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EXPERIMENTAL INVESTIGATION OF DOMESTIC REFRIGERATOR WITH HELICAL COIL CONDENSER

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Abstract

The objective of the present study is to improve the performance of the domestic refrigerator by increasing the heat transfer through the condenser. Two condensers 1) Conventional (straight tube) and 2) helical with cross flow configuration tested. The temperature and pressure data recorded by keeping the mass flow rate through both the condenser constant. The COP and temperature values compared to some literature values of similar work. The helical coil condenser offers advantages over straight tube condenser due to consequence of the curvature of the coil, which induced the centrifugal forces on the flowing fluid resulting in the development of secondary flow, where the centrifugal forces governed by the coil pitch and the coil diameter. The present investigation reported the 52.85% increase in heat transfer rate from the condenser, which may increase the refrigerating effect by 32.81% and COP by 17.74%. The experimental investigation reported the 15.17% reduction in energy consumption due to a lower cooling time. Results are affected by the geometry of the condenser; study confirms the helical coil condenser has the edge over straight tube condenser.

I. Introduction

The condenser is a component which decides the refrigerator performance. Condenser offers an area to reject the heat from the vapour refrigerant to increase the liquid content in the fluid flow. Condenser temperature has a direct effect on liquid content in the flow, which increases the heat extraction rate from the surrounding. An increase in turbulence would increase the heat transfer rate from the condenser, which results in

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the centrifugal forces into the flow as the flow passes through the helical coil. Condenser temperature has a direct effect on the liquid content in the evaporator and also, the cooling capacity of the refrigerator this would decrease the COP of the refrigeration system [8]. More the liquid content more will be the heat extraction from the evaporator surrounding, this increases the cooling capacity of the refrigerator, so as COP. The only way to increase the liquid content in the evaporator is to provide additional sub cooling of refrigerant at the condenser exit.

In the current scenario, the researchers are exploring condenser geometry to improve the heat transfer from the fluid. J. K. Gupta et al. [9] present a simulated this model to predict the effects of hot wall condenser and operating parameters on the condenser capacity and COP of the refrigerator, where the predictions show 4K drop in condenser temperature along with the increase in heat transfer coefficient of the condenser [9]. Byeong-Sun Kim [7] patented various geometries of condensers for domestic refrigerator other than conventional (straight tube), the article also reported an improvement in the refrigerator performance. Centrifugal forces induced on the fluid flow when passing through the helical coil develops the secondary flow [7]. Extension to the study of Kim [7], Bagade and Borikar [3], further explores the possibilities of an elliptical helical condenser to improve the COP of the refrigerator. An experimental investigation shows an improvement in COP and heat transfer coefficient as a result of turbulence on both sides of the condenser coil [3].

In continuation with the previous research of Bagade and Borikar [3] experimentally investigate the performance of the refrigerator by retrofitted the condenser. An experimental investigation shows up to 30% increase in COP [6]. S. A. Berger [4] investigated the effect of curved and helically coil circular tubes on the heat transfer coefficient and heat transfer rate. Experimentation reported that the centrifugal forces on the fluid flow when flowing in a circular path, which develops the secondary flow normal to the direction of the flow, which increases the friction factor, that increases heat transfer coefficient of the condenser [4]. B. Chinna Ankanna [2] reported 55% (0.45 compared to 0.29) improvement in the effectiveness of the helical coil tube condenser than straight tube condenser when uses helically coiled condenser [2]. Based on experimental evidence (M. Hosoz, [12]) the refrigerator with water-cooled helical coil condenser ought to enhance COP (14.2%) and cooling capacity (31.1%) compared to the air-cooled condenser [12].

