CFD Analysis of Helical Coil Heat Exchanger –A Review

Raghulnath D[1], Santhosh R B[2], Siva P[3], Varish R[4], Yogesh S[5]
[1]Assistant professor
[1, 2, 3, 4, 5] K. Ramakrishnan College of Technology, Trichy, Tamilnadu, India.

Abstract- *5G stands for fifth generation wireless technology. It is the latest Computational Fluid Dynamics (CFD) is the software used to analyse the heat transfer performance of any devices that work for fluids. In CFD, the results are easily generated and it is evaluated accurately. For example, for the analysis of heat transfer in the boiler, the water is converted into steam where the heat transfer rate will be high.So, for the analysis the CFD software is used to calculate the efficiency of the boiler. In this paper, we are going to review the results of previous researches on CFD analysis of the Helical coil heat exchanger. The purpose of this project is to compare the parameters such as heat transfer rate, effectiveness, overall heat transfer coefficient, shell side and tube side heat transfer coefficient, pressure drop, the friction factor of helical coil heat exchanger using CFD analysis.*

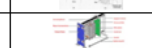
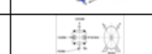
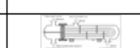
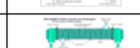
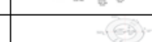
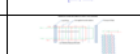
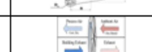
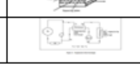
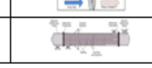
Keywords- Computational Fluid Dynamics (CFD), Shell and helical coil heat exchanger, Heat transfer rate, Heat transfer performance.

I. INTRODUCTION

The heat exchanger is a device in which heat transfers from high-temperature fluid to low temperature fluid. The main function of the heat exchanger is to either remove the heat from the hot fluid or to add heat from the cold fluid. Transfer of heat takes place by the law of conservation of energy, where the heat lost by the hot fluid will be always equal to the heat gained by cold fluid.Heat transfer between the fluids takes place without any external heat or work interactions. In some heat exchangers, the fluids exchanging heat are in direct contact. In other heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner.A heat exchanger consists of heat exchanging elements such as core or a matrix containing the heat transfer surface and fluid distribution elements such as headers, manifolds, tanks, inlet, and outlet nozzles or pipes and seals. The heat transfer surface is a surface of the heat exchanger core that is in direct contact with fluids and through which heat is transferred by conduction. The Helical coil in the heat exchanger has a greater surface area which allows the flowing fluids to be in contact with each other for a greater period so that there is an enhanced heat transfer compared to that of straight pipe. Alsoin this construction, there are more possibilities of increased turbulence in the hot fluid flow.

With the development of thermal engineering and industrial intensification, the need for more efficient and compact heat transfer systems has increased. In general, the heat transfer enhancement methods can be classified into two groups, they are (i) Passive Techniques, (ii) Active Techniques. These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. The different type of heat exchangers are shown in Table 1.The heat exchanger in the indirect evaporative cooling (IEC) energy recovery system. The influence of inlet air temperature, relative humidity, mass flow rate and channel height on the heat exchanger, the capacity of heat exchangers under conditions including high temperature and high humidity was studied. It introduces a method of indirect evaporative cooling heat exchanger based on CFD [1].

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	

The heat exchanger in the indirect evaporative cooling (IEC) energy recovery system. The influence of inlet air temperature, relative humidity, mass flow rate and channel height on the heat exchanger, the capacity of heat exchangers under conditions including high temperature and high humidity was studied. It introduces a method of indirect evaporative cooling heat exchanger based on CFD[1]. Heat exchanger for different fluid flow rates and the CFD analysis has been conducted to perform and study the effect of outer and inner tube flow rates on the heat transfer coefficients. As the inner tube flow rate increased with constant outer tube flow rate, the LMTD is increased and as well as the outer tube flow rate increases with constant inner tube flow rate, the LMTD decreases[2]. Computational Fluid Dynamic (CFD) analyses for calculating the friction pressure losses of isothermal flows of liquid sodium, water, and helium gas, on the shell side of annular heat exchangers (HEXs) of concentric, helically coiled tubes[3].

