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HEAT TRANSFER ENHANCEMENT IN SPIRAL PLATE HEAT EXCHANGER USING NANOFLUIDS

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Abstract: A possible way to enhance the rate of heat transfer in a spiral plate heat exchanger is by employing nanofluids as their working medium. Hence, in the present work, effects of nanofluids on the thermal performance of spiral plate heat exchanger has been investigated numerically and validated with experimental work. First, a counter-current spiral plate heat exchanger is designed and modeled. Later, simulation of spiral plate heat exchanger has been carried out by employing conventional fluid water-water, *TiO_2-water, and SiO_2-water* to investigate the heat transfer rates. Finally, the performance of the spiral plate heat exchanger using nanofluid is compared with that of using water and nanofluids. The results reveal that approximately 20 to 25% heat transfer augmentation with nanofluids of 3% overall volume concentration. It is observed that the use of nanofluids improves the thermal performance of spiral heat exchangers.

***Index Terms* – Spiral plate Heat Exchanger, CFD Analysis, Nanofluids.**

I. INTRODUCTION

A heat exchanger is a device used to exchange or transfer heat between two or multiple fluids i.e., liquids, vapors, or gases of various temperatures. Depending on the type of heat exchanger employed, the heat transferring process can be fluids of the same phase or different phases i.e., 2-phase fluids, and occur through a solid separator, which prevents mixing of the fluids, or direct fluid contact. They are widely used in space heating applications, refrigeration, HVAC, thermal power stations, chemical processing, petrochemical plants, waste heat treatment, natural-gas processing, and slurry and sludge treatment processes, etc.

In heat exchangers, there are several types of components employed and a wide range of materials are used in their fabrication. While coming to a selection of appropriate components and materials, it depends upon the type of heat exchanger and its application. As discussed in earlier sections, the most common components used in heat exchangers are fins, drums or wheels, shells, tubes, plates and spiral coils, etc. The desirable property to fabricate the components in the heat exchanger is high thermal conductivity. So, the materials used in constructing heat exchangers should have high thermal conductivity. Metals such as copper, brass, aluminum, titanium and stainless steel, etc. Other materials such as graphite, composites, ceramics, etc., which can withstand high temperatures are also used.

Classification of heat exchangers based on their construction are:

- Recuperative vs. Regenerative
- Direct vs. Indirect
- Static vs. Dynamic
- Types of components and materials used

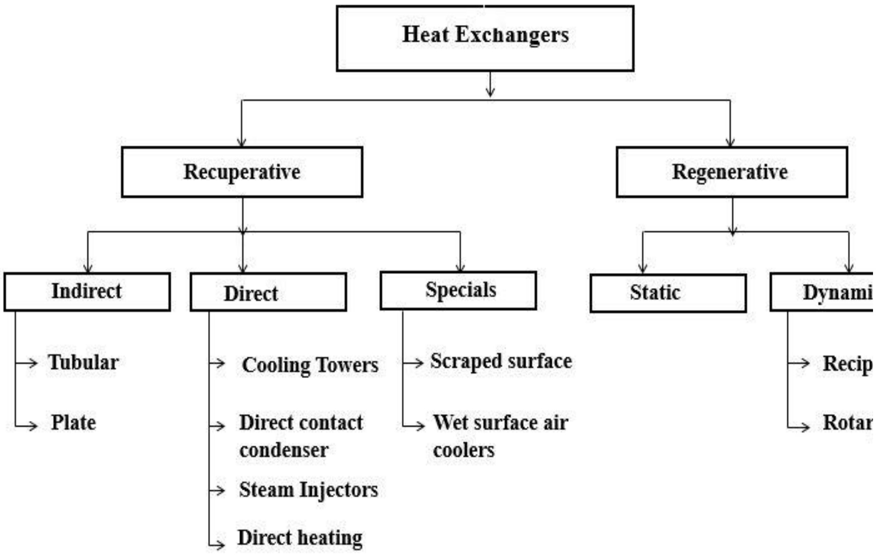

Figure 1. Classification based on the Construction method

The spiral plate heat exchangers are made by rolling two long metallic plates around a center rod to form two coaxial spiral flow channels were one for each fluid. The plate edges are closed completely by welding such that each fluid stays in its channel and there are no intermixing or flow diversions. Here, in this heat exchanger thermally conducting component is a metallic plate that serves as a separator to the two fluids and facilitates the heat exchange through it. Based on certain factors such as specified duty, the maximum amount of heat transfer, and ease of access, geometric attributes like spiral plate width and channel spacing (the gap between plates) are optimized. In some variants of the spiral plate heat exchanger, the plate gap is maintained by welded spacer studs and some designs do not employ them.

