INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.3 Issue.2, February 2015. Pgs: 28-35

Experimental study of effect of spiral tube heat exchanger in domestic refrigerator: A Literature Review

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Abstract

This paper presents a critical review of spiral tube heat exchanger to compute COP of domestic refrigerator. Studies aimed for spiral tube in the heat exchanger device to carry an experimental study for COP increment in any heat transfer applications; a review. The purpose of this article is to compare the COP of refrigerator by using air cooled condenser & hollow spiral tube heat exchanger of same length & same diameter. It was observed from the past research that the effectiveness of the heat exchanger for other varying shaped coil is more than that for the U- shape coil. In this context, it is essential to carry out the research for COP increment; this spiral tube air cooled heat exchanger will be attached in the domestic refrigeration test rig to find out the COP of the system.

***Keywords**: Spiral tube air cooled heat exchanger; heat transfer; domestic refrigerator, COP.*

1. Introduction

Energy recovery is the prime requirement today to optimize energy consumption. The maximum utilization of thermal energy is achieved by properly designed Heat Exchangers, and selection of temperature program. The selection of heat exchanger geometry is also important for particular heating /cooling application. There are various heat exchanger geometries exist and to be selected based on applications. However, the spiral tube heat exchanger is a unique geometry of compact heat exchange for gas/liquid; vapor/liquid heat transfer applications. The secondary flow of fluid through curved tubes and in particular horizontal spiral tube heat exchanger ensure the higher rate of heat flow through the fluid. The mechanical agitating is induced due to fluid motion hence higher heat transfer rate achieved without any external mechanical induced devise in tube.

The heat exchanger is the process heat transfer equipment. The type of heat exchanger governs the effectiveness of heating and cooling. The different geometries of heat exchanger are possible however the proper selection required based on application. More performance and/or reduced the size of heat transfer devices can be achieved by heat transfer enhancement techniques. In general, these techniques can be divided into two groups: active and passive techniques. Tubes with spiral have been used as one of the passive heat transfer enhancement techniques and are the most widely used tubes in several heat transfer applications, for examples, heat recovery processes, air conditioning and refrigeration systems and chemical reactors.

2. Literature Review

Use of spiral tube heat exchanger in the refrigeration system is a new technique altogether. The focus is placed on a need to develop effective, less costly and maintenance-free auxiliary integrated with main system to achieve enhancement in COP of the domestic refrigerator. If this idea is implemented at system design level, then there would be considerable saving of energy. Following researchers contributed to the area of heat transfer enhancement significantly.

Cavallini et al. [**1**] presents a critical review of correlations to compute heat transfer coefficients and pressure drop, for refrigerants condensing inside commercially available tubes with enhanced surfaces of various types, and a theoretical analysis of the condensation phenomenon. Predictions from some of the above equations are compared with experimental data. In addition, information is presented about the influence of small amounts of compressor oil on the condensation of refrigerants in enhanced tubes.

Shinde D. & Dange M. [**2**] experimental investigation of heat transfer in cone shaped helical coil heat exchanger is reported for various Reynolds number. The purpose of this article is to compare the heat transfer in cone shaped helical coil and simple helical coil. The pitch, height and length of both the coils are kept same for comparative analysis. The calculations have been performed for the steady state condition and experiments were conducted for different flow rates in laminar and turbulent flow regime. The coil side flow rate is kept varying while the coil side flow rate is kept constant. It was observed that the effectiveness of the heat exchanger for the cone shaped helical coil is more than that for the simple helical coil. Results show that the heat transfer rates for the cone shaped helical coil are comparatively higher than that of the simple helical coil. It was found that the heat transfer rates are 1.18 to 1.38 times more for the cone shaped helical coil than that of simple helical coil.

Wisam A. Kattea [**3**] experimental study is carried out on the effect of vortex generators (Circular and square) on the flow and heat transfer at variable locations at (X = 0.5, 1.5, 2.5 cm) ahead of a heat exchanger with Reynolds number ranging from $62000<Re < 125000$ and heat flux from $3000 \leq q \leq 8000$ W/m2. In the experimental investigation, an apparatus is set up to measure the velocity and temperatures around the heat exchanger. The results show that there is an effect for using vortex generators on heat transfer. Also, heat transfer depends on the shape and location. The circular is found to be the best shape for enhancing heat transfer at location [X_m=0.5 cm] distance before heat exchanger is the best location for enhancing heat transfer. The square is the best shape for enhancing heat transfer at location [X_m=2.5 cm] distance before heat exchanger is the best location for enhancing heat transfer. The results of flow over heat exchanger with vortex generators are compared with the flow over heat exchanger without vortex generators. Heat transfer around heat exchanger is enhanced (56%, 50%, 36%) at location (X=0.5, 1.5, 2.5cm) respectively by using circular vortex generators without turbulator and heat transfer around heat exchanger is enhanced (39%, 42%, 51%) at location (X=0.5, 1.5, 2.5cm) respectively by using square shape vortex generators without turbulator.

