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Review on Research Design and Applications of Spiral Heat Exchanger

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ABSTRACT

Energy saving is major matter in our global world, and heat exchanger is very useful for energy saving. Of course heat exchanger is most significant component for chemical reaction, distillation, dissolution, crystallization, fermentation etc. So the correct selection of heat exchanger is important in these processes. Spiral heat exchangers are known as excellent heat exchanger because of far compact and high heat transfer efficiency. This paper discusses about the applications of spiral tube heat exchanger.

Keywords: Heat transfer rate, Heat transfer coefficient, Overall heat transfer coefficient, Nusselt number, Reynolds number.

I. INTRODUCTION

Rosenblad Patenter in 1930s developed spiral heat exchanger in Sweden to recover waste energy from contaminated water effluents in pulp mills. The main advantage of Spiral heat exchanger is self-cleaning equipment with low fouling tendencies, easy for inspection or mechanical cleaning with minimum space requirement. Due to the curvature of the tube, a centrifugal force is generated as fluid flows through the curved tubes. Secondary flows induced by the centrifugal force have significant ability to enhance the heat transfer rate. Helical and spiral coils are known types of curved tubes which have been used in a wide variety of applications for example, heat recovery process, air conditioning and refrigerating systems, chemical reactors, food and dairy processes. An advantage which the spiral coil heat exchanger has over conventional heat exchanger systems is its ability to accommodate differential thermal expansion.

II. METHODS AND MATERIAL

Applications of Spiral Heat Exchanger

A. Oil Extraction

Kondhalkar and Kapatkat carried research work on performance analysis of spiral tube heat exchanger over the shell and tube type heat exchanger used in oil extraction system. During their research they discussed the problem of settling the oil at the inner periphery which was due to the low velocity in the straight tube of shell and tube heat exchanger. To overcome above problem they have increased the velocity of the mixture that resulted collection of the condensate at higher temperature. They found out that process at higher velocity greater than 0.5 m/s was not suitable in shell and tube heat exchanger. So they decided to keep the low velocity with more turbulence. They have carried out work at high turbulences which increases the heat transfer rate and oil will not stick to the inner surface of the tubes by using spiral tube heat exchanger instead of shell and tube type heat exchanger. They concluded that continuously curved flow section in spiral heat exchanger contributes to improvement in overall heat transfer coefficient as compared to shell and tube type heat exchanger from 400 to 650W/m^2 K. They also find out that true concurrent flow increases the heat exchanger effectiveness from 0.3 to 0.5 for spiral heat exchanger[1].The cost saving using spiral tube heat exchanger is around 15 – 20 % as compared to shell and tube type heat exchanger. They found out that scrubbing effect of the fluids in both spiral passages inhabits deposition of slug and other deposits. Their research showed that using spiral tube heat exchanger the oil sticking problem as in case of straight tube is reduced and total productivity is increased from 3.6 lit/day to 6.2 lit/day.

