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Modeling and CFD simulation of double pipe heat exchanger with different mass flow rates

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ABSTRACT

In this study, the efficiency of double pipe heat exchanger with plain tube as well as coil insert tube is investigated by using water and various nano fluids mixed with water. Silicon Oxide and silver nano fluid are the nano fluids mixed with water at volume fractions of 0.35 percent. The properties of nano fluids are determined by theoretical calculations, which are then used as inputs for analysis. CATIA parametric software is used to build a 3D model of the double pipe heat exchanger (plain and coil insert tube). At different mass flow rates of 0.32, 0.52, and 0.72 kg/sec, CFD analysis is performed on the double pipe heat exchanger with water, silicon oxide, and silver nano particle. Furthermore, theoretical calculations on the double pipe heat exchanger were performed.

Keywords: *CFD, Nano Fluid, CATIA, Coil Inserts and Mass Flow Rates*

1. INTRODUCTION

Temperature can be described as the proportion of energy that a substance has. Transmission of energy from one medium to another is carried by heat exchangers. Temperature control of both incoming and outgoing medium is essential. The medium can either be gases or liquids. Heat exchangers aid in enhancement or reduction of temperatures of participating medium. By way of design, the participating medium are separated by a solid barrier and the temperature differential between the participating medium is the driver for heat exchange. Heat exchange happens between the medium by the three modes of heat transfer i.e. Conduction, convection and radiation. Though heat exchange takes through radiation, it is negligible compared to conduction and convection. Heat exchange takes place by conduction phenomenon when higher temperature medium passes through solid barrier.

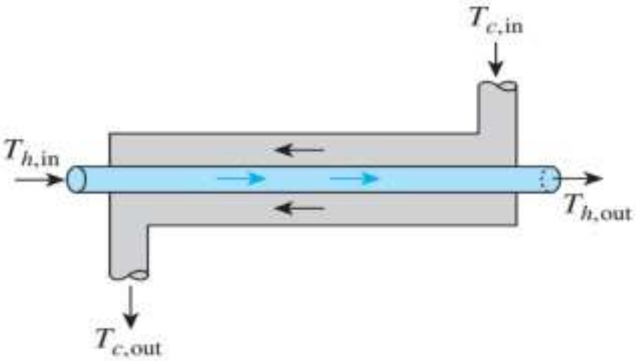


Figure 1: Inward medium (blue) is moving from left to right and the external medium (grey) moves in opposite direction in heat exchanger (Counter flow).

2. LITERATURE SURVEY

Z. Said et.al [1](2019) researched on improvement of effectiveness of heat exchanger without compromising on overall cost and consumption of energy. Shell-and tube heat exchanger working with CuO/water nano fluid is examined. Test results highlight the improvement of heat exchange by usage of nano fluids. In terms of improvement, heat transfer by convection (11.39 %), area reduction (6.81%) and overall heat transfer coefficient (7%) are observed.

Kevin J. Albrecht et.al [2] (2019) worked on heat exchanger of plate and shell with moving packed bed. Heat exchanger design and performance are evaluated with the help of a steady-state reduced-order model. It is an effective demonstrating procedure for recreating moving packed bed heat exchangers for the study of heat exchange of molecule to-s CO2 in technically advanced concentrating sunlight based force (CSP) plants. Generally speaking coefficient of heat transfer for the molecule to-s CO2 heat exchanger at CSP working temperature (500-800 °C) can move toward 400 $Wm^{-2}K^{-1}$. This is due to utilization of molecule channel measurements of 4 mm and molecule of 200 μm diameter.

Uttam Roy et.al [3] (2019) used simulation modeling to assess the performance attributes of shell and tube heat exchanger (STHX). FFBN (forward back propagation network) algorithm is used to study attributes such as efficiency of plant & cycle, cost, fouling and power. In the approval cycle distinctive preparing calculation are utilized to prepare the organization structure. The outcome shows that the proposed framework augments vivacious efficiency of plant & cycle and power by 98.11%, 97.4%, and 96.35% individually.

Xuen Chen et al [4] (2019) investigated mathematically the attributes of the heat exchanger which is loaded up with open cell permeable structure. The outcome showed that the heat radiation enhances the heat exchange between hot side liquid and cold side liquid. The heat exchange is affected by the porosity, it increments with diminishing porosity. In the mean time the heat exchange rate is straightforwardly relative to the pore thickness, annulus measurement and exchanger length. The improvement is noticed most extreme with the dimensionless length under 35. Aside from each one of the improved outcomes in heat exchange execution by coordinating coupling impact between the two sides of the liquids, barrier thickness and heat radiation. Increase of pressure drop is also observed.

