tube condenser of a vapour compression cycle for air conditioning system. The purpose of the analysis is to investigate the potential benefit of fin distribution on the heat flux and thermal gradient for the same length without failing the load conditions. This paper reviews the different methods researched for improving the heat transfer through fins.

Key words: Fin Density, Heat Transfer, Air cooled Condenser

I. INTRODUCTION

Condensers have been widely used in the fields of refrigeration, air conditioning, water cooler, space heating, automobile and chemical engineering. A fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increase convection. Adding a fin to an object increases the surface area and can sometimes be an economical solution to heat transfer problems. Fin-tube heat exchanger with two rows of round tubes is widely used in air-conditioning and refrigeration systems. The reduction in the size and cost of fins is achieved by the enhancement of the heat transfer carried out by the fins. The enhancement of heat transfer from fins has become an important factor that has captured the interest of many researchers. Various techniques and large number of works had been carried out in the aspect of fin material and fin shapes. Also, the optimization process has been carried out under the effect of variable convection heat transfer coefficient. With the development of design of heat exchanger and making some changes without affecting the cost.

II. LITERATURE REVIEW

The fins industry has been seeking ways to reduce the size and cost of fins. This demand is often justified by the high cost of the high-thermal-conductivity metals that are employed in the manufacture of finned surfaces and by the cost associated with the weight of the fin. The reduction in the size and cost of fins is achieved by the enhancement of the heat transfer carried out by the fins. The enhancement of heat transfer from fins has become an important factor that has captured the interest of many researchers.

So, if material is considered, large number of works has been conducted to find the best materials for fin. For example, Srividhya and Venkateswara [1] had compared the heat flux generation for three types of Aluminum and concluded that Al 6063 must be preferred over other Aluminum alloys. Extending their work Khadimali [5] and Arunakumari altered the material of both Tubes and Fins. They recorded that Copper tubes proven best with Al 6063 instead of Aluminum tubes, which are lighter and cheaper when compared with copper.

Some of the researchers not only worked on material but also varied the refrigerants in the system likewise a paper by Mallikarjun and Anandkumar [9] includes the comparisons of HCFC and R 404 with the former materials i.e. Al 1100, Al 6063 and Magnesium and leaded to the conclusion that Thermal flux is more when Aluminum alloy 6063 is used for fin and refrigerant used is R 404 than other combinations. The comparison of R12, R22 and R134a has also been done by Mr. Bhimesh and Vankateshwarlu [2] who in their analysis found that R 22 gives maximum heat flux and hence have better heat transfer. Although R 22 because of its toxic properties may get phased out by 2020 as it was banned in many countries in 2015 and we must rely on some of the new blends of refrigerant. R 404A is a blend of HFC refrigerants commonly used for medium and low temperature refrigeration applications. Its composition comprises: HFC-125 (44%), HFC-143a (52%), HFC-134a (4%). It is nontoxic and non-flammable and gives better heat transfer at condenser side which is negotiated by Raghu Babu and Srikanth [4]. Even some researchers tried to enhance the heat transfer by using colloidal solutions which are called nanofluids. Henderson and Jacobi [10] evaluated that if R134a is used with 0.04% CuO volume fraction the average heat transfer is improved by 52% which is great achievement in the field of heat transfer and Refrigeration.

Recently M.A. Al Nimr and Kiwan [11] suggested that thermal performance of fin can be enhanced by using porous fins alternative to conventional solid fins. It increases the initial designing cost but proven to save about 70% of fin material. One of the experimental investigation shows that the creation of turbulence of air on fin by providing vortex generators is also one of the techniques for improving heat transfer suggested by Kumar and Choube [8].

Stewart [3] and his team also found that heat transfer rate also gets affected by some of the geometric parameters like width of condenser, vertical and horizontal tube spacing, number of rows and diameter of tube. Their result shows that the condenser with single row and smaller size gives best performance and aspect ratio must be kept higher in order to reduce number of tube bends which in turn reduces the pressure drop. Mostafa and Elbooz [7] presented the case where a new type of tube called Extruded Microchannel Flat Tube made of Aluminum with flat tube profile was used for improving the Heat Transfer Coefficient.

