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Compact Helical Counter-Flow Heat Exchanger Numerical Analysis

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ABSTRACT: The performance of the compact countercurrent heat exchanger with helical paths was tested using a 1-D analytical model and compared with a high-precision 3-D numerical simulation. The 1-D model can evaluate general trends related to heat transfer efficiency and fluid pressure loss, while a high-fidelity 3-D digital model is needed to provide a high degree of accuracy. higher accuracy. For water flow rates from 0.01 kg/s to 1 kg/s, models are used to predict the overall heat transfer coefficient ratios for straight and counter torsion heat exchangers. The maximum difference between the 3D numerical model and the 1D analytical model for heat transfer efficiency is 2.6%, with a larger difference related to fluid pressure drops of up to 37.5%. The main reason for the difference in numerical results is due to secondary flux effects, which are ignored in the 1-D analytical model. Heat exchanger efficiency is studied by varying geometrical parameters such as length and number of revolutions per length of heat exchanger, number of fins in flow passages, height of heat exchanger. internal and external channels, fins and walls. thickness. Heat transfer rates and pressure drop on helical and straight blade heat exchangers are compared by keeping the impeller length and hydraulic channel diameter constant. Finally, the heat transfer rate of the helical design is increased by 56% compared to conventional countercurrent heat exchangers of the same length and outer diameter. In addition, by using a spiral flow path, the volume of the device can be reduced by 33%. The recovery of waste heat has been a topic of concern for large-scale industrial companies for several decades. This recovery not only makes an operation more environment friendly, but it also helps to cut costs.

Key Word:Helical Fin Heat Exchanger, Counter Flow, Thermal Conductivity, Hot fluid, Cold fluid, Fins, Annular Fin Heat Exchanger.

I. INTRODUCTION

A heat exchanger is a device used to transfer thermal energy from one liquid to another separated by suitable heat transfer surfaces. Heat exchangers are widely used in a number of industrial applications. They are used in aerospace and automotive applications, power plant industry, manufacturing industry, transportation power systems, chemical and medical fields, air conditioning, oil and gas, and more. They can be classified according to heat transfer process, structure, degree of surface compaction, flow arrangement, passage arrangement, process fluid phase and heat transfer mechanism. The classification of heat exchangers is explained briefly in chapter 2. Choosing the right heat exchanger for a particular problem is a difficult task because several variables must be taken into account. The most limiting factors in heat exchanger construction are pressure drop, thermal efficiency, cost, fluid flow range, maintenance and repair, material selection, etc.

Heat transfer can be improved by increasing the surface area by means of fins or can be increased by selecting a working fluid with high thermal conductivity or by changing the direction of the channel and changing the geometry. first]. In this thesis, the first and third ways can be chosen, i.e. spiral fins are introduced to increase the heat transfer surface and the channel orientation is changed by spiral fins. Although these heat exchanger designs are compact (mass and volumetric) and increase heat transfer rates, the fabrication of these designs (helical fin heat exchangers) is very complex compared to conventional heat exchangers. conventional production methods. Today, compact heat exchangers are growing in popularity due to their high heat transfer rates in a smaller volume and lighter weight compared to conventional heat exchanger designs. The development of new manufacturing technologies, such as existing 3D printing, has facilitated the production of compact heat exchanger designs [2]. The potential of additive manufacturing technology is driven by its ability to produce complex designs at a reduced cost compared to traditional manufacturing methods. It also offers functional designs without production limitations and avoids investment in production tools.

There are different types of 3D printing technologies depending on the material selection. Fused deposition modeling (FDM), SLS technology, or laser sintering are used to print complex 3D designs in plastic and aluminum. Embossing (SLA), Digital Light Processing (DLP), Continuous Liquid Interface Manufacturing (CLIP), Multijet Printers use resin or wax to print models. Metals such as titanium, aluminum, stainless steel can be printed with DLP, Direct Metal Laser Sintering (DMLS) and Electron Beam Melting (EBM) [3]. The schematic diagram of the direct metal laser sintering is shown below in Figure 1.