Sheikholeslami and Ganji [5] (2019) have used ANSYS 14 to examine the performance of heat exchanger with sporadic helical fins. Hydro thermal performance is checked in the air to water heat exchanger.The outcome showed that the contact factor and Nusselt number (Nu) expanded with the ascent in the Reynolds number (Re). Enhancement of Nusselt number and friction factor are observed with stepped up values of open area and pitch ratio. Augmentation of ratio of helical pitch caused reduction of pressure loss. Decrease of the ratio resulted in increase of Nusselt Number. The examination showed that for all estimations of Reynolds number (Re), the helical square balance gives higher heat exchange than the round one. Coefficient of heat transfer decreases with Reynolds number (Re), ratio of pitch but increments with ratio of open area.

Bahmani et al. [6] (2108) detailed the impact of water/alumina nano fluid in the parallel as well as counter flow heat exchanger. It showed that expanding nanoparticles volume division caused increment of Nusselt number(Nu) and coefficient of heat transfer. By expanding nanoparticles division the Reynolds number(Re) increments, yet thusly, the heat exchange effectiveness upgrade incline of heat exchanger slowly arrives at a consistent worth which is more apparent in equal stream contrasted with counter stream, that suggests utilizing of counter stream in higher Reynolds numbers(Re). Likewise found that at a nanoparticles volume part of 5%, the improvement of warm proficiency discovered to be most extreme occurred in twofold line heat exchanger .

Heyhat et al. [7] (2108) conducted experiments to observe the heat exchanger behavior by air bubble injection. Performance observed at various positions of heat exchanger i.e. horizontal, 45 degrees and vertical. Effectiveness maximized at vertical position for various mass flow rates.Air bubble injection helped in enhancing the performance of the heat exchanger.

MarwaA.W.Ali et al. [8] (2108) did the mathematical examination to improve the heat exchange rate by pivoting internal line of twofold line alongside changing line erraticism, in the wake of making 3D consistent state, incompressible CFD model. Accepted the pivoting internal line at an alternate speed and furthermore erraticism of line transformed from the external for differed range from 0 to 40mm. It brought about huge expansion of heat exchange rate by 223%, and the greatest rate is streamlined at pipe pivoting at 500 rpm and unusualness change of 40mm from the external line. It likewise found that the inward line revolution improved the exhibition rate at low Reynolds number(Re) while the unusualness increment increase the presentation rate for both low and high Reynolds number(Re). Though 53% of pressure drop is observed with the rotation of internal pipe, it is within the permissible values.

2.1 Objective

The aim of this study is to make a 3D model of the heat exchanger with two pipes and conduct CFD study with the help of finite element .CATIA is used for creation of 3D models and analysis is done by using ANYSYS software programs. Following approach is adopted to carry the study:

- CATIA 3D parametric modeling is used to create a 3D model of the heat exchanger with two pipes
- Created Surface model is converted to Para Solid file and transferred to ANSYS for analysis.
- CFD analysis is carried out on plain cylinder model
- Mass flow rate of medium is varied and parameters such as rate of heat exchange, coefficient of heat transfer, drop of pressure of the medium, temperature variation are noted

3. MODELING AND ANALYSIS

Dassault Systèmes has developed CATIA as a multi stage 3D programming that consist of CAD, CAM & CAE for product design, simulation, manufacturing and more. Many technological industries such as Automobile, Aviation etc. are employing CATIA 3D programming to create and solve technological challenges.