The optimization of circuits of flow of refrigerant, using staggered fin structure for reducing the bypass factor and utilization of HTC Porous Carbon foam as a fin material are some other identified methods of improving effectiveness of condenser which are suggested by various researchers.

III. Objective of Work

The reduction in the size and cost of fins is achieved by the enhancement of the heat transfer carried out by the fins. The enhancement of heat transfer from fins has become an important factor that has captured the interest of many researchers. Enhancement of heat transfer from fin can be accomplished through the following techniques:

1) Increasing the surface area to volume ratio
2) Increasing the thermal conductivity of the fin, and
3) Increasing the convective heat transfer coefficient between the surface of the solid fin and the surrounding fluid.

Regarding the above two techniques large number of works had been carried out in the aspect of fin material and fin shapes. Also, the optimization process has been carried out under the effect of variable convection heat transfer coefficient.

A combination of uniform-thickness fins evenly spaced along a round tube is a common use for current condenser configuration because on ease of manufacturing. Unfortunately, more often than not, the air velocity distribution is not uniform and subject to the influence of many factors such as the structure of the duct and the heat exchanger's orientation with respect to the fan. This necessitates the investigation of optimizing fin distribution for a defined thickness of fin. In the present work thermal performance of condenser is studied by Parametric optimization of Fin. The base of the work is taken from a research work by Raghu Babu and Srikanth. Their work parameter was only regarding material for fins and they also shown its compatibility is better with R 134a compared to HCFC. But their work could be extended with further improvement by working on Density of Fins.

IV. Modification

Applying the above modifications in new design the fin density will be studied for a condenser with fin thickness of 0.34 mm. It will be compulsory first of all to find out the heat flux through a fin of thickness 0.34 mm in order to compare heat flux through various fin densities and optimize the same.

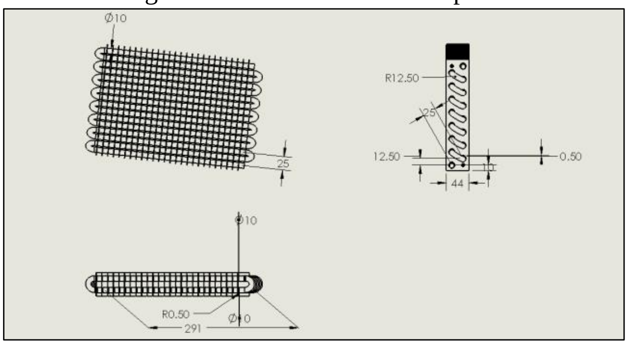

Fig. 1: Design Modification

The analysis of the above modified models has been performed under the conditions as was given in the reference paper and studied. After design meshing was generated in order to carry out thermal analysis. The material used for it is Al 6063, as it is considered as one of the best aluminium alloy by many of the papers. Analysis was performed in ANSYS 18.2. The data that were important for analytical purpose were recorded into the table.

The main aim of modification in existing design is to maximize heat flux through fins, which is achieved by parametric optimization of fins. Although there are innumerable number of methods to increase heat flux through fins but the effect of heat transfer through fin is obtained by varying Fin Density.

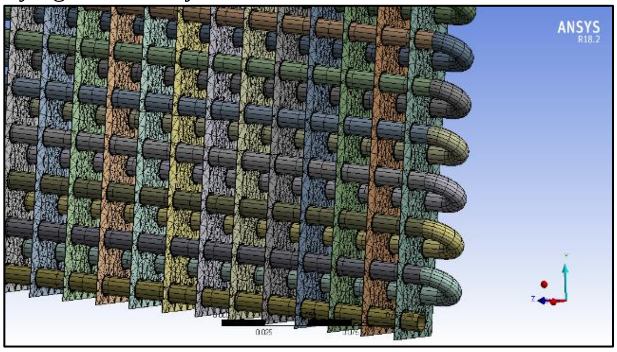

Fig. 2: Meshing Generation in 1.25 FPI Condenser

The above figures we can observe that finer mesh is generated in condenser with 1.25 FPI and as the system becomes more complex i.e. condenser with 15 FPI the mesh size is changed to reduce the load of analysis on system.

