Performance Analysis of a Domestic Refrigerator by Changing the Design of Condenser Fins

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***Abstract* - The condenser is an essential component of the refrigeration system of domestic refrigerator. The purpose of the condenser is to remove heat from the refrigeration cycle and dissipate that heat into the atmosphere. To serve that purpose very efficiently and effectively, the fins are used over the condenser. The main purpose of using fins is to increase heat transfer surface area of the condenser so that heat transfer rate can be increased. The main aim of conducting this experiment is to increase the heat transfer rate of the condenser of a domestic refrigerator by changing the design (geometry) of condenser fins from circular to rectangular. We are using first wire on tube type of condenser and then rectangular plate type of condenser for the domestic refrigerator which is under study. In the performance analysis of the domestic refrigerator refrigerating effect, work supplied to the compressor and coefficient of performance are to be calculated, studied and compared for both wire on tube type of condenser and rectangular plate type of condenser. The performance analysis also includes the comparative study between natural and forced convection condensers. For forced convection study, we have to provide fans and do their arrangement properly with respect to the condenser so that the expected results can be obtained. In this article extensive literature survey is carried out for doing the performance analysis of domestic refrigerator by changing the design of condenser fins. The literature survey gives the ideas, concepts and guidelines for performing the experiment.**

***Keywords* - Condenser, Evaporator, Coefficient of Performance, Sub-cooling, Free Convection, Forced Convection.**

I. INTRODUCTION

Domestic refrigerator is the machine which works on vapor compression refrigeration system (VCRS) cycle. In VCRS cycle, there are four main components viz., compressor, condenser, capillary tube and evaporator. All the components work together and run the VCRS cycle. The main reason of using VCRS cycle in domestic refrigerator is that it is compact, versatile, reliable and efficient as compared to other refrigeration cycles. The fig.1 shows the schematic diagram of a refrigeration system.

In the actual VCRS cycle, the compressor compresses the low temperature low pressure refrigerant coming from the evaporator to high pressure high temperature refrigerant into the condenser; in the condenser, first de-superheating then phase change from saturated vapor to saturated liquid and then sub-cooling of refrigerant occur; in the capillary tube, the high pressure sub-cooled liquid refrigerant expands to low pressure low temperature refrigerant (throttling process) and in the evaporator, the liquid refrigerant first evaporates to saturated vapor then saturated vapor becomes superheated. The fig.2 shows the p-h diagram of actual VCRS cycle.

The condenser has the purpose of giving away the heat into the atmosphere which was once absorbed in the evaporator and heat added during the compression process in the compressor. The purpose of evaporator is to absorb the latent heat from the space (refrigerator compartment) to produce the refrigerating effect.

This experiment mainly focuses on to improve the performance of the domestic refrigerator through the increase in heat transfer rate of the condenser by changing the design of condenser fins. Hence interest is taken in the condenser and condenser fin design besides considering other components of domestic refrigeration system.

The air-cooled wire on tube type of condenser is being used in the existing domestic refrigerator. The performance of this condenser can be improved by multiple techniques such as enhancements on inner pipe surface, changing the condenser tube geometry from round to flat shape and external fins [11]. But in the experiment, interest is taken in the geometry of external fins, therefore change is being done in the geometry of fins from circular to rectangular. The condenser with rectangular plate fin geometry has the advantage of having more heat transfer surface area available when compared to wire on tube type of condenser for the same condenser tubing dimensions (its cross sectional area and length) [3]. Due to increase in the heat transfer area, heat transfer rate also increases in rectangular plate type of condenser. One another parameter also affects the heat transfer rate through the condenser and that parameter is fin spacing. And for reason of that optimum fin spacing should be taken while designing the condenser with fins for a domestic refrigerator [4], [5].

The increased heat transfer rate from the refrigerator condenser will allow improving in the performance parameters of the domestic refrigerator like increase in the coefficient of performance of refrigerator, increase in the refrigerating effect and lower down the work supplied to the compressor.

