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Comparison of Heat Exchanger Performance Using Titanium Dioxide Nanoparticles in Cold Fluid Using Computational Analysis.

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ABSTRACT

In this computational fluid dynamics (CFD) research, the performance of a heat exchanger with and without Titanium dioxide nanoparticles used in cold fluid is examined. Water and both hot and cold fluids were used to create the standard arrangement for a counter-flow heat exchanger. Hot liquid is maintained at a constant temperature of 1700C using electric heaters. 300C is the intake temperature for cold liquids. The mass flow rate of the hot fluid is kept constant while examining four different mass flow rates for the cool fluid. The outlet temperatures of hot and cold fluids, as well as the rate of heat transfer, were monitored and estimated using computational fluid dynamics.

In this Computational fluid dynamics (CFD) study deals with Considering both fluids to be water when analyzing the output temperatures of the two. Analyze the outlet temperatures of the two fluids that contain a partial mixture of titanium dioxide nanoparticles in cold fluid at various mass flow rates &compare the findings from the two analyses.

Keywords: Nanofluids, Titanium dioxide, nanoparticles, Heat transfer, CFD.

I. INTRODUCTION

The size of nanoparticles, sometimes known as ultra-fine particles in the 1970s and 1980s, is typically less than 100 nm. When a material is thought of in bulk, its physical characteristics are almost constant, however this is not true in the case of nanoparticles. Numerous consumer products, including paints, cosmetics, and textiles, employ nanoparticles. To enhance the qualities of a base fluid, nanoparticles are added to water, ethylene glycol, and oil. Different heat transfer applications can make use of this nanofluid, which is a blend of nanoparticles and base fluid.

The implications of utilizing titanium oxide nanofluids in heat transfer applications are discussed in the chapter that follows. In comparison to basic liquids, titanium oxide nanofluids have improved thermal characteristics. They may replace basic liquids in many heat transfer systems, including automotive radiators, heat exchangers, and heat sinks, because to their superior heat transmission properties. Because of their potential for toxicity, these nanoparticles have a drawback.

II. LITERATURE REVIEW

In many heat transfer applications, including radiators, heat sinks, and heat exchangers, achieving efficient heat transfer is our primary concern. Technology advancement has raised the need for effective systems. In these applications, liquid is frequently employed as the cooling medium to remove heat from the system. In comparison to solids, liquids have weak heat conductivity. High thermal conductivity cooling medium should be employed to increase system efficiency. The addition of nanoparticles to base liquid is one of the techniques used in the quest to increase thermal conductivity. The use of nanofluids, a blend of base fluid and nanoparticles, demonstrated an improvement in heat transfer rate that is not attainable with basic liquids. TiO2 nanoparticles were utilized by several researchers in various heat transfer applications to study the outcomes. When titanium oxide nanoparticles were added to base fluid, the fluid's thermal conductivity improved.

N. Parthiban et al. (2022), In this experimental study deals about the comparison in between performance of heat exchanger with and without Silicon dioxide nano particle used in cold fluid. The common counter flow heat exchanger setup created with both hot and cold fluid as water. Hot fluid is maintained at the temperature of 170 _C by using electric heater. Cold fluid is in 30 _C as inlet temperature. There are individual temperature measuring thermocouples used in desired places of the experimental setup. There are four different mass flow rate considered for the cold fluid but the mass flow rate of hot fluid maintained as constant.[1]

Fei Wang et al. (2022) This paper investigated the thermal behaviors of energy storage process of eutectic hydrated salt phase change materials (EHS PCMs) modified by Nano-TiO2, including energy storage efficiency and energy storage density of the sample. The energy storage process of EHS PCMs with different mass fraction of Nano-TiO2 was divided into three stages – solid-solid stage, solid-liquid stage and liquid-liquid stage.[2]

Yixin Wang et al. (2020) As a hardware carrier for informatization development, data centers will generate huge heat flux density during operation. Liquid cooling technology is considered as a thermal management method to solve this problem. The development of heat transfer fluids is of paramount importance. In this experiment, TiO2 nanoparticles were successfully modified by supramolecular β-CD, and the corresponding nanofluids were prepared by using the modified nanoparticles. The experimental results show that the nanofluids can be stabilized for more than 50 days, and the average particle diameter of the nanoparticles can be maintained at 38.9 nm after 50 days. At 60 °C, the thermal conductivity of the 0.1 vol% nanofluids is increased by 36.01% compared with the base fluid, and the thermal diffusivity is increased by 58.28%.[3]