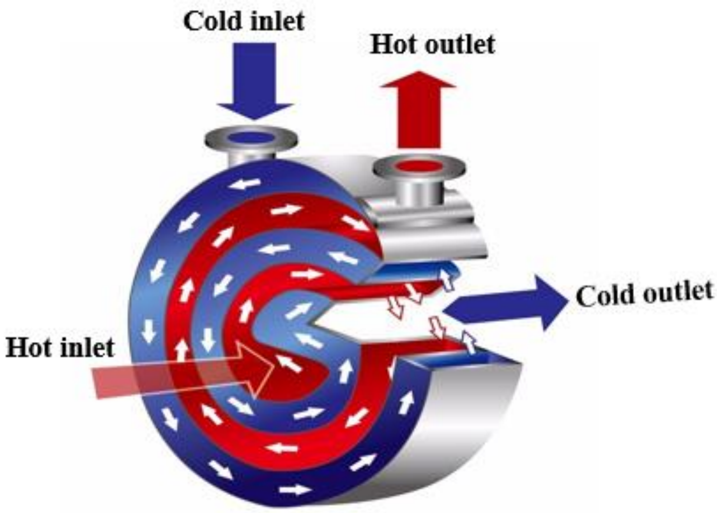

Figure 2. Spiral plate heat exchanger

As shown in figure 1, the spiral plate heat exchangers are circular units containing two concentric or coaxial spiral flow channels where each channel is for its respective fluid. One fluid enters the center of the heat exchanger and flows towards the periphery. While the other fluid enters at the periphery and moves towards the center of the unit, which results in true counter-current flow. Both the channels are curved and have a uniform rectangular cross-section.

A heat exchanger having a surface area density greater than above $700m^2/m^3$ for a liquid or gas is arbitrarily referred to as a compact heat exchanger. Some examples are vehicular heat exchangers, Condensers and evaporators in air-conditioning and refrigeration industry, aircraft oil coolers, automotive radiators, etc. Compact heat exchangers are of two types: Spiral and Plate type heat exchangers. A combination of both these types of heat exchangers is Spiral plate heat exchanger which was first proposed by Boothroyd [1] is made by rolling two long metal plates around a central core to form two concentric spiral flow passages, one for each fluid.

When coming to thermal analysis of this Spiral heat exchanger, TH. Bes and W. Roetzel [2] developed an analytical method by assuming constant overall heat transfer coefficients and heat capacities for the accurate calculation of the temperature changes in counter-current flow Spiral Heat Exchangers. They also investigated the influence of various geometrical parameters. Also, the same researchers [3] proposed a new dimensionless Criterion number CN evaluate the thermal performance of this heat exchanger and a simple formula is developed to calculate the mean temperature difference correction factor F of a spiral plate heat exchanger.

An experimental investigation was carried out by Kaliannan Saravanan and Rangasamy Rajavel [4] on the convective heat transfer coefficients of the spiral plate heat exchanger when electrolytes were used. The experiments were carried out by making the mass flow rate of hot fluid constant and varying the mass flow rate, temperature, and pressure of the cold fluid. From, the obtained data, a new correlation for Nu is proposed. S. Ramachandran and P. Kalaichelvi et al.,[5] conducted experimental studies on a spiral plate heat exchanger with hot water as the service fluid and the two-phase system of water-palm oil in different mass fractions and flow rates at the cold process fluid. They formulated correlations based on quality(X), $\emptyset_L$ and L-M parameter which can be used for the prediction of two-phase heat transfer coefficients.

S. Sathiyan, M. Rangarajan, et al.,[6] experimentally analyzed the two-phase (immiscible liquids) system of nitrobenzene-water in different mass fractions and flow rates as a cold process fluid. They formulated a new correlation for determining Nusselt for two-phase flows. M.thirumarimurugan, T. Kannadasan, et al.,[7] done an experimental investigation on a solvent and solution. They have considered steam and water, steam and acetic acid solution, and varied the volume fraction of acetic acid. The effectiveness of heat exchangers and overall heat transfer coefficients are calculated and a general regression model was used for artificial neural network simulation using MATLAB.

