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Experimental Analysis and Mathematical Model of Air Cooled Condenser in Domestic Refrigerator

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Abstract: Refrigerator is one of the home appliances operating on vapour compression cycle in its process. Performance of the system becomes the main issue and many researches are still going on to evaluate and improve the performance of any used system. The main objective of this experimental investigation is to enhance the heat rejection rate of the condenser by incorporating axial fan with maximum speed of 4.6m/s at the bottom of condenser tube and the performance is analysed by natural and forced convection condenser under varying mass flow rate of air and refrigerant (R134a). Results of experimentation revealed that Heat rejection rate of forced convection condenser increased by 36.5% and COP is improved up to 33.43%. The performance of system is also evaluated by multiple linear regression analysis and a mathematical model is developed for both natural and forced convection to computed predicted COP.

Keywords: Refrigerator- COP Enhancement of Household Refrigerator – Condenser – Multiple linear regression.

I. INTRODUCTION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. The second law of thermodynamics, as stated by Clausius, asserts that heat can be transferred from a body of low temperature to a body of higher temperature only if external work is expended [1].

The mechanical system used for this purpose is a vapour compression refrigeration system, which normally consists of a compressor, a condenser, an evaporator, and an expansion device A condenser is a heat exchanger is which desuperheating of high temperature vapour changes the phase from vapour to liquid and sub cooling of condensate occurs. The condenser is an important device used in the high pressure side of a refrigeration system. Its function is to remove heat of hot vapour refrigerant discharged from the compressor. The heat from the hot vapour refrigerant in a condenser is removed first by transferring it to the walls of the condenser tubes and then from the tubes to the condensing or cooling medium. The cooling medium may be air or water or a combination of the two. An air cooled condenser is one in which the removal of heat is done by air. Majority of the domestic refrigerators uses the natural convection air cooled condenser.
In the present work refrigerator uses the forced convection air cooled condenser. In forced convection air cooled condenser, the heat transfer from the condenser coils to the air is by forced convection. This paper is an experimental approach to increase the heat to be rejected in the condenser as well as increase the performance of the system [2]. Air cooled condensers are working on two types

- Natural Convection
- Forced Convection.

Natural Convection- In natural convection type, heat transfer from the condenser is by buoyancy induced natural convection and radiation. Since the flow rate of air is small and the radiation heat transfer is also not very high, the combined heat transfer coefficient in these condensers is small .As a result a relatively large condensing surface is required to reject a given amount of heat. Hence, these condensers are used for small capacity refrigeration systems like household refrigerators and freezers.

Forced convection- It is a mechanism, or type of transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.). It should be considered as one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently. The maximum velocity of fan is 4.6m/s since the flow rate of air is large and the radiation heat transfer is also very high, the combined heat transfer coefficient in these condensers is more when the air comes in contact with the warm condenser tubes, it absorbs heat from the refrigerant and thus the temperature of air increases.[3] The warm air being lighter, rises up and cold air from below rises to take away the heat from the condenser. This paper is an experimental approach to increase the heat to be rejected in the condenser as well as increase the performance of the system. Therefore more heat rejection takes place in the condenser. Because of more heat rejection sub cooling occurs at the exit of the condenser which in turn increases the performance of the system.[2] Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Mechanism of Forced Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate). The rate of convection heat transfer is expressed by Newton's law of cooling:

$$Q=h\,A\,(T_s-T_\infty)\quad W$$

The convective heat transfer coefficient h strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent).

In this study, Multiple linear regression equations is used to calculate COP of four variables i.e. time, mass flow rate of air, mass flow rate of refrigerant and load. COP is the output parameter.

II. EXPERIMENTATION AND DATA ANALYSIS

Fig 2 : Actual Experimental setup of domestic refrigerator

The household refrigerator was properly instrumented with one temperature indicator of twelve thermocouple set, two pressure gauges one is high pressure gauge of condenser another is low pressure gauge of evaporator, one energy meter which indicate the power consumption of compressor and fan. Ammeter is used to measure current and voltmeter is used to indicate voltage. Rotameter is used to measure mass flow rate of refrigerant. Mass flow of refrigerant varying by using control valve. Temperature at various points has noted using digital thermometer.

The evaporator and condenser pressure has noted with the pressure gauges. The power consumption of the domestic refrigerator has calculated by using an energy meter, ammeter and voltmeter air cooled condenser with fins are used.