K h Hosseinzadeh et al. (2021) To tackle global warming, a reliable storage system seems crucial due to unpredictability of renewable energy. As a result, storage units based on Phase Change Material (PCM) are found to be of great worth where latent heat transfer occurring in an almost isothermal condition lay the foundation for far more compact and easy-to-fabricate storage components. Despite their advantageous, one major drawback being weak thermal conductivity needs to be addressed. So, in this study a triplex-tube heat exchanger with tree-like and rectangular fins along with hybrid nanoparticles made of MoS2-TiO2 are put into perspective to dispose of this weakness and Galerkin Finite Element Method (GFEM) is applied using FlexPDE to analyze the solidification process and evaluate the influence of single and combined usage of fins and nanoparticles.[4]

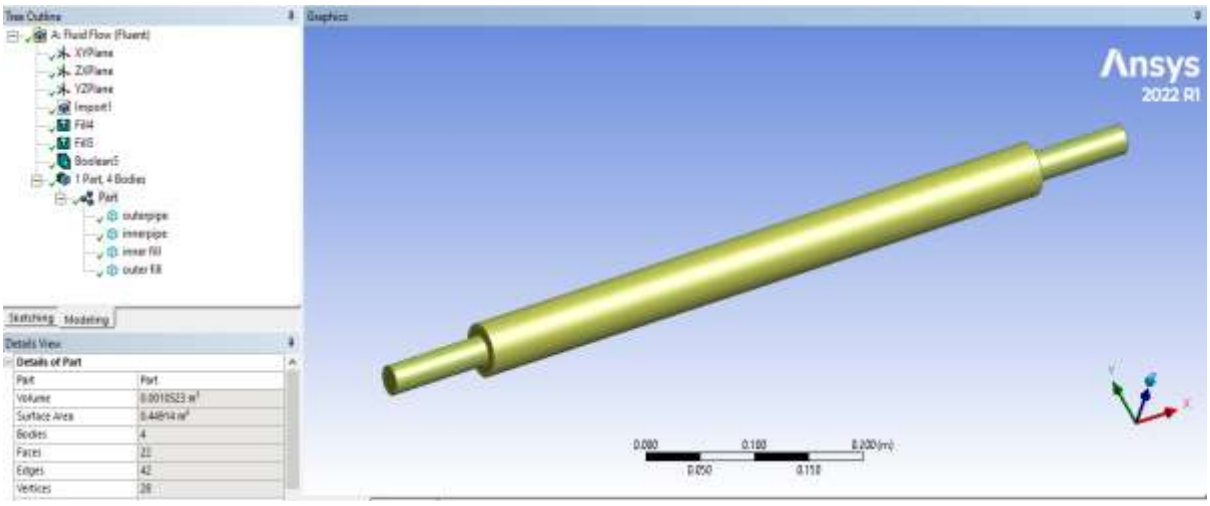
Bizhan Mehrvarz et al. (2019) In this paper, a three-phase distribution transformer is simulated three-dimensionally in order to study the heat transfer efficiency for pure oil (single phase) and nanofluid (TiO2 nanoparticles- transformer oil). For both models, the electromagnetic field in solid sections and heat transfer in fluid and solid sections of the transformer are simultaneously investigated. The simulation results show that the presence of TiO2 nanoparticles in the transformer oil increases the heat transfer coefficient.[5]

T.Salahuddin, Muhammad HabibUllah Khan, et al. (2021) The peristaltic transport of hybrid nanofluid (SiO2–TiO2/H2O) flow in a sinusoidal wavy channel under the heat generation effect is reported in present analysis. We have simplified two dimensional equations of hybrid nanofluid for peristaltic transport by using long wavelength ($\delta \ll 1$) and small Reynolds (Re) number assumptions. We also modeled temperature equation for hybrid nanofluid flow with the effect of heat generation.[6]

Md Imteaz Ahmed et al. (2022) TiO2 nanolubricant has been used in this experimental work to study the performance of domestic air conditioner. Air conditioner capacity was 1 ton and the original system has R22 refrigerant. Three alternate refrigerant blends-Blend 1 (B1) composed of R32 and R22 (75:25 wt%), Blend 2 (B2) composed of R32 and R600a (75:25 wt%) and R32 refrigerant have been used in this experimental work to compare the thermo-physical performance with R22.0.01% and 0.02% volume concentration TiO2 nanolubricant have been used.[7]