The design procedure of a heat exchanger theoretically and then its performance will be analyzed and optimized using computational fluid dynamics. The number of tubes used within a heat exchanger has an influence on tube flow velocity to maintain the required mass flow rate, where the lower the number of tubes the higher the pressure drop[4].A pore-scale CFD approach that has been adopted to improve the phenomenological understanding of transport phenomena governing heat transfer in consolidated, highly porous media with single-phase fluid flow[5]. The multi-pipe EAHEs flow characteristics were investigated experimentally and numerically to analyze the influence of its geometrical parameters on the pressure losses and airflow division uniformity structures with main pipes diameter bigger than parallel pipes diameter less significant differences were obtained for EAHEs in U-type structures because it’s flow characteristic are naturally better than Z-type and the possibility of improvement is lower, total pressure losses of long branch-pipes exchangers are higher than short ones and the airflow division uniformity is higher for the long branch-pipe exchangers[6].

The evaluation and analysis are necessary to understand the dynamic charging and discharging processes of the PCM HX with spiral– wired tubes, a 3D CFD model of the heat exchanger has been developed and validated with experimental results.

It is found from the simulation results that at specific operating conditions such as the charging times are much faster than the discharging time due to the contributions of convection heat transfer and buoyancy effect generated on the PCM side during charging or liquefying process[8]. The performance analysis of a shell-and-double concentric tube heat exchanger (SDCTHEX) is carried out using commercially available CFD software ANSYS FLUENT 14.0. First, the SDCTHEX having fixed inner tube diameter is compared with a classical shell-and-tube heat exchanger (STHEX) for their thermo-hydraulic performances for different mass flow rates of the hot fluid. Then, the effects of different inner tube diameters on the performance of SDCTHEX are investigated and the results obtained from the CFD analysis are the overall heat transfer rate, U and the overall pressure drop increase as the hot fluid mass flow rate is increased for both types of heat exchangers[10]. Heat transfer characteristics inside a helical coil for various boundary conditions are compared. It is found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger does not yield proper modeling[11].

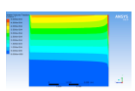
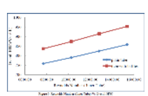
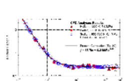
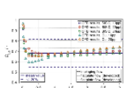
ANSYS-FLUENT 14.5 CFD package is used to investigate the characteristics of heat transfer of laminar flow in the annulus formed by multi tubes in tube helically coiled heat exchanger. The numerical results are validated by comparison with previous experimental data and fair agreements existed[12]. The possibility to increase the heat transfer efficiency by using simple wire coil inserts to create turbulent flow in the boundary layer as well as air blowing into the annulus of the pipe. The experimental results were compared with numerical simulations. The assumptions were not proper for the whole range of considered experimental conditions[13]. Heat transfer in a helical coil is higher than that in a corresponding straight pipe. However, the detailed characteristics of fluid flow and heat transfer inside the helical coil. The variation of local Nusselt number along the length and circumference at the wall of a helical pipe[15].

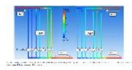
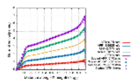
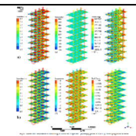
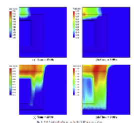
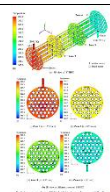
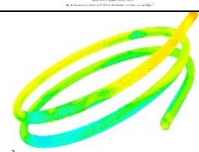
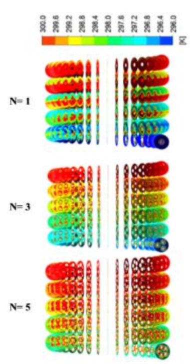
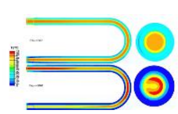
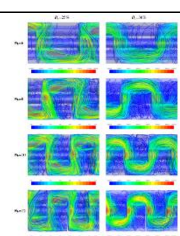
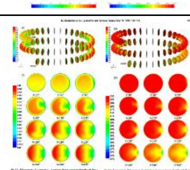
The influence of coiled wire inserts on the Nusselt number, friction coefficient and overall efficiency in double pipe heat-exchangers has been employed. For this purpose, some wire coil inserts fitted inside heat-exchangers were meshed and simulated at various Reynolds numbers by using the CFD software of Gambit and Fluent. The outcome of this work indicates that taking advantage of proper wire coils could improve Nusselt values[17]. Latent heat energy storage systems have superior features over conventional sensible storage systems with a large latent heat of fusion. A phase change material (PCM) can absorb and release a great amount of thermal energy at nearly a constant temperature. This improves the capacity and efficiency of the energy storage unit while extending the service time[18]. Energy consumption can be economized by using nanofluids as a heat transfer medium in heat exchangers. The thermal performance of a helically baffled heat exchanger combined with a 3D fined tube operated with nanofluids is investigated numerically[20].

