An Experimental Analysis of Heat Transfer Through Spiral Coil Condenser in Domestic Refrigerator

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Abstract
The present study deals with Experimental analysis of Heat Transfer through Spiral Coil Condenser in Domestic Refrigerator. An experimental setup was built for carrying out the outside heat transfer coefficient under natural (free) convection. The experimental setup was developed with domestic refrigerator of 165 liters capacity. A straight copper tube of 5.5 mm inner diameter, 6.0 mm outer diameter and 9 meter length was bent to fabricate the spiral coil condenser. Spiral coil condensers used in this experiment. The main objective of this investigation was to obtain outside heat transfer coefficient of existing condenser as well as that of spiral coil condenser. A comparative analysis based on the experiments has been done. The effect of coil was investigated and the results show that outside heat transfer coefficient increases as surface area unit volume increases.

Keywords
Heat Transfer, Spiral Coil Condenser, Domestic Refrigerator, Evaporator chamber, Pressure gauge, Refrigeration tools.

I. Introduction

Domestic refrigerators are widely used home appliance for refrigeration and freezing of food. A domestic refrigerator works on vapour compression refrigeration system. This system consists of four basis parts i.e. compressor, condenser, expansion device and evaporator. The system is divided in to two parts i.e., after expansion device to the inlet of compressor it is known as low pressure system and after compressor to inlet of expansion device it known as high pressure system. Evaporator is a device for extracting heat from the refrigerator compartment with evaporation of the liquid refrigerant. In this process the refrigerant changes its phases from liquid to vapour. The refrigerator is designed for a certain evaporation capacity and evaporating temperature. This can be controlled by keeping the pressure of the evaporator to a predefined value. Similarly the condenser is used for rejecting the heat absorbed by the refrigerant in the evaporator to a sink, which is generally ambient air. For rejecting the heat to the environment it is necessary that the temperature of the refrigerant remains higher than atmospheric air. This is also maintained by keeping the high side pressure to the saturation pressure to the temperature to be maintained. In this process the refrigerant changes its phases from vapour to liquid again. The compressor is used to raise the pressure of the system from a low to high value by consuming electrical work. During the process the temperature of the refrigerant increases isentropically. For the cycle to complete, it is required that the temperature of the refrigerant is again brought to its initial value i.e. to evaporator temperature, and this is done by expanding the refrigerant isoenthalpyally with the help of a capillary ore some kind of expansion value. In doing so some refrigerant is converted from liquid phase to vapour phase which is also sometimes called as flash.

Jader et al. [1] Investigated experimentally air side thermal hydraulic performance spiral wire and tube condenser. The inspection of out-side thermal conductance and pressure drop were carried out for air flow rate, from 70 to 220m^3/h. largest value of pressure drop is for which have less radial spacing, since these give to smallest face area.

Naphon et al. (2) the heat transfer characteristics and performance of spiral coil condenser under cooling and dehumidifying conditions are investigated. Air and water used as working fluid Newton-Raphons iterative method used to heat transfer characteristics. The enthalpy effectiveness and humidity effectiveness decreases as the air and water mass flow rate increases. Air mass flow rate and in let air temperature have significant effect on the increase of the out let air and water temperature.

Ameen et al. (3) they investigated different kind of thermo physical properties. The exit of the compressor is superheated vapour that contains 3 tubes which have to be investigated.

Ohgaki et al. (4) investigated the air side heat transfer and pressure drop characteristic of spiral wire-on- tube condenser, he stated that spiral coil condenser has relatively larger heat transfer rate per unit volume s compare to existing one.

Bansal et al. (5) It was experimentally tasted a condenser in a real refrigerator for some operating conditions by using finite element method and variable conductance approach along with thermodynamics correlations. They optimized the condenser capacity per unit weight. Using variety of wire, tube pitches and diameter.

The experiment is carried in closed door- experiment on the refrigerator pressure and mass flow rate and power consumption by the refrigerator.

Patil et al. (6) produce the double- pipe heat exchanger is to be used for much continuous system having small to heavy work. However spiral coil heat exchanger better choice (a) where space is limited so that not straight pipe can be laid, (b) where the pressure drop of one fluid is limited, by setting the velocity of the annulus fluid in spiral coil heat exchanger at about 1m/s, pressure drop will be low.