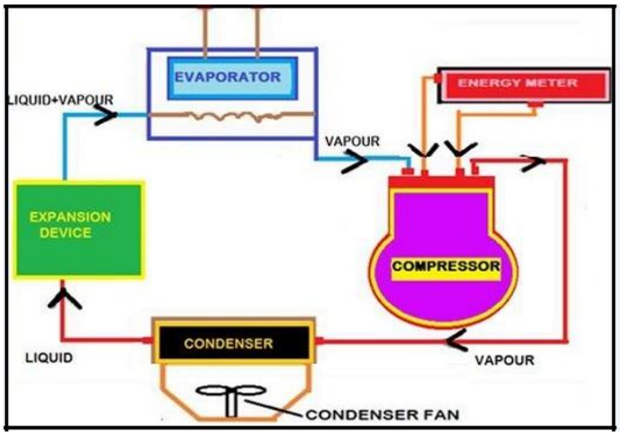

Fig 3 .Schematic Diagram of the (VCRS) of Experimental Setup

Nomenclature:

Ma =Mass flow rate of air (kg/s)

Mr = Mass flow rate of refrigerant (kg/s)

Tci =Condenser inlet temp (℃)

Tco =Condenser outlet temp (℃)

Tei =Evaporator inlet temp (℃)

Teo =Evaporator outlet temp (℃)

Tf =Freezer temp (℃)

Tr =Refrigerator temp (℃)

Th =Hot air temp past the condenser (℃)

Ta =Ambient air temp (℃)

Pc =Condenser pressure (bar)

Pe =Evaporator pressure (bar)

Tc =Time for 10 pulse of compressor energy

Cpv= specific heat of refrigerant R134a in vapour state (KJ/kg K).

Cpl =specific heat of refrigerant R134a in liquid state. (KJ/kg K)

Qc = Heat rejection rate of condenser (W)

Table 2.1.Comparision of Forced and Natural Convection Results.

Readings	**COP (Theoretical)**	**Heat rate(W)**
Natural convection	2.6	50.96
Forced convection (4.6m/s)	3.55	68
Percentage increment	36.5%	33.43%

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III. MULTIPLE LINEAR REGRESSION ANALYSIS

In a regression analysis we study the relationship, called **the regression function**, between one variable **y**, called the **dependent variable**, and several others **xi**, called the **independent variables**. Regression function also involves a set of unknown parameters **bi**. If a regression function is linear in the parameters (but not necessarily in the independent variables!**)** we term it a **linear regression model**.

Otherwise, the model is called **non-linear**. Linear regression models with more than one independent variable are referred to as **multiple linear models,** as opposed to **simple linear models** with one independent variable.[4] The multiple linear regression model is an extension of a simple linear regression model to incorporate two or more explanatory variable in a prediction equation for a response variable. In multiple linear regression analysis, the method of least squares is used to estimate the regression coefficients. The regression coefficients illustrate the unrelated contributions of each independent variable towards predicting the dependent variable [5]

3.1. Main Objectives of Multiple Linear Regression Analysis

The primary goal of present study is to determine the best set of parameters **bi**, such that the model predicts experimental values of the dependent variable as accurately as possible (i.e. calculated values **yc** should be close to experimental values **ya**). Also wish to judge whether our model itself is adequate to fit the observed experimental data (i.e. whether we chose the correct mathematical form of it).[4]

Syntax for MATLAB

```
b = regress(y, x)
[b,bint] = regress(y, x)
[b,bint,r] = regress(y, x)
[b,bint,r,rint] = regress(y, x)
[b,bint,r,rint,stats] = regress(y, x)
```

Load the sample data. Identify Time, Mass flow rate of refrigerant (Mr), Mass flow rate of air (Ma), Load as predictors, and coefficient of performance (COP) as the response.

x_1 = Time;
x_2 = Mass flow rate of refrigerant(Mr);
x_3= Mass flow rate of air(Ma);
x_4= Load
y = Actual coefficient of performance (COP);

Compute the regression coefficients for a linear model with an interaction term.

```
[b,bint,r,rint,stats] = regress(y, x)
```

General Multiple linear regression Model equation,
$y_c = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$

Table 3.1 Comparison of Experimental and Multiple Linear Regression Results.