III. GEOMETRY SETUP AND MODELLING

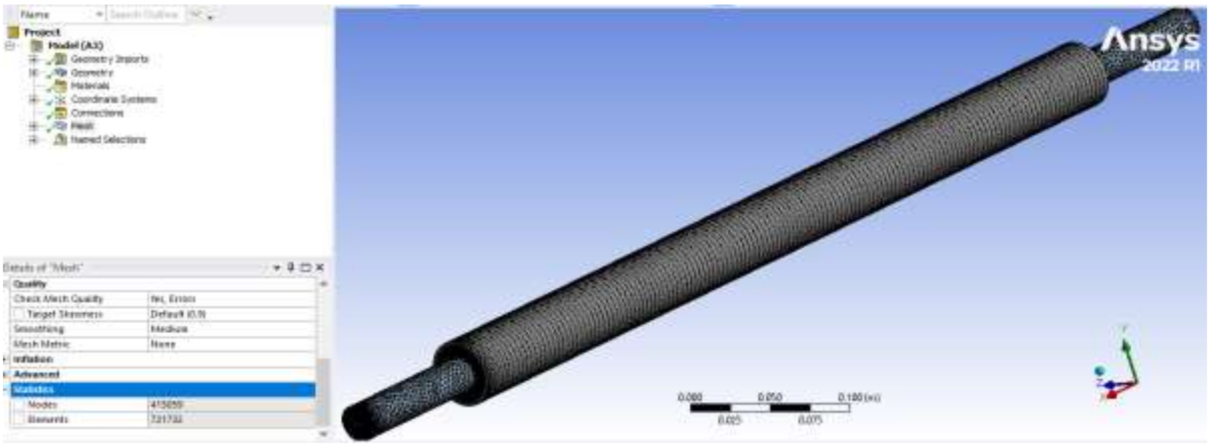
The experimental apparatus is shown schematically in Fig. 5.1; titanium oxide nanofluid is utilised in a cold fluid. In this experimental technique, heat is transmitted from water to titanium oxide nanofluid using a concentrictube heat exchanger. Fig. 5.2 depicts the heat exchanger's design. The heat exchanger's inner tube L measures 800 mm in length, whereas L1 is the measurement for the outer tube. The top tube's exterior and inner diameters are 20 mm and 25 mm, respectively. Its outside and inner diameters are also 40 mm and 45 mm, respectively.



Details of Part	
Part	Part
Volume	0.0010523 m³
Surface Area	0.44814 m²
Bodies	4
Faces	22
Edges	42
Vertices	28

Figure 1. Computational model of heat exchanger.

In the pre-processor phase of ANSYS FLUENT 22 R1, a three-dimensional discretized model was created. Although the grid types are linked to simulation results, the structure as a whole must be discrete in the final volume; the ANSYS software generates a coarse mesh. Mesh is made up of unit-size mixed cells with triangular frontier faces (ICEM Tetrahedral cells). In this investigation, a mesh metric with a medium fluid curvature is utilised.



Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.9)
Smoothing	Medium
Mesh Metric	None
Nodes	415059
Elements	721732

Figure 2. Meshing of heat exchanger.

Table 1. Meshing detail of model

S. No.	*Parameters*	
1	Curvature	On
2	Smooth	Medium
3	Number of nodes	415059
4	Number of elements	721732
5	Mesh metric	None
6	Inflation Option	Smooth Transition

The Fluent 22 R1 was used to calculate computationally. In research, the approach used to differentiate the governing equations was a finite element. A standard k-epsilon equation was used with flow and energy equations to solve turbulence.
Which implies the following hypotheses:

1) There is negligence of thermal radiation and normal convection;
2) The average of fluid and solid properties is calculated
3) Flow is incompressible;
4) Heat transfer steady state;
5) Transitional fluid flow and turbulent regimes, and
6) The fluid is distributed uniformly between the channels and the inlet channels have a uniform velocity profile.

The numerical simulation was with a 3-Dimensional steady state turbulent flow system. In order to solve the problem, governing equations for the flow and conjugate transfer of heat were customized according to the conditions of the simulation setup.