B. Cooling and Dehumidification

Paisarn Naphon and Somchai Wongwises carried research work on heat transfer characteristics and the performance of a spiral coil heat exchanger under cooling and dehumidifying conditions. The heat exchanger unit consists of a steel shell and a spirally coiled tube unit. Spiral-coil unit consists of six layers of concentric spirally coiled tubes. Each tube was fabricated by bending a 9.27mm diameter straight copper tube into a spiral-coil of five turns. They used Air and water as working fluids. During experimentation chilled water entered the outermost turn flows along the spirally coiled tube, and flows out at the innermost turn. The hot air entered the heat exchanger at the center of the shell and flows radially across spiral tubes to the periphery. They developed mathematical model based on mass and energy conservation and solved it by using the Newton–Raphson iterative method to determine the heat transfer characteristics. They found reasonable agreement between the results obtained from the experiment and those from the developed model. They observed that air mass flow rate and inlet-air temperature have significant effect on the increase of the outlet-air and water temperatures. The also concluded that outlet-air and water temperatures decrease with increasing water mass flow rate. They explored that enthalpy effectiveness and humidity effectiveness decrease as the air and water mass flow rates increase[2].The results showed that the enthalpy effectiveness and humidity effectiveness increases as inlet-air temperature increases. J.C. Ho and N.E. Wijeysundera carried out research work on spiral coil heat exchanger consisiting of a number of horizontal layers of spirally wound,finned tubes connected to vertical manifolds at the inner and outermost turns of each coil. They developed a theoretical model predicting the thermal performance of the spiral col heat exchanger as cooling and dehumidifying unit. They performed experiments on a laboratory model of the spiral coi[11]l. The results obtained confirmed the theoretical predictions. They concluded that performance charts of enthalpy, effectiveness and humidity ratio effectiveness Vs Ntu suitable for air handler unit design. Paisarn Naphon and Somchai Wongwises carried out an experimental study on in tube convective heat transfer coefficients in a spiral coil heat exchanger. They investigated that average in tube heat exchanger coefficients in a spiral coil heat exchanger. During experimentation spiral coil was considered as test section which consist of six layers of concentric spirally coiled tubes. They fabricated each tube by bending a 9.27mm diameter straight copper tube into a spiral coil of five turns.They conducted experiments under dehumidifying conditions.They discussed effects of the inlet conditions of both workng fluids[13].They compared experimental results with those calculated. They concluded and proposed a new correlation for the in tube heat exchanger coefficient for spirally coiled tube used under dehumidifying conditions for practical applications.

C. Water-Electrolytes System

R. Rajavel and K. Saravanan carried experimental investigation on convective heat transfer coefficient for electrolytes using spiral heat exchanger. Experimental test section consists of a plate of width 0.315m and thickness 0.001m and mean hydraulic diameter of 0.01m.During experimentation the mass flowrate of water (hot fluid) was kept 0.636kg/sec and mass flowrate of electrolytes (cold fluid) varied from 0.483 kg/sec to 0.704 kg/sec. They performed experiments by varying the mass flowrate,temperature and pressure of cold fluid and keeping the mass flowrate of hot fluid constant. They investigated effects of relevant parameters on spiral heat exchanger[3]. They studied and compared experimental and theoretical data. They developed a new correlation for Nusselt number which can be used for practical applications.

D. Water-Water System

Dr M A. Hossain, M I. Islam, S A. Ratul and Erin has carried out experimental study to investigate the overall heat transfer co-efficient and effectiveness for water using spiral coil heat exchanger. They designed a physical model of the spiral coil heat exchanger, built, and instrumented for temperature measurements. The study showed that mass flow rate of hot fluid was varied from 0.049 kg/sec to 0.298 kg/sec and the mass flow rate of cold fluid was varied from 0.029 kg/sec to 0.225 kg/sec. They conducted experiments by varying combination of the mass flow rates of cold and hot water. They investigated effects of relevant parameters on spiral coil heat exchanger. The result they achieved in the research was impressive and encouraging. They concluded that results have explained the better understanding of heat transfer co-efficient and effectiveness of a spiral coil heat exchanger, which was newly attraction for the researcher. They also concluded that heat transfer rate depends directly on mass flow rate of hot and cold water in which maximum heat transfer rate is obtained at lower hot water flow [4]. Their results showed that heat transfer coefficient is increased with the increase of both Reynolds Number and hot water flow whereas the effectiveness is inversely proportional to the hot water flow and the optimum effectiveness is obtained when the temperature difference between hot and cold water is maximum. Finally they concluded that their work will contribute mostly for further study.

