© 2018 IJSRSET | Volume 4 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

A Review on Various Enhancement Techniques of Heat Transfer by Using Tube in Tube Heat Exchanger with Twisted Tape Insert

Satish Kumar Aharwar [1], Dr. Ajay Singh [2] and Ashish Verma [3]

[1]M.E. Scholar, Department of Mechanical Engineering, Radharaman Institute Technology & Science, Bhopal, MP, India

[2]Professor & Head, Department of Mechanical Engineering, Radharaman Institute Technology & Science, Bhopal, MP, India.

[3]Assistant Professor, Department of Mechanical Engineering, Radharaman Institute Technology & Science, Bhopal, M.P., India.

ABSTRACT

Working towards the goal of saving energies and to make compact the design for mechanical and chemical devices and plants, the enhancement of heat transfer is one of the key factors in design of various equipment's such as heat exchangers, refrigerator, air-conditioner etc. In this process without application of external power we can enhance the heat transfer rate by modifying the design by providing the roughness in tubes. Various artificial roughness in tubes finds applications in automobile, aerospace, power plant and food industries due to certain advantages such as compact structure, larger heat transfer surface area and improved heat transfer capability. Nusselt number, friction factor, pumping power required and LMTD variation of flowing fluid with respect to Reynolds number is studied for different parameters. This paper describes complicated behavior of fluid flow and is captured for both the fluids flowing inside and outside the tube. From literature, it has been found that with increases in P/d ratio the Nusselt number will decrease and the outer wall boundary condition does not have any significant effect on the inner Nusselt number. The Darcy friction factor decreases with increase in Reynolds number. The Pumping power increases with increase in Reynolds number for all the condition of P/d ratio and for all the boundary conditions. The optimization point between Nu and pumping power with respect to Re; shifts toward the higher Reynolds number with increase in P/d ratio.

Keywords : Nusselt number, Reynolds number, friction factor, pumping power, LMTD and pitch diameter ratio (P/d ratio).

I. INTRODUCTION

Effective utilization, conservation and losses of energy in the form of heat are critical engineering problems faced by the process industry. The economic design and operation of process plants are often governed by the efficient usage of heat. A majority of heat exchangers used in thermal power plants, chemical processing plants, air conditioning equipment, refrigerators and food processing plants serve to heat and cool different types of fluids. Both the mass and overall dimensions of heat exchangers employed are continuously increasing with the increase in energy requirement. This involves massive investments annually for both operations and capital costs. Hence, the size of the heat exchanger should be optimized (reduced) by augmenting heat transfer rate. The need to optimize and conserve these expenditures has promoted the development of efficient heat exchangers

Different techniques are employed to enhance the heat transfer rates, which are referred to as heat transfer enhancement, augmentation or intensification technique.

1.1 Heat Transfer Enhancement

Heat transfer enhancement is one of the key issues of saving energies and compact designs for mechanical and chemical devices and plants. In the recent years, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. Energy and materials saving considerations , space considerations as well as economic incentives have led to the increased efforts aimed at producing more efficient heat exchange equipment through the augmentation of heat transfer.

The heat exchanger industry has been striving for enhanced heat transfer coefficient and reduced pumping power in order to improve the thermo-hydraulic efficiency of heat exchangers. A good heat exchanger design should have an efficient thermodynamic performance, i.e. minimum generation of entropy or minimum destruction of energy in a system incorporating a heat exchanger. The major challenge in designing a heat exchanger is to make the equipment compact and to achieve a high heat transfer rate using minimum pumping power. Heat transfer enhancements can improve the heat exchanger effectiveness of internal and external flows. They increase fluid mixing by increasing flow vorticity, unsteadiness, or turbulence or by limiting the growth of fluid boundary layers close to the heat transfer surfaces. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity like gases or oils, it is necessary to increase the heat transfer rates. This is further compounded by the fact that viscous fluids are usually characterized by laminar flow conditions with low Reynolds numbers, whose heat transfer coefficient is relatively low and thus becomes the dominant thermal resistance in a heat exchanger. The adverse impact of low heat transfer coefficients of such flows on the size and cost of heat exchangers adds to excessive energy, material, and monetary expenditures. As the heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. Augmented surfaces can create one or more combinations of the following conditions that are indicative of the improvement of performance of heat exchangers.