Table 2. Thermodynamic Properties of Titanium dioxide & water

Input Parameters	**Symbols**	**Units**	**Water**	**TiO2**
Specific heat capacity	cp	J/kg-K	4182	686.2
Density	ρ	(kg/m3)	998.2	4250
Thermal conductivity	k	W/m-K	0.6	8.593

Table 3. Thermodynamic Properties of TiO2 nanoparticles with 1 wt % of 20 nm TiO2.

Input Parameters	**Symbols**	**Units**	**1 wt % of 20 nm TiO2**
Specific heat capacity	cp	J/kg-K	4034.86
Density	ρ	(kg/m3)	1029.62
Thermal conductivity	k	W/m-K	1.0333
Viscosity	v	Kg/ms	0.00284

The discrete flow domain has been defined under sufficient limits. Inlets were allocated the mass flow rate requirements, while pressure outlet limits were allocated for outlets. The surfaces of the heat exchanger is regarded as normal wall limits. The interior walls were fitted with couplings of thermal walls.

Table 4. Details of boundary conditions.

Detail	***Value***
Hot fluid (water) flow rate	*.05 kg/s*
Cold fluid (with nano particals) flow rate	*0.05 kg/s, 0.10 kg/s, 0.15 kg/s, 0.2 kg/s*
Hot fluid inlet temperature	*170 °C*
Cold fluid inlet temperature	*30 °C*
Outer surfaces (Adiabatic wall)	*Heat flux=0*

IV. RESULTS AND DISCUSSIONS

Utilizing nanofluids, this part aims to assess the heat exchanger's thermal performance. To investigate the effectiveness of the heat exchanger employing flowable nanofluids, the fluctuations in temperature range and thermal conductance are studied at various mass flow rates.

4.1. Data Reduction Equations

The values of Nusselt number, and Heat transfer coefficient calculated from the CFD modeling On the basis of temperature of hot and cold fluid obtained were compared with the values obtained from the analysis performed by **Hu Chen et al. (2020)**.

The data reduction of the measured results is summarized in the following procedures:

The Reynolds number is given by,

$$Re = \frac{\rho V D}{\mu}$$

The mass flow rate is calculate on the basis of below formula,

$$\dot{m} = \dot{}\rho A V$$

Where, ρ is the density of fluid, A is the cross sectional area of the pipe and V is the velocity of fluid.

Therefore, for fluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid in the outer tube can be expressed as:

$$q_h = \dot{m}_h c_{ph}(T_{hi} - T_{ho})$$

Where $\dot{m}_h$ is the mass flow rate of hot fluid, c_{ph} is the specific heat of hot fluid, T_{hi} and T_{ho} are the inlet and outlet temperatures of hot fluid, respectively.

While, the heat transfer rate of the cold fluid in the inner tube can be expressed as:

$$q_c = \dot{m}_c c_{pc}(T_{co} - T_{ci})$$

Average heat transfer rate is given by:

$$Q_{avg} = \frac{q_h + q_c}{2} = UA\theta_m$$

Where, $\theta_m = \frac{\theta_1 - \theta_2}{2}$

θ_m is the logarithmic mean temperature difference.

U is the overall heat transfer coefficient.

4.2. Validation of Numerical Computations

To validate the accuracy of developed numerical approach, comparison was made with the work reported in **N. Parthiban. (2020)**. The heat exchanger geometry that used for validation of numerical computations was considered as same as the geometry shown in Fig. 5.2.