P. Naphon & S. Wongwises [**4**] the heat transfer characteristics and the performance of a spiral coil heat exchanger under cooling and dehumidifying conditions are investigated. The heat exchanger consists of a steel shell and a spirally coiled tube unit. The spiral-coil unit consists of six layers of concentric spirally coiled tubes. Each tube is fabricated by bending a 9.27mm diameter straight copper tube into a spiral-coil of five turns. Air and water are used as working fluids. The chilled water entering the outermost turn flows along the spirally coiled tube, and flows out at the innermost turn. The hot air enters the heat exchanger at the center of the shell and flows radially across spiral tubes to the periphery. A mathematical model based on mass and energy conservation is developed and solved by using the Newton–Raphson iterative method to determine the heat transfer characteristics. The results obtained from the model are in reasonable agreement with the present experimental data. The effects of various inlet conditions of working fluids flowing through the spiral coil heat exchanger are discussed.

Yanuar et al. [**5**] presents an experimental investigation of convective heat transfer coefficient for nanofluids using spiral pipe heat exchanger. The aim of this study is to investigate experimentally flow and convective heat transfer characteristics of water-based nanofluids flowing through a spiral pipe. The test section consist of spiral pipe with ratio pitch per diameter is 7.0 and mean hydraulic diameter of 30 mm. The straight spiral tube with 1600 mm length is used as the test section. At the inner of spiral pipe installed a circular copper pipe with 10 mm diameter. Measurements of pressure drop and convective heat transfer are carried out for Al2O3, TiO2 and CuO at 1% and 3%, particle volume with pure water. The convective heat transfer coefficient of the nanofluids increases by up to 28% at a concentration of 3 vol. % compared with that of pure water.

Bibin Prasad et al. [**6**] helical pipes are universally used for heat transfer enhancement in heat exchangers. In the present work, CFD simulations are carried out for a counter flow double pipe helical heat exchanger by varying the flow rates of a single fluid (water). The heat transfer characteristics of the same are compared with that of a counter flow double pipe straight tube heat exchanger for the same flow rates. The results were interpreted by developing correlations between Nusselt number and Dean Number for both the inner and outer helical pipes which shows a strong linear relationship.

R. J. Yadav & A. S. Padalkar [**7**] CFD investigation was carried out to study the heat transfer enhancement characteristics of air flow inside a circular tube with a partially decaying and partly swirl flow. Four combinations of tube with twisted-tape inserts, the half-length upstream twisted-tape condition (HLUTT), the half-length downstream twisted-tape condition (HLDTT), the full-length twisted tape (FLTT), and the plain tube (PT) with three different twist parameters (λ = 0.14, 0.27, and 0.38) have been investigated. 3D numerical simulation was performed for an analysis of heat transfer enhancement and fluid flow for turbulent regime. The results of CFD investigations of heat transfer and friction characteristics are presented for the FLTT, HLUTT, and the HLDTT in comparison with the PT case.

Xie Pengchenget et al. [**8**] single-phase pressure drop and heat transfer in a rotor-assembled strand inserted tube were measured using water as the working fluid. Experiment using a smooth tube was carried out to calibrate the experimental system and the data reduction method. In the experiment, fixed mounts were used to eliminate the entrance effect. The experimental results of smooth tube show that employment of fixed mounts leads to a visible bias of friction factor at relative low Reynolds numbers, although it does not significantly affect the Nusselt numbers. The measured data of inserted tube reveal that rotor-assembled strand can significantly improve heat transfer with the Nusselt number increased by 101.6%-106.6% and the overall heat transfer coefficient increased by 58.1%-67.4% within the Reynolds number range of 20000 to 36000. Meanwhile, friction factor increases by 52.2%-84.2% within the same Reynolds number range. The correlations of Nusselt number and friction factor as function of the Reynolds number and Prandtl number were determined through multi variant linear normal regression.