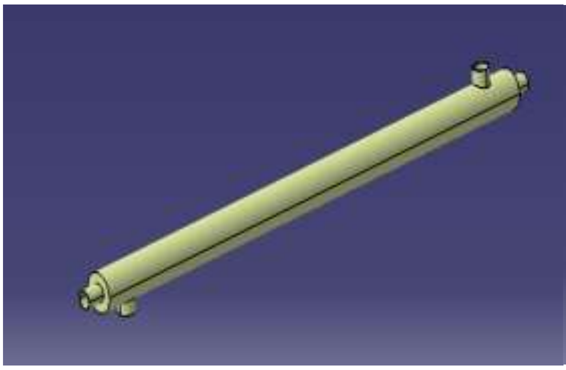


Figure 2: plain tube DPHE

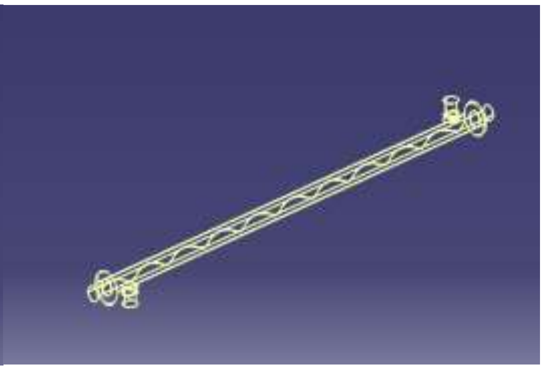


Figure 3: Coil insert tube DPHE

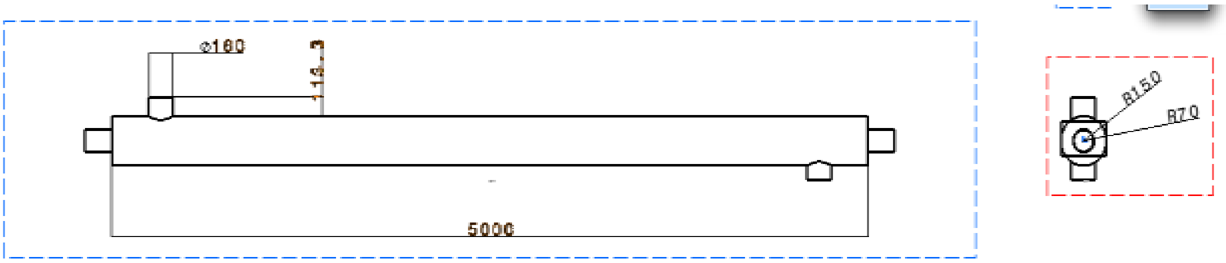


Figure 4: 2d drawing of DPHE

CFD

In a system, action of thermo fluids can be replicated by using engineering tools such as CFD. Many industries are using CFD for analysis, optimization and design performance. Physical testing and expenses for prototyping can be avoided by using CFD.

Complex problems can be resolved with uncompromised accuracy within short duration due to innovations to modeling, meshing, high-performance computing and post-processing.

Fluid flow can be predicted by way of mathematical modeling, (partial differential equations) numerical methods (discretization and solution techniques), software tools (solvers, pre- and postprocessing utilities).

Calculations To Determine Properties Of Nano Fluid By Changing Volume Fractions

- **Density of Nano Fluid**

$$\rho_{nf} = \phi \times \rho_s + [(1-\phi) \times \rho_w]$$

- **Specific Heat Of nano Fluid**

$$C_{pnf} = \frac{\phi \times \rho s \times Cps + (1-\phi)(\rho w \times Cpw)}{\phi \times \rho s + (1-\phi) \times \rho w}$$

- **Viscosity Of Nano Fluid**

$$\mu_{nf} = \mu_w\,(1+2.5\phi)$$

- **Thermal Conductivity of Nano Fluid**

$$K_{nf} = \frac{Ks+2Kw+2(Ks-Kw)(1+\beta)^3 \times \phi}{Ks+2Kw-2(Ks-Kw)(1+\beta)^3 \times \phi} \times k_w$$

Table :1Nano Fluid Properties

FLUID	Volume fraction	Thermal conductivity (w/m-k)	Specific heat (J/kg-k)	Density (kg/m^3)	Viscosity (kg/m-s)
Silicon oxide	**0.35**	0.870	2121.459	1576.33	0.0018806
Silver		2.156	831.28	4323.83	0.0018806

Theoretical calculations for outlet temperature, heat transfer and heat transfer coefficient

$$Q_c = M_c C_p (T_{co} - T_{ci})$$

$$T_{ho} = T_{hi} - \frac{Qc}{Mc\ Cp}$$

For LMTD

$$\Delta T_1 = T_{hi} - T_{co}$$

$$\Delta T_2 = T_{ho} - T_{ci}$$

$$\Delta T_{lm} = \frac{\Delta T1 - \Delta T2}{In\frac{\Delta T1}{\Delta T2}}$$

$$\text{Velocity} = U_c = \frac{Mc}{\rho A1}$$

$$\text{Reyonlds number} = R_e = \frac{U \rho D}{\mu c}$$

$$\text{Friction factor} = f = (1.82 \text{ in } R_e - 1.64)^{-2}$$

$$\text{Colburn factor} = j = \frac{f}{2}$$

$$\text{Prandlt number} = P_r = \frac{\mu c\ Cp}{Kc}$$

$$\text{Heat transfer coefficient} = h_o = j * R_e * P_r^{2/3} * \frac{Kc}{De}$$

Pressure drop

$$\Delta p = f\frac{L}{D_e}\frac{\rho u_m^2}{2}$$

Nusselts number

$$Nu_b = \frac{((f/2))(Re_b)Pr_b}{1.07 + 12.7(f/2)^{1/2}(Pr_b^{2/3} - 1)}$$

Case: 1 Plain tube results

Fluid	**Mass flow rate(kg/sec)**	**Pressure (Pa)**	**Temperature (k)**	**Heat transfer coefficient**	**Nusselts number**	**Heat transfer rate(w)**
Water	**0.32**	3100	620	12800	3.20	6987.312
	0.52	3279	626	13050	0.8951	14528.15
	0.72	3425	628	14197	0.8233	38523.52
Silicon oxide	**0.32**	2760	623	9582	0.695	1885.72
	0.52	2823	629	9856	0.705	40321.512
	0.72	3062	630	9952	0.697	28524.159
Silver nano fluid	**0.32**	784	627	10834	0.1784	8073.128
	0.52	833	630	11285	0.0324	10525.37
	0.72	852	632	12956	0.03	4937.317