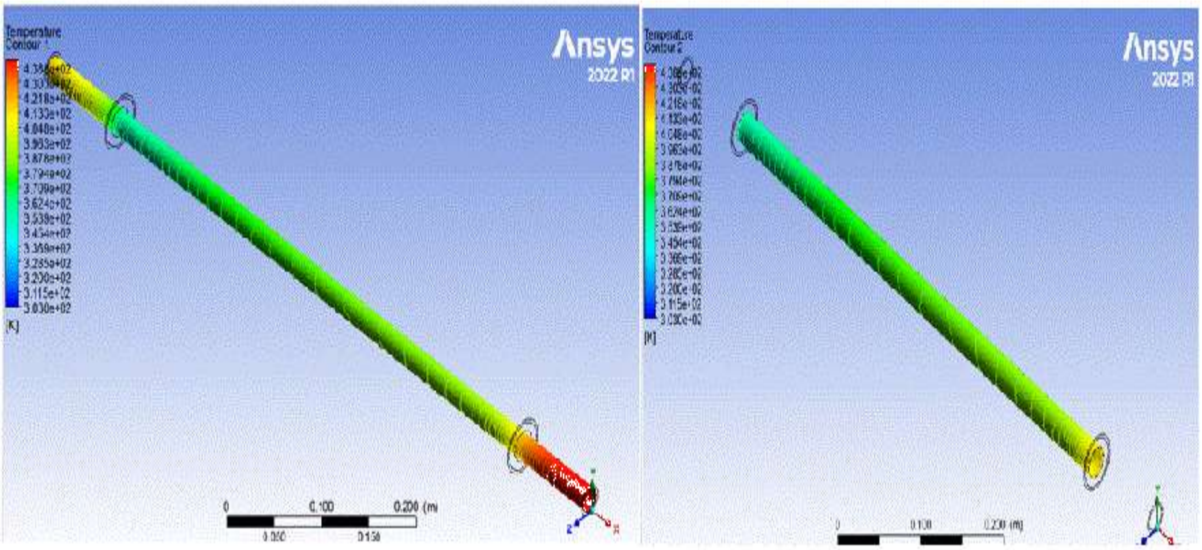


Figure 3. Temperature contour at 0.05 kg/s mass flow rate for heat exchanger using titanium dioxide nanofluid in a cold fluid.

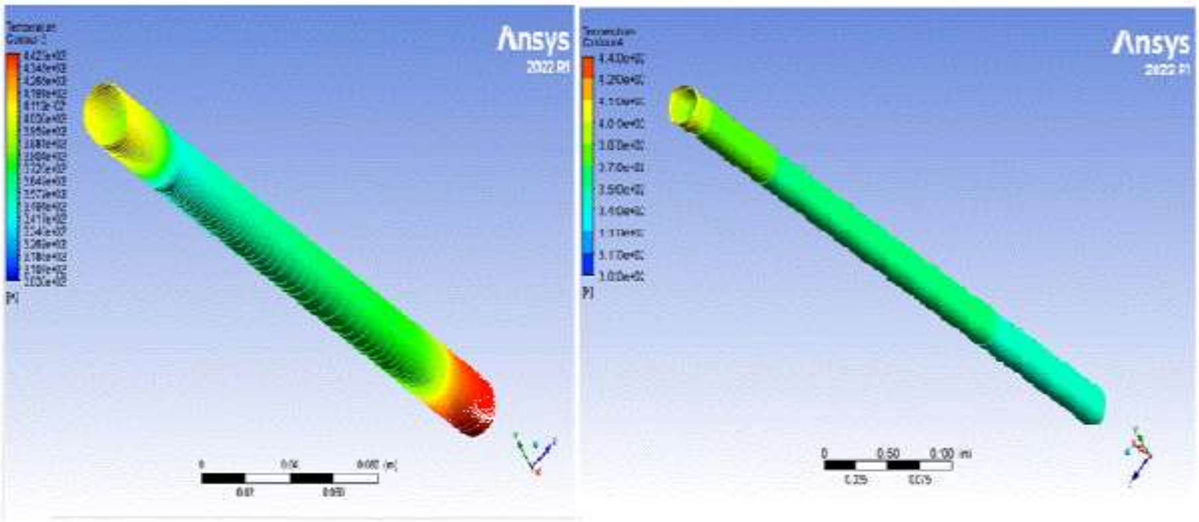


Figure 4. Temperature contour at 0.10 kg/s mass flow rate for heat exchanger using titanium dioxide nanofluid in a cold fluid

