Enhancement of Heat Transfer Performance With Helical Tube In Heat Exchangers – A Review

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Abstract- *Heat exchanger is a device that is transferring heat from hot fluid to cold fluid. Based on the area of application the heat exchangers have different types working procedures and constructions. For example, the heat transfer in radiator of automobiles requires water flow in tube and air flow in the perpendicular direction. Likewise, many constructions are available for different area of applications. In all the configurations, the main objective is to transfer heat from hot fluid to cold fluid effectively. The performance of one construction is different from another. This is because of some additional changes in configuration and flow arrangements. There are many methods available for performance improvement in a particular type of heat exchanger broadly classified under two categories as follows: Active techniques and passive techniques. This study gives the broad view of methods incorporated to improve the performance of heat exchangers by many researchers. The method employed for heat transfer enhancement, the additional attachment given and the improvement achieved in performance are compared between many researches and tabulated.*

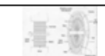
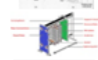
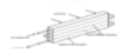
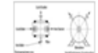
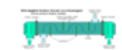
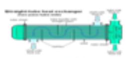
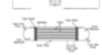
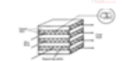
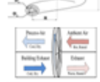
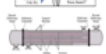
Keywords- Helical coil heat exchanger, twisted tape, turbulator, heat transfer enhancement.

I. INTRODUCTION

Transferring heat from one part to another part is major concern in many industries. That may be in any one mode of heat transfer like conduction, convection or radiation. For transferring heat between liquids, heat exchangers can be used. Base on the area of application any one type of heat exchanger can be chosen. Selecting a particular type of heat exchanger is more important to make the heat transfer process more effectively. The various types of heat exchangers with the constructions are given in table 1. Heat exchangers performance can be improved by heat transfer enhancement techniques.

There are three broad classifications of heat transfer enhancement techniques: Passive techniques which do not require any external power such as treated surfaces, rough surfaces, extended surfaces, swirl flow devices, displaced enhancement devices, coiled tube, surface tension device, and additives such as nanoparticles: Active techniques which require external power to facilitate the desired flow modification for augmenting heat transfer such as mechanical aids, surface vibration, fluid vibration, electrostatic fields, injection, suction, and jet impingement: Compound technique is the combination of any two or more of the above mentioned techniques simultaneously [26]. Coiled tube-in-tube heat exchangers (CTITHEs) belong to the most common passive heat transfer enhancement devices in many applications. They provide a large surface area per unit volume. Enhancement in heat transfer due to helical coils has been reported by many researchers. Thus, several studies have investigated the flow and heat transfer characteristics for single-tube and double tube helical heat exchangers, both experimentally, as well as numerically. The secondary flow motion induced by the curvature effect and the resultant centrifugal force make heat transfer coefficient greater than that in a straight pipe. Also, torsion of helically coiled tubes causes more complication in temperature and velocity fields [27, 28]. Known for the heat transfer performance, compact structure, anti-scaling ability, obvious advantages in processing cost and tube bundle compensation, the helically coiled tube heat exchanger is widely employed in various applications, such as pharmaceutical, petroleum, food, chemical, metallurgical, power and textile industries due to multi-stream heat transfer and greater heat transfer obtained simultaneously in the case of small temperature difference [2]. Helically coiled tubes including compact heat exchangers are used in various industrial applications such as petroleum, refrigeration, HVAC, food, nuclear, solar systems, etc. The reason for selecting these heat exchangers is their high thermal performance and compactness [3].