E. Acid-Water System

Dr. M. Thirumarimurugan, Dr. T. Kannadasan, A. Sivalingam, T. S. Krushnathej and Prof. S. Gopalakrishnan has carried out a research on comparative heat transfer study on a solvent and solution using Spiral Heat Exchanger. The study showed that steam was kept as hot fluid, whereas acetic acid -water miscible solution as cold fluid. They carried series of runs between steam and water, steam and Acetic acid solution. They varied volume fraction of Acetic acid. The flow rate of the cold fluid was maintained from 120 to 720 lph and the volume fraction of Acetic acid was varied from 10-50%. They investigated exchanger effectiveness, overall heat transfer coefficients. They used generalized regression model for artificial neural network simulation using matlab and the data obtained was compared with experimental findings and found to be valid. They carried out studies on spiral heat exchanger with different cold side flow rates and different compositions of cold fluid in both parallel flow and counter current flow pattern. They made comparison between parallel flow and counter current flow spiral heat exchanger with respect to the performance characteristics i.e. overall heat transfer coefficient, effectiveness, hot side efficiency and cold side efficiency [5]. They used Experimental data to develop neural network using general regression. The study showed that the predicted results are close to experimental data by ANN approach. It is recommended that ANN can be applied to simulate thermal systems, especially for engineers to model the complicated heat exchangers in engineering applications.

F. Handling Nano fluids

Yanuar, N. Putra, Gunawan and M. Baqi carried an experimental investigation of convective heat transfer coefficient for nanofluids using spiral pipe heat exchanger. They investigated experimentally flow and convective heat transfer characteristics of water-based nanofluids flowing through a spiral pipe heat exchanger. Their experimental setup consist of test section of spiral pipe with ratio pitch per diameter was 7.0 and mean hydraulic diameter was 30 mm. They used straight spiral tube with 1600 mm length as the test section. They installed a circular copper pipe with 10 mm diameter at the inner of spiral pipe heat exchanger. They measured pressure drop and convective heat transfer for Al2O3, TiO2 and CuO at 1% and 3%, particle volume with pure water. The results shows that convective heat transfer coefficient of the nanofluids increases by up to 28% at a concentration of 3 vol. % compared with that of pure water. They concluded that experimental study has been performed to investigate enhancement of coefficient heat transfer, pressure drop that occur with spiral pipe and nanoparticles. They also concluded that the TiO_2 behaves as the Newtonian fluids for 1%, 3% and the shear thinning fluid (pseudoplastics fluid) for 5% particle volume consentration[8]. They observed that power law model describes approximately the behavior of TiO_2 and the range of the power law fluids index is n = 0.9 to 1.

G. Waste Heat Recovery Unit

Parinya Pongsoi, Santi Pikulkajorn and Somchai Wongwises carried out research work on air-side performance of spiral (or helical) fin-and-tube heat exchangers. They studied that the spiral fin and tube heat exchanger is a favored type of heat exchanger for the waste heat recovery unit (WHRU),a kind of economizer system. Their research study was broadly divided into an experimental section and numerical and simulation sections. They studied and reviewed many research papers for the effect of fin configurations, tube arrangements, operating conditions, and other factors on the air-side performance of the spiral fin-and-tube heat exchangers. They refered fourty published articles related to spiral fin-and-tube heat exchangers. They found out that the air-side performance correlations of spiral fin and circular fin-and-tube heat exchangers for practical industrial applications. They concluded that the spiral-finned tube heat exchanger may present a challenging subject for further investigation. They investigated factors to improve the air-side performance that to reduce the weight and size of heat exchangers (compact heat exchanger), the various fin configurations, tube arrangements, operating conditions, and other. They also concluded that future research will use their study as a foundation for enhancing effects on the air-side performance of the spiral fin and tube heat exchangers [12].Their main objective was to develop a well-designed heat exchanger for effective heat transfer and cost savings. They also concluded that their research work will play a defining role in future research for bringing it to commercialization and industrial applications.