- Decrease in heat transfer surface area, size, and hence the weight of heat exchanger for a given heat transfer requirement and pressure drop or pumping power
- Increase in heat transfer rate for a given size, flow rate.
- Reduction in pumping power for a given size and heat duty.
- Reduction in fouling of heat exchangers.

1.2 Heat Transfer Augmentation Techniques

Heat transfer augmentation techniques are generally classified into three categories namely: Active techniques, Passive techniques and Compound techniques

Active Techniques

As the name indicates, these techniques involve some external power input for enhancement of heat transfer. This has not shown much potential due to complexity in design. They are classified as Mechanical aids, Surface vibrations, Fluid vibration, Electrostatic field**s, etc.**

Passive Techniques

Passive techniques do not require any direct input of external power. They generally use geometrical or surface modifications to the flow channel by incorporating inserts or additional devices. Except for the case of extended surfaces, they promote higher heat transfer coefficients by disturbing or altering the existing flow behavior. Passive techniques are classified as below:

(1) Treated surfaces
(2) Rough surfaces
(3) Extended surfaces
(4) Twisted tape insert
(5) Displaced enhancement devices.
(6) Swirl flow devices
(7) Coiled tubes
(8) Surface-Tension devices
(9) Additives for gases
(10) Additives for liquids

Compound Techniques

Two or more of the above techniques may be utilized simultaneously to produce an enhancement that is larger than the individual technique applied separately. Some examples of compound techniques are given below:

1. Rough tube wall with twisted tape
2. Rough cylinder with acoustic vibrations
3. Internally finned tube with twisted tape insert
4. Finned tubes in fluidized beds
5. Externally finned tubes subjected to vibrations
6. Gas-solid suspension with an electrical field
7. Fluidized bed with pulsations of air

1.3 Type of Heat Exchangers

Heat Exchanger is classified based on criteria given below:-

According to Heat Transfer process

(1) Direct Contact type
(2) Transfer Type heat Exchanger.
(3) Regenerators

According to Constructional Features

(1) Tubular Heat Exchanger
(2) Shell and Tube type Heat Exchanger
(3) Finned tube Heat Exchanger
(4) Compact Heat Exchanger

According to Flow Arrangement

(1) Parallel Flow
(2) Counter Flow
(3) Cross Flow

According to Heat Transfer Process

(1) **Direct contact type Heat exchangers** are the heat exchanger in which two immiscible fluids are directly mixed with each other to transfer heat between two fluids. The efficiency of this type Heat exchanger is more compared to other type heat exchangers. Cooling tower, jet condenser, de-super heaters, open feed water heater are the example of this type of heat exchanger.

(2) Transfer type or Recuperated type heat exchanger two fluid flows simultaneously through two tubes separated by walls.

(3) Regenerator type heat exchanger, the hot and cold fluid flow alternatively on same surface. During the hot fluid transfer the wall of exchanger get heated and when the cold fluid flows through it, this heat get transferred from the wall of the heat exchanger to the cold fluid so that the temperature of cold fluid increases. The common example of this type heat exchangers are pre-heaters for steam power plant, blast furnace etc.

According to Constructional Features

(1) Tubular heat exchangers are placed concentric to each other and two fluids flows in two tubes separated by wall. These are generally used in most of the engineering application.

(2) Shell and tube type heat exchanger consists of shell and large number of parallel tubes. The heat transfer takes places when one fluid flows through the tube and other flows outside the tube inside the shell of the exchanger this type of heat exchanger have large surface area to volume. Baffles plates are provided to enhance the turbulence hence the heat transfer rate.