Mathematical Model to calculate predicted COP of natural convection of any variables x1,x2,x3,x4	$\mathbf{y_c = 2.0905-(0.0026)x_1+ (0.2818)x_2 + (0)x_3 - (0.1833)x_4}$
Error between Mathematical Model COP and Experimental COP(NATURAL CONVECTION).	
Maximum Error	**3.63**
Minimum Error	**0.34**
Correlation coefficient	**0.96**
Mathematical Model to calculate predicted COP of forced convection of any variables x1,x2,x3,x4	$\mathbf{y_c = 2.54-(0.0036)x_1+ (0.2004)x_2 + (7.5794)x_3 - (0.1173)x_4}$
Error between Mathematical Model COP and Experimental COP(FORCED CONVECTION)	
Maximum Error	**3.99**
Minimum Error	**0.07**
Correlation coefficient	**0.964**

IV. RESULTS AND DISCUSSION

Results are the pure comparison of the vapour compression system having natural convection with the modified forced convection air cooled condenser for the refrigerant R134a and with the variables Mr and Va.It also shows the comparision of Experimental and Multiple regression results.This graph shows that both the values of COP are in good agreement with each other.

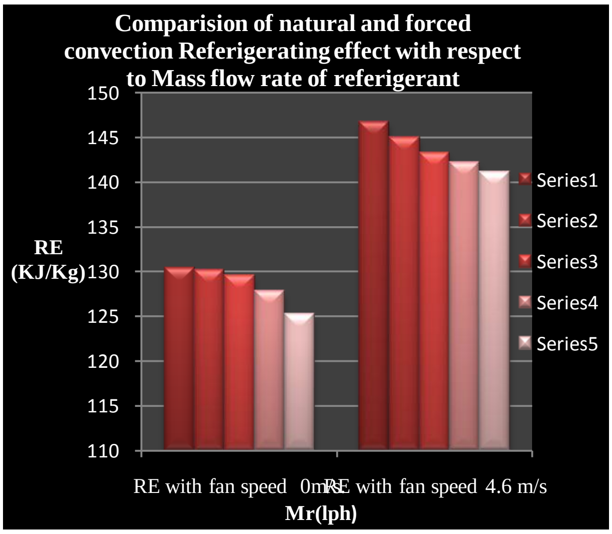

Fig 4.1 Change of Refrigerating Effect with respect to Mr

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Fig 4.1 shows the comparisons of natural and forced convection at 0m/s and maximum speed 4.6 m/s It can be seen that the refrigerating effect of natural convection is less than that of forced convection at different mass flow rate which is shown by series1 (1.5 lph) , series 2 (1.2 lph) ,series 3 (0.9 lph) ,series 4 (0.6 lph),series 5(0.3 lph) of refrigerant because in forced convection subcooling is occurred at the exist of condenser so work done will reduced.

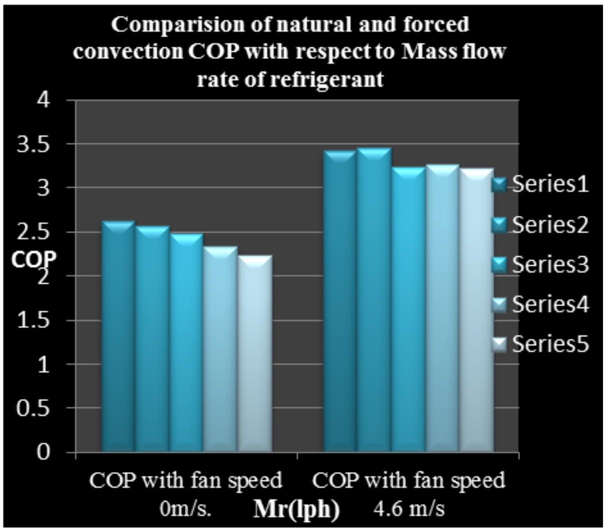

Fig 4.2 Effect of COP with respect to Mass flow rate of Refrigerant.

Fig 4.2 shows the comparisons of natural and forced convection at 0m/s and maximum speed 4.6 m/s. It can be clearly seen that COP of forced convection is maximum as compared to natural convection at different mass flow rate which is shown by series1 (1.5 lph) , series 2 (1.2 lph) ,series 3 (0.9 lph) ,series 4 (0.6 lph),series 5(0.3 lph) of refrigerant because heat transfer is maximum at maximum fan speed so work done will reduce and gradually refrigerating effect will increase.

