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Research Article

Convective Heat Transfer Enhancement of Fe_3O_4-Water Nanofluid under the effect of External Magnetic Field and Twisted Tape Insert

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Abstract

Convective heat transfer of water based ferrofluid flowing through a pipe was analyzed. Effect of externally applied magnetic field and twisted tape insert on convective heat transfer of water based ferrofluid flowing through a pipe was studied and examined. Working fluid is Fe_3O_4-Water. Ansys 2019 was used for simulation and analysis. Double pipe heat exchanger arrangement was modeled. Tube was modeled with consideration of, inner diameter of tube, di = 25mm and outer diameter of tube, do = 35 mm. Length of the tube was considered, L= 700 mm. Twisted tape of 5mm thickness and width of 10mm and 20mm was modelled. Meshing was done with the help of ICEM CFD and hooked up with Fluent 2019. Magnetic field was applied with the help MHD module in the fluent add on-model. External magnetic field intensity ranges from B=0-500 G. Reynolds number range of 250-800 was studied to understand its effect on heat transfer augmentation. The convective heat transfer was analyzed under both the condition, that are under the effect of with and without magnetic field. It was observed that ferrofluid responds to externally applied magnetic field. Under the application of constant magnetic field, heat transfer rate was observed to get increased by 12-14 % for without twisted tape arrangement and 18.7-21.4 % for with twisted tape arrangement for all Reynolds number range. This is because the under constant magnetic field application, dipoles of ferrofluid gets aligned in a same direction as that of direction of externally applied magnetic field, which leads transfer of heat at a faster rate as compared to the condition when dipoles are not aligned in a same direction, during the absence of magnetic field. Also due to twisted tape arrangement flow recirculation occurs. Significant improvement in heat transfer rate occurs due to disruption of velocity boundary layer, thermal boundary layer and increased flow mixing due to twisted tape

Keywords: *Ferrofluid, Convective Heat transfer, External Magnetic field, Twisted Tape*

Introduction

Ferrofluid are colloidal liquids made of nanoscale ferromagnetic, or ferrimagnetic, particles suspended in a carrier fluid (usually an organic solvent or water). Its important property is, though it is liquid still responds to externally applied magnetic field and become highly magnetic in the presence of same. Every nano particle is coated with a surfactant to restrain clustering. In the absence of an externally applied field, ferrofluid usually do not retain magnetization. In the absence of external magnetic field, magnetic dipoles of ferrofluid remains randomly oriented, but when magnetic field will be applied externally on ferrofluid, its magnetic dipole gets oriented in a same direction as that of externally applied magnetic field. It indicates that ferrofluid responds to externally applied magnetic field. Due to this property, use of ferrofluid is widened in many applications like convective heat transfer, electronic cooling, seal, lubricant and damping. By applying external magnetic field ferrofluid's thermophysical properties can be controlled, which will enhance the convective heat transfer rate and thus performance of equipment, using ferrofluid as a working medium.

Aursand *et al*. (2016) investigated use of thermomagnetically pumped ferrofluid to enhance performance of natural convection cooling system. Experimentation results revealed thermomagnetic driving force is significant compared to natural convection in single phase. Bozhko *et al*. (2004) investigated the interplay of buoyancy and thermo-magnetic convection mechanisms in a horizontal fluid layer heated from one wide side and cooled from another in the presence of external uniform transversal magnetic field. Influence of gravitational settling of magnetic particles and their aggregates on heat transfer and convection instability was studied.