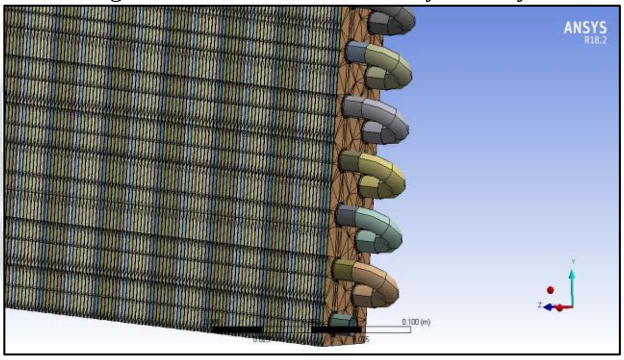

Fig. 3: Meshing Generation in 1.25 FPI Condenser

In the condensers with 12.5 FPI and 15 FPI the mesh is uniform in size along with medium relevance centre, while in other cases i.e. in condensers with lower FPI the mesh grid is adaptive type and coarse relevance centre.

V. Thermal Analysis

According to the ref. [4] the following parameters are used. Al 1100 for Fins with Thermal conductivity= 192 W/mK, Specific heat=880 J/Kg K, Density=2800 Kg/m^3, and Copper tubes with Thermal conductivity= 390w/mk, Specific heat=390J/Kg K, Density=8900Kg/m^3, Inlet Surface Temperature= 50C, Outlet Surface Temperature= 41C, Convective Heat Transfer Coefficient (R134a = 243 W/m^2K, Air= 78 W/m^2K). The analysis is carried out in the same way as earlier, the conditions applied are as per the reference paper and the temperature distribution results are following for different densities.