Table 1 Types of heat exchanger constructions

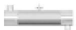
S. No	Name	Construction	S. No	Name	Construction
1	Parallel flow heat exchanger		14	Rotating heat exchanger	
2	Counter flow heat exchanger		15	PHE heat exchanger	
3	Finned tubular heat exchanger		16	Spiral heat exchanger	
4	U-tube heat exchanger		17	Plate coil heat exchanger	
5	Single pass straight heat exchanger		18	Gasketed heat exchanger	
6	Two pass straight heat exchanger		19	Welded heat exchanger	
7	Plate and frame heat exchanger		20	Brazed heat exchanger	
8	Plate fin heat exchanger		21	Double pipe heat exchanger	
9	Micro channel heat exchanger		22	Shell and tube heat exchanger	
10	Tubular heat exchanger		23	Spiral heat exchanger	
11	Plate type heat exchanger		24	Pipe coils heat exchanger	
12	Extended surface heat exchanger		25	Rotary heat exchanger	
13	Regenerative heat exchanger		26	Fixed heat exchanger	

Helical heat exchanger is used to control the temperature of the reactors for exothermic reactions. They have less expensive design. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. Helical coil heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations [4]. The aim of augmenting heat transfer is to accommodate high heat fluxes (or heat transfer coefficients). To date, there have been a large number of attempts to reduce the size and costs of heat exchangers. The most significant variables in reducing the size and cost of a heat exchanger are basically the heat transfer coefficient and pressure drop. An increase in the heat transfer coefficient generally leads to another advantage of reducing the temperature driving force, which increases the second law efficiency and decreases entropy generation [5]. The most significant variables in reducing the size and cost of a heat exchanger are basically the heat transfer coefficient and pressure drop. An increase in the heat transfer coefficient generally leads to another advantage of reducing the temperature driving force, which increases the second law efficiency and decreases entropy generation [7]. The enhancement of heat transfer rate in helical coil is high as compared to straight tube. Helical coil heat exchangers are used in nuclear industry, refrigeration, heat recovery systems etc. due to its solid structure and enhanced heat transfer coefficient [8].

Since conventional heat transfer (HT) fluids including water, oil, and ethylene glycol (EG) show relatively poor HT characteristics, NF has been introduced. NFs are formed by dispersing solid particles, fibers, or tubes of 1 to 50nm length in conventional HT fluids. There are significant characteristics associated with NFs such as high HT rate, low fluctuation ability through passages, and thermal homogeneity. The advances in nanotechnology have resulted in the development of a category of fluids termed nanofluids, first used by a group at the Argonne National Laboratory in America in 1995 [9]. In chemical industries heat is removed from one fluid and transferred to another fluid in heat exchangers. Heating or cooling enhancement results in energy savings and increases the efficiency of the process. Heat transfer can be enhanced by employing various techniques and methodologies, such as increasing either the heat transfer surface or the heat transfer coefficient between the fluid and the surface that allow high heat transfer rates in a small volume e.g. helical coil heat exchangers [10]. Helical tubes are considered as one of the most interesting tubes because of their smaller size and higher performance. Nonetheless, other heat transfer enhancement techniques such as nanofluids, conical tubes and bubble injection etc [11]. Helical coils offer advantageous over straight tubes due to their compactness and increased heat transfer coefficient. The increased heat transfer coefficients are a consequence of the curvature of the coil, which induces centrifugal forces to act on the moving fluid, resulting in the development of secondary flow. Fluid from the inside of the tube is thrown through the center of the tube towards the outer wall and then returns to the inner wall via the wall region. This secondary flow enhances heat transfer and temperature uniformity due to increased mixing especially in laminar flow (Ruthven 1971).

However, the required pressure gradient to obtain a given mass flux is increased compared to a straight tube. Both the increased heat transfer rates and temperature uniformity can be advantageous for food processing [12]. Heat transfer enhancement is one of the most important topics help in designing compact heat exchangers for various applications such as refrigeration, automotive and chemical process industries, etc. Several enhancement techniques have been developed in order to improve heat transfer and reduce a heat exchanger size. Most techniques deal with flow destabilization to promote fluid mixing within the exchanger [13]. Helically coiled tubes and double-pipe helical heat exchangers belong to the most common passive heat transfer enhancement devices in many applications including nuclear reactors, food processing, electronics, air-conditioning, waste heat recovery, power production, environmental engineering, manufacturing industry and space applications, due to their high heat and mass transfer coefficients, compact design, narrow residence time distributions and ease of manufacture [14]. Details of some available research papers on helical coils with their constructions, flow type used, fluid type, type of analysis, parameter chosen and some specific details are given in Table 2.