H. Double Spiral Heat Exchanger

Matthew J. Targett, William B. Retallick, and Stuart W. Churchill carried out research work by using the MACSYMA code for symbolic manipulation to obtain solutions in closed form for double-spiral heat exchangers of a few turns, both with and without heat losses to the surroundings. The study shows that the solutions, which are for an equal rate of flow of the same fluid in both directions, reveal the existence of an optimal number of transfer units (an optimal rate of flow) for which the temperature rise for the heated stream is a maximum for a given thermal input or temperature difference. They observed anomalous behavior, which is of obvious importance in the design and operation of double-spiral exchangers, has generally been overlooked or misinterpreted in prior experimental work and numerical solutions[17].They also studied that for realistic heat losses to the surroundings, double-spiral exchangers of multiple turns are shown to be superior to true countercurrent exchangers in terms of producing a temperature rise.

I. Heat Regenerative Adsorption Refrigerator

R.Z.Wang, J.Y.Wu, Y.X.Xu, Y.Teng and W.Shi carried research work on continuous heat regenerative adsorption refrigerator using spiral plate heat exchanger as adsorbers. They proposed that spiral plate heat exchanger can be used as adsorbers. They developed and tested heat regenerative adsorption refrigerator using activated carbon methanol pair. They observed that adsorption system using 12 Kg activated carbon has a cycle time of 40 min. and 14 Kg ice per day was made. They concluded that spiral heat exchanger is suitable for adsorption refrigeration system to be used as an adsorber. They also concluded that the constructed adsorption refrigeration using activated carbon-methanol can make ice properly[16].Their experimental results show that the system can make more than 1 Kg ice per Kg adsorbent per day.

III. RESULTS AND DISCUSSION

Design Research on Spiral Heat Exchanger

Jay J. Bhavsar, V K. Matawala and S. Dixit designed spiral heat exchanger for particular process engineering. They developed a new arrangement for flow of hot and cold fluids. The study shows that hot fluid flows in axial path while the cold fluid flows in a spiral path. They designed model to measure the performance of the spiral tube heat exchanger and fabricated to perform experimental tests. They studied analysis of spiral tube heat exchanger over the shell and tube heat exchanger. They concluded that design methodology available in literature is in scattered manner. They also concluded that previous works carried out by different authors were limited to helical coil heat exchanger and spiral plate heat exchanger. They studied that spiral tube heat exchanger is compact in size and more heat transfer can be carried out. Their objective of research work was to have streamline design methodology of spiral tube heat exchanger [6].Finally they concluded that designed spiral tube heat exchanger has to be developed and experiments will be performed on it to analyses pressure drop and temperature change in hot and cold fluid on shell side and tube side. Dr.Rajavel Rangasamy has carried out research work on experimental and numerical study of heat transfer and flow characteristics of spiral plate heat exchanger. The study shows that effects of geometrical aspects of the spiral plate heat exchanger and fluid properties on the heat transfer characteristics. They designed three spiral plate heat exchangers with different plate spacing (4mm, 5mm and 6 mm) were designed, fabricated and tested. In their study physical models have been experimented for different process fluids and flow conditions. They have taken water as test fluid. The study shows that effect of mass flow rate and Reynolds number on heat transfer coefficient. They developed a correlation to predict Nusselt numbers. They investigated numerical models by simulation using CFD software package FLUENT 6.3.26. They calculated numerical Nusselt number and compared with that of experimental Nusselt number. They concluded that heat transfer and flow characteristics of a spiral plate heat exchanger were studied. They compared experimental Nusselt number to that of literature data for three different configurations. They obtained empirical correlation to predict Nusselt numbers for water .They studied heat transfer coefficient for water. The study shows that space between the plates was varied from 4 mm to 6 mm. They finally concluded that the plate having space 4 mm shows more heat transfer coefficient [7]. They compared numerical Nusselt number with the experimental data which shows a reasonable fit.

