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Experimental Investigation of Heat Transfer in Double Pipe Heat Exchanger Using Cerium Oxide Nano fluid

P.R.Nakate[1]*, Prof.R.D.Shelke[2], Prof.H.N.Deshpande[2]
[1]Student, [2]Assistant Professor
Department of Mechanical Engineering,
Progressive Education Society's Modern College of Engineering, Pune, Maharashtra, India
***Email:** prashant5488@gmail.com*
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Abstract
Heat exchanger is a very important device in every modern industry. In this research work, the thermal performance analysis of a pipe in pipe heat exchanger is performed by varying the composition of nanofluid used, which is a mixture of Cerium Oxide (CeO_2) and water. An experimental analysis will be performed on pipe in pipe heat exchanger by varying volume concentration (2%, 3%, 4%) of nanoparticles in nanofluid at different flow rates (7, 8, 9 litres/min) of nanofluid flow. Experimental results such as heat transfer rates, overall heat transfer coefficient, Reynolds number, Nusselt number and heat exchanger effectiveness will be calculated to analyse the performance of heat exchanger. The objective of this research work is to check the use of Nano fluids to improve the heat exchanger's performances and at what percentage of Nanoparticle-coolant mixture, the performance of pipe in pipe heat exchanger will obtain maximum heat exchange rate.

***Keywords:** Cerium Oxide, Double pipe heat exchanger, Nanofluids,*

INTRODUCTION

Heat transfer can be improved by many methods. The flow of heat in a process can be calculated using, $Q = h \times A \times \Delta T$
Where Q is the heat flow, h is the heat transfer coefficient, A is the heat transfer area, and ΔT is the temperature difference that results in heat flow.
Increased heat transfer can be achieved by

- Increasing ΔT
- Increasing A
- Increasing h

The heat transfer coefficient can be increased by enhancing the properties of the coolant for a given method of heat transfer as first two methods have some restrictions. Additives are added into liquid coolants to improve specific properties. The heat transfer coefficient can be improved via the addition of solid particles to the liquid coolant. In the case of Nano sized particles, the resulting dispersion is known as a Nano fluid. In general the size of these nanoparticles varies from 1-100nm. The type of Nano particle used is directly dependent on the enhancement of a required property of the base fluid. All physical mechanisms have a critical length scale, below which the physical properties of materials are changed. Therefore particles having size less than 100 nm exhibit properties that are considerably different from those of conventional solids. The noble properties of Nano phase materials come from the relatively high surface area to volume ratio that is due to the high proportion of constituent atoms residing at the grain boundaries. The thermal, mechanical, magnetic, and electrical properties of Nano phase materials are superior to those of materials which were used previously with coarse grain structures.

The incorporation of nanoparticles in the base fluid leads to change in the thermo-physical properties such as thermal conductivity, viscosity and specific heat that affect the convective heat transfer. Different Nano-materials change their parameters to different extent

Concentration of nanoparticles; purity level, shape and size of Nano-materials are some of the prime factors that significantly alter the thermo-physical properties [6].

After literature review, Cerium Oxide (CeO_2) nanoparticles are used as it has better thermal conductivity than previously used Nano fluids like Al_2O_3, CuO, TiO_2, ZnO. CeO_2 nanoparticles are synthesized by Co-Precipitation technique from the powder mixture of Cerium Nitrate and Sodium Hydroxide (NaOH) obtained from a chemical route synthesis. Synthesized nanoparticle characterization measured by using XRD and SEM analysis. CeO_2/water nanofluid with volume concentrations from 2%, 3% and 4% will be prepared by dispersing the synthesized nanopowder in water. The experimentation will be carried out for investigation of enhancement in heat transfer by prepared nanofluid with varying nanoparticle volume concentration with varying flow rate [8-9].

LITERATURE REVIEW

D. Cabaleiro, et al [1]., used nanofluid as dispersions of dry ZnO Nano powder in ethylene glycol + water (50/50% in volume) were investigated at three mass nanoparticle concentrations up to 5%. The results were expressed in Nusselt number.

N.T. Ravi Kumar [2], et al., investigated the convective heat transfer, friction factor and effectiveness of different volume concentrations of Fe_3O_4 nanofluid flow in an inner tube of double pipe heat exchanger with return bend. New correlations for Nu and friction factor have been developed.

Lu Zheng, Yonghui Xiea, et a [3]l., examines heat transfer and flow in circular tubes fitted with dimpled twisted tape inserts, and Al_2O_3-water nanofluid is employed. The results show that dimple side and protrusion side both experience great heat transfer enhancement, and dimple side performs better compared with protrusion side. Liu yang et. Al [4]., reviewed heat transfer characteristics of TiO_2. Most of the results indicated the thermal conductivity can be increased as the increase in particle loading and temperature as well as the decrease in particle size.