Table 2 Details of some available review papers on helical coils with specific details

Review papers	Heat exchanger		Fluid type		Parameters chosen	Experimental / Numerical / Analytical study	Additional comments
	Type	Construction	Single phase fluid	Two phase fluid			
Wael I.A. Aly [1]	Coiled tube in tube		x	✓	• Heat transfer • Pressure drop	Numerical study	Nanofluid is used to performance improvement.
Guanghui Wang et al. [2]	Shell and helical coil		✓	x	• Nusselt number • Friction factor	Experimental and Numerical study	Heat exchanger was analyzed for different geometrical values.
Ehsan Gholamalizadeh et al. [3]	Helically coiled tube		✓	x	• Thermal energy transfer • Pressure drop	Numerical study	Wire insert is used in helical coil to improve performance.
Vishwas M. Palve et al. [4]	Helical coil		✓	x	• Temperature drop • Pressure drop	Analytical study	Tube diameter varied to find optimum value.
Ebru Kavak Akpinar [5]	Concentric double pipe		✓	x	• Heat transfer • Friction factor • Exergy loss	Experimental study	Helical wire is used to improve performance.
M. Chandra Sekhara Reddy et al. [6]	Double pipe		x	✓	• Heat transfer coefficient • Friction factor	Experimental study	With and without helical coil inserts.
Smith Eiamsa-ard et al. [7]	Concentric tube heat exchanger		✓	x	• Nusselt number • Pressure drop	Experimental study	Helical tape swirl generator is added to conduct performance test.
R.Thundil Karuppa Raj et al. [8]	Helical coil heat exchanger		✓	x	• Pressure drop • Nusselt number • velocity	Numerical study	Used CFD to demonstrate the numerical analysis on different pitch length.
Heydar Maddah et al. [9]	Double pipe heat exchanger		X	✓	• Overall heat transfer coefficient	Experimental study	Twisted tape turbulators is used to experiment the results.
T Srinivasan et al. [10]	Agitate helical coil		X	✓	• Energy saving in different flow regimes	Experimental study	Nanofluids
Davood Panahi et al. [11]	Shell and coil tube		✓	x	• Heat transfer coefficient • Reynolds number • Effectiveness	Experimental study	Helical wire turbulator
D G Prabhanjan et al. [12]	Straight tube and Helical coil	-	✓	x	• Heat transfer coefficient • Outlet temperature	Experimental study	Impact of helical coil geometry on heat transfer coefficient was studied
C.Thianpong et al[13]	Tube Heat exchangers		✓	X	• Nusselt number • Friction factor	Experimental study	Twisted-ring turbulator
Zan Wu et al[14]	Double-pipe helical heat exchanger		X	✓	• Pressure drop • Convective heat transfer coefficient	Experimental study	Nanofluid is used perform comparative study with water
Chaohui Zhou et al[15]	Multi row helically coiled tube heat exchanger		✓	X	• Nusselt number • Thermal conductance resistance	Experimental study	Water source heat pump was used for study thermal performance in winter and summer season.
R.N.Radkar et al[16]	Helical coil		X	✓	• Reynolds number • Nusselt number	Experimental study	Helical coiled geometry at constant wall temperature is experimented with the ZnO Nanofluid.
Eda Feyza Akytrek et al[17]	Concentric tube		X	✓	• Turbulent forced convective heat transfer • Pressure drop	Experimental study	Heat exchanger was experimented with and without wire coil turbulators.
Swapnil Ahire et al. [18]	Helical coil		✓	X	• Reynolds number • Nusselt number • Dean number	Experimental study	Dimensionless numbers are studied with counter flow arrangement.
Smith Eiamsa-ard et al. [19]	Double tube		✓	X	• Heat transfer • Friction characteristics	Experimental study	Experimented with and without core rod.
Mrunal P.Kshirsagar et al. [20]	Tube in tube helical coil		✓	X	• Reynolds number • Dean number	Experimental and analytical study	Change in heat transfer rate was studied by wire insert
M. Jafaryar et al. [21]	Tube in tube		X	✓	• Reynolds number • Pressure drop	Experimental study	Effect of Reynolds number, pitch and height ratios were reported by FVM
J.S. Jayakumar et al. [22]	Helical coil heat exchanger		✓	X	• Inner heat transfer coefficient • Nusselt number • Overall heat transfer coefficient	Experimental and analytical study	Heat transfer characteristics inside helical coil for various boundary conditions were compared
Saleh Khorasani et al. M.R. Salimpour [23]	Helically coiled tube		✓	X	• Pressure drop Dean number Heat transfer coefficient	Experimental study	Spiral wire with geometrical properties was employed to study the thermal behavior
M.R. Salimpour et al. [24]	Shell and coiled tube		✓	X	• Nusselt number	Experimental study	New correlations were proposed and compared with existing correlations
M. Sheikholeslami et al. [25]	Pipe heat exchanger		X	✓	• Second law efficiency • Exergy loss	Analytical study	Twisted tape turbulators was used to study the selected parameters using FVM