Shopping Yang, Kohsuke Furukawa, et al., [8] derived a nonlinear model by investigating a small volume of the spiral heat exchanger. This model is based on the Bessel function. The results obtained demonstrated that the hot fluid and cold fluid outlet temperature distribution is following the heat exchange principle. R.W.Tapre, Jayant. P et al.,[9] researched various studies on spiral plate heat exchangers done by many scientists. They studied various effects of feed flowrate, coil diameter, pressure drop, etc. involved in the analysis of spiral plate heat exchangers.

To enhance the heat transfer rates and to reduce heat transfer time in heat exchangers we are going for passive methods like the addition of Nano-sized particles in conventional working fluids. Common coolants such as water, ethylene glycol, have the limitation of poor inherent thermal conductivity. Nanofluids are engineered suspensions of fine nanoparticles(d<100nm) in coolants. From previous investigations [10], these nanofluids have been found to possess enhanced thermophysical properties and rheological properties such as thermal conductivity, viscosity, and convective heat transfer coefficients when compared to conventional coolants.

II. CFD ANALYSIS

Computational fluid dynamics or CFD analysis is the most commonly used key analysis method in many engineering applications for generating numerical solutions for fluid flows with or without solid interaction. A typical CFD problem deals with fluid properties such as fluid flow velocities, mass flow rates, pressure, density, temperature, and their interaction concerning space and time coordinate systems.

With CFD analysis, we can understand the fluid flows and heat transfer involving throughout our required designed unit. The basic methodology involved in CFD analysis is as follows:

- Understanding the flow model – Flow separations, transient conditions, physical and surrounding interactions
- Validation proof of assumed model – Experimental and numerical results validation, physical model simulations, parametric studies
- Optimization of the physical model – Reducing the fluid properties like pressure drops, shifting laminar to turbulent and vice-verse

In this work, we considered the SPHE Type 1 which has the most versatile feature i.e., the flow of the fluids in this type is pure counter-current. It is the best choice for handling both the fouling fluids containing solids, fibres, slurries, and sludges. It serves as Preheater and also in waste heat recovery applications.

As mentioned earlier, SPHE has two inlets and two outlets for both hot and cold fluids. In this model, the hot fluid which is pure water enters from the periphery and exits from the centre of the unit, whereas cold fluid which is water or nanofluid enters from the centre of the heat exchanger and exits from its periphery. This domiciliates pure counter-current flow in the heat exchanger.

2.1 Mesh Topology

The Spiral plate heat exchanger has been divided into 3 bodies where two bodies for fluid (hot and cold fluid domains) and the other for solid (channel plate). The figure shows the mesh domain of SPHE done in ICEM for better quality. A mesh convergence test has been carried out by varying the number of elements in any one of the 3 bodies with their corresponding operating parameter as represented in the figure. An optimum number of nodes and number of elements in the mesh as 3,28,670 and 13,70,044 respectively was obtained. After generating the mesh, maximum cell equi-volume skewness of 0.7529 and maximum orthogonal quality of 0.6351 have been obtained.

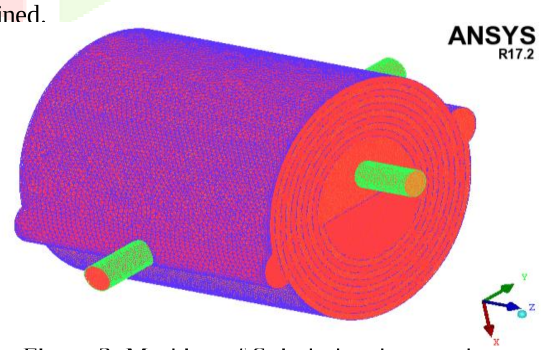

Figure 3. Meshing of Spiral plate heat exchanger in ICEM CFD

2.2 Boundary Conditions

At both inlets of the spiral plate heat exchanger, uniform temperature and uniform velocity are applied.

At the inlets: $v = v_o$, $T = T_o$

Furthermore, zero relative pressure is applied at the two outlets of the heat exchanger

At the outlets: $P_{gauge} = 0$

The outer wall of the spiral plate heat exchanger is insulated. No slip condition is employed at all walls of the heat exchanger.