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Chaudhary *et al*. (2012) investigated self-pumping magnetic cooling effect so as to eliminate use of mechanical pump to circulate working fluid. Gavili *et al*. (2012) carried experimental investigation on thermal conductivity of ferrofluid under the influence of magnetic field. Experimental results indicated that thermal conductivity of ferrofluid is a function of intensity of magnetic field. Ghasemian *et al*. (2015) numerically studied laminar forced convection heat transfer of water based ferrofluid in a mini channel in the presence of constant and alternating magnetic fields The heat transfer enhancement due to the magnetic field was more significant at lower Reynolds numbers. Goharkhah *et al*. (2014) investigated numerically, forced convective heat transfer of water based Fe3O4 nanofluid (ferrofluid) in the presence of an alternating non-uniform magnetic field. Experimental results, as compared with zero magnetic field case, showed that the heat transfer enhancement increases with the Reynolds number. Goharkhah *et al*. [2015] experimentally investigated the effects of constant and alternating magnetic field on the laminar forced convective heat transfer of ferrofluid in a heated tube. Results indicated that in the absence of a magnetic field, ferrofluid improves convective heat transfer as compared to DI- water. Goharkhah *et al*. (2016) experimentally investigated laminar forced convective heat transfer of ferrofluid under the effect of external magnetic field. It was observed that the convective heat transfer has a direct relation with the Reynolds number and ferrofluid concentration. Jafari *et al*. (2008) studied heat transfer phenomena in a kerosene based ferrofluid. The flow behavior was investigated. When magnetic field is perpendicular to the temperature gradient, the heat transfer will increase more compared to the case with magnetic field parallel to temperature gradient. Krichler *et al*.(2013) proposed two methods to calculate thermal conductivity of ferrofluid, hot wire technique and hot plate technique. In hot wire technique, line heat source is used. In hot plate technique, plane heat source is used. Hot wire technique is mainly used for liquid specimen and hot plate technique for solid specimen. Lajvardi *et al*. (2016) investigated experimentally convective heat transfer of ferrofluid flowing through a heated copper tube in the presence of magnetic field. Effect of various orders of magnetic field, concentration of magnetic nanoparticles and magnet position on heat transfer enhancement was investigated. Li *et al*. (2009) investigated experimentally convective heat transfer features of the aqueous magnetic fluid flow under the influence of an external magnetic field. The experimental results showed that the external magnetic field is a vital factor that affects the convective heat transfer performances of the magnetic fluids and the control of heat transfer processes of a magnetic fluid flow is possible by applying an external magnetic field. Mohammadi *et al*. (2016) carried experimental investigation on four-turn pulsating heat pipe (PHP)At higher charging ratio, better thermal performance was obtained in the presence of magnetic field. Mojumder *et al*.(2016) numerically analyzed magneto-hydrodynamic convection in a half-moon shaped cavity filled with ferrofluid. Numerical simulation was carried out for a wide range of Rayleigh number It was observed that increment of magnetic field reduces the heat transfer rate, whereas increment of heater distance augments the heat transfer rate significantly. Mehrali *et al*. (2016) proposed ecofriendly approach to generate a graphene-based nanofluid. A novel mode of graphene oxide reduction through functionalization with polyphenol extracted from red wine was introduced. Present study indicated that, red wine can be prosperously utilized to prepare W-r GO nanofluid. Sheikholeslami *et al*.(2016) analyzed ferrofluid convective heat transfer in a sinusoidal cold wall cavity under the effect of external magnetic field. Impact of magnetic field on hydrothermal behavior of nanofluid in a cavity with sinusoidal cold wall was investigated. Sundar *et al*. (2013) carried experimental investigation on effective thermal conductivity and viscosity of ferrofluid. It was observed that thermal conductivity and viscosity of nanofluid, both are function of particle volume concentration and temperature. Xuan *et al*.(2011) investigated thermomagnetic convection over natural convection for electronic cooling application. It was observed thermomagnetic convection strongly depends upon temperature difference. At higher temperature difference, thermomagnetic convection effect is remarkably higher.