(3) For improving the heat transfer rate fins are provided on the outer surface of the heat exchangers. These are generally used in gas to liquid type heat exchanger and fins are generally provided in gas side.

These are used in gas turbines, automobiles, aeroplane, heat pumps etc

(4) A compact heat exchanger can be defined as heat exchanger which has area density (β) greater than700 m^2/m^3 for gas or greater than 300 m^2/m^3 when operating in liquid or two-phase streams. For example automobile radiators which has an area density in order of 1100 m^2/m^3.Compact heat exchanger are generally cross flow type where two fluid flow perpendicular to each other.

According to Flow Arrangement

(1) Parallel flow type heat exchanger two fluids flow parallel to each other that is they flow in same direction. These are also called concurrent heat exchanger.

(2) Counter flow heat exchanger two fluids flow in opposite direction.

(3) Cross flow type heat exchanger two fluids flow perpendicular to each other. This is further divided in to mixed flow type and unmixed flow type heat exchanger.

1.4. Applications of Heat Transfer Enhancement

The petrochemical and chemical industries are under economic pressure to increase the energy efficiency of their processing plants to compete in today's global market. Hence, these industries must invest in innovative thermal technologies that would significantly reduce unit energy consumption in order to reduce overall cost. In recent years, heat transfer enhancement technology has been widely applied to heat exchanger applications in boiling and refrigeration process industries. Most significantly, the uses of enhancement extend well beyond surface reduction i.e., they can also be used for capital cost reduction, the improvement of exchanger operability, the mitigation of fouling, the improvement of condenser design and the improvement of flow distribution within heat exchangers. Important applications of heat transfer enhancement are listed below:

- Heating, Ventilating, Refrigeration and air conditioning.
- Automotive Industries.
- Power sector.
- Process Industries.
- Aerospace and others.

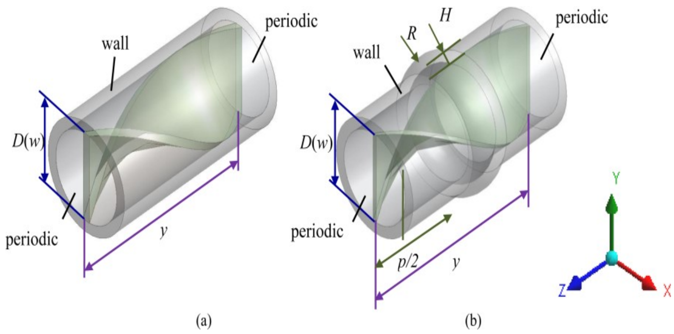

Fig-1.1 circular pipe with spiral tape insert [17]

II. Literature Review

The following papers have been studied and referred in this work. Researchers suggested that the various types of artificial geometries can be used to increase heat transfer in various equipment's such as heat exchanger, power plant refrigerator, air-conditioning, etc.

Manglik et al [1] has studied and developed the Laminar flow correlations for friction factor 'f' and Nusselt number 'Nu' based on experimental data for water and ethylene glycol with tape inserts of three different twist ratio. Uniform wall temperature condition has been considered which represents practical heat exchangers in the chemical and process industry. Depending upon flow rates and tape geometry, the enhancement in heat transfer is due to flow blockage, longer flow path, and secondary fluid circulation. The onset of swirl flow and its intensity is determined by a swirl parameter, $Sw = Re_{sw}/y$, that defines the interaction between viscous, convective inertia, and centrifugal forces. Buoyancy-driven free convection that comes into play at low flow rates with large y and ΔT w is shown to scale as Gr/Sw2 ≫ 1. These parameters, along with numerical baseline solutions for laminar flows with $y = \infty$, are incorporated into correlations for f and Nu by matching the appropriate asymptotic behavior. The correlations describe the experimental data within ±10 to 15 percent.