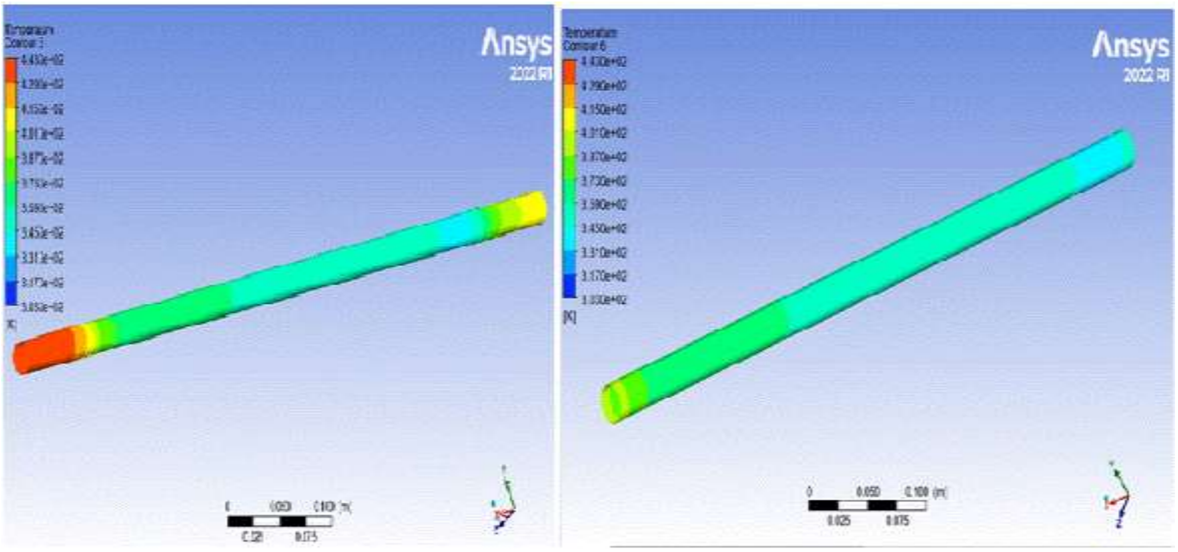


Figure 5. Temperature contour at 0.15 kg/s mass flow rate for heat exchanger using titanium dioxide nanofluid in a cold fluid.

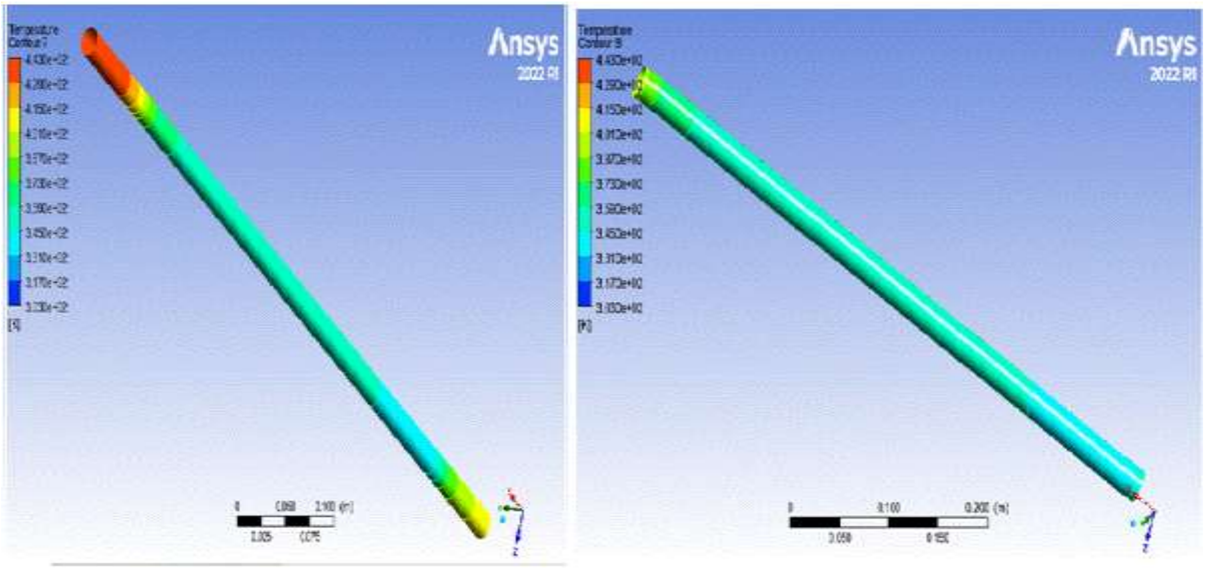
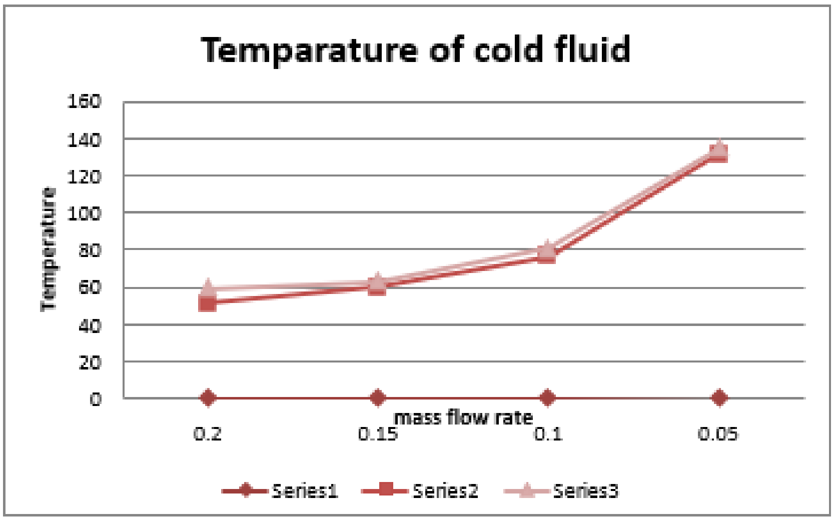