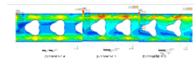
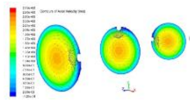
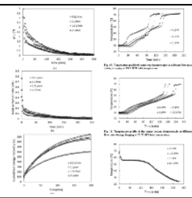
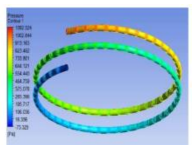
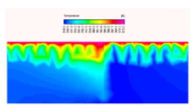
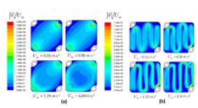
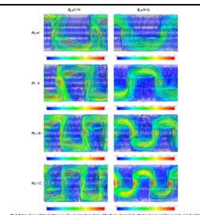
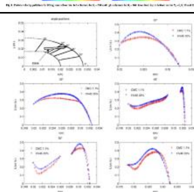
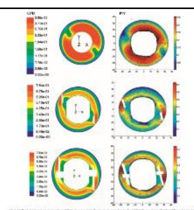
It is found that the dependence of the Nusselt number on the Peclet number can be described by the modified Sieder-Tate equation. Although the flow pattern is highly complex, under an adequate definition of the characteristic parameters, it is possible to establish simple correlations between the dimensionless numbers that characterize the thermal-hydraulic behaviour of plate heat exchangers[21]. The flow and temperature fields inside the shell are resolved using a commercial CFD package. For two baffle cut values, the effect of the baffle spacing to shell diameter ratio on the heat exchanger performance is investigated by varying flow rate. The best turbulence model among the ones considered is determined by comparing the CFD results of heat transfer coefficient, outlet temperature and pressure drop with the Bell–Delaware method results[22]. Numerous studies have been carried out for investigating the heat transfer characteristics in helically coiled tubes applied numerical method. Among them, the standard k−ε model and realizable k-ε model are most widely used [26].The simulated results showed that the heat transfer rate in terms of Nusselt number increased, whereas, the friction factor also increased for wire wrapped tube, the tube with helical screw insert in comparison to the plain tube. The thermal performance factor was evaluated and the maximum value is found at a constant pumping power. The pressure drop was estimated which was increased due to the increased flow restrictions by inserted coils[27].The corresponding average temperature of the liquid sodium exiting the reactor core is 752 K. This temperature is not only suitable for attaining high plant thermal efficiency (35–38%), but also compatible with the HT-9 steel cladding and core structure for the long operation lives of the VSLLIM reactor [28]

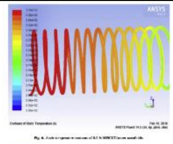
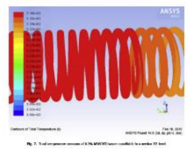
The performed 3-D thermal hydraulics and Computational Fluid Dynamics (CFD) analyses investigate the effects of using metal fins along the guard vessel wall and changing the width of the cold air intake duct on the decay heat removal rate and the time after shutdown for cooling the in-vessel liquid sodium to 400 K. Results demonstrate the effectiveness of natural circulation of ambient air, with and without metal fins, for passively and safely removing the decay heat generated in the reactor core after shutdown [29]. Twisted-tape is one of the most common method of passive heat transfer augmentation techniques for forced convection. In this paper, a numerical investigation of the heat transfer and pressure drop under natural circulation for in-tube twisted-tape geometry is performed using computational fluid dynamics (CFD). The Table 2 consists of the CFD analysis carried out considering various parameters.