III. RESULTS AND DISCUSSIONS

The performance parameters of a counter current spiral heat exchanger working with water and different nanofluids are evaluated and compared in this analysis. Initially, water is taken on both sides to evaluate the effectiveness. The simulations used an inlet temperature of 333 K for hot fluid and 298 K for cold fluid, with Reynolds numbers ranging from 25 000 to 65 000.

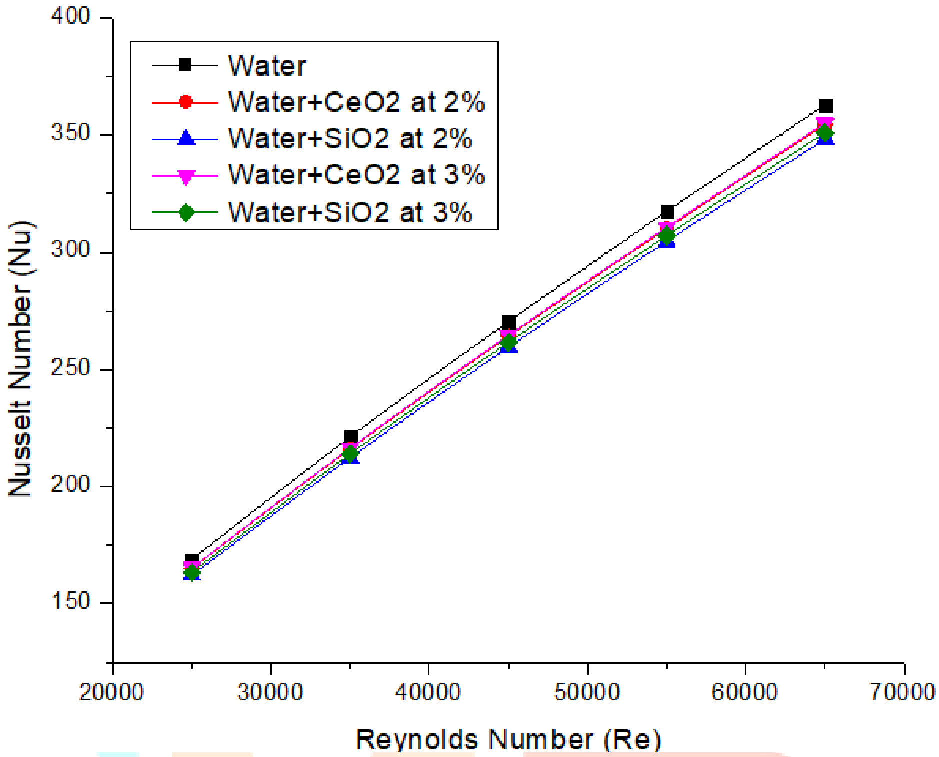

Figure 4. Variation of Nusselt Number with Reynolds Number

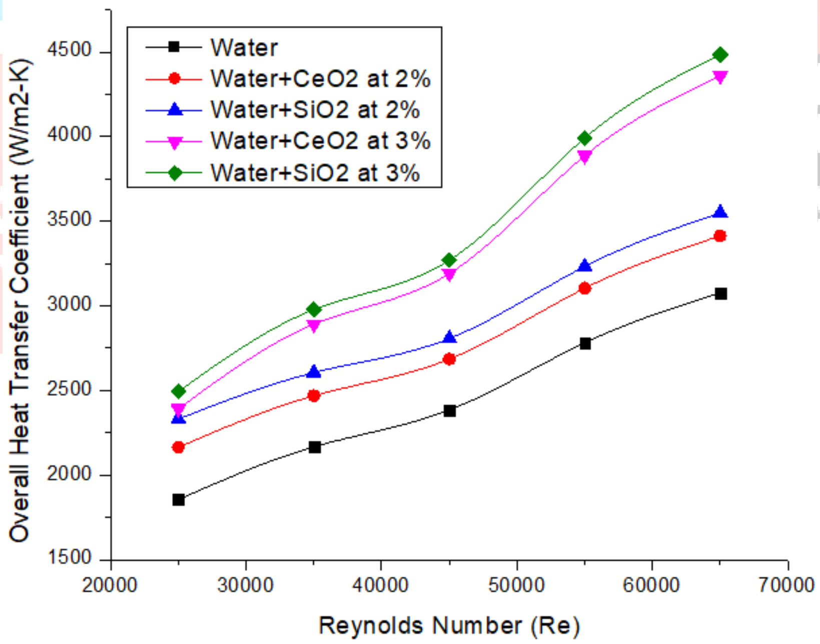

Figure 5. Variation of Overall heat transfer coefficient with Reynolds Number

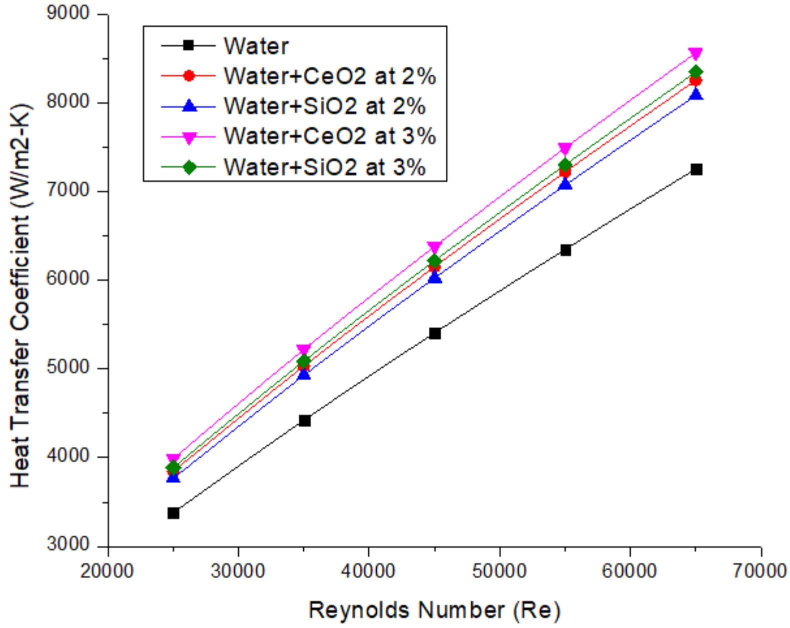

Figure 6. Variation of heat transfer coefficient with Reynolds Number

Figure 4 demonstrates how the Nusselt number varies with Reynolds number for several nanofluids (2 & 3 percent volume fraction). When compared to pure water, all nanofluids have a considerable increase in convective heat transfer coefficient. For all Reynolds number values, SiO_2-water has the greatest improvement in heat transfer rate. The greater thermal characteristics of SiO_2 nanoparticles, when compared to other nanoparticles employed in the study, account for the maximum heat transfer for SiO2-water. Secondly increase in volume concentration also results in a higher heat transfer coefficient for all the Reynolds numbers. An increase in Reynolds number results in the increased value of heat transfer rate.