Kumbhar G. & Sane K. [**9**] in last decade on heat transfer enhancement in a circular tube. In the present paper emphasis is given to works dealing with twisted tape inserts because according to the recent studies, these are known to be economic heat transfer enhancement tool. The thermo hydraulic performance of twisted tape insert depends on the flow conditions i.e., laminar or turbulent flow apart from the insert configuration. The present review is organized separately for laminar & turbulent flow.

D. R. Waghole et al. [**10**] augmentation techniques refer to different methods to enhance rate of heat transfer without affecting much the overall performance of the system. These techniques are used in various applications such as solar power plants, thermal power plants, refrigeration and air conditioning, process industries, radiators for automobile systems etc. These techniques are of three types which are active, passive and compound techniques. The present paper is review of passive augmentation technique used in recent past.

J.P. Meyer & S. Vyver [**11**] potential of a very simple and inexpensive method of heat augmentation that could be used by small manufacturing companies is investigated. It consists of an aluminium heat exchanger comprising a round tube inside a twisted square tube. The aim is to increase the heat transfer between the flow in the inner tube and the flow in the annulus by increasing the heat transfer coefficient in the annulus. This investigation was conducted with measurements on five different heat exchanger configurations: the first, without any twist and the rest, with the square tube twisted at angles of 45˚, 60˚, 90˚ and 105˚ per metre respectively. The nusselt number and friction factor in the annulus of each, case study where measured as functions of the Reynolds number. While the Prandtl numbers were kept constant; and for each heat exchanger configuration an equation was deduced that describes this functional relationship. The relationships are shown in graphical format. It 'was found in general that the heat transfer und pressure drop increase with twist, angle and Reynolds number. Furthermore that for a twist angle of 60˚ and a Reynolds number lower than4000, the heat transfer rate per unit pumping power is the highest ,while for higher Reynolds numbers a twist angle of90˚ gives the highest heat transfer per unit pumping power.

Kevin Stone [**12**] discussion on the application of enhanced heat transfer surfaces to compact heat exchangers. The motivation for heat transfer enhancement is discussed, and the principles behind compact heat exchangers are summarized. Next, various methods for evaluating and comparing different types of heat transfer enhancement devices using first and/or second law analysis are presented. Finally, the following plate-fin enhancement geometries are discussed: rectangular and triangular plain fins, offset strip fins, louvered fins and vortex generators.

P. Naphon and S. Wongwises[**13**] heat transfer characteristics and the performance of a spiral coil heat exchanger under cooling and dehumidifying conditions are investigated. The heat exchanger consists of a steel shell and a spirally coiled tube unit. The spiral-coil unit consists of six layers of concentric spirally coiled tubes. Each tube is fabricated by bending a 9.27mm diameter straight copper tube into a spiral-coil of five turns. Air and water are used as working fluids. The chilled water entering the outermost turn flows along the spirally coiled tube, and flows out at the innermost turn. The hot air enters the heat exchanger at the centre of the shell and flows radially across spiral tubes to the periphery. A mathematical model based on mass and energy conservation is developed and solved by using the Newton–Raphson iterative method to determine the heat transfer characteristics. The results obtained from the model are in reasonable agreement with the present experimental data.

Paisarn Naphon et al. [**14**] results of the heat transfer and pressure drop characteristics in horizontal double pipes with helical ribs are presented .Nine test sections with different characteristic parameters of: helical rib height to diameter, v/di = 0.12, 0.15, 0.19, and helical rib pitch to diameter, p/di = 1.05, 0.78, 0.63, are tested. Cold and hot water are used as working fluids in the shell side and tube side, respectively. Experiments are performed under conditions of mass flow rates varying from0.01 to 0.10 kg/s for cold water and from 0.01 to 0.10 kg/s for hot water, respectively. The inlet cold and hot water temperatures are between 15 and 20 ˚C and between 40 and 50˚C, respectively. The results obtained from the tubes with helical ribs are compared with those without helical ribs. It is found that the helical ribs have a significant effect on the heat transfer and pressure drop augmentations. Based on fitting the experimental data, non-isothermal correlations of the heat transfer coefficient and friction factor are proposed. The majority of the data falls within ±15%, ±15% of the proposed correlations for heat transfer coefficient and friction factor, respectively.

An extensive literature review of all types of augmentation technique with external inserts till the year 2005 has been discussed by Waghole [**10**]. In the following subsections literature involving recent work on passive methods by employing air cooled spiral tube heat exchanger is replace in place of air cooled condenser in domestic refrigerator it has been reviewed.