Wu Dongwu carried research work on geometric calculation for spiral heat exchanger. He developed equation for calculating length of the spiral passage, length of spiral plates. He also developed equation for pole radius of the outer lateral line terminal point for spiral plates and to calculate the outer diameter of spiral heat exchanger [9]. Wu Dongwu concluded that number of rounds of the spiral is based on an arc of 2π as a circle. Paisarn Naphon and Somchai Wongwises reviewed research papers to improve the performance of heat exchangers to a certain heat-transfer duty by heat transfer enhancement techniques. They explored that these techniques can be divided into twogroups: active and passive techniques. They found that active techniques require external forces, e.g. electric field, acoustic or surface vibration, etc. and the passive techniques require fluid additives or special surface geometries. They have used curved tubes as one of the passive heat transfer enhancement techniques and are the most widely used tubes in several heat transfer applications. of single-phase and two-phase flow in curved tubes. They categories curved tubes into three main types helically coiled tubes, spirally coiled tubes, and other coiled tubes. They concluded that for helical coil tubes numerous theoretical and experimental works have been reported on single-phase heat transfer characteristics, single-phase and two-phase flow characteristics. They also concluded that for spiral coil tubes few papers had been published; only one paper presented the correlation of the in-tube heat transfer coefficient. They observed that none of the papers presented the flow characteristics and pressure drop. They also studied that for other curved tubes, single-phase, two-phase heat transfer characteristics and singlephase heat transfer characteristics have been numerously presented. They found out that only one research work was done on two-phase flow characteristics. They also concluded that some papers have presented the effects of the combined active andpassive method on the enhancement of heat transfer rate and pressure drop [10]. Their study points out that although numerous studies have been conducted on the characteristics of heat transfer and flow in curved tubes, study on some types of curved tubes is limited, especially on spirally coiled tubes. M.Picon-Nunez, L.Canizalez-Davalos, G. Martınez-Rodrıguez and G. T. Polley carried out research work on shortcut method for the sizing of spiral plate heat exchangers. Their study consists of an iterative process where physical dimensions like plate width and external spiral diameter are given initial values; convergence is achieved until the calculated pressure drop and heat duty meet the required specifications of the design problem. They compared results of the application of the approach with case studies reported in the literature. They studied and performed numerical study using computational fluid dynamics to rate the performance of the geometry. They calculated temperature profiles of the exchanger analytically to show the same tendency as those obtained numerically. They concluded that the method provides a good starting point for estimating the dimensions of spiral heat exchangers in single-phase applications. They concluded that a new methodology for the sizing of spiral heat exchangers. They found out that major simplification involved in the derivation of this method is the use of empirical correlations that do not account for the variation of the heat transfer coefficient with the curvature and do not consider the entry length effects. They purposed that their research work is to provide a simple methodology that will serve as a preliminary step in the design, selection and costing of this type of units. They also concluded that variation of the heat transfer coefficient will bring about larger values at the entry length, as large as 50% as suggested by some authors, whereas the variation of the heat transfer coefficient with the curvature is less important as the fluid moves in the outer direction[14].They also studied that the differences between the numerical and analytical temperature profiles around the middle part of the unit, the target temperatures are close enough to indicate, that for practical purposes, this design approach provides good estimates of the required heat transfer area. Yuehong Bi, Lingen Chen and Chih Wu carried out research work on ground heat exchanger temperature distribution analysis and experimental verification. Their study included designed underground two dimensional symmetry temperature field of a vertical double spiral coil ground heat exchanger(GHX) for a ground source heat pump(gshp)system was simulated using the volume control method. They designed and fabricated heat transfer model of underground coil. They solved numerically the underground temperature distribution of the coil. The experimental temperature data was compared with the analytical results. They developed mathematical model which will provide design guidance for the design of GHX for GSHP systems.They finally concluded that heat load of the GSHP hepends on the underground temperature field of the GHX[15].They