Londons et al. (7) investigated the method of entropy generation and minimization. It was found that higher effectiveness heat exchanger has not necessarily that best thermal hydraulic design. It was also found that higher mass flow rate for the same pumping power reduces the condenser temperature and increase the evaporative temperature. It was also found that the heat exchanger design prevents the local performance in terms of minimum entropy generation leads to the global performance.

Hook et.al. (8) Analyzed the experimentally the thermal performance of single layer coil made from carbon. It was found that ±16.7% error in heat transfer coefficient; also conclude that angle of attack is important parameter for heat transfer coefficient increases two times as angle of attack is increases 0 to 20. It was found that as radial and longitudinal spacing is small heat transfer coefficient increases.

Bukasa et.al (9) reported that condensations heat transfer and pressure drop of three micro tube of 12.7 mm outside and three different angles 15^{0}C, 18^{0}C and 25^{0}C it was found that as the spiral angle increases heat transfer coefficient increases for different refrigerant. 15⁰C is best for refrigerant R-12, 18⁰C for refrigerant R-22 and 25⁰C is for R-134a.

From a critical review of the literature on a spiral coil heat exchanger presented above, it is apparent that further studies are warranted to provide better understanding of comparative study of existing conventional condenser and spiral coil used in domestic refrigerator.

Symbol	Explanation
T2	Condenser inlet temperature ^oC
T3	Condenser out let temperature ^oC
P2	Condenser inlet pressure psi
P3	Condenser outlet pressure psi
Ta	Ambient temperature ^oC
T_s	Condenser surface temperature ^oC
T_m	Mean film temperature ^oC
β	Coefficient of thermal expansion
ho	Out side heat transfer coefficient

II. Material and Methods

1. Refrigerator 190 lt.LG make model GL- D201AMLN, RS16750
2. Flaring tool.
3. Tube bender.
4. Tube cutter.
5. Copper tube of length 9 meter and diameter outside 6 mm and inside 5.5 mm respectively.
6. Required 50 piece spoke.
7. Temperature and pressure measuring device viz. thermocouple, pressure gauge.

A. Tools Used in Experiment

1. Flaring Tool

A flaring tool was used to spread the end of the cut copper tubing outward. Note that the flaring is done by holding the end of the tubing rigid at a point slightly below the producing part of the tube. This producing part allows for the starching of the copper. A flare is important for a strong, solid and a leak- proof joint. Fig shows the flaring tool used in the present experiment.

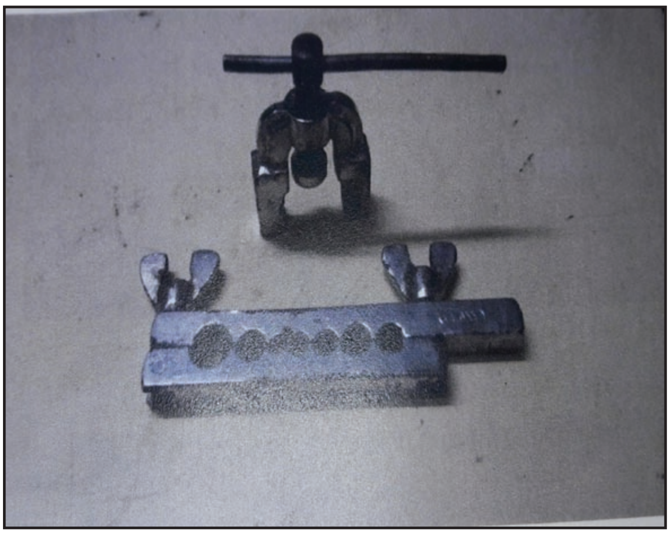

Fig. 1: Flaring Tool Used in Present Experiment

2. Tube Bender

The tube bender is a device to bend a tube such that it conforms to the contour of the bending die this is done by applying pressure on the stock against the bending die.