Case: 2 Coil insert tube results

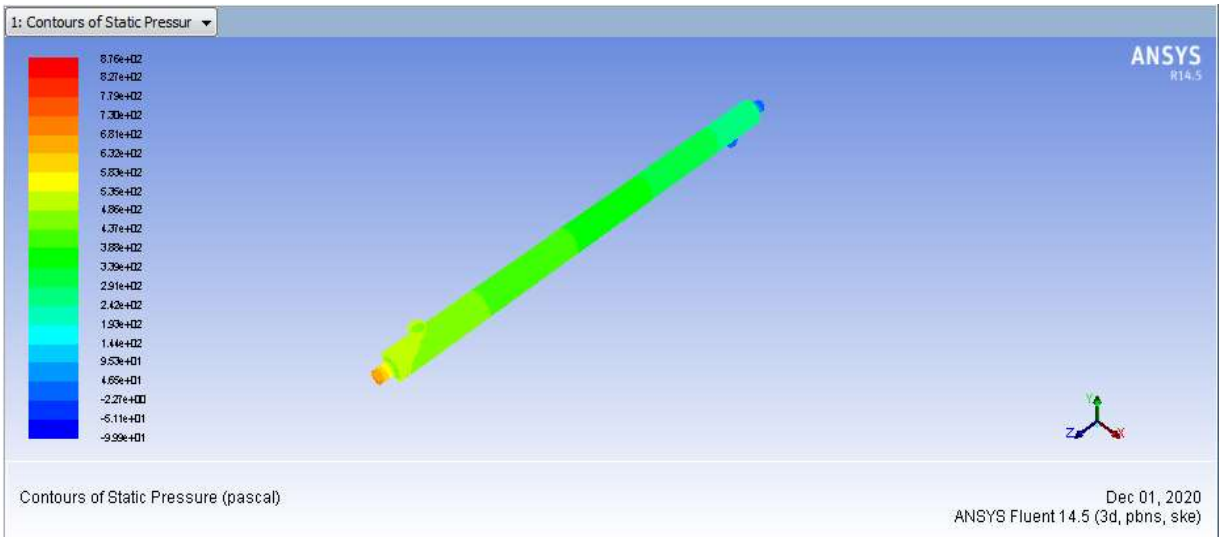
Fluid	**Mass flow rate(kg/sec)**	**Pressure (Pa)**	**Temperature (k)**	**Heat transfer coefficient**	**Nusselts number**	**Heat transfer rate(w)**
Water	**0.32**	3198	621	13823	2.01	33246.64

	0.52	3370	626	13954	0.00897	45943.24
	0.72	3495	628	14200	0.0827	30374.65
Silicon oxide	**0.32**	2190	627	9733	0.176	28354.52
	0.52	2205	631	9820	0.0630	25736.10
	0.72	2300	632.2	9960	0.0706	19149.25
Silver nano fluid	**0.32**	783	628.1	10023	0.0817	197073.04
	0.52	819	632	10943	0.0410	17324.25
	0.72	843	637	11085	0.00375	14239.83