In the experiment, condenser fin material is not to be changed for rectangular plate type of fins (change only in the geometry of fins)

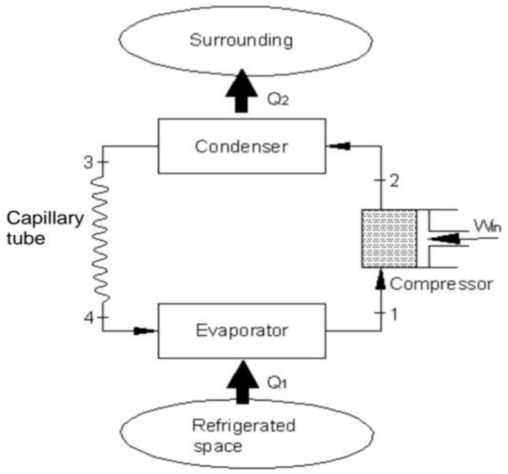

Fig.1 Schematic diagram of a refrigeration system [1]

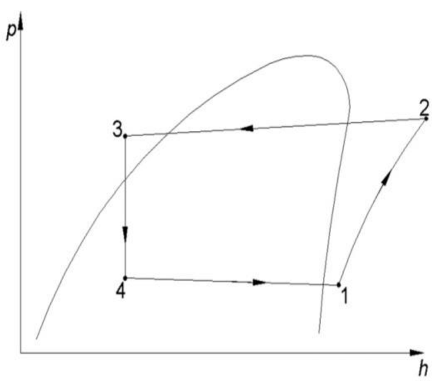

Fig.2 p-h diagram of actual VCRS cycle

II. LITERATURE SURVEY

M. Y. Taib, A. A. Aziz and A. B. S. Alias [1], 2010, In this paper performance analysis of a domestic refrigerator has been done. They have developed the refrigerator test rig and done the performance analysis of refrigerator. The construction method of temperature measurement point and assembly method of pressure measurement using bourdon type pressure gauge have been discussed in this paper. They used thermocouples, bourdon tube pressure gauges and a metal tube flow meter with magnetic coupled indicator to measure temperatures, pressures and refrigerant flow rate in the refrigeration system. They assigned total eight points of temperature measurement, six points were placed inside the refrigerator circuit to measure the refrigerant temperature at different points in the refrigeration cycle and another two points were placed in the refrigerator compartments for measuring the compartment temperature. They also assigned total four points of pressure measurement for measuring the pressure of the refrigerant at different points in the refrigeration cycle. The flow meter was assembled between condenser and capillary tube to measure the refrigerant flow rate in liquid form. A sight glass was installed before the flow meter to observe the liquid phase of the refrigerant. The experiment was conducted for 3 times in order to evaluate the performance of the domestic refrigerator. The COP was found out to be 2.75 and refrigeration capacity was ranging from 150 W to 205 W.

Djelloul Azzouzi, Merouane Kelkouli and Fouad Amaryoucef [2], 2017, In this paper a parametric study of the wire-on-tube condenser sub-cooling effect on the performance of vapor compression refrigeration system has been presented. They used three refrigerants viz., R12, R134a and R600a for undertaking the study of different parameters of the refrigerator. In the research paper firstly they introduced an analysis methodology which makes it possible to determine the COP of the refrigeration cycle with sub-cooling for the three used R12, R134a and R600a as refrigerants. While later an analytical approach was developed in order to calculate the additive surface of wire-on-tube type of condenser used in application apparatus. The paper showed that the coefficient of performance (COP) increases with the increase of sub-cooling temperature under different pressure ratios for all three refrigerants. However, for the same sub-cooling temperature of the three refrigerants, it can be seen clearly that the COP decreases with pressure ratio increase. In the sub-cooling temperature zone from 0^0C (without sub-cooling) to 2^0C, the R-134a refrigerant presents the maximal COP reached comparatively to the two other refrigerants R12 and R600a under the pressure ratio varying from 10 to 13. When the sub-cooling temperature increases from 2^0C to 14^0C, the refrigerant R600a under a pressure ratio of 10 presents the better COP comparatively to R-12 and R134a and when the sub-cooling temperature increases from 8^0C to 14^0C, the refrigerant R600a under a pressure ratio of 11 presents the better COP comparatively to R-12 and R-134a.

G. Kiran Kumar [3], 2012, In this paper comparative study of heat transfer rate through the condenser for circular fin geometry and rectangular fin geometry has been done. He found that heat transfer rate for rectangular fin geometry of condenser was more than circular fin geometry. He used LMTD method to find out the heat transfer rate through the condenser. He also found that heat transfer rate in rectangular fin geometry had increased by 4.68 % as compared to circular fin geometry.

Hamid Reza Goshayeshi and Reza Vafa Toroghi [4], 2014, In this paper the effect of free convection heat transfer on a vertical surface on which the triangular fins are vertically placed has been investigated numerically and experimentally. For numerically solving the system of governing equations, they used finite volume method. They conducted the analysis by FLUENT software. They used 4 different types of fin configurations, the different fin configurations having different number of fins i.e. 4, 7, 8, 13 for the same space (decreasing the fin spacing for adjusting the increased number of fins in the same space) for testing and analyzing the results. They found that heat transfer rate increases as the space between the fins increases in the same height and length of the fins, until it reaches to a maximum point; then the heat transfer rate decreases as the space between the fins increases. The maximum point is optimum distance (7/9 mm). They also found that if the number of fins increases or the space between the fins decreases, heat transfer rate will increase but the length of the surface should not be considered too high, because turbulence may be observed.