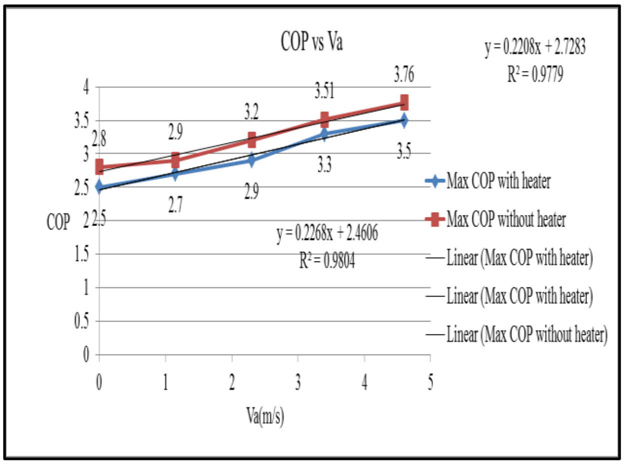

Fig 4.3 Effect of COP on different Velocity of air

Figure 4.3 shows the variation of COP of the forced and natural convection at load and no load condition with varying velocity of air. It can be seen that at same velocity of air COP at no load condition is more as compared to Load condition. This is because the constant heat is supplied to evaporator. In no load condition heater is not ON while taking readings.i.e COP is more. At maximum velocity COP is higher than other because the heat transfer is more and the heat rejection rate is higher for maximum speed.

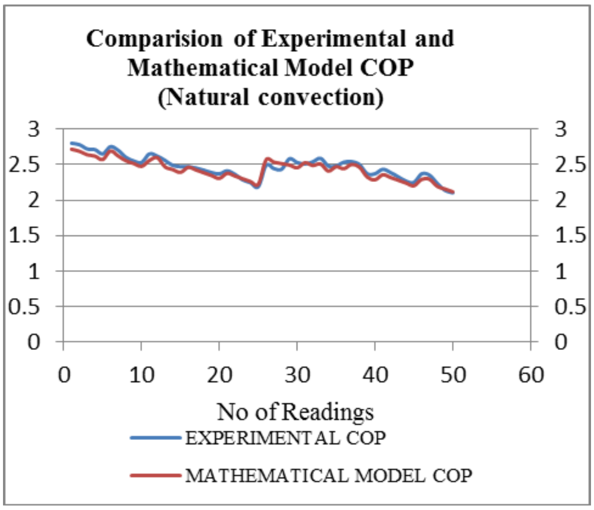

Fig 4.4: Comparison of Mathematical Model and Experimental COP Results (Natural convection)

Fig 4.4. Shows that there are satisfied results between Mathematical Model and Experimental COP with respect to no of readings for natural convection and there is maximum error of 3.63% in results.

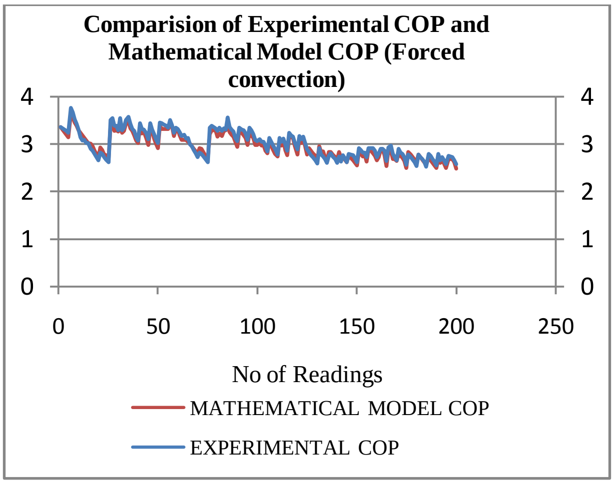

Fig 4.5: Comparisons of Mathematical Model and Experimental COP Results (Forced convection)

Fig 4.5 shows that there is good correlation between Mathematical Model and Experimental COP results with respect to no of readings for forced convection and there is maximum error of 3.88% in results.

V.CONCLUSION

As a result of the current experimental study many conclusions can be drawn regarding the replacement of natural with forced convection condenser of domestic refrigerator.

- The values of the heat rejected from the condenser and COP of the refrigeration cycle is increased gradually with working time until it reaches a steady state conditions after around 45 minutes.
- At maximum velocity of air 4.6m/s heat rejection rate and COP is maximum.
- The forced convection condenser gives about 36.5 % higher amounts of heat rejection rate and 33.43% improvement in COP over the natural convection condenser
- For different values of cooling load, the forced convection condenser gives the best performance as compared to the natural convection condensers. and The work done by the compressor using fan is less in case of this system as 1/10 HP compressor is used.
- The result of multiple linear regression model using MATLAB is used to validate the results. COP of experimental results and multiple linear regression which shows the error of 3.63% for natural convection and 3.99% for forced convection.
- Correlation coefficient for the COP of experimental and multiple linear regression results of natural convection and forced convection is 96%.

VI. FUTURE SCOPE

- Different type of Fan can be used to check the Performance.
- CFD simulation can be carried out to validate theresults,
- Different designs of condenser can be used.

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