Methodology

Ansys 2019 was used for simulation and analysis. Double pipe heat exchanger arrangement was modeled as shown in Fig. 1. Tube was modeled with consideration of, inner diameter of tube, d_i = 25mm and outer diameter of tube, d_o = 35mm. Length of the tube is L= 700 mm. Hot ferrofluid flows through inner pipe while cold water flows through outer pipe. This arrangement was made in fluent. Magnetic Field was applied with the help MHD module in the Fluent Addon-Model. The local convective heat transfer was observed for both, with and without magnetic field condition. The effect of constant magnetic field on convective heat transfer for water based magnetic nanoparticles *(Fe_3O_4)* was studied. Reynolds number range of 250-800 was studied to understand the effect on heat transfer augmentation. External magnetic field intensity was varied in a range of B=0-500 G.

In this model, a double pipe heat exchanger with Fe_3O_4 /water nanoofluid under magnetic field was proposed. For this analysis, a steady model was developed in order to obtain boundary conditions for the CFD model. A CFD simulation was employed to analyze the proposed heat exchanger with counter flow and twisted tape model. A 3D steady state turbulent k–ε RNG model (with around 35 million of elements) along with standard wall functions and SIMPLE solution algorithm are used to simulate the heat transfer in the heat exchanger. The second order upwind differencing scheme is used for momentum and energy equations. The convergence limits are set to be equal to 10−3 for momentum and mass and 10−6 for energy equations. Velocity (varies for hot and cold fluids) and zero pressure is considered for inlet and outlet boundary conditions for both cold and hot fluids. In addition, inlet and outlet temperature for both hot and cold fluid were defined, according to transient model outputs.

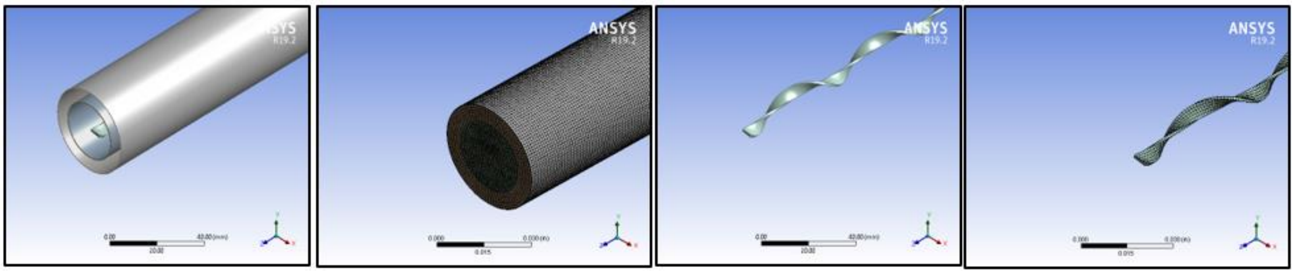

Figure 1. Model of counter flow heat exchanger with twisted tape arrangement

Following are considerations

- The heat exchanger piping were considered as perfectly isolated.
- The fluid was in Eulerian phase model DPM.
- The properties of the fluids were considered uniform within a cross-section of the exchanger.
- Conduction of heat in the radial direction within the wall of the tubes was fast enough to ensure that the inner and outer walls of the inner tube are always at the same temperature.
- The fluid flows in counter flow direction.
- The potential energy variation of fluids was negligible.

Result and Discussion

Effect of magnetic field on the convective heat transfer of ferrofluid was analysed. Optimum range of temperature was from 298K and 328K and that for magnetic field was B=0-500G (B=0.00-0.5T). The results demonstrated that increasing the mass flow rate of secondary fluid (water and Fe3O4/water Nano fluid) decreased the value of hot fluid temperature. CFD simulation for the double pipe heat exchanger has shown that the magnetic field has the minimum effect on the water flow specifications. In addition, using ferrofluid (Fe_3O_4/water Nano fluid under magnetic field) as the secondary fluid in the heat exchanger increased the outlet temperature comparing to the Variation in the temperature of ferrofluid in the presence and absence of magnetic field was observed as shown in Fig.2 and Fig.3. In Fig 2, temperature contour of ferrofluid under the application of magnetic field intensity of B=0.5 Tesla was plotted. In Fig 3, temperature contour of ferrofluid without the application of magnetic field intensity of B=0.5 Tesla was plotted. Enhanced heat transfer was observed when external magnetic field was applied. The heat transfer augmentation increases with the application of constant magnetic field without any pumping power. This is because, under the constant magnetic field application, dipoles of ferrofluid gets aligned in a same direction as that of direction of externally applied magnetic field, which leads transfer of heat at a faster rate as compared to the condition when dipoles are not aligned in a same direction, during the absence of magnetic field.