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

Review papers	Heat Exchanger Type	CFD Image	Parameters chosen	Additional comments
Yuwen You [1]	IEC Heat Exchanger		• Heat transfer • Pressure drop	Relative Humidity can obtain lower temperature and moisture content.
Vijayakumar Reddy K [2]	Helically Coiled Tube in Tube		• LMTD • Overall Heat transfer coefficient	The overall heat transfer coefficient increases which can be observed as convection dominates.
Denise A. Haskins [3]	Shell side of concentric, Helically-coiled tubes		• Pressure Loss • Reynolds Number • Friction Factor	Total friction pressure losses are the bases of developing friction factor correlation for these Heat exchanger.
ChamilAbey koon [4]	Compact Heat Exchangers		• Heat Transfer Coefficient • Pressure Drop	A decrease in baffle-cut ratio increases the heat transfer coefficient in shell-side but this also causes to increase the pressure drop.
Sebastian Meinicke [5]	Highly porous media using a hybrid-scale		• Pressure Drop • Convective Heat Transfer Coefficient	The CFD analysis has been extended to regular representatives of consolidated, Highly porous media-including Kelvin, Weaire-Phelan and cubic unit cell structures.

Lukasz Amanowicz [6]	Multi-pipe earth-to-air		• Pressure Loss • Uniformity air flow	Choosing U-Type Structure can be considered as costless method of decreasing total pressure losses and increasing the air-flow equality in parallel branch-pipes of multi-pipe EAHEXs.
Moon Soo Lee [7]	Air-to-refrigerant		• Pressure Drop • Air flow rate	The momentum resistance coefficient has shown to affect substantial variation in the velocity profile.
W. Youssef [8]	Phase change material		• Thermal Conductivity • Flow rate	It is found that the charging times are much faster than discharging times.
JianGe [9]	Passive residual heat removal		• Heat transfer coefficient • Void Fraction	The heat flux in the upper horizontal tube region is much larger than that in the lower horizontal tube region due to large heat transfer coefficient and the large temperature difference between primary side and secondary side fluid.
S.M. Shahril [10]	Shell-and-double concentric tube		• Mass Flow Rate • Overall heat transfer rate • Pressure drop	It is safe to conclude that the SDCTHEX provides a good alternative solution for industrial heat transfer applications compared to classical STHEX.
J.S. Jayakumar [11]	Helically coiled		• Heat transfer coefficient • Mass flow rate	It is observed that the use of constant values for thermal and transport properties of the heat transport medium results in prediction of inaccurate heat transfer coefficient.
S.A. Nada [12]	Multi tubes-in-tube helical coil		• Heat transfer coefficient • Mass Flow Rate	Optimization study including constructing and operating costs is needed as a further study to detect the optimal coil.
RafalAndrzejczyk [13]	Straight and U-Bend Double Tube		• Pressure drop • Heat transfer coefficient	It is worth to add that especially in heat exchangers configurations working in two-phase flow conditions the results of numerical calculation were under predict two-phase flow pressure drops.
Ender Ozden [14]	Small shell-and-tube		• Mass flow rate • Pressure drop	It can be said that correlation based approaches may indicate the existence of a weakness in design, but CFD simulations can also pinpoint the source and the location of the weakness.
J.S. Jayakumar [15]	Helically coiled tubes		• Nusselt number • Velocity	Nusselt number at various point along with the length of the pipe was estimated. Nusselt number on the outside of the coil is found to be highest among all other points, inner side of the coil is lowest.