A. Seozen, et al. [5], studied Nano fluids produced from alumina or fly ash, which is comprised of various types of metal oxides in varying concentrations, on the performance of a PFCTHE, CFCTHE. The key finding of the study was the attainment of stable and high heat conductivity through the use of fly ash nanofluid, which has an amorphous structure and is comprised of a range of metal oxides.

Munish Gupta, et al [7]., reviewed studies of the change in the thermo-physical properties of different conventional cooling fluids and the factor affecting them on the basis of different base fluids. According to results by different researchers, the particle material, particle size, temperature, pH value of base fluids has impact on the thermal conductivity of the Nano fluids. Thermal conductivity depends on the Brownian motion and particle clustering of the nanoparticles.
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OBJECTIVE

The objective of this research work is to check the thermal performance of Cerium Oxide (CeO_2) nanofluid to improve heat exchanger performance.

- To determine percentage of nanoparticle-coolant mixture at which performance of double pipe heat exchanger will obtain maximum heat transfer rate.
- To determine convective heat transfer coefficient, friction factor and effectiveness of heat exchanger with different volume concentrations of Cerium Oxide (CeO_2) nanofluid flow.

COMPUTATIONAL FLUID DYNAMICS PROCEDURE

Computational Fluid Domain

Computational fluid domain of heat exchanger is developed as per the selected parameters.

Grid Generation
Three dimensional models are divided using tetrahedral mesh elements. Fine mesh size are selected with nodes of 213485 and 971101 elements.

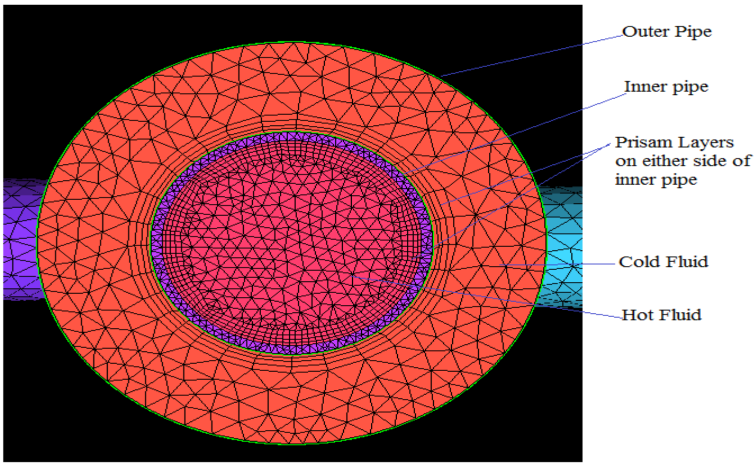

Figure 1: *Discretized domain.*

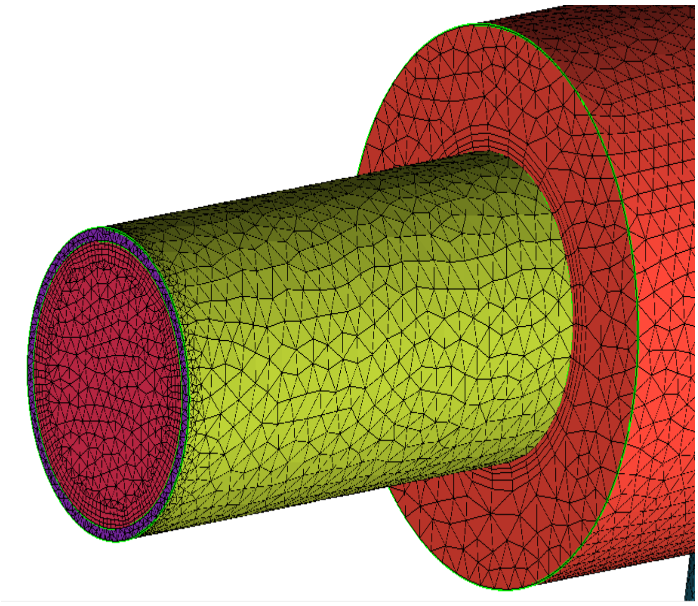

Figure 2: *Discretized domain.*

Mathematical Foundation
Numerical model is developed with assumptions given below:
- Steady fluid flow and heat transfer
- Constant fluid properties
- Fluid in single phase
- Outer wall is Adiabatic