Figure 6. Temperature contour at 0.20 kg/s mass flow rate for heat exchanger using titanium dioxide nanofluid in a cold fluid.

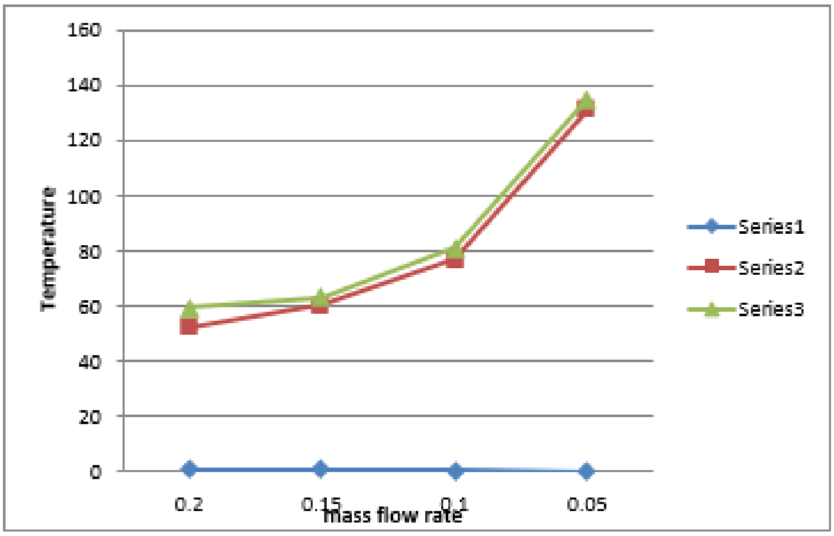


Series 1 – different mass flow rate

Series 2- outlet temperature of cold fluid with nano particle

Series 3- outlet temperature of cold fluid without nano particle

Figure 7. Values of cold fluid temperature from the CFD modeling compared with the values of with or without nanoparticle temperature



Series 1 – different mass flow rate

Series 2- outlet temperature of hot fluid with nano particle

Series 3- outlet temperature of hot fluid without nano particle

Figure 8. Values of hot fluid temperature from the CFD modeling compared with the values of

From the above graph, it is found that the value of cold fluid & hot fluid temperature with or without nanoparticle using CFD. Both of graph represent the outlet temperature of the cold fluid & hot fluid respectively at a different mass flow rate. We are found that some result depending on the boundary condition using CFD.

V. CONCLUSIONS

In this experimental study of comparison in performance of heat exchanger with and without Titanium dioxide nano particle used in cold fluid produced the following results as a conclusion.

- The Titanium dioxide nano particle mixed cold fluid produce greatest values of heat transfer when compared with the cold fluid without nano particles
- Similarly, the exit temperature of the hot fluid and cold fluid reached the lesser value in Titanium dioxide nano particle mixed cold fluid used experiment when compared with the without nano particles experiment.

- Mass flow rate of the cold fluid create the significant impact on the results of each experiment.
- Mass flow rate (0.15 kg/s and 0.05 kg/s) produced the furthermost effectiveness, heat transfer rate and exit temperature of the cold fluid when compared among the different mass flow rates considered.

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