Fig. 2: Tube Bender Used in Present Experiment

3. Tube Cutter

Copper tube can be cut with a copper tube cutter or a hacksaw the hacksaw should have a wave set. No filling or chips can be allowed to enter the tubing. Hold the tubing so that the when it is cut the scraps will fall out to the usable end. Fig. shows the tub cutter used in the present experiment the tube cutter was moved over the spot to be cut. The cutting wheel was adjusted to touch the copper tube. A slight pressure was applied to the tightening knob on the cutter to penetrate the slightly. Then the knob was rotate around the tube. After one round, the knob was tightened and the cutting wheel was rotated again to make deeper cut. This process was done until the tube was cut completely to avoid crushing of tube during the cutting operation.

Fig. 3: Tube Cutter Used in Present Experiment

4. Temperature Measuring Instrument

Temperature measuring instruments used for more accurate value for this work we use digital thermometer which sense and record the temperature. It has measuring range between -40⁰C to 100⁰C. the accuracy is about ±0.5⁰C fig shows the digital thermometer which was used in the experimental set up.

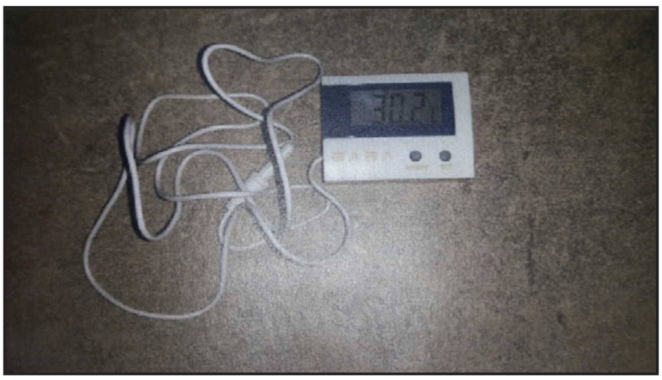

Fig. 4: Digital Thermometer Used in Present Experiment

5. Pressure Gauge

Pressure gauges are simple in function, they read positive pressure and negative pressure, or both. The gauge used in this experiment measure up to 500 Psi and also reads from 0 to 30 Psi for vacuum. Fig shows the pressure gauges which was used in the experimental set up.

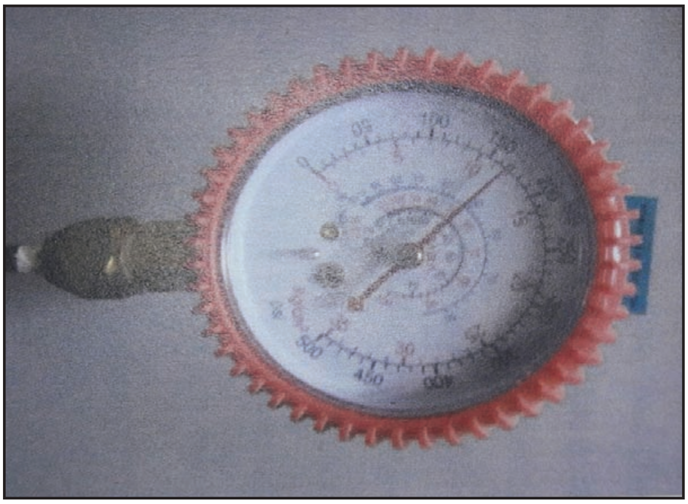

Fig. 5: Pressure Gauge Used in Present Experiment

6. Vacuum Pump

The vacuum pump is mainly employed for evacuating undesirable fluids like moisture and hydrochloric acid present inside the tubing and ducts of the refrigeration system.

III. Experimental Setup

Spiral coil condenser consists of soft copper tube, screw and aluminum plated fins. This is contracted from copper tube, fixed dimension 5.5 mm inner diameter, outside diameter is 6.0 mm and length of the spiral coil is 9 meter. The spiral- coil condenser consists of a single layer of copper tube. A straight tube is constructed by the bending a 6 mm diameter straight copper tube into a spiral coil of three turns maintaining parallel to the central line. Each end of the spiral- coils is connected to the vertical manifold tube with compressor and expansion valve respectively. Painting outside of the tube so that the escape from the corrosion. The aluminum fins are welded to the surface of spiral coil.