Patnalla Sankara Rao [2] has analysed the experimental and numerical data of double pipe heat exchanger with twist tape insert and compared both the result. A 3-D numerical model has been developed to study the performance of (i) bare tube-in-tube heat exchanger, (ii) tube in tube with twisted tape insert and (iii) helical insert at annulus and twisted tape insert inside the inner tube of the heat exchanger. Numerical results have been compared with the available analytical solution. The investigation revealed that there is a good agreement between these two results: within ±19.78 percentage error limit for Nusselt number measurement and ±25 percentage error for friction factor. The numerical simulation for twisted tape insert with twist ratio (y) 5 has been performed using different turbulent models by varying Reynolds number ranging from 2000 to 10000. Experiments on double pipe heat exchanger with twisted tape inserts with twist ratios y= 4.167, 5.556, 6.944 and helical tape insert in annulus has been performed. By comparing experimental and numerical data, its has been observed that by using twisted and helical tape inserts the heat transfer enhancement takes place on the expense of pressure drop.

Liu et al. [3] has enlisted different passive techniques to enhance the heat transfer rate & to increase thermal performance factor. Twisted tapes inserts, coiled wire inserts, turbulators, swirl generators etc. are the few passive heat augmentation equipment used. This paper reviews experimental and numerical works taken by researchers on this technique since 2004 such as twisted tape, wire coil, swirl flow generator,y etc. to enhance the thermal efficiency in heat exchangers and useful to designers implementing passive augmentation techniques in heat exchange. Twisted tape inserts perform better in laminar flow than turbulent flow. Full length twisted tape (FLTT) increases the pressure drop comparing to an empty tube. The pressure drop depends on the tape geometry and is always larger than 185% for any FLTT geometry.

Garcia et al. [4] experimentally studied the helical-wire-coils fitted inside a round tube in order to characterize their thermo-hydraulic behavior in laminar, transition and turbulent flows. The experimental result revels that in laminar flow, wire coils behave as smooth tube but accelerate transition to critical Reynolds numbers down to 700. At the low Reynolds numbers about Re = 700, transition from laminar to turbulent flow occurs in a gradual way. Within the transition region, heat transfer rate can be increased up to 200% by keeping the pumping power constant. Wire coils have a predictable behavior within the transition region since they show continuous curves of friction factor and Nusselt number, which involves a considerable advantage over other enhancement techniques. In turbulent flow, wire coils cause a high pressure drop which depends mainly on the pitch to wire-diameter ratio (p/e). In turbulent flow, the pressure drop and heat transfer are both increased up to nine times and four times respectively, compared to the empty smooth tube.

Kumar et al. [5] has investigated hydrodynamic and heat transfer characteristic of tube in tube helical heat exchanger at pilot plant scale. Experimental study has been performed on a counter flow heat exchanger and overall heat transfer coefficient was evaluated. Nusselt number and friction factor coefficient for inner and outer tube was found and compared with numerical value got from CFD package (FLUENT). It was observed that the overall heat transfer coefficient increases with inner coil tube Dean Number for constant flow rate in annulus region. The agreement with the numerical and experimental predictions of Nusselt number values was well within 4% for inner tube and 10% in outer-coiled tube, respectively.

Jayakumar et al. [6] had done numerical and experimental work on helical coil heat exchanger considering fluid to fluid heat transfer. Different boundary conditions has been considered for various parameters constant heat flux, constant wall temperature and constant heat transfer coefficient. In their observation they found that constant value of thermal and transport properties of heat transfer medium results inaccurate heat transfer coefficient. Based on the numerical and experimental analysis within certain error limits correlation was developed to calculate the inner heat transfer coefficient of helical coil.

Gunes et al. [7] experimentally investigated the coiled wire inserted in a tube for a turbulent flow regime. The coiled wire has equilateral triangular cross section and was inserted separately from the tube wall. They discovered that the Nusselt number rises with the increase of Reynolds number and wire thickness, and the decrease of pitch ratio; the best operating regime of all coiled wire inserts is detected at low Reynolds number, which leads to more compact heat exchanger. The pitch increases, the vortex shedding frequencies decrease and the maximum amplitudes of pressure fluctuation of vortices produced by coiled wire turbulators occur with small pitches.