Table 1: *Boundary conditions.*

Quantities	Boundary Conditions	
Working Fluid	Water	
Inner Pipe	Hot Inlet	
	Mass Flow Rate	Temperature
	0.1329 Kg/s	25 ˚C
Outer Pipe	Cold Inlet	
	Mass Flow Rate	Temperature
	0.0830Kg/s	60 ˚C

RESULT

Temperature and velocity distribution plots are shown below:

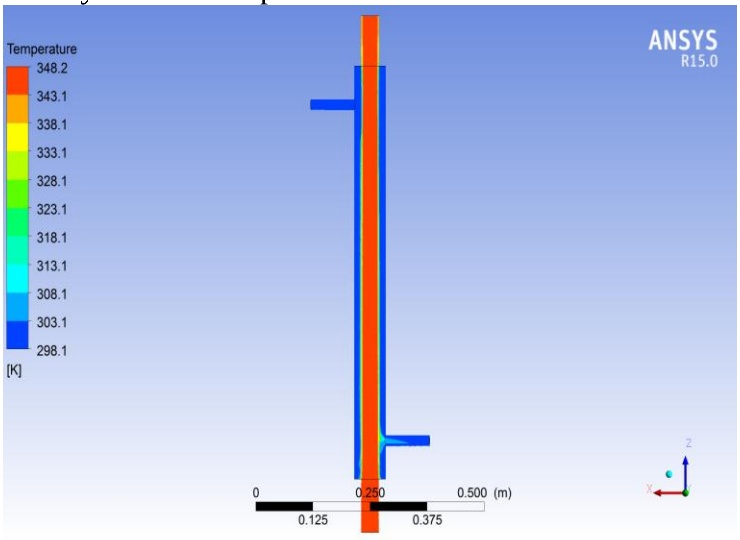

Figure 3: *Temperature distribution along DPHE.*

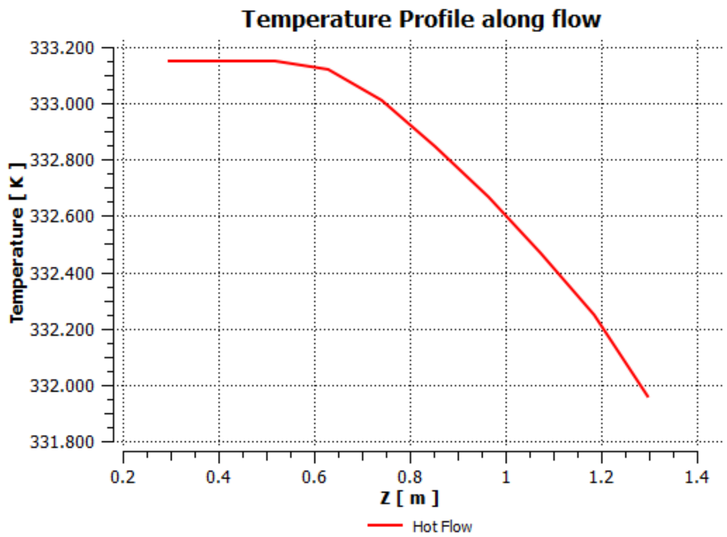

Figure 4: *Plot of temperature distribution along inner pipe (hot).*

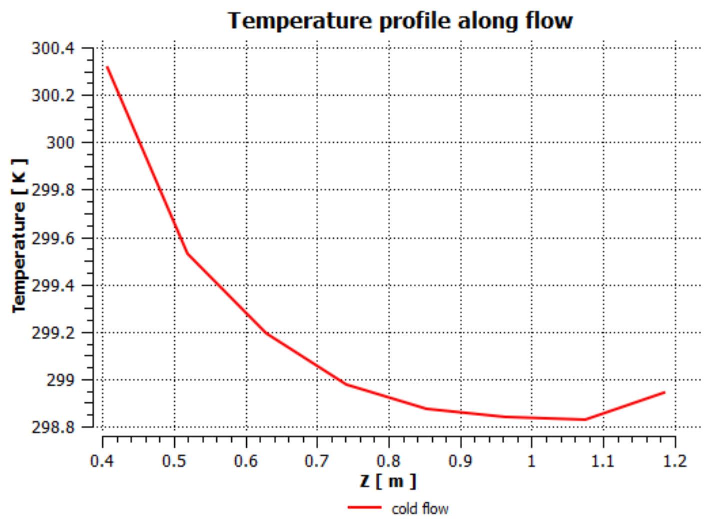

Figure 5: *Plot of temperature distribution along outer pipe (cold).*

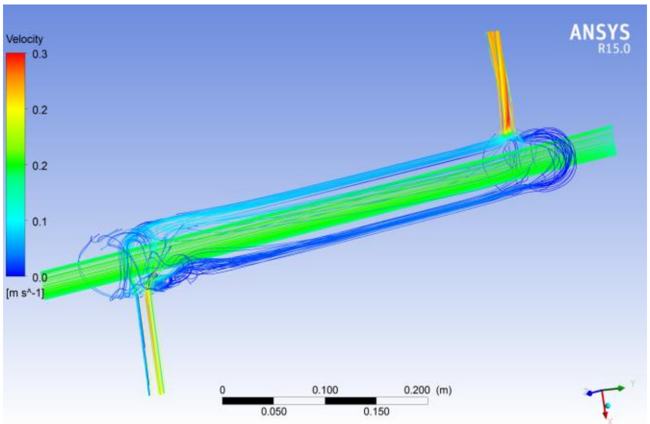

Figure 6: *Plot of velocity distribution along DPHE.*

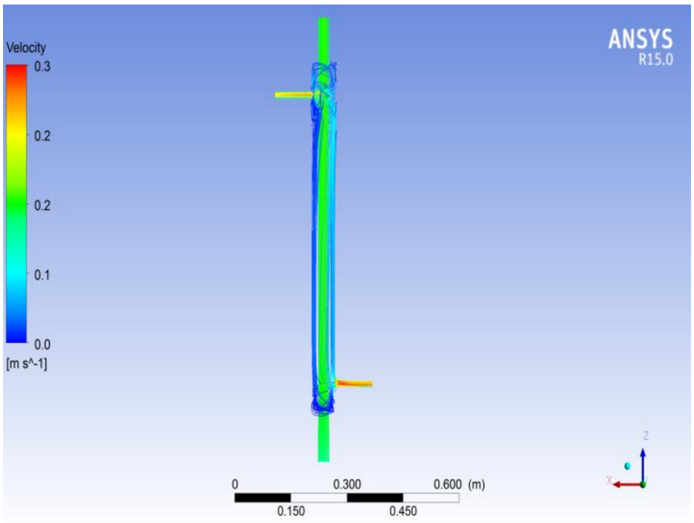

Figure 7: *Plot of velocity distribution along DPHE.*

Table 2: *Temperatures at outlets are as below.*

Area Weighted Average	
Cold Inlet	298.149 K
Cold Outlet	301.23 K
Hot Inlet	333.14 K
Hot Outlet	331.24 K

THEORETICAL CALCULATIONS

- Obtain properties of hot and cold water at average temperature such as density, viscosity, specific heat and thermal conductivity.
- For properties of Nano fluid pak and cho relations are used