CFD ANALYSIS OFDOUBLE PIPE HEAT EXCHANGER WITH COIL INSERT

Fluid- Silver Nanofluid Particles

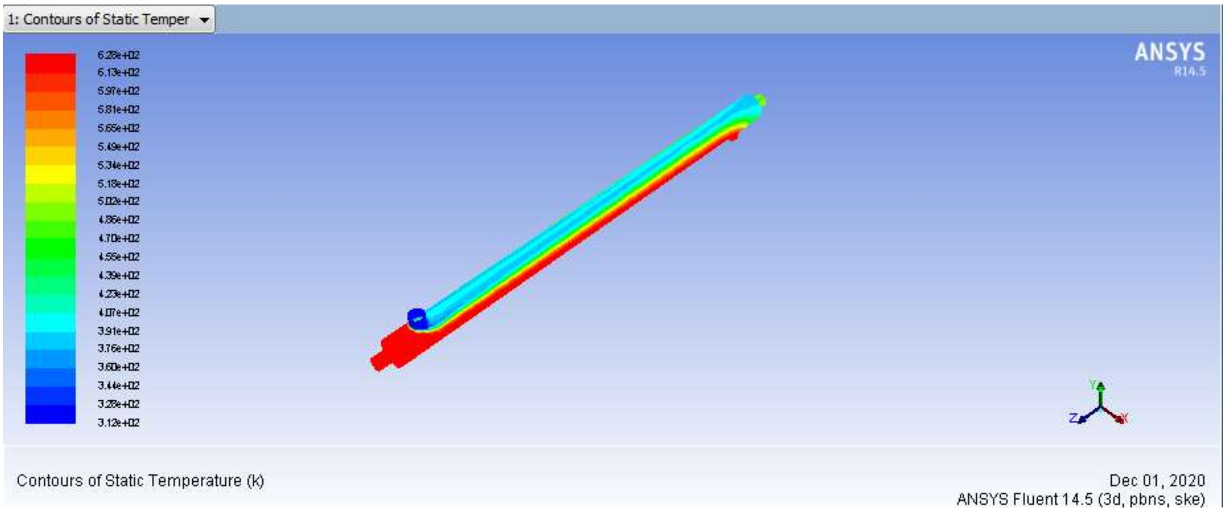
At mass flow rate-1.12 kg/sec



Contours of Static Pressure (pascal)

Dec 01, 2020
ANSYS Fluent 14.5 (3d, pbns, ske)

Figure: 5 pressure drop



Contours of Static Temperature (k)

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ANSYS Fluent 14.5 (3d, pbns, ske)

Figure: 6 Temperatures

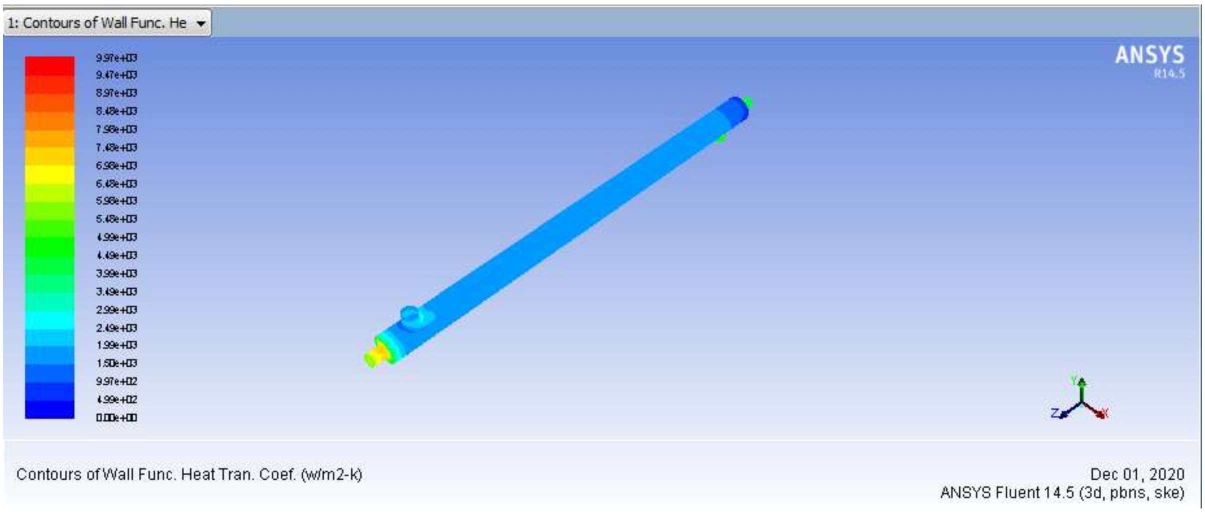


Figure: 7Heat Transfer Coefficient

Heat Transfer Rate

```
        Total Heat Transfer Rate                     (w)
-------------------------     --------------------
                   cold_inlet              13825.847
                  cold_outlet             -891045.31
                    hot_inlet                1277008
                   hot_outlet             -391458.72
                  wall-____msbr            14.097899
        ----------------     --------------------
                          Net              8343.9133
```