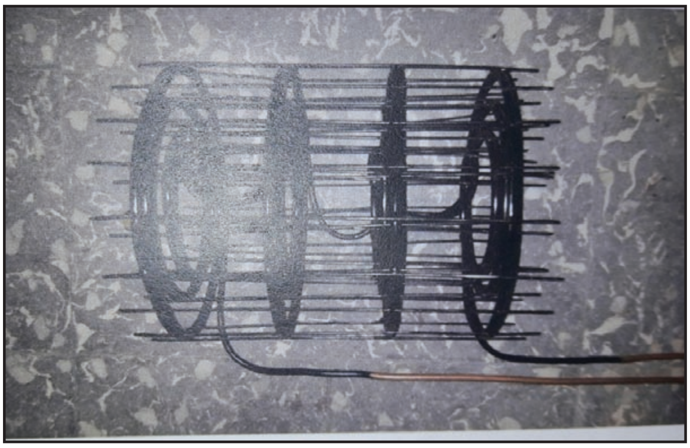

Fig. 6: Spiral Coil Condenser Used in Present Experiment

IV. Results

Experiments have been carried out to calculate outside heat transfer coefficient through spiral coil condenser in domestic refrigerator.

A. Calculation of Outside Heat Transfer Coefficient for Existing Condenser

The ambient temperature, T_a=31.8^{0}C
The condenser surface temperature. T_s=36.2^{0}C

The mean film temperature,

$$T_m = \frac{Ta+Ts}{2}$$
$$= \frac{36.2+31.8}{2}$$

= 34^{o}C
Coefficient for thermal expansion,

$$\beta = \frac{1}{T}$$
$$= \frac{1}{Tm+273}$$
$$= \frac{1}{34+273}$$
$$= \frac{1}{307} K^{-1}$$

Acceleration due to gravity, g=9.81 m/s^2

The properties of air were taken from heat and mass transfer data book at mean film temperature. 34^{0}C
Thermal conductivity, k=0.02707 W/mK
Prandtl number, Pr=0.70002
Kinematic viscostity, ϑ 16.384×10^{-6} m/s^2
Grashoff number, Gr was calculated frim;

$$\text{Grashoff number,Gr}= \frac{L3\ \beta g\ (Ts-Ta)}{\vartheta 2}$$

= 3.81830×10^{11}
The product of Grashoff number and prandtl number was calculated as follows.

Gr. Pr = 2.67357×10^{11} (10^9<Gr.Pr<10^{13})
The product of grashoff number and prandtl number lies between 10^9 and < 10^{13}, Hence flows is turbulent.
Outside heat transfer coefficient of the condenser was calculated from equation (which was taken from heat and mass transfer data book)

For turbulent flow :

$$N_u = \frac{hoL}{K}$$

ho = 1.93765W/m^{2}K

B. Calculation of Outside Heat Transfer Coefficient for Spiral Coil Condenser

For calculation of mean film temperature the ambient temperature and condenser surface temperature were taken from experimental reading for existing condenser.

The ambient temperature, Ta=32.0^{0}C
The condenser surface temperature,Ta=45.0^{0}C
The mean film temperature,

$$Tm= \frac{Ta+Ts}{2}$$
= 38.5^o

Coefficent for thermal expansion,
$\beta = \frac{1}{T}$

$= 3.2102\times10^{-3}K^{-1}$
Acceleration due to gravity, $g=9.81m/s^2$
The properties of air were taken from heat and mass transfer data book at mean film temperature. 38.5°C
Thermal conductivity, K =0.02707W/mk
Prandtl number, Pr=0.08304
Kinematic viscosity, $\vartheta=16.7872\times10^{-6}$ m/s²

Grashoff number, Gr was calculated from;

Grashoff number, $Gr=\frac{L3\beta(Ts-Ta)}{\vartheta 2}$

$=1.6966\times10^{12}$
The product of Grashoff number and prandtl follow. $Gr.Pr=8.76450\times10^{11}(10^9 < Gr.Pr < 10^{13})$
The product of Grashoff number and prandtl number lies between 10 and< 10. Hence flow is turbulent.
Qutside heat transfer coefficient of the condenser was calculated from equation (which was taken from heat and mass transfer data book)
For turbulent flow:

$N_u = \frac{hoL}{K}$

ho = 2.9150 W/m²K

C. Experimental Readings

The experimental readings were taken during experiments for existing condenser as well as spiral coil condenser shown in table 1 and 2 respectively.