Mun-oz-Esparza and Sanmiguel-Rojas [8] employed the CFD simulation package and investigated the heat transfer and fluid flow performance inside a circular pipe with the helical wire coils inserts. They found that the friction factor becomes constant in the Re range of 600–850. The effect of the pitch on the friction factor has been addressed by performing a parametrical study with a pitch-periodic computational domain for wire coils within the dimensionless pitch range (p/d), $1.50<p/d<4.50$, and dimensionless wire diameter, $e/d = 0.074$, showing that the increase of p/d, decreases the friction factor.

Jamshidi et al. [9] had done experimental work to enhance the heat transfer in shell and helical tube heat exchanger. In the helical tube section of the heat exchanger hot water flows. The cold water flows in the shell side of the heat exchanger. The heat transfer coefficients are determined using Wilson plots. Taguchi method is used to find the optimum condition for the desired parameters in the range of $0.0813 < Dc < 0.116$, $13 < Pc < 18$, tube and shell flow rates from 1 to 4 litter per minute. From their results it is found that the higher coil diameter, coil pitch and mass flow rate in shell and tube can enhance the heat transfer rate for this type of heat exchanger. Contribution ratio obtained by using Taguchi method and it shows that shell side flow rate, coil diameter of helical coil, tube side flow rate and coil pitch are the most important design parameters in coiled heat exchangers.

Srbislav et al. [10] had done the experimental work to predict the performances of heat exchangers with helical tube coils. In their work they had presented the results of thermal performance measurements on three heat exchangers with concentric helical coils. It was found that the shell-side heat transfer coefficient was affected by the geometric parameters. Winding angle, radial pitch and axial pitch are the geometric parameters which affect the heat transfer coefficient. From the results it was concluded that the shell-side heat transfer coefficient is based on shell side hydraulic diameter.

Yang et al. [11] had done experimental work to predict the characteristics of convective heat transfer in helical coil heat exchanger. They considered a heat exchanger with membrane helical coils and membrane serpentine tubes. The efficiency of the power generating system was affected by heat transfer performance of syngas cooler. They had done the experimental investigation on heat transfer in convection cooling section of pressurized coal gasifier with the membrane helical coils and membrane serpentine tubes under high pressure. They found that the working pressure, gas composition and flow symmetry influence the convection heat transfer coefficient of high pressure gas. By analyzing the results they found that under the same conditions heat transfer coefficient of heat exchanger with membrane helical coils is greater than that of the heat exchanger with membrane serpentine-tube. They found that the heat transfer coefficient increment was due to the increase of gas pressure and velocity.

Hossain et al. [12] has performed the Finite Element based model study of the heat transfer problem. The Enhancement of heat transfer with mass in a tube has been investigated without insert and with insert i.e. combination of horizontally and vertically arranged rectangular boxes of 5 mm thickness are being fitted perpendicular to the flow direction respectively at equal distance from each other along the length. The combinations are composed of without insert, two inserts, four inserts, six inserts, eight inserts and ten inserts. The purpose of using inserts is to scatter the fluid particles in the laminar flow which increases the heat transfer. An 800 mm long pipe with 26 mm inner diameter and 5 mm thickness is considered in our simulation. The simulations have been completed for both stationary and time dependent conditions with Reynolds number 1600~2400. A constant heat flux is generated at the boundary layer of the tube close to the flowing fluid around the boundary layer. They have also shown the comparisons of heat transfer rate among different combinations of inserts to understand the heat transfer phenomenon for the computational domain.