4. RESULTS AND DISCUSSIONS

Case: 1 Plain tube results

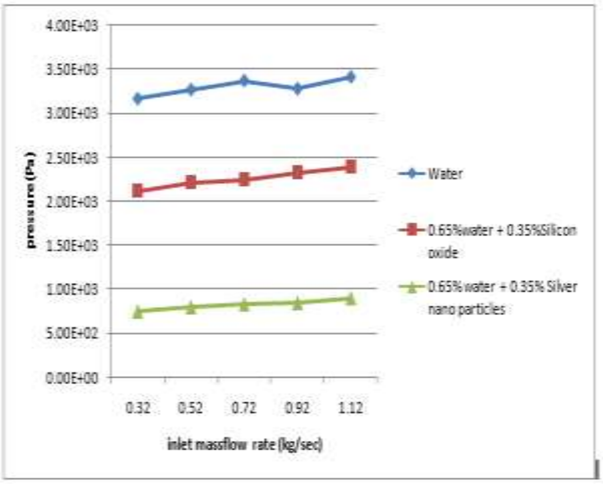
Fluid	Mass flow rate(kg/sec)	Pressure (Pa)	Temperature (k)	Heat transfer coefficient	Nusselts number	Heat transfer rate(w)
Water	**0.32**	3050	619	12600	3.14	6571.317
	0.52	3190	621	12800	0.8356	14323.19
	0.72	3220	624	13100	0.7971	34707.64
Silicon oxide	**0.32**	2160	620	9230	0.647	1628.619
	0.52	2260	622	9330	0.607	38304.764
	0.72	2330	626	9350	0.601	38921.784
Silver nano fluid	**0.32**	772	621	9850	0.1583	7372.043
	0.52	821	623	9910	0.0257	9180.522
	0.72	845	627	9940	0.0221	9339.838

Case: 2 Coil Insert tube results

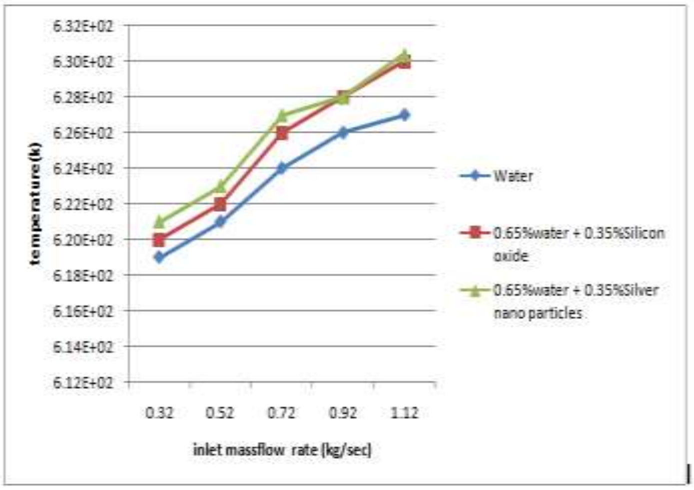
Fluid	Mass flow rate(kg/sec)	Pressure (Pa)	Temperature (k)	Heat transfer coefficient (w/m K)	Nusselts number	Mass flow rate(kg/sec)	Heat transfer rate(w)

Water	**0.32**	3170	620	13000	1.88	0.01388	30131.955
	0.52	3270	622	13100	0.0763	0.01209	42844.258
	0.72	3370	625	13200	0.0732	0.00981	28641.531
Silicon oxide	**0.32**	2120	620.2	9330	0.0915	0.02098	27218.1072
	0.52	2210	623.1	9340	0.0568	0.02673	23148.104
	0.72	2250	625.3	9350	0.06068	0.012403	18991.374
Silver nano fluid	**0.32**	753	621	9870	0.07321	0.05791	18054.525
	0.52	802	623.2	9890	0.0268	0.01941	17097.976
	0.72	836	627	9930	0.0222	0.00541	13960.04

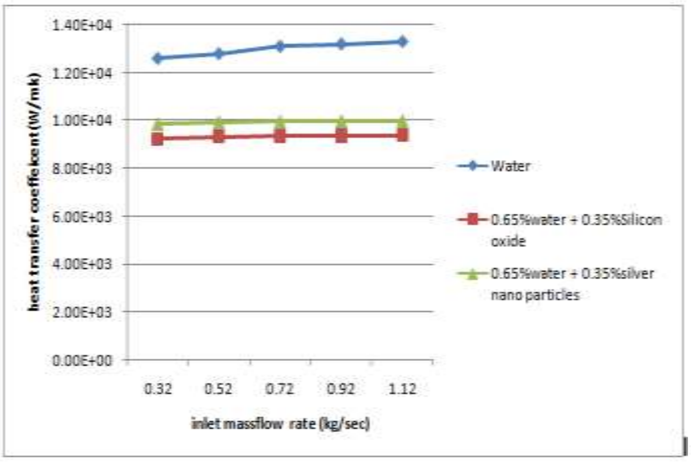
Plain Tube Heat Exchanger Graphs



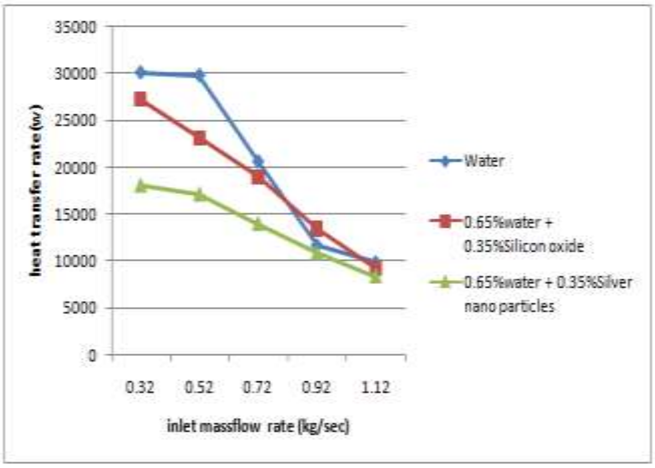
Graph1: Different fluids-mass flow rates Vs Pressure