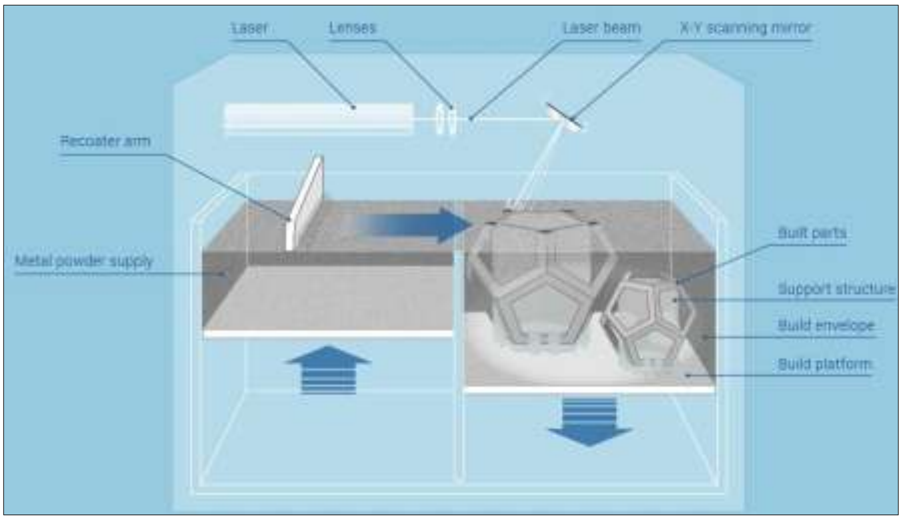


Figure 1 : Metal Printing

II. LITERATURE REVIEW

Jayakumar et.al [1] The performance of helically coiled heat exchanger was investigated for heat removal system used in nuclear energy by CFD simulation on helical coil heat exchanger has been carried out by varying geometry such as coil pitch, pipe diameter and pitch circle diameter have been studied and their influence on heat exchanger performance has been brought out. He also reported that unlike the flow through a straight pipe, the prediction of heat transfer coefficient is inaccurate with constant thermal properties of heat transport medium. Heat transfer can be enhanced by increasing the heat transfer surface by incorporate extended surface such as fins.

Yinhai Zhu et.al [2] The heat transfer behaviors in developed and developing regions on four basic fins of plate fin heat exchanger was numerically analyzed by Yinhai Zhu and Yanzhong Li. Three dimensional geometries such as plain fin, strip offset fin and wavy fin were investigated for the Reynolds number range of 132.3 to 1323. Data reduction method was used to calculate the local Nusselt number and pressure drop. Heat transfer characteristics were obtained using j and f factors.

Lingadi Tang et al [3] Flow characteristics inside the helical pipe was analyzed by Lingadi Tang. In this study, the numerical simulation was carried out to find velocity distribution, pressure field and secondary flow variation by varying coil parameters. It also stated that secondary flow is the major factor in pressure loss, however, increase in curvature radius and coil pitch can reduces friction factor. The numerical method was validated by experimental analysis and found that the deviation between the numerical and experimental analysis was 2.9%.

Vinous M. Hameed et al.[4] The characteristic of flow inside the helical coil, pressure drop, and heat transfer have been studied by many investigators. The performance of triangular finned tube heat exchanger was performed experimentally and numerically investigated by Vinous M. Hameed Experimental work carried out by designing and manufacturing of triangular fins using copper material and the results showed that the enhancement of heat dissipation for triangular finned tube is 3 to 4 times than smooth tube. Numerical simulation was carried out using COMSOL CFD package model and reported that the numerical results showed good agreement with experimental work.

Pranita Bichkar et.al. [5] doing research on the impact of various types on Shell and Tube Heat Exchangers This research offers numerical simulations of unmarried segmental, double segmental, and vertical arrangements. This implies that the shell has an influence on the pressure drop of the shell and tube warmth exchanger. Unmarried-segmented blocks exhibit the creation of dead zones in which the warmth switch cannot be turned green. When compared to single segment beams, double section beams lessen vibration damage. Because dead zones are eliminated when using a vertical shell, pressure is reduced. Fewer dead zones result in a greater heat switch. Reduced stress results in less pump energy, which boosts system efficiency. The comparison results reveal that the vertical is more beneficial than the horizontal.

Vidula Vishnu Suryawanshi et.al. [6] carried out research on the designing and assessment of helical coil heat exchangers CFD analyses are performed in this work on several compounds with varying sizes. The following tasks must be completed to further develop the helical heat exchanger: wall temperature and consistent wall warmness flux in both laminar and turbulent drift. To maximise the heat transfer coefficient, examine the results and alter the spiral winding pitch.