Background work

Jasmin Geppert et al. [13] experimentally analyses the effect of various parameters such as ambient temperature, opening and closing of door and heat load on energy consumption of refrigerator. The analysis shows that the variation in ambient temperature affects in larger than the heat load to food compartment, there is 6%-7% increase in energy consumption as ambient temperature varies in the range of 25°C where as 0.03%-0.04% variation in the energy consumption as heat load varies into the food compartment. The study evidenced that the flowing fluid experienced a centrifugal force due to the curved shape of the condenser coil. Further it dealt that the flow bifurcated to the wall side and develop a counter rotating vortices i.e. secondary flow, this produce additional fluid flow transport which increases the heat transfer rate and pressure compared to straight tube condenser [13]. The research also targeted to explore the possibilities of the condenser geometry to improve the COP of the refrigerator. The results show that the additional temperature drop observed as compared to the conventional condenser coil as a result of the helical pattern of condenser. Further, elliptical helical coil condenser was investigated, experimentations carried out on 165 lit refrigerators with existing straight loop air cooled condenser and with elliptical helical condenser under controlled ambient conditions, the results of experimentation shows substantial increase in COP than existing, with reduction in compressor operating cycles and cooling time [5, 6]. Harith Noori Mohammed et al. [11] investigated the effects of curvature ratio $(d/D = 0.1101$ and 0.0942) of the helical coil condenser on the various dimensional fewer numbers (Nu, Re, and Gr) and heat transfer coefficient. The investigation reported increased curvature ratio influence the centrifugal forces into the flow, therefore, it increases the Nusselt number and heat transfer coefficient as a result of increased turbulence in the flow [11].

J. M. Gonçalves et al. [10], develop a steady state model for predicting the energy consumption of domestic refrigerator, the model comprises of 600-liter refrigerator with fresh food-freezer compartment temperature settings. The prediction shows that the 4.5% decrease in compressor power if replaced with low capacity compressor and increased by 20% if replaced with high capacity compressor. Study also presents an evidence on condenser impact on energy consumption, increasing the row of condenser coil from 18-24, the energy consumption reduces by 4%, as a result of increase in air-side turbulence and sub cooling due to more heat transfer from condenser to ambient air [10].

The proposed research introduces the new concept of helical coil tube condenser into the domestic refrigerator. An investigation had performed to understand and examine the influence of helically coiled condenser on COP, compressor performance, heat rejection from condenser and sub cooling of the refrigerant.

II. Experimental Setup

An experimental set-up fabricated to examine the effect of the condenser on the various parameters like COP, compressor work, refrigerating effect also sub cooling.

The system equipped with a digital energy meter (kWh) used to measure the electric consumption of the compressor. Pressure in the inlet and exit of condenser measured by special type Bourdon gauges suitable for a refrigeration system with an accuracy ±0.05 bar. The temperature of the refrigerant and air at different locations in the refrigerator were measured by K type thermocouple with accuracy ±1°C. Schematic of the experimental set of 168-liter refrigerator is shown in figure 1 gives the information regarding the locations of the measuring instruments such as pressure gauges and the temperature sensors.

The experimentation was performed by following the standard guidelines laid down by the Bureau of Energy Efficiency (BEE) in India [15, 16]. Before temperature measurement, the surface of the condenser was cleaned and to reduce the effect of thermal contact oil was used in the point of contact. To prevent the instrument from any convection or radiation affect the thermocouple probe is covered with the insulated tape.

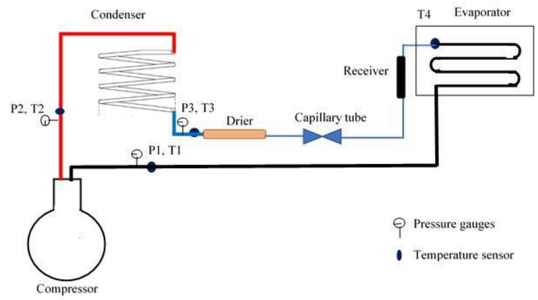

Figure 1. schematic of experimental set-up.

III. Results and Discussion

In order to estimate the effect of the condenser on sub cooling and the performance of the refrigerator, the comparison is made between the existing refrigerator with a wire-on-tube condenser and retrofitted refrigerator with helical coil tube condenser. The experimentation was performed in two stages. In the first stage, the experimentation was performed on both refrigerators and the data were recorded after the steady-state condition was established in the system at an interval of 5 minutes.