Graph 2: Different fluids-mass flow rates Vs Temperature

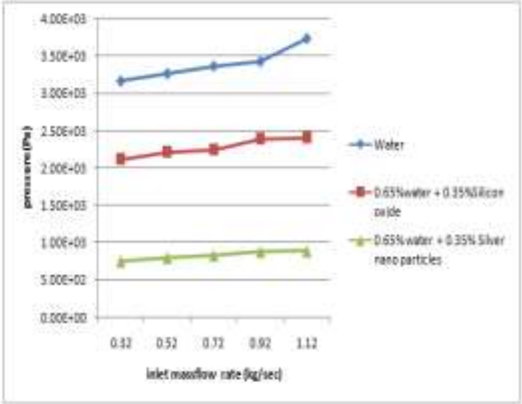


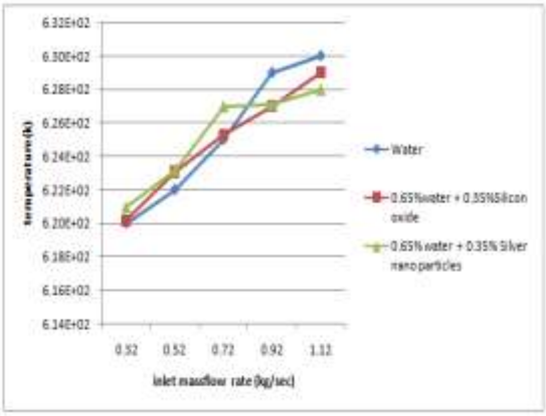
Graph3: Different fluids-mass flow rates Vs heat transfer coefficient



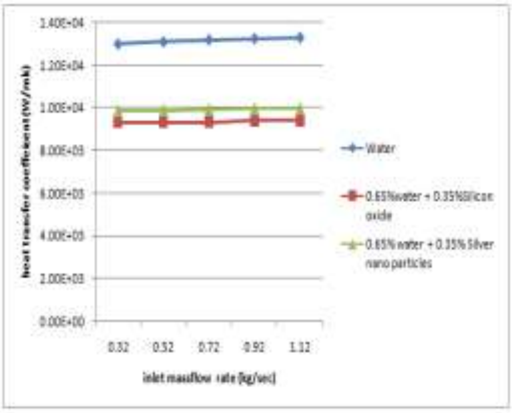
Graph 4: Different fluids-mass flow rates Vs heat transfer rate

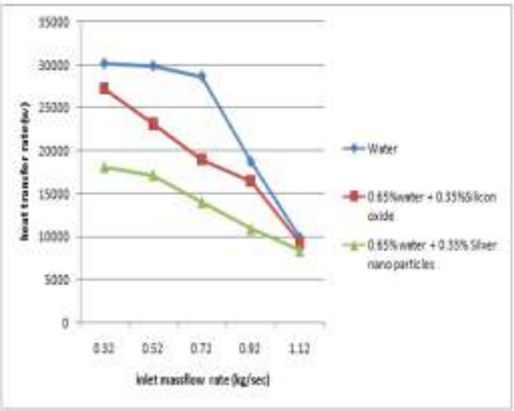
COIL INSERT TUBE HEAT EXCHANGER GRAPHS





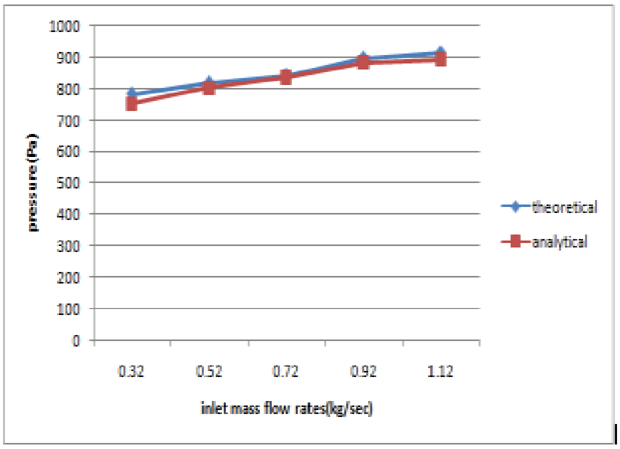
Graph5: Different fluids-mass flow rates Vs Pressure Graph 6: Different fluids- mass flow rates Vs Temperature