The Mohamed Ali et.al. [7] The experimental inquiry of herbal convection created to examine, constant type natural Convection became obtained from turbulent herbal convection to water. The experiments were carried out with a coil diameter to tube diameter ratio of four for five and ten coil tubes, as well as a pitch outer diameter ratio of five. He correlated Rayleigh amount for two distinct coil sets and discovered that the warmth switch coefficient falls with coil length for tube diameter do =.012m but increases with coil length for do=.008m. For a most heat switch coefficient, a tube diameter of zero.012 m with either five or ten coil turns yields a significant D/d0.

R. Patil et.al. [8] A design method for a spiral coil heat exchanger was suggested. The heat transfer coefficient is calculated primarily based on the internal diameter hello of the coil using the Sieder-Tate relationship or the instantly pipe method by plotting the Colburn coefficient JH against Re. External heat transfer coefficients are calculated using correlation for specific stages of Reynolds numbers. Spiral coil warmness exchangers are preferred when space is limited, as well as in low drift or slow flow circumstances.

N. Ghorbani et.al. [9] For the purposes of this paper, an experimental examination of the thermal performance of shell and coil warmth exchangers was carried out. The calculations were done in steady state, and the trials were done in laminar and turbulent glide within the coil. It has been established that the tube aspect to shell mass drift ratio is effective for the heat exchanger's axial temperature profile. He observed that raising the mass flow ratio reduces the logarithmic average temperature difference and decreasing the mass waft rate reduces the adjusted effective temperature distinction.

Sunil Kumar et.al. [10] The first configuration of a helical coil warmth exchanger with fins was explored, as well as stress and temperature comparisons with a standard structure. The end outcome of this investigation is an increase in the overall heat switch coefficient within the domain. Increase the strain decrease within the range. The bloodless water outlet temperature is increased to 320k while the water outlet temperature is dropped to 315k. The total stress decrease increases as the temperature rises. When the CFD numbers were compared to the prior statistics, the entire pressure drop for Case 2 increased to 0.65 bar. The system's overall performance ranges between 5% and 6%.

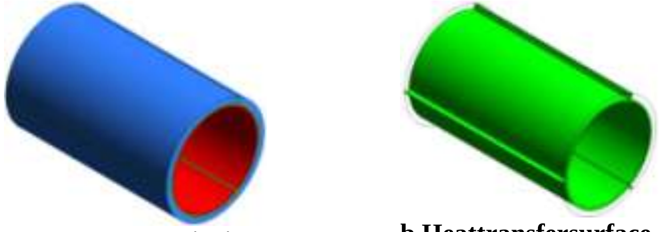
III COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics, as the name implies it is a subject that deals with computational approach to fluid dynamics with numerical solution of the equations which bring about the flow of the fluid and although it is also called computational fluid dynamics; it does not just deal with the equations of the fluid flow, it is also generic enough to be able to solve simultaneously together the equations that direct the energy transfer and as well the equations that determine the chemical reaction rates and how the chemical reaction proceeds and mass transfer takes place; all these things can be tackled together in an identical format. So, this outline enables us to deal with a very complex flow circumstances in reasonably fast time, such that for a particular set of conditions, an engineer will be capable to simulate and see how the flow is taking place and what kind of temperature distribution there is and what kind of products are made and where they are formed, so that we can make changes to the parameters that are under his control to modify the way that these things are happening. So, in that case CFD becomes a great tool of design for an engineer. It is also a great tool for an analysis for an examination of a reactor or equipment which is not functioning well because in typical industrial applications.

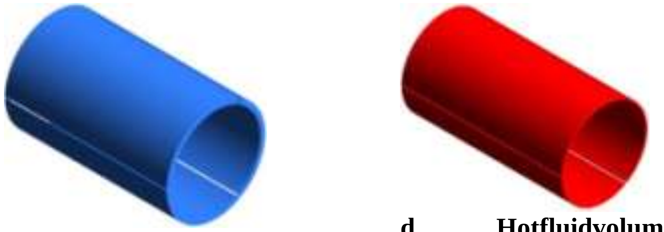
IV METHODOLOGY

The creation of a three-dimensional geometric model of the current problem using CATIA software. To obtain a suitable mesh between solids and liquids, the liquid volume is separated from the solid volume using the built-in drawing module of the CFD software (ANSYS Design Modular) and then converted into a single part. The compute domain grid was created with the ANSYS Fluent grid tool. To capture boundary layer effects (effect close to the wall on fluid flow), the boundary layer thickness is calculated and fed into the mesh. The management equations for stable turbulent flow and heat transfer on optimized helical heat exchangers are solved using commercial ANSYS Fluent CFD code. Secondary flows are visualized by illustrating straight lines in cross sections. Pressure drop, heat exchange across the heat transfer surface is shown in different planes along the length of the heat exchanger. The outlet temperatures of hot and cold liquids are obtained using surface integrals.