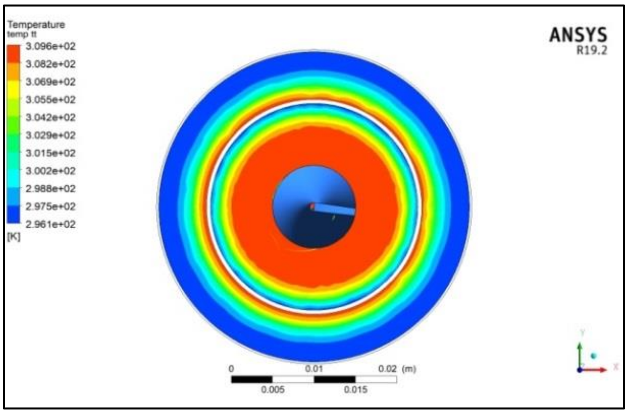

Figure 2. Temperature contour of ferrofluid with application of magnetic field, B=0.5 Tesla

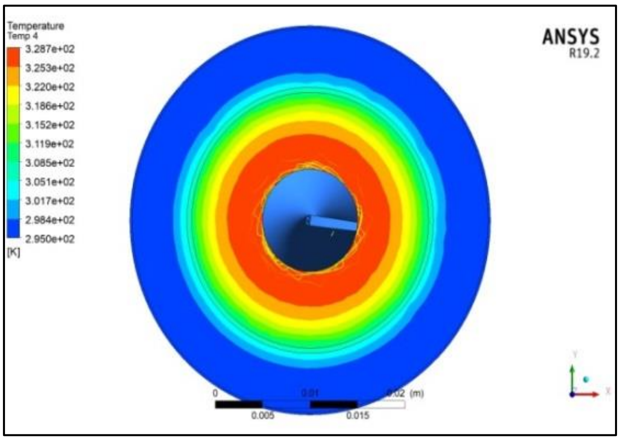

Figure 3. Temperature contour of ferrofluid without application of Magnetic field

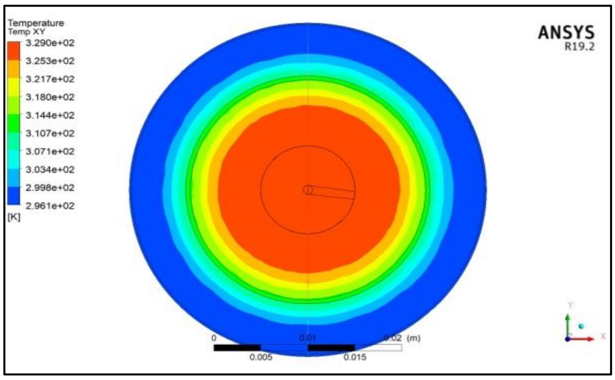

Figure 4. Temperature contours of ferrofluid in XY plane with application of magnetic field of B=0.5Tesla with twisted tape arrangement

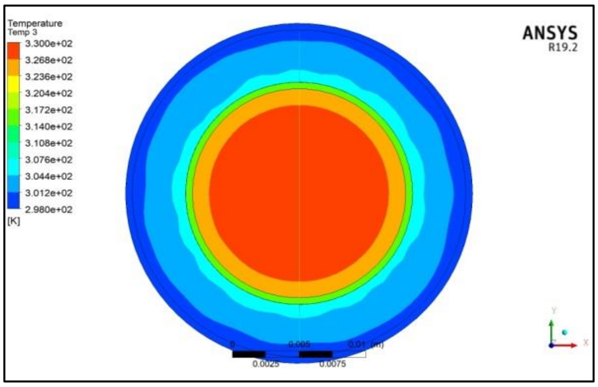

Figure 5. Temperature contours of ferrofluid in XY plane with application of magnetic field of B=0.5 Tesla without twisted tape arrangement.