Rahimi et al. [13] has performed the numerical investigation of the heat transfer and friction factor characteristics of a circular tube fitted with V-cut twisted tape (VCT) insert with twist ratio (y = 2.93) and different cut depths (w = 0.5, 1, and 1.5 cm) has been studied for laminar flow using CFD package (FLUENT). The data obtained from plain tube has been verified with the literature correlation to ensure the validation of simulation results. Classical twisted tape (CTT) with different twist ratios (y = 2.93, 3.91, 4.89) were also studied for comparison. The results show that the enhancement of heat transfer rate induced by the classical and V-cut twisted tape inserts increases with the Reynolds number and decreases with twist ratio. The results also revealed that the V-cut twisted tape with twist ratio y = 2.93 and cut depth w = 0.5 cm offered higher heat transfer rate with significant increases in friction factor than other tapes. In addition the results of V-cut twist tape compared with experimental and simulated data of right-left helical tape inserts (RLT), it was found that the V-cut twist tape offered better thermal contact between the surface and the fluid which ultimately leads to a high heat transfer coefficient. Consequently, 107% of maximum heat transfer was obtained by using V-cut twisted tape configuration.

Xing et al. [14] has performed an investigation on the shell-side flow and heat transfer performances of multilayer spiral-wound heat exchanger SWHXs under turbulent flow has been implemented by using experimental and numerical methods. An experiment on the shell-side flow and heat transfer performance of a self-manufactured SWHX with three layers of coils is carried out under heat flux specified boundary conditions (BC) to validate a numerical method. The results obtained by the simulations agree well with those from the experiment. Furthermore, to study the effects of different thermal boundary conditions of the tube wall on the shell-side heat transfer performance in the multilayer SWHXs, numerical simulations were performed under the thermal BC of constant heat flux and constant temperature. The results were compared to those of the water-to-water conjugate heat transfer and found that the maximum relative deviation is 11.4% and 3.5%, respectively. Finally, the correlation of the shell-side Nusselt number, Nu_s is obtained by the Wilson plot method, which is

$Nu_s = 0.179*Re_s^{0.862}$, with the available range of Res from 500 to 3500.

Paisarn et al. [15] has performed the experimental investigation on spiral coil heat exchanger under cooling and dehumidifying conditions and presented a mathematical model for heat transfer characteristics and performance. 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 were used as working fluids. 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 were in reasonable agreement with the present experimental data.

Pawar et al. [16] has performed the experimental investigation on isothermal steady state and non-isothermal unsteady state conditions in helical coils for Newtonian as well as for non-Newtonian fluids. The experiments were performed for coil curvature ratios as δ = 0.0757, 0.064 and 0.055 in laminar and turbulent flow regimes. The CFD analyses for laminar and turbulent flow were carried out using FLUENT 12.0.16 solver of CFD package. They have presented an innovative approach of correlating Nusselt number to dimensionless number, 'M', Prandtl number and coil curvature ratio using least-squares power law fit. Several other correlations for calculation of Nusselt number for Newtonian and non-Newtonian fluids, and two correlations for friction factor in non-Newtonian fluids are proposed

III. CONCLUSION

This paper deals with the investigation carried out by various researchers to enhance the heat transfer and its effect on friction factor by the use of artificial roughness of different shape, size and others parameters in the form of twisted tape inserts, helical coil inserts, multi-layer spiral coil, multi start grooves, etc. It has been studied that there is a considerable enhancement in heat transfer with little penalty of power requirement in heat exchanger, refrigerator, air-conditioner, etc. Numerical simulation and experimental studies has been carried out for tube in tube heat exchanger for different shaped roughness and the optimized values of parameters used are presented. Variation of Nusselt number, Darcy friction factor, pumping power required, with respect to Reynolds number for different P/d ratio has been studied. Heat transfer behaviours for different boundary conditions are predicted and optimized condition for maximum Nusselt number (Nu) and minimum pumping power against Reynolds number has also been observed.