In computer analysis, the first step is to create a three-dimensional virtual computer model. In this numerical analysis, all solid models were created using CAD software CATIA v5. To achieve a consistent mesh between the solid and liquid domain, the liquid volume was extracted from the solid and made into one piece using ANSYS Design Modular. Calculation ranges for straight and helical fin heat exchangers (solids and liquids) are shown below. In the figure, red represents the hot liquid domain and green represents the solids volume (solid tubes and fins) and blue represents the cold liquid volume of the heat exchanger.

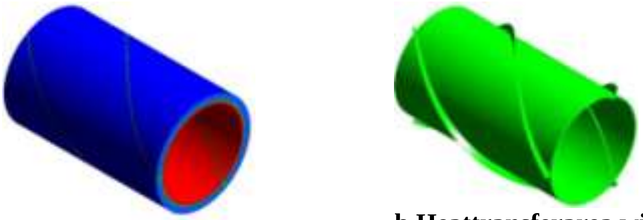


a. Isometricview **b.Heattransfersurface**



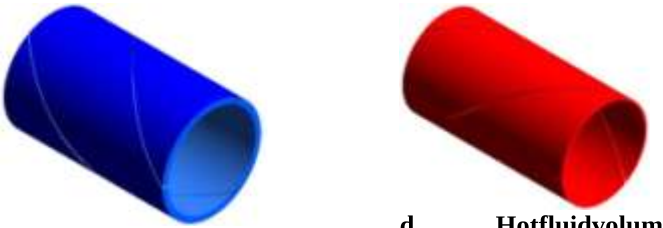
c. Coldfluidvolume **d. Hotfluidvolume**