Table 1. Compiled comparative test results of stage-1 experiments.

Refrigerator with straight tube condenser						Refrigerator with helical coil condenser				
Time (min)	T3 (°C)	RE (W)	Wc (W)	Qr (W)	COP	T3 (°C)	RE (W)	Wc (W)	Qr (W)	COP
5	36.2	226.48	98.34	1971.1	2.30	33.2	283.1	110.26	2940.8	2.56
30	43.6	210.09	104.3	2509.2	2.01	35.7	277.1	110.26	3570.6	2.51
60	46.8	202.64	107.28	2992.5	1.88	38.3	272.6	122.18	4245.6	2.23
90	48.3	202.64	101.32	3347.6	2.00	41.5	272.6	117.71	5216.2	2.31
120	49.1	195.19	110.26	3645.2	1.77	43.9	265.2	123.67	6138.6	2.14

Table 2. compiled comparative test results of stage-2 experiments.

Refrigerator with straight tube condenser						Refrigerator with helical condenser				
Time (min)	T3 (°C)	RE (W)	Wc (W)	Qr (W)	COP	T3 (°C)	RE (W)	Wc (W)	Qr (W)	COP
5	39.3	208.6	96.85	857.9	2.15	34.1	311.41	117.71	3216.9	2.53
30	44.2	190.72	107.28	1225.7	1.77	35.7	314.39	117.71	4034.9	2.52
60	47	189.23	101.32	1532.6	1.86	37.6	312.9	111.75	4512.0	2.42
90	48.2	187.74	102.81	1421.6	1.82	39.4	312.9	111.75	4661.7	2.18
120	50.9	187.74	102.81	2057.1	1.82	41.3	312.9	111.75	5086.3	1.90

In the second stage of experimentation, both the refrigerators were loaded with 30 litres of water at room temperature with the desired thermostat setting.

Experimentations were performed to investigate the parameters like sub-cooling, refrigeration effect (RE), compressor work (Wc) and COP of the refrigerator. The compressor operating cycle and cooling time was also analyses during this experimental study. Comparative results of satage-1 and stage-2 tests is presented in the table 1 and table 2.

Table 3. Comparison of compressor operating cycles and energy consumption.

Refrigerators with condenser	Operating hours	Energy consumed (kWh/day) Without thermostat setting	Energy consumed (kWh/day) With thermostat setting	Average operating time (minutes)	% increase in operating cycle	% decrease in energy consump tion
Conventional	24	100.1	1.45	22.07	0	0
helical	24	119.2	1.23	18.14	10.88	15.17

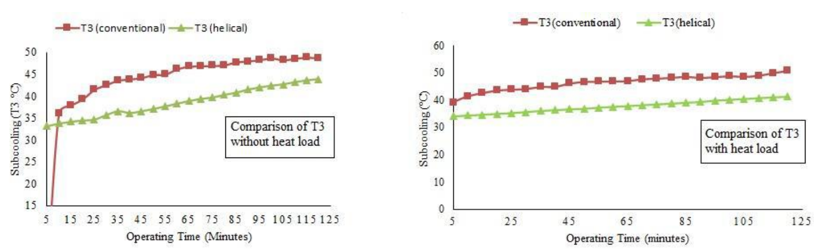

Figure 2. Comparison of sub cooling with and without heat load to evaporator.

Figure 2 presents a comparison between sub cooling of refrigerator with conventional and helical coil condenser. it is seen that the sub cooling is more in a refrigerator with helical coil tube condenser than a refrigerator with wire-on-tube(conventional) condenser. with reference to the compiled results of stage-1 experiments listed in table 2, the figure 2 shows average 14.91% increase in sub cooling compared to an existing refrigerator. The Mohamed-E. Ali [14], stated that vertical helical coil tubes offer more natural heat transfer as a result of an increase in Rayleigh number and turbulence. The heat transfer coefficient was more in case of a helical coil of tube diameter 12mm and 8mm for numbers 10-13 numbers of turns [14].