Vivek Sahu, Pooja Tiwari, K.K. Jain and Abhishek Tiwari [5], 2013, In this paper experimental investigation of domestic refrigerator condenser has been done by varying the fin spacing of the condenser. They checked the results for 3 mm, 6 mm & 9 mm fin spacing. They observed that compressor discharge pressure and condenser discharge pressure drops as the fin spacing is increased.

L. Prabhu, M. Ganesh Kumar, Prasanth M and Parthasarathy M [6], 2018, In this paper a comparative study of heat transfer performance of different fin configurations such as circular, square and rectangular has been done. All the fins under study were having same base temperature & same volume. They used ANSYS as the workbench to analyze the heat transfer performance thermally at steady state. The results showed that the temperature at the end of the fin with rectangular configuration is minimum, as compared to fins with other types of configurations. The effectiveness of fin with rectangular configuration is greater than other configurations and heat transfer through fin of rectangular configuration is also higher than that of other fin configurations. Table I shows different fin configurations and their temperature details and Table II shows the volumes (same) of different fin configurations.

TABLE I

DIFFERENT FIN CONFIGURATIONS AND

THEIR TEMPERATURE DETAILS

Fin Configuration	Maximum Temperature (^{0}C) (Base Temp.)	Minimum Temperature (^{0}C)	Temperature Difference (^{0}C)
Circular	200	166.34	33.66
Square	200	162.46	37.54
Rectangular	200	155.62	44.38

TABLE II

DIFFERENT FIN CONFIGURATIONS HAVING SAME

VOLUME

Fin Configurations	Volume (m^3)
Circular	4.15 x 10^{-5}
Square	4 x 10^{-5}
Rectangular	4 x 10^{-5}

Vivek Aggarwal, Peeyush Chauhan and Pavan Kumar [7], 2017, In this paper an experimental investigation has been carried out to improve the performance of a domestic refrigerator by replacing its natural convection condenser by a forced convection condenser. They took the readings for forced convection at different air velocities. They noted the surface temperature of the condensing coil, ambient temperature and the cabinet air temperatures and compared with those available with natural convection condenser at constant loads. In this study, they used R-134a as a refrigerant. The experimental values of governing temperatures and pressures at different air velocities and cooling loads were recorded. Effect on the cooling of cabinet air was determined by varying air velocity and cooling load. Effect on power consumption was also determined by varying air velocity and cooling load. They found that the cabinet air temperature of the refrigerator goes down in forced convection condenser in comparison with that when it is operating with the natural convection condenser.

They also found the following things:

- Power consumption increases with increase in air velocity and cooling load.
- COP of the system increases with the increase in the load at constant air velocity.
- COP goes down with the increase in air velocity.
- Air velocities around 1.0 m/s will be ideal for cooling load of the range of 125 W and above. For loads lower than 100 W, lesser air velocity will be sufficient for the same cooling performance.
- At free convection condition cooling performance does not get changed with increase in cooling loads; while in forced convection condition, study shows that at higher cooling loads, cooling is better than lower loads when the fan speed is high (of the order of 1.0 m/s).
- The study carried out with forced fan heat transfer to the condenser showed that forced convection heat transfer from the condenser may be economical for the large installations. This system is also recommended where more refrigerating effect is of prime importance.

Yoav Peles, Ali Kosar, Chandan Mishra, Chih-Jung Kuo and Brandon Schneider [8], 2005, In this paper the investigation of heat transfer and pressure drop phenomena over a bank of micro pin-fins has been carried out. They derived, discussed and experimentally validated a simplified expression for total thermal resistance. They discussed geometrical and thermo-hydraulic parameters affecting the total thermal resistance. They found that very low thermal resistances are achievable using a pin fin heat sink. The thermal resistances values were comparable with the data obtained in micro-channel convective flows. They also found that the increase in the flow temperature results in a convection thermal resistance, which is considerably smaller than the total thermal resistance.

Bharti Sharma, Dr. Satyendra Singh, Vinod Kumar and Ravi Kumar [9], 2016, In this paper geometrical study of fins has been done by using ANSYS software. They studied fins of different geometries viz., circular, rectangular, trapezoidal and helical.