II. PERFORMANCE ANALYSIS OF HELICAL COIL

Experimental study and verified numerical calculation methods were employed to study shell side of helically coiled tube heat exchanger. First and foremost, the optimization model was determined, and subsequently shell side of helically coiled tube heat exchanger was studied using the double-layer Multi-objective driving optimization method based on the calculation model and the optimization model. Re and structural parameters greatly impact the change trend of Nu, PEC and FSP, whereas they exert no influence on the tendency of f change [2]. The Transition SST model was the best model for the simulation of the impact of turbulence. By using a wire with diameter of 0.008 *m* in the range of the inlet mass flow rate of 0.05–0.1 kg/s, the Nusselt number can increase by 131.9–340.9% while, the friction factor enhances by 338.9–536.1% compared to the empty smooth coiled tube [3]. Heat transfer rates increased with decreasing pitch and with increasing helical number of the helical wires used in the experiments. The highest enhancement was seen to occur in counter current flow mode of the exchanger with the helical wire having the pitch of 9 mm and the helical number of 137. The heat transfer rates in this heat exchanger increased up to 2.64 times with the help of the helical wires [5]. Increasing the concentration of nanopowder in the base fluid resulted in more energy savings. Further, higher stirrer speed and shell-side temperature also resulted in more energy savings. As the flow rate was increased, energy savings were found to increase during laminar and turbulent flow regimes [10].

III. HELICAL COIL APPLICATIONS IN HEAT EXCHANGERS

Helical coiled tubes are used in a variety of applications including food processing, nuclear reactors, compact heat exchangers, heat recovery systems, chemical processing and medical equipment [12], electronics, air-conditioning, power production, environmental engineering, manufacturing industry and space applications, due to their high heat and mass transfer coefficients, compact design, narrow residence time distributions and ease of manufacture [14].

IV. EXISTING LACUNAE AND FUTURE SCOPE

The underlying lacunae in the studies of helical coil in heat exchangers have been distinctly brought into limelight by the works discussed hitherto. Following major ambiguities have been observed from this review; the research work is done on helically coiled tube heat exchanger (HCTHE) with water and water Nanofluids (two phase) is critically reviewed. From the review, it is studied that most of the research group carried out their work on helically coiled heat exchanger for their improved heat transfer performances. In a single helically coiled heat exchanger, it is due to easy fabrication, wide application and easy to maintain. It is also studied that very few types of research carried out their work on double helically coiled heat exchangers experimentally, simulation and numerically because of complex to fabrication, very few application, and more maintenance needed. Further, it is observed that a little work has been done on the double tube helically coiled heat exchanger with twisted tapes. Therefore the double tube helically coiled heat exchanger has a potential to explore is application along with twisted tapes/turbulators in the engineering field.

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