3. Experimental method

3.1 Experimental setup

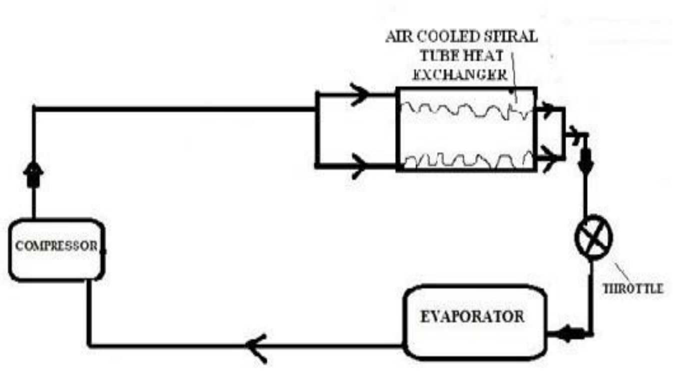

Figure 1: Flow diagram of experimental set up

The apparatus for experimental studies on COP increment in domestic refrigerator with using air cooled spiral tube heat exchanger and control panel shown in Figure 1 & 2. It consists of evaporator, air cooled spiral tube heat exchanger and thermostatic expansion valve with the knob for on/off operation. In this heat exchanger R134a refrigerant used; this unit is connected to refrigerator test rig by replacing air cooled condenser. Each unit of refrigerator system are placed as per the refrigeration cycle only the addition of the spiral tube air cooled heat exchanger with replacement of air cooled condenser in the path of refrigerant. The thermostatic expansion valve are attached in the path to find the optimum increment of COP of Vapour compression refrigeration system. Control panel consist of On/Off switch for evaporator, Dimmerstat, energy meter, digital temperature indicator connected with 9 k- type thermocouple.
To study the calculation of refrigeration system control panel is most important for calculation part for experimentation.

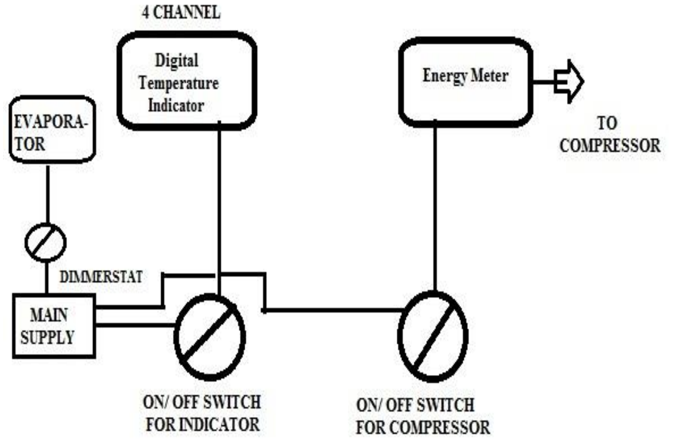

Figure 2: Photo image of Control Panel

3.2 Test procedure

Fill the tank in vapour compression test rig with the water. Switch on the evaporator, temperature indicator and compressor switch. Measure the Suction and Delivery pressure of Refrigerant with the help of Low pressure and High pressure gauge. Take initial energy meter reading of both compressor and stirrer. Before starting the experiment measure the atmospheric pressure. Wait for about 40 minutes so that the system gets stabilized. After the 40 minute completion, take the reading of nearly 5 minute of time span measure the various temperature of the setup from digital temperature indicator i.e. T_1, T_2, T_3, T_4; Measure evaporator (L.P) and condenser (H.P) pressures of the refrigerant. Experiment is conducted at no load condition at evaporator for this work. Then note down the measure temperature in tabular format along with the pulse rate per sec time. Repeat test procedure for after 5min spam.

4. Result & discussion

The literature comparison with current research on the basis of different geometry has been taken by replacing air cooled condenser in domestic refrigerator with reported heat exchanger whereas the all the author who work on spiral tube geometry included in evaporator in refrigeration system[1-4].The hydrodynamic study of spiral tube air cooled heat exchanger suggest that the pressure drop varies with the flow; however the pressure drop is maximum at a velocity indicating the maximum turbulence exists at certain velocity. The detail investigation with varied number of coil turns is under investigation. Use of such type of heat exchanger is beneficial to include in domestic refrigerator; for increasing COP.