Table 1: Experimental Reading for Existing Condenser

T_2 (°C)	T_3 (°C)	P_2 (psi)	P_3 (psi)	T_a (°C)	T_s (°C)
58.80	37.10	200	200	31.80	36.20

Table 2: Experimental Reading for Spiral Coil Condenser

Spiral coil condenser	T_2(°C)	T_3(°C)	P_2 (psi)	P_3 (psi)	T_a (°C)	T_s (°C)
	56.0	35.0	200	200	32.0	45.00

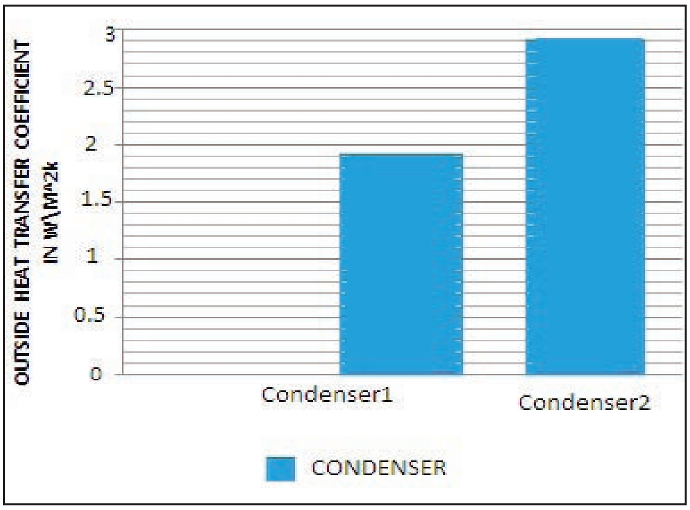

Fig. 7: Outside Heat Transfer Coefficient for Existing Condenser and Spiral Coil Condenser

The outside heat transfer coefficient spiral coil condenser to existing condenser is 50.44% increases.

D. Validation of the Mathematical and Experimental Results

$Y = \Delta\iota$
=105.81613 Cm
Since, the temperature of the condenser is its outer surface temperature therefore there is no need to consider conductive and refrigerant side convective heat transfer coefficient.
Using mathematical equations for heat losses
Heat losses in super-heated state to saturation line
$Q_1 = \dot{m}c_p (T_2 - T_a) [1 - e \ - Uo\pi do\Delta\iota]$

ṁcp= 1.29332 Watts,
= 1.3 Watts

E. Latent Heat Removed

$Q_1 = \dot{m}h_{fg}$
$= 7.78869\times10^{-4}\times(421.28 - 248.94) \times 1000$
= 134.199
= 134.2 Watts
Total heat rejected by the condenser
$Q_{total} = Q_1 + Q_\hat{\imath}$
= 1.3 + 134.2
= 135.5
= 135.5 Watts
From experimental observation,
At 56⁰C, pressure = 13.78 bar
Enthalpy of saturated vapour,
h_2 = 439.74204 kJ/kg
h_3 = 248.94 kJ/kg
Heat losses by the condenser on the basis of experimental observation

$Q = \dot{m}(h_2-h_3)$
$=7.78869\times10^{-4}\times(439.74204.28-248.94)\times1000$
= 148.575 kJ/kg

$= \frac{2.9150-1.93765}{1.93765}\times100$

=50.43%

V. Conclusion

Objective of the present investigation was set to obtain outside heat transfer coefficient for spiral coil condenser to be used in domestic refrigerator. The existing conventional (wire and tube) condenser used in domestic refrigerator was replaced by spiral coil condensers. A comparative study of existing conventional condenser and spiral coil condenser was present in chapter. Experiment had been carried out for existing condenser and spiral coil condenser for same dimension. Summary of the results obtained from the experiments on existing condenser as well as spiral coil condenser and conclusion have been described in this chapter. Following conclusion have been drown because of experiments on spiral coil condenser.
Spiral coil condenser increases the outside heat transfer coefficient as compare to existing condenser. Since centrifugal force increases at each section heat transfer rate per unit volume is larger as compare to existing one.

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