Figure2:Straightannularheatexchangergeometry



a. Isometricview

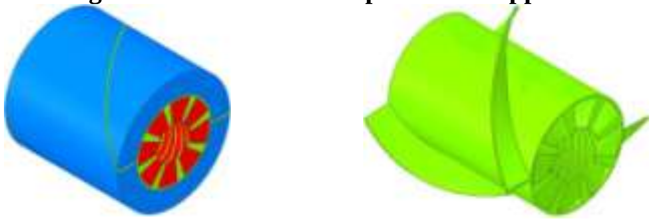
b.Heattransferarea withhelicalfin



c. Coldfluidvolume

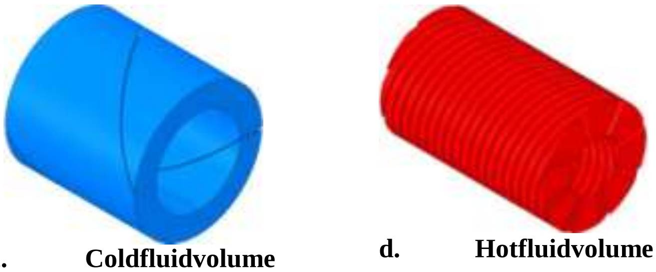
d. Hotfluidvolume

Figure3: Heattransfer andpressure dropprioritized geometry



a. Isometricview

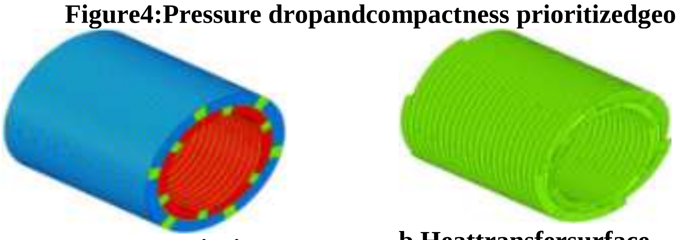
b.Heattransfersurface



c. Coldfluidvolume

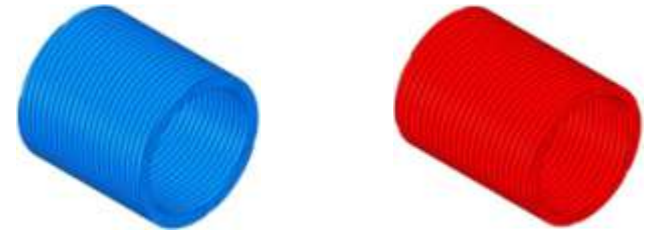
d. Hotfluidvolume

Figure4:Pressure dropandcompactness prioritizedgeometry



a. Isometricview

b.Heattransfersurface



c. **ColdFluidvolume** d. **Hotfluidvolume**

Figure5:Heattransfer andcompactnessprioritizedgeometry

Meshonfluidvolume Helicalfinheatexchanger Meshonsolidvolume

Figure6: Meshedmodelofhelicalfinheatexchangergeometry

CFDcases		**Coldfluid**	**Hotfluid**	**Solid**
Straight annularheatexchanger	Nodes	388741	249708	634275
	Elements	337145	215489	474856
Helicalfinheatexchanger	Nodes	1245476	441719	1154845
	Elements	1151974	363145	845178

Table1: Meshstatistics

V RESULTS & DISCUSSION

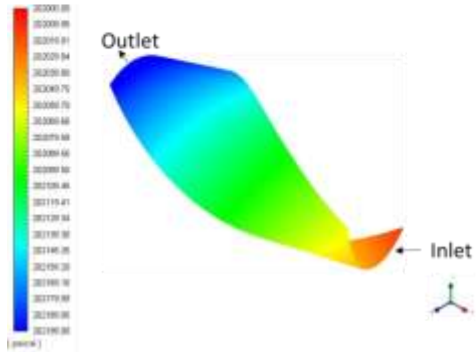


Figure7:Pressure contourforheat transferandpressuredropprioritizedgeometry

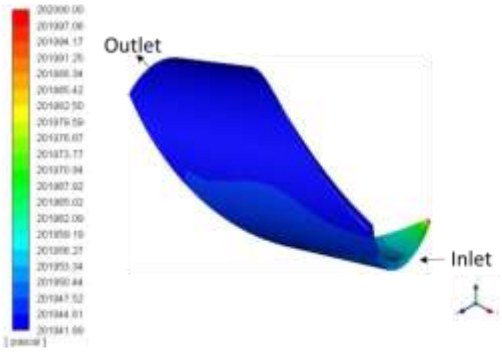


Figure8:Pressurecontourforheattransferandpressuredropprioritizedgeometry

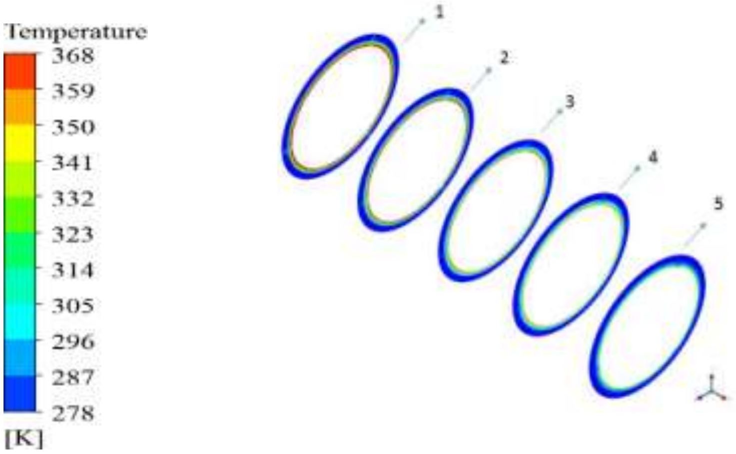
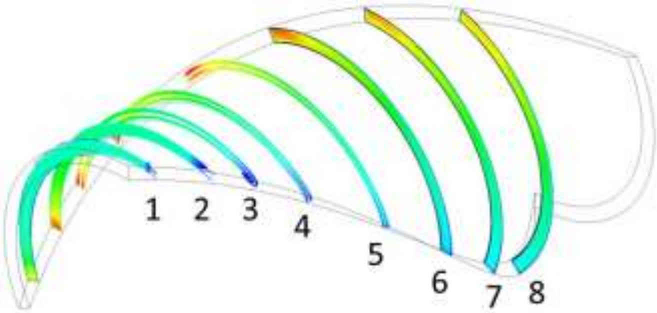
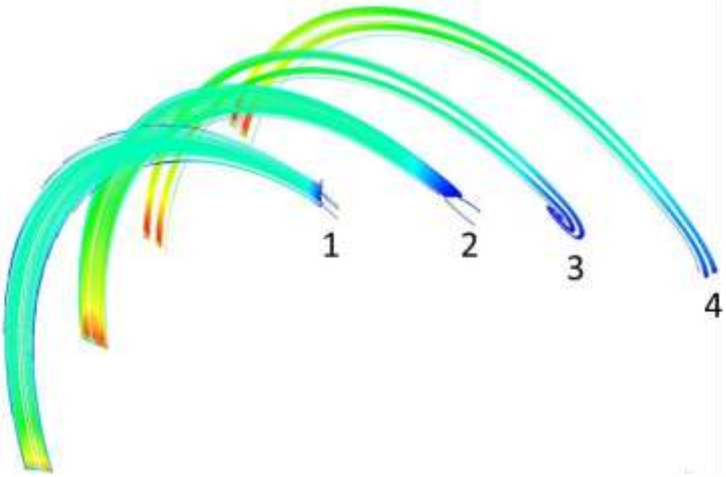