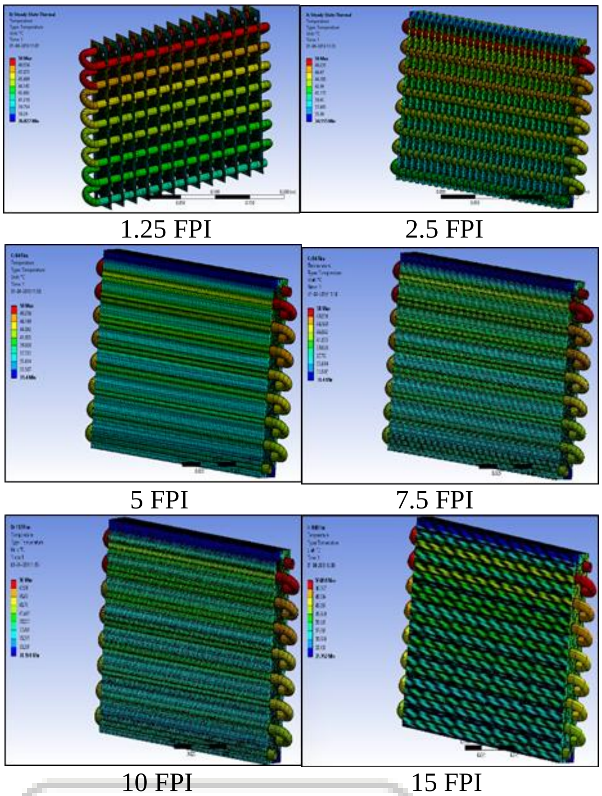

Fig. 4: Temperature Distribution for Different FPI's

Design 0.34	Temperature (K)		Heat Flux (W/m²)		Directional Heat Flux (W/m²)		
FPI	Max	Min	Max	Min	X Axis	Y Axis	Z Axis
1.25	323.15	309.98	86107	5.63×10^{-8}	68566	60330	36598
2.50	323.16	306.58	1.078×10^{5}	5.63×10^{-8}	83694	87430	55728
5.00	323.15	304.90	1.98×10^{5}	5.63×10^{-8}	1.609×10^{5}	1.577×10^{5}	88522
7.50	323.15	304.55	2.11×10^{5}	5.63×10^{-8}	1.721×10^{5}	1.63×10^{5}	95899
10.00	323.15	304.34	2.20×10^{5}	5.63×10^{-8}	1.79×10^{5}	1.72×10^{5}	1.08×10^{5}
12.50	323.26	304.57	2.179×10^{5}	2.00×10^{-8}	2.05×10^{5}	1.76×10^{5}	1.06×10^{5}
15.00	323.21	304.91	2.06×10^{5}	2.00×10^{-8}	1.48×10^{5}	1.46×10^{5}	82366

Fig. 5 Result of Varying Fin Density

From the above table we can observe that as we fall downstream i.e. increasing fin density, it can be clearly visualized that heat flux increases while temperature drop is quite low. Also, it can be observed that when fin density is 5 FPI, the heat flux is 1.98 x 105 W/m2, but even if fin density is doubled to 10 FPI the heat flux doesn't double. Hence, it may be concluded that heat flux doesn't follow linear relation with Fin Density. The following graph indicates behaviour of heat flux with varying fin density.

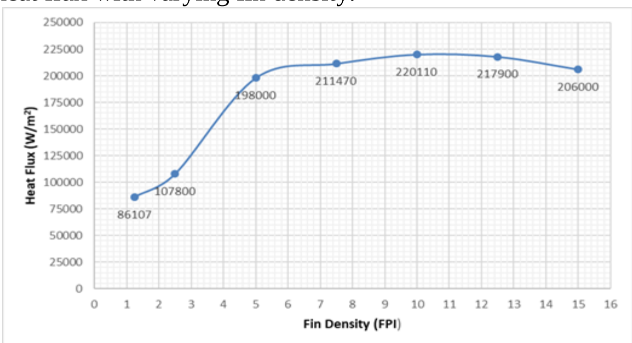

Fig. 6 Fin Density v/s Heat Flux

It can be observed that when fin density is 5 FPI the heat flux is 1.98 x 105 W/m2, but even if fin density is doubled to 10 FPI the heat flux doesn't double. There is a hike in heat flux when Fin Density is increased from 2.5 FPI to 5 FPI but after that curve almost remains stagnant and no significant change in Heat flux is seen beyond.

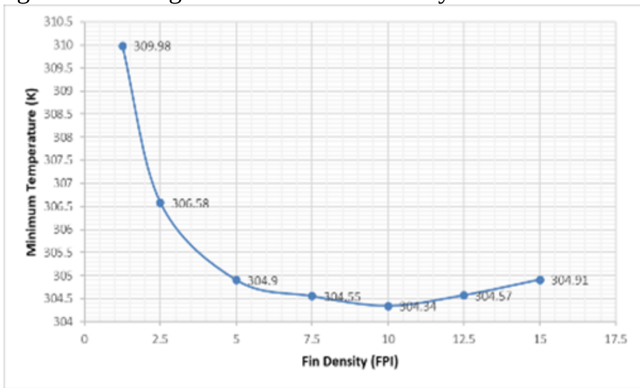

Fig. 7: Fin Density v/s Minimum Temperature

Another curve in Fig 4.17 represents the minimum temperature on fin and it is observable that it is attended at 10 FPI. There is very sharp fall in temperatures between 1.25 FPI and 5 FPI, onwards that there is a small drop and then again increment is seen.

VI. CONCLUSION

It can be observed that when fin density is 5 FPI the heat flux is 1.98 x 105 W/m2, but even if fin density is doubled to 10 FPI the heat flux doesn't double. There is a hike in heat flux when Fin Density is increased from 2.5 FPI to 5 FPI but after that curve almost remains stagnant and no significant change in Heat flux is seen beyond. Hence, 5 Fins per Inch give the best results in both the cases.

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