They found that heat transfer coefficient (h) of the fins without holes increases in the following order :

Trapezoidal < Circular < Rectangular < Helical

4589.53 < 5620.03 < 6078.93 < 14776.42 ($W/m^{2o}C$)

They also found that heat transfer coefficient (h) of the fins with holes increases in the following order :

Trapezoidal < Rectangular < Circular < Helical

4122.54 < 7486.41 < 8835.46 < 1245227.62 ($W/m^{2o}C$)

Finally they concluded that geometry of helical fins with holes has largest heat transfer coefficient (h).

Md. Shamim Hossain, J. U. Ahamed, Farzana Akter, Debdatta Das and Santoshi Saha [10], 2013, In this paper the heat transfer analysis of pin fin array has been conducted and the fabrication of pin fin array has also been done. They used aluminum as the material for the fabrication of pin fin arrangement. Aluminum metal was used as fin material and also a base plate material. In this experiment, seven fins were used. The fins of diameter 8.2 mm and length 70 mm were arranged in-line manner. The experiments were conducted for various mass flow rate of air. In free or natural convection, researchers found that heat transfer rate and efficiency of fins increase with the heat transfer coefficient. In forced convection, researchers found that heat transfer rate from the fins increase rapidly with the fan speed; this is due to increase in heat transfer coefficient but the efficiency of fin decreases as the velocity of fan is increased because increase in fan velocity offers less time of contact between fin and air. The results are given in the Table III.

TABLE III

HEAT TRANSFER COEFFICENT AND FIN EFFICIENCY FOR BOTH FREE AND FORCED CONVECTION

Test No.	Free Convection		Force Convection	
	h ($W/m^{20}C$)	Ƞ %	h ($W/m^{20}C$)	Ƞ %
1	31.61	52.87	54.14	23.6
2	35.39	60.16	58.85	20.84
3	38	63	64.78	16.17

III. DISCUSSIONS

This literature survey helps to understand the concepts and designs which may be required to conduct and execute the experimentation. The literature survey also gives the guidelines for performing the experiment and obtaining the expected results.

The main aim of the experiment is to do the performance analysis of a domestic refrigerator by changing the design of condenser fins. So for executing the experiment and obtaining the results, we need to change the design of condenser fins.

The literature survey gives the following findings which may be necessary for performing the experiment.

- Thermocouples, bourdon tube pressure gauges and a metal tube flow meter with magnetic coupled indicator should be used to measure temperatures, pressures and refrigerant flow rate in the refrigeration system [1].
- The coefficient of performance (COP) increases with the increase of sub-cooling temperature [2], so there will be the need to attempt to increase the sub-cooling temperature.
- The heat transfer rate for rectangular fin geometry of the condenser of a domestic refrigerator is more than circular fin geometry of the condenser [3]. The temperature at the end of the fin with rectangular configuration is minimum, as compared to fins with other types of configurations (circular and square) [6]. The heat transfer coefficient (h) is maximum for the helical fin without hole out of the fins without holes viz., trapezoidal, circular, rectangular, helical and the heat transfer coefficient of rectangular fin is maximum after helical fin [9]. So the geometry of fins should be changed from circular to rectangular.
- For triangular fins, the heat transfer rate increases as the space between the fins increases in the same height and length of the fins, until it reaches to a maximum point; then the heat transfer rate decreases as the space between the fins increases. The maximum point is optimum distance (7/9 mm) [4]. Compressor discharge pressure and condenser discharge pressure drops as the fin spacing is increased [5]. So the spacing between the fins should be increased to optimum level (7-9 mm) for the desired results.
- The heat transfer rate in rectangular fin geometry increases by 4.68 % as compared to circular fin geometry [3]. So in the experimental work, there will be the need to check that whether the heat transfer rate from the condenser having rectangular fin geometry increases as compared to previous work [3] or remains approximately the same or increases.

The coefficient of performance for the refrigerator (COP) is given by,

$$COP = RE / WD_{comp}$$

Where,

RE – Refrigerating Effect

WD_{comp} - Work Done by the Compressor

The heat removed from the space (Q) is given by,

Q = ṁ x (change in enthalpy of the refrigerant passing through the evaporator) (kJ/s) or (kW)

Where,

ṁ - Mass flow rate of the refrigerant (kg/s)

change in enthalpy of the refrigerant passing through the evaporator – (kJ/kg)

IV. CONCLUSION

The extensive literature survey has been carried out for doing the performance analysis of a domestic refrigerator by changing the design of condenser fins. The literature survey has provided the information and guidelines for conducting the experiment. The information provided by the literature survey will help for executing and undergoing the experiment.

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