Figure9:Temperaturecontourforheattransferandpressuredropprioritizedgeometry

The temperature contour has been shown in 5 different planes, evenly spaced from hot inlet/cold outlet to hot outlet/cold outlet. Plane 1 represents hot input/cold output while plane 5 represents hot output/cold input. The temperature curves obtained for mass flow are 0.01 kg/s and 1 kg/s for hot and cold liquids, respectively. The hot liquid is cooled from 368 K to 296.2 K while the temperature of the cold liquid goes from 278 K to 284.6 K and this is clearly noted from plane 1 to plane 5. Results The numerical results show that the outlet temperature of the hot liquid is cooled by more than 0.6% compared to the analysis result while the cold liquid temperature is increased by more than 0.56% compared to the analysis result.



a.Secondaryflowatcoldfluidchannel



b.Secondary flowviualizationatfirstfourplanes

Figure10:Secondaryflowvisualizationofheattransferandpressuredropprioritizedgeometry

er	Hot fluidoutlettemperature(K)	Cold fluidoutlettemperature(K)	Cold fluidpressureloss (ΔP)	Hot fluidp oss (ΔP)
ytical	347	292	24.57	1.449
	338	298	33.70	1.92
e(%)	2.59	2.01	37.15	32.5

Table2:Resultsofpressuredropandcompactness prioritized

VI CONCLUSIONS

This work determined the flow characteristics within the helical passage by 3D computational analysis. The numerical results of four different cases with the mass flow rate of 0.01kg/s and 1 kg/s of hot and cold fluid mass flow rates respectively, were calculated and compared with one dimensional analytical model. Finite Volume Method is used to solve conservative equations of mass and momentum and energy equations. SST K-omega model was considered for modeling the turbulence in helical passage heat exchanger.Analytical model can be used as tool to rapidly scope and optimize new heat exchanger designs within a now determined level of accuracy (as compared with a detailed 3D CFD model)

Maximum outlet temperature and pressure drop difference between 3D CFD 1-D analytical results was determined for several HEX concepts. For a straight annular heat exchanger with range of inlet mass flow rates corresponding to 0.01kg/s and 1kg/s for hot and cold fluid respectively, CFD predicted maximum pressure drop difference of +4.24% and outlet temperature is +0.58% as compared with 1-D model

For a helical heat exchanger is 27% and outlet temperature is -4.63%.By keeping channel length, hydraulic diameter and number of fins constant, results obtained for straight and helical fin heat exchangers are compared. Straight fin heat exchangers have 30% more volume and mass than helical heat exchangersHowever, the heat transfer rate is 56% higher than that of a straight ring heat exchanger and the pressure drop is also increased in a spiral fin heat exchanger.

The secondary current is visualized by illustrating the flows in different planes along the length of the heat exchanger.

Geometric compaction is determined by calculating the surface density of the heat exchanger and it is greater than 400 m2/m3.

This concept can be applied in the design of heat exchangers for aerospace and automotive applications with different fluids. Future work will include structural analysis and experimental studies of the proposed compact heat exchanger design.

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