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_w$$

$$Cp_{nf} = \phi Cp_{np} + (1-\phi)Cp_w$$

- The Reynolds number and Prandtl's number of nanofluid are calculated using following relations.

$$\mathrm{Re} = \frac{\rho \times .V \times d_i}{\mu}$$

$$\mathrm{Pr} = \frac{\mu \times Cp}{K}$$

- Nusselt number is calculated using following relation

$$Nu_o = 0.023(Re)^{0.8}\,(Pr)^{0.4}$$

- Convective heat transfer coefficient is calculated using following relation

$$Nu = \frac{h \times .d}{K}$$

- Overall Heat Transfer Coefficient is calculated from following relation

$$\frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + \frac{\ln(d_0/d_i)}{2\Pi KL} + \frac{1}{h_o A_0}$$

Where A_0 and A_i are outer and inner surface areas of Inner pipe and h_o, h_i are outer and inner convective heat transfer coefficients respectively.

- Effectiveness of Heat Exchanger
- NTU method

$$NTU = \frac{U \times A}{C_{min}} \Rightarrow NTU = \frac{Q}{(\Delta T)_{LMTD} \times C_{min}}$$

Where, C_{min} is minimum of C_c and C_h which are heat capacity rates of cold and hot fluids respectively.

$$\text{Effectiveness}, \varepsilon = \frac{1 - exp[-NTU(1-Z)]}{1-Z \quad exp[-NTU(1-Z)]}$$

Where $Z = C_{min}/C_{max}$.