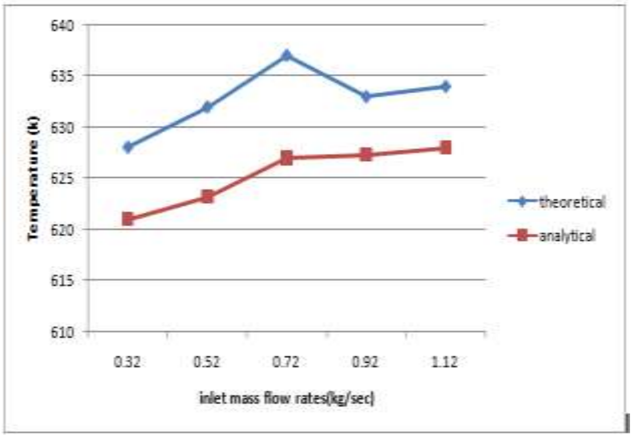


Graph7: Different fluids- mass flow rates Vs heat transfer coefficient Graph 8: Different fluids-mass flow rates Vs heat transfer rate

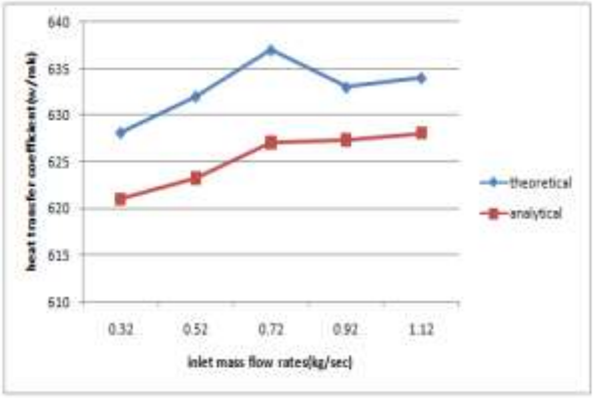
COMPARISON GRAPHS



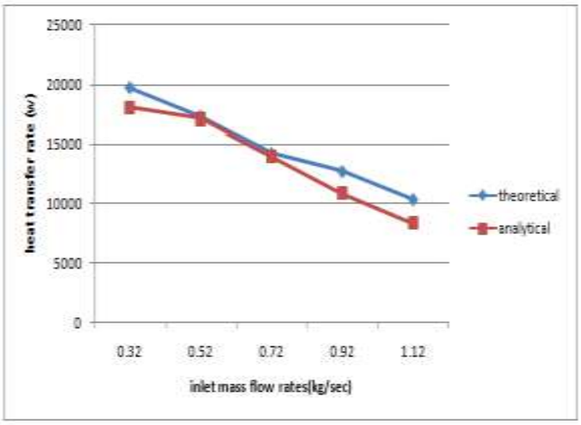
Graph9:Coil inserts tube at fluid is water 0.65% +silver 0.35% pressure values of theoretical and analytical



Graph10: Coil inserts tube at fluid is water 0.65% +silver 0.35% temperature values of theoretical and analytical



Graph11: Coil inserts tube at fluid is water 0.65% +silver 0.35% heat transfer coefficient values of theoretical and analytical



Graph12:Coil inserts tube at fluid is water 0.65% +silver 0.35% heat transfer coefficient values of theoretical and analytical

5. CONCLUSION

In this study, CATIA parametric software is used to create a 3D model of a double pipe heat exchanger (plain and coil insert tube). CFD analysis is performed on the double pipe heat exchanger using water, silicon oxide, and silver nano particle at various mass flow rates of 0.32, 0.52, and 0.72 kg/sec, as well as theoretical calculations.

ANSYS FLUENT 15 was used to perform numerical and theoretical simulations for a double pipe plain and coil tube heat exchanger.The graphs show the temperature, pressure heat transfer rate, and heat transfer coefficient for water and nano fluids with a turbulent flow state. The findings of the above analysis are as follows:

- Pressure, Temperature, heat transfer rate are observed to be superior with coil insert tube + nano fluid when compared to plain tube + nano fluid.
- In terms of geometry - Pressure, Temperature, heat transfer rate are observed to be superior with coil insert tube to plain tube heat exchanger
- In terms of fluids - Pressure, Temperature, heat transfer rate are observed to be superior with nano fluid mixed with water than silicon oxide + water and plain water
- In terms of mass flow rate – Higher mass flow rate 0.72 Kg/Sec caused higher Pressure, Temperature, heat transfer rate compared to other mass flow rates of 0.52, 0.32

As a result, the silver nano particle at 0.35 percent fluid weight percentage is the best, and the geometry is the double pipe coil insert tube heat exchanger.

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