observed that temperature distribution is important to the performance improvement of the GSHP, especially for GHX.They finally concluded that GHX design is reasonable. Probal Guha and Vaishnavi Unde carried research work on Compact Heat Exchangers (CHEs) which are increasingly being used on small and medium scale industries due to their compact size and efficient design. CHEs facilitate more efficient heat transfer. They observed that heat transfer would imply lesser fuel consumption for the operations of the plant, giving improvement to overall efficiency. This reduction in consumption of fuel is a step towards sustainable development.They studied that design considerations for spiral heat exchanger is that the flow within the spiral has been assumed as flow through a duct and by using Shah London empirical equation for Nusselt number design parameters are further optimized. They developed mathematical model accompanied by a detailed energy balance. They study shows that the heat balance equation and applying the LMTD method, the optimum design parameters for a spiral heat exchanger were achieved. They explored that their research work dealt with the design of a compact heat exchanger,heat balance was carried out for the spiral heat exchanger taking into account both the conductive and convective modes of heat transfer. They represented design equation with physical parameters that decide the dimensions of the entire heat exchanger. They concluded that initial heat exchanger network calculations of any plant provides the heat flux and the changein temperatures of the streams, upon feeding those values to the above modeled equations, the design parameters for the heat exchangers can be estimated. Thier study helps to estimate the width of the spiral ‘b’. They developed the equation using the Shah London’s equation for Nusselt number which is dependent on ‘ϵ’ has been optimized to produce a design that would provide the best heat transfer while using minimum material to construct the spiral heat exchanger. Finally they concluded that by this approach, a more efficient design can be approached[18].Reducing the material would have direct impact on the capital expense of the heat exchanger. N.E.Wijeysundra, J.C.Ho and S. Rajasekar carried out research work on effectiveness of a spiral coil heat exchanger.They obtained an expression for the effectiveness of a spiral coil heat exchanger which consists of a number of horizontal layers of spirally wound finned tubes.They fabricated and tested in a closed loop test set up to obtain the effectiveness. They studied the effect of the various design parameters on the effectiveness of the spiral coil heat exchanger. They compared the effectiveness of the spiral coil heat exchanger with that of a rectangular multipass cross flow heat exchanger. They found out that the effectiveness of the spiral coil heat exchanger exceeds that of the cross flow heat exchanger by about 2 percent[19].They concluded that advantage of spiral coil heat exchanger is that it is about 15 percent smaller than that of the equivalent cross flow heat exchanger. Th. Bes and W. Roetzel carried out research work to evaluate the thermal performance of spiral heat exchanger. They proposed a new dimensionless criterion number (CN). They developed formula to calculate the mean temperature difference correction factor (F) of a spiral plate heat exchanger: $F = \ln(1 + CN^2)/CN^2$. They discussed that accuracy of the theory increases with the growing number of channels. They concluded that problem of thermal analysis in countercurrent spiral heat exchangers was solved on the basis of the energy balance equations by using the regular mathematical transformations. They also concluded that all thermal and geometrical parameters of spiral heat exchanger are combined in only one new dimensionless number (CN) which could be recognized as criterion number for spiral heat exchanger[20].They finally concluded that their new theory appears useful for the design of countercurrent spiral heat exchanger.

IV. CONCLUSION

The research was carried out by various scientists on spiral heat exchanger and the results obtained were found valid and satisfactory. Kondhalkar and Kapatkat concluded that continuously curved flow section in spiral heat exchanger contributes to improvement in overall heat transfer coefficient as compared to shell and tube type heat exchanger from 400 to 650W/m^2 K. Paisarn Naphon and Somchai Wongwises concluded that the enthalpy effectiveness and humidity effectiveness increases as inlet-air temperature increases. They concluded and proposed a new correlation for the in tube heat exchanger coefficient for spirally coiled tube used under dehumidifying conditions for practical applications. R.Rajavel and K. Saravanan studied and compared experimental and theoretical data.They developed a new correlation for Nusselt number which can be used for practical applications. Dr M A. Hossain, M I. Islam, S A. Ratul and Erin concluded that heat transfer rate depends directly on mass flow rate of hot and cold water in which maximum heat transfer rate is obtained at lower hot water flow.

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