- The friction factor is calculated based on the pressure difference the expression is given below.

$$f = \frac{\Delta P}{\frac{L_i}{D_i} \times \left(\frac{\rho v^2}{2}\right)}$$

EXPERIMENTATION

Experimental set up for double pipe heat exchanger is shown in Fig. 7. The outer pipe is made up of SS 304 material having outer diameter, inner diameter and length of 75 mm, 69 mm and 800 mm, respectively [10]. The inner pipe is also made up

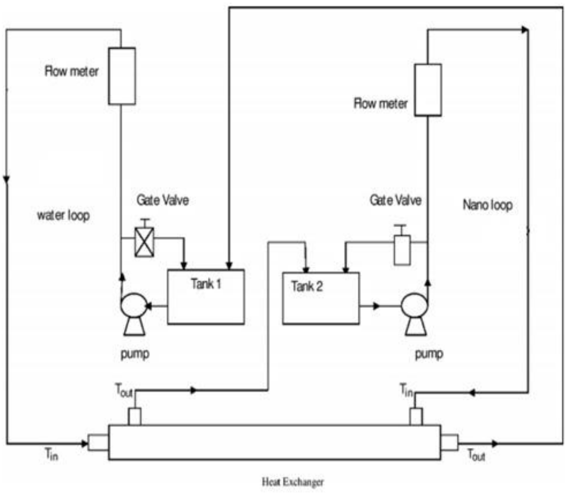

Figure 8: *Experimental set up.*

of copper having outer diameter, inner diameter and length of 38.2 mm, 35.2 mm and 1 m respectively. Cladding of mineral wool is provided on outer pipe which acts as insulation over outer pipe. Two valves are provided on each pipe which can be open and closed alternatively to control flow rates. Two water tanks are provided to store hot water and cold nanofluid.

Immersion type heater is provided to heat water to desired temperature. Flow meters having capacity from 0.5 lpm to 9 lpm are used to measure flow rates of Cold Nanofluid and Hot Water. Thermocouples are provided to measure inlet outlet temperature of Hot and Cold fluids [11].

Instrument Specification

- Heat Exchanger type: Pipe in pipe
- Nanofluid used- Cerium Oxide/Water
- Outer Pipe Outer Diameter: 75 mm
- Outer Pipe Inner Diameter: 69 mm
- Material- M.S.
- Inner pipe Outer Diameter: 38 mm
- Inner pipe Inner Diameter: 35 mm
- Material- Copper.
- Heat Exchanger length: 1 m (1000mm)
- Temperature Indicator - Digital indicator.
- Heater - 1000watt immersion heater (230 volt)
- Tank -20 liters
- Flow meter - 9 lpm Capacity.

Table 3: *Test matrix various tests as per test matrix will be conducted on experimental apparatus.*

Sr. No.	Flow Rate of Nanofluid in lpm	Flow Arrangement	Volume Concentration of Nanoparticles in %
1	7	Parallel Flow Counter Flow	2
			3
			4
2	8	Parallel Flow Counter Flow	2
			3
			4
3	9	Parallel Flow Counter Flow	2
			3
			4

RESULT AND DISCUSSION

Table 4: *Results for theoretical overall heat transfer coefficient.*

Sr. No	Hot Side			Cold Side			
	Re	Nu	H W/m^2 °C	Re	Nu	h W/m^2 °C	$Uo_{(th)}$ W/m^2 °C
1	8716	50.95	949.12	1145	5.74	112.7	99.82
2	10070	57.17	1066.76	1148	5.74	112.86	101.2
3	11347	62.85	1173.01	1150	5.74	112.89	102.17

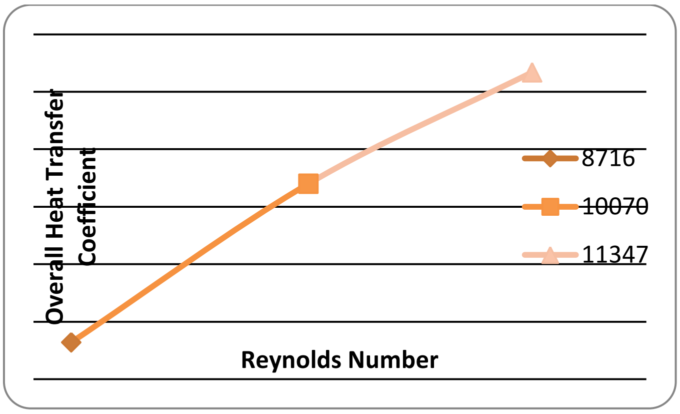

Figure 9: *Graph of Re vs.* U_o.

CONCLUSION

Based on CFD results and theoretical calculations, we can conclude that overall heat transfer coefficient increases with increases in Reynolds number. Convective heat transfer constant will increase with increase in painter range. It also increases pressure drop along the length of double pipe heat exchanger.

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