Following are the outcomes from the above studies :

(1) With increase in p/d ratio the Friction factor decreases, for a particular value of Reynolds number.
(2) With increase in p/d ratio the Pumping power decreases, for a particular value of Reynolds number.
(3) The optimization point moves towards lower Reynolds Number with increase in p/d ratio.

IV. REFERENCES

[1]. Manglik, R.K and Bergles, A.E., Heat transfer and pressure drop correlation for twisted-tape insert in isothermal tube, Trans. ASME, J. Heat Transfer; Vol.-115: pp.881-889 (1993)

[2]. Patnala Sankara Rao ,K Kiran Kumar, Numerical and experimental investigation of heat transfer augmentation in double pipe heat exchanger with helical insert. International Journal of Emerging Technology and Advanced Engineering; ISSN 2250-2459, ISO 9001:2008 (2014)

[3]. S. Liu, and M. Sakr. A Comprehensive Review on Passive Heat Transfer Enhancements in Pipe Exchangers. Renewable and Sustainable Energy Reviews; 19:64-81 (2013)

[4]. García A, Vicente PG, Viedma A. Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers, Int. Journal of Heat and Mass Transfer; 48:4640–4651 (2005)

[5]. Kumar V., Saini S., Sharma M., Nigam K.D.P., Pressure drop and heat transfer in tube in tube

helical heat exchanger, Chemical Engineering Science, Vol.-61: 4403–4416 (2006)

[6]. Jayakumar J.S, Mahajani S.M., Mandal J.C., Iyer Kannan N., Vijayan P.K., CFD analysis of single-phase flows inside helically coiled tubes, Computers and Chemical Engineering, Vol.-34:430–446. (2010)

[7]. Gunes S, Ozceyhan V, Buyukalaca O. Heat transfer enhancement in a tube with equilateral triangle cross sectioned coiled wire inserts. Experimental Thermal and Fluid Science; 34:684–691 (2010)

[8]. Mun˜oz-Esparza D, Sanmiguel-Rojas E. Numerical simulations of the laminar flow in pipes with wire coil inserts. Computers & Fluids; 44:169–177 (2011)

[9]. N. Jamshidi, M. Farhadi, , D.D. Ganji, K. Sedighi, Experimental analysis of heat transfer enhancement in shell and helical tube heat exchangers, Applied Thermal Engineering,Vol.-51: 644–652 (2013)

[10]. Srbislav B. Genic, Branislav M., Jac´imovic´, Marko S. Jaric, Nikola J. Budimir b, Mirko M. Dobrnjac, Research on the shell-side thermal performances of heat exchangers with helical tube coils, International Journal of Heat and Mass Transfer 55:4295–4300 (2012)

[11]. San Jung-Yang., Hsu Chih-Hsiang., Chen Shih-Hao., Heat transfer characteristics of a helical heat exchanger, Applied Thermal Engineering, vol.-39: 114-120 (2012)

[12]. Sabbir Hossain, Ujjwal Kumar Deb, Kazi Afzalur Rahman, The Enhancement of Heat Transfer in a Circular Tube with Insert and without Insert by Using the Finite Element Method, Procedia Engineering, Vol.-105, Pages 81-88 (2015)

[13]. Rahimi M, Shabanian S.R. and Alsairafi A.A, Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts, Chemical Engineering and Processing 48: 762–770 (2009)

[14]. Lu Xing., Du Xueping., Zeng Min., Zhang Sen., Wang Qiuwang., Shell-side thermal-hydraulic performances of multilayer spiral-wound heat exchangers under different wall thermal boundary conditions, Applied Thermal Engineering, Article in press, 1-12 (2014)

[15]. Naphon Paisarn., Wongwises Somchai., A study of the heat transfer characteristics of a compact spiral coil heat exchanger under wet-surface conditions, Experimental Thermal and Fluid Science, vol.-29: 511–521 (2005)

[16]. Pawar S.S., Sunnapwar Vivek K., Experimental and CFD investigation of convective heat transfer in helically coiled tube heat exchanger, CHERD-1475 (2014)