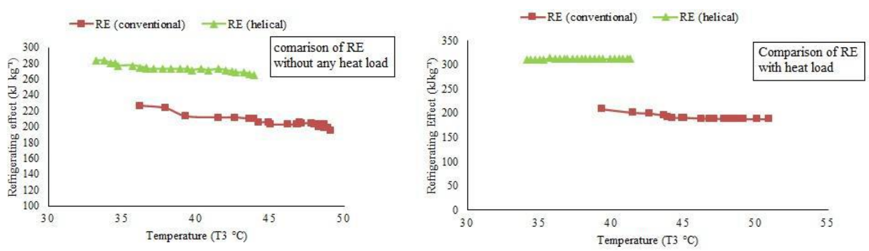

Figure 3. Comparison of Refrigerating Effect with and without heat load to evaporator.

With reference to this study, it is observed from figure 2, that the increase in sub cooling in a refrigerator with helical coil tube condenser compared to the conventional. The helical coil tube condenser offers more heat transfer rate, the reasons for this enhancement is the additional turbulence due to the centrifugal forces acted on the flow, the fluid molecules reject more heat to the tube wall and fluid internally, the helical nature of condenser boost the air-side turbulence, this improves the overall heat capacity of the system and resulting overall heat transfer coefficient. The overall heat transfer coefficient for helical condenser was calculated as 3.36 $Wm^{-2}K^{-1}$ experimentally.

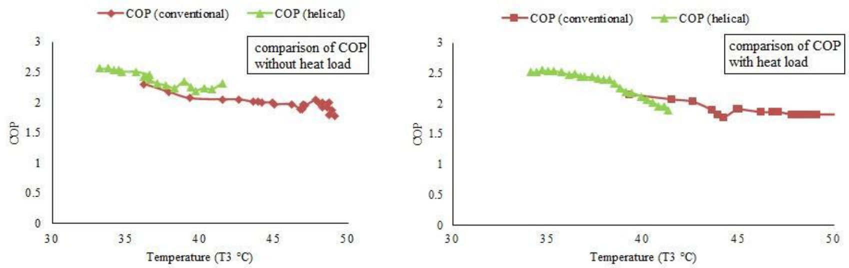

Figure 4. COP comparison with and without heat load to the evaporator.

Amount of liquid content in the fluid flow increases the heat extraction from the evaporator, this increases the refrigerating effect [8]. With reference to the figure 2, increase in sub cooling increases the liquid contents into the flow at the condenser exit, the figure 3 shows an increase in refrigerating effect compared to the conventional. The result shows an average 32.81% increase in refrigerating effect for a refrigerator with helical coil tube condenser. The net effect of an increase in sub cooling reflected in figure 4. COP is the ratio of refrigerating effect to the compressor work to produce the same [1], experimental analysis shows 17.74% average improvement in COP compared to the conventional. The results of the experimental analysis are reported in table 2 and table 3. The stage-1 and stage-2 testing shows identical behavior of T3 and RE trends as per the expectations before performing the experiments.

IV. Conclusion

The experimental investigation on the domestic refrigerator has performed with two geometries of condenser 1) conventional (straight tube) condenser and 2) helical coil condenser. An analysis of the test data shows the difference between the heat transfer rate of the condensers. Helical-coil condenser offers 50.85% more heat transfer compared to the conventional (straight tube) condenser.

The stage 1 and stage 2 experimentation reported the increase in refrigerating effect and COP of the refrigerator with helical coil condenser. An Average the 15.17% reduction in energy consumption reported by refrigerator compared to the conventional (straight tube) condenser with the helical-coil condenser. Inclusive, it gives an impression that the condenser geometry plays a role in improving refrigerator performance.

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Nomenclature

Symbol	Description	Unit
COP	Coefficient of performance	…
D	Coil diameter	m
d	Tube diameter	m
Gr	Grashoff's number	…
Nu	Nusselt number	
Qr	Heat rejection rate	W
RE	Refrigerating effect	W
Re	Reynolds number	…
T_3	Condenser temperature (exit)	**°C**
Wc	Compressor work	W

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