Ferrofluid heat transfer results for twisted tape arrangement in the presence of magnetic field were plotted as shown in Fig 4 and Fig. 5. Fig. 4 indicates the temperature contour plot of ferrofluid with application of magnetic field of B=0.5Tesla with twisted tape arrangement. Fig. 5 indicates the temperature contour plot of ferrofluid with application of magnetic field of B=0.5Tesla without twisted tape arrangement. It was observed that with the twisted tape arrangement heat transfer rate was found to be more enhanced than the no twisted tape arrangement. This is because flow recirculation occurs around twisted tape and nearby inner wall of inner pipe. Due to twisted tape arrangement, velocity boundary layer and thermal boundary layer breaks near twisted tape surface which leads to effective flow recirculation and thus effective flow mixing, which further enhances the heat transfer rate.

Fig. 6 indicates the effect of magnetic field on heat transfer rate for different Reynolds number for twisted tape arrangement. From fig.6 it can be observed that as magnetic field intensity increases, convective heat transfer rate also increases. This is because, under the constant magnetic field application, dipoles of ferrofluid gets aligned in a same direction as that of direction of externally applied magnetic field, which leads transfer of heat at a faster rate as compared to the condition when dipoles are not aligned in a same direction, during the absence of magnetic field. Also it can be observed that as Reynolds number increases, convective heat transfer rate also increases. But for a same Reynolds number, due to twisted tape insert, heat transfer rate decreases as velocity decreases in the absence of externally applied magnetic field.

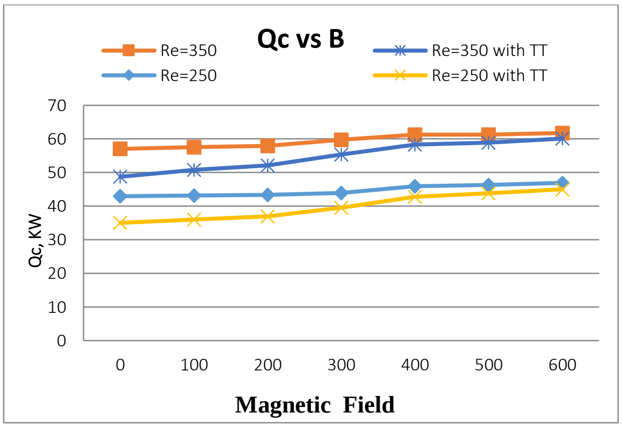

Figure 6. Effect of magnetic field on heat transfer rate for different Reynolds number for twisted tape arrangement

Conclusion

- Ferrofluid responds to externally applied magnetic field. It becomes magnetic in the presence of externally applied magnetic field.
- Under the application of constant magnetic field heat transfer rate increases as it leads to alignment of dipoles of ferrofluid in a same direction as that of direction of externally applied magnetic field forming a chain like structure, which increases thermal conductivity of a ferrofluid as compared to base fluid.
- Heat transfer rate also increases due to twisted tape arrangement as leads to disruption of velocity boundary layer, thermal boundary layer and increased flow mixing.
- Also it was observed that as Reynolds number increases, convective heat transfer rate also increases.
- But for a same Reynolds number, due to twisted tape insert, heat transfer rate decreases as velocity decreases in the absence of externally applied magnetic field.
- Therefore so as to get better heat transfer enhancement with twisted tape insert, external magnetic field should be applied for ferrofluid as a working medium. Under the application of constant magnetic field, heat transfer rate was observed to get increased by 12-14 % for without twisted tape arrangement and 18.7-21.4 % for with twisted tape arrangement for all Reynolds number range.

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