Figure 5 shows the variation of the overall heat transfer coefficient for the various nanofluids and compared with water. Enhancement in convective heat transfer coefficient is noted with nanofluids. The increased convective heat transfer coefficient (Figure 5) is owing to the synergistic influence of nanocomposites on the base fluid's density and viscosity. SiO_2-water nanofluid has the largest convective heat transfer coefficient, whereas CeO_2-water nanofluid has the lowest convective heat transfer coefficient. The main causes are its high thermal conductivity and faster heat transfer rates. The rise in Reynolds number from 25 000 to 65 000 is equivalent to the increase in Nusselt number of cold fluids.

IV. CONCLUSIONS

The simulation study of spiral heat exchanger with CeO_2-water, SiO_2-water nanofluid is performed in the present investigation to assess the thermal and flow dynamics inside the spiral heat exchanger. After evaluating the various data obtained from the simulations, the following conclusion has been made-

1. The convective heat transfer is improved with the incorporation of nanofluids in the spiral heat exchanger. SiO_2-water nanofluid shows the highest increase while CeO_2-water shows the least enhancement for a given Reynolds number.

2. Increase in the volume fraction of the nanoparticles in the base fluid also results in a higher heat transfer coefficient for all the considered nanofluids with the highest enhancement with SiO_2-water.

3. The higher thermal conductivity of SiO_2 nanoparticle result in a higher Nusselt number.

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