Guanghui Wang [16]	Shell side of helically coiled		• Friction Factor • Heat transfer rate	The fitting correlation equation of the nusselt number and friction factor o structural parameters, flow parameters and physical parameters in shell side of HCTT with the orthogonal experiment design point under various flow condition.
KhashayarSharifi [17]	Double pipe heat exchanger		• Friction coefficient • Heat transfer rate	The swirl motion was observed during heat transfer process. The higher Reynolds number the process has, the higher intensive swirl motion it produces.
VahitSaydam [18]	Helically coiled phase change heat exchanger		• Discharge in time • Temperature	It found that higher flow rate leads to higher recovery efficiency. Flow direction of the HTF was found to have an insignificant of the total charging and discharging time but showed were the effect on the temperature variations.
R.ThundilKaruppa Raj [19]	Helically coiled heat exchanger		• Velocity • Nusselt number	The Nusselt number to heat removed shows that the values are directly linear to each other. The ratios for different velocities are nearly the same. So no much variation has been observed when comparing flow and Dimensional parameters in this case.
Mahdi Saeedan [20]	Double pipe helically baffled heat exchanger		• Heat transfer coefficient • Pressure	The heat transfer coefficient and pressure gradient increased by an increase in Reynolds number and volume concentration.
Erika Y. Rios-Iribe [21]	Plate heat exchanger		• Friction factor • Heat transfer coefficient	It was found that, a high flow rates the higher the number of plates used, the lower the ratio between the heat transfer rate and pumping power.
MehediTusar [22]	Tube with twisted tapes		• Fluid flow • Heat transfer enhancement	Pipe wall temperature is reduced in case of insert fitted tube meaning lower irreversibility and higher heat transfer characteristics. It has twisted contour of relatively higher and lower temperature like the twist of the insert mainly caused by velocity in the region effected by twisted tape.
MouradYataghene [23]	Scraped surface heat exchanger		• Shear rate • Viscosity	For Shear-tinning fluids, because of the low value of the viscosity, the viscous forces are not important enough to oppose centrifugal forces and the position of the plates does not depend on the rotating velocity.
MouradYataghene [24]	Scraped surface heat exchanger		• Heat performance • Mass flow rate	The plotting of temperature profiles in axial direction has shown asymptotic behaviour and temperature profiles distortion is observed in the wake of attachment points of blades.

P.C. Mukesh Kumar [25]	Double helically coiled tube heat exchanger	 	• Volume Concentrations • Pressure Drop	The CFD data were compared with experimental data and hold good agreement with the deviation of CFD Nusselt number.

II. PERFORMANCE ANALYSIS USING CFD

In the present work CFD analysis of Heat Transfer Tube-in tube helical coil Heat Exchanger is performed to study the effect of the outer and inner tube flow rates on the heat transfer coefficients. As the inner tube flow rate increased from 400 to 600lph with constant outer flow rate of 700LPH, theLMTD increased by 1.33%. As the outer flow rate increases with constant inner tube flow rate, the LMTD decreases [2]. In the first part of the work the suitability and reliability of the proposed CFD approach to reproduce the underlying momentum heat transfer characteristics is being verified. This has been done along dimensionless result analysis for the pressure drop and the convective heat transfer coefficient in different ceramics (SiSiC) and metal (Cu) sponges [5]. The dimensional simulation for the secondary side fluid flow and heat transfer for PRHR HX is performed and it is modelled by the porous media approach. The heat flux in the upper horizontal tube region due to the larger heat transfer coefficient and the large temperature difference between the primary side and secondary side fluid. About 95% of the total residual heat is removed by the upper horizontal and vertical tubes [9]. It can be said that correlationbased approaches may indicate the existence of a weakness in design but CFD simulations can also pin point the source and the location of the weakness. Using CFD together with supporting experiment may speed up the shell and tube heat exchanger design process and may improve the quality of the final design [14].

III. APPLICATIONS OF CFD IN HEAT EXCHANGERS

The analogy of heat and momentum transfer processes, has been discussed and is supported by using the results from the CFD analysis. Different authors have shown that CFD simulations can be a suitable instrument to conduct deeper analysis of the underlying transport processes. The CFD methodology described and used in this allows to derive this quantity quite easily and precisely [5].CFD is used to predict the overall thermo hydraulic performances for models of heat exchangers under the assumptions of steady state conditions, flow being turbulent and incompressible [10].

IV. CONCLUSION

Based on the taken journal papers, most of the papers are stating that the CFD is the best way in the analysis of the fluid flow properties. They are so many software in analysing the fluid flow property. They are, ANSYS FLUENT, ANSYS FLUENT 14.0, ANSYS WORKBENCH, ANSYS-FLUENT 14.5 and many more versions based on requirements. In most of the heat exchangers the calculation of results may be correct in approximate value but for accuracy the experimental results are not up-to the expectation. So, the analytical results using CFD is the best way to get results accurately. Thus, for the accurate results of fluid flow the CFD can be used for the analytical results and it can be slightly deviated from the experimental results.

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