Experiments are carried out with air cooled spiral tube heat exchanger. Mass flow rate of water circulation is changed and its effect on system performance is studied. It is found out that by using air cooled spiral tube heat exchanger the cycle, discharge pressure is reduced and work required to drive the compressor is reduced. For the analysis of cycle, software “Cool Pack” is used. Table-1 show outcomes of system. Table-1 shows the refrigerating effect QE, condenser heat rejection QC, power consumed in kW, actual COP, and theoretical COP* with air cooled spiral tube heat exchanger. Figure-3 shows p-h chart obtained by using Cool-Pack software.

Table 1: Results with air cooled spiral tube heat exchanger

Time	Q_E	Q_C	Q_S	KW	COP	COP*
12.10	13.9	16	1.5	3.2	4.34	4.8
12.50	6.93	14.1	1.56	3.4	2.03	3.8
1.30	5.12	13.9	1.96	3.4	1.50	3.2
2.10	4.43	12.7	2.12	3.4	1.30	3
2.50	8.98	12.3	2.12	3.4	2.64	3
3.30	9.48	11	2.12	3.4	2.78	2.8
4.10	10.02	13.3	2.40	3.4	2.94	3.6

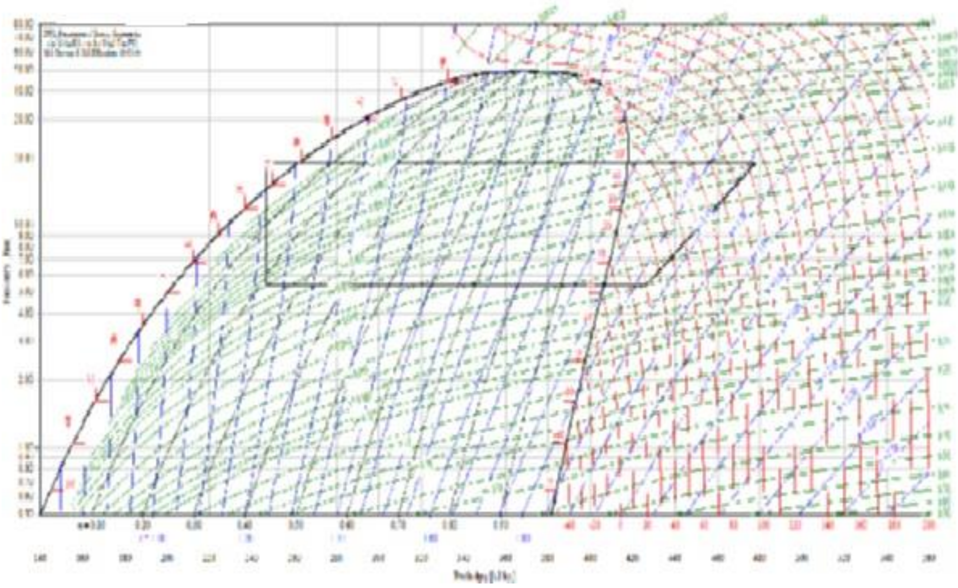

Figure 3: p-h chart obtained by using Cool-Pack software.

4. Conclusion

New experimental data for the measurement of the COP and the performance of a spiral tube heat exchanger are calculated. The results obtained from the developed experimental set up need to validate comparing with the measured data of the literature. The effects of the inlet conditions of the working fluids flowing through the spiral tube heat exchanger are discussed.

The following conclusions can be given on the basis of extensive review:

• There is reasonable agreement between the results obtained from the experiment and those from the literature data.

• Air mass flow rate and inlet-air temperature have significant effect on the increase of the outlet-air temperatures.

• The enthalpy effectiveness and humidity effectiveness decrease as the air flow rates increase.

• The enthalpy effectiveness and humidity effectiveness increase as the inlet-air temperature increases.

The horizontal spiral tube heat exchanger has higher pressure drop as compared to double pipe heat exchanger; however there is an enhancement in heat transfer rate, which off sets the disadvantage of pressure. The compact construction is suitable for heat transfer enhancement in vapour compression system.

By installing air cooled spiral tube heat exchanger in the refrigerant cycle; COP of the cycle is increase in initial level and more effects has to be under process on refrigeration cycle in deeply. This result is only from the simple calculation and experiment work carried on the basis of no load condition. Extensive experimentation result will be validate with the literature this work has to carry out.

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A Brief Author Biography

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