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Optimization of Performance of Heat Exchanger through Nano Fluid Particles

Mr. Akash Anilkumar Bhavsar[1], Dr. Sadanand Namjoshi[2]
[1]Research Scholar, Madhav University and Assistant Professor, GSFC University, Vadodara, Gujarat, India
[2]Associate Professor, Madhav University, Pindwara, Rajasthan, India

ABSTRACT

This paper study about the use nanofluid as base fluid, stability control, thermo- physical properties, pressure drop and CFD Analysis. Our project is based on CFD Analysis "Performance Analysis of Heat Exchanger" using Fluent. This paper presents the effect of using Al2O3 nanofluid in shell and tube type heat exchanger, addition surfactant on nanofluid for long term stability, and also shows the changes in heat transfer coefficient and pressure drop. Upon geometrical optimization, the first phase of this work aims at studying the influence of Al2O3 nanofluid at 0.2% concentrations size of 20nm by admitting water along the shell side and Al2O3 nanofluid along the tube side and also water as base fluid having water in both shell and tube side of heat exchanger. The shell and tube heat exchanger of various geometrical configurations is modelled using ANSYS 2019 R3. The heat transfer and fluid flow characteristics through the heat exchanger are obtained by using ANSYS Fluent CFD. Temperature, pressure contours and velocity streamlines of the shell and tube heat exchanger are obtained for various geometrical configurations and for 0.2% volume concentration of nanofluid. The use of nanofluid resulted in increase of both the pressure drop and heat transfer coefficient. The heat transfer coefficient is increased by 7.6% than water by using 0.2% volume fraction Al2O3 nanofluid and pressure drop is increased upto 11%.
Keywords : Dengue, Serotypes, NS2B-NS3 Protein, CADD (Computer Aided Drug Design)

I. INTRODUCTION

Thermal fluids are vital to remove excess heat from a system or assist heating process in industrial field such as electronic engineering, medical, automotive and HVAC. Thus, thermal conductivity of fluids acts as the main properties to be apprehensive in developing energy efficient heat transfer equipment.

1.1 Nanofluid

As there is a lot of advancement in research and technology in the area of nanotechnology, promising results has been carried out in the use of Nanofluid instead of normal fluid. The use of Nanofluids has a very high impact on the performance of shell and tube heat exchanger mainly on its pressure drop and heat transfer. Nanofluid is a fluid in which the particles size is in nanometre and the particles form a colloidal suspension with the base fluid. Many different particle materials are used for Nanofluid preparation Al2O3, CuO, TiO2, SiC, TiC, Ag, Cu, and Fe.

1.2 Shell & Tubes

Heat exchangers are devices in which heat is transfer from one fluid to another. The most commonly used type of heat exchanger is a shell-and-tube heat exchanger. Shell-and-tube heat exchangers are used extensively in engineering applications like power generations, refrigeration and air-conditioning, petrochemical industries etc. These heat exchangers can be designed for almost any capacity.

1.3 Constructional Details of Shell and Tube Heat Exchanger

It is essential for the designer to have a good knowledge of the mechanical features of shell- and-tube heat exchangers and how they influence thermal design. The principal components of shell and tube heat exchangers are: Shell, shell cover, tubes, channel, channel cover, tube sheet, nozzles, baffles and other components include tie rods and spacers, pass partition plates, impingement Plate, longitudinal baffles, sealing strips, supports, and foundation. The Tubular Exchanger Manufacturer is Association, TEMA, has introduced a standardized nomenclature for shell-and-tube heat exchangers. A three-letter code has been used to designate the overall configurations. The three important elements of any shell-and-tube heat exchangers are front head, the shell and rear head design respectively.

1.4 Nanofluid preparation

Nanoparticles used in nanofluids range in size from 1 to 100 nm and different shapes such as nanospheres (spherical), nanoreefs, nanoboxes, nanoclusters and nanotubes. The shape formation of nanoparticles is defined during synthesis, and the average size of nanoparticles plays a significant role in the enhancement of thermal conductivity a primary factor for heat transfer enhancement.

There are two popular methods used in the preparation of nanofluids:

The single-step method and the two-step. The single-step method involves the simultaneous production of nanoparticles and suspension of the particles into the base fluid. For example, the nanoparticles may be formed by condensation from the vapour phase directly into the heat transfer liquid. This method has the advantage of producing minimal nanoparticles agglomeration; however, it is characterised by high costs, and is therefore likely to be infeasible on an industrial scale.

In contrast, in the two-step method, nanoparticles are produced in a separate process before being dispersed into the basefluid. Stabilising agents such as surfactants can be added to reduce the interfacial forces between the nanoparticles and basefluid molecules. Subsequently, the solution may be mixed using mechanical devices such as homogeniser, stirrer and ultrasonicator. The two step method is widely used, since it is generally less labour intensive and more cost effective.

This is due to two forces:

(1)Van der Waals attractive forces on the particles surface which causes the

particles to be attracted to each other into forming clusters or agglomerations of particles and then separate from the basefluid and settle at the bottom due to gravitational force.

(2) The electrical double layer repulsive force which tends to separate the particles from each other via steric and electrostatic repulsion mechanisms. Stability is a very vital element in commercialising nanofluids as it extends the shelf-life of the product while conserving its thermophysical properties. For stable nanofluid the electrical double layer repulsive force should surpass the Vander Waals attractive forces.

1.5 Zeta Potential Analysis

The zeta potential analysis evaluates the stability of nanofluids through the observation of electrophoresis behaviour of the fluid. The free charges in the basefluid get attracted to the opposite charges on the dispersed particles surface, causing the development of a layer of charged ions known as the stern layer. Another layer that surrounds the stern layer, defined as the diffuse layer, which has its individual charges and is more diffusive. The zeta potential can be defined as the potential difference between the base fluid and the stern layer in contact to the dispersed particles. Formula selecting a suitable surfactant is determined by the basefluid used in preparing the nanofluids. In general, if the basefluid is a polar solvent, then a water-soluble surfactant should be used; otherwise, an oil-soluble is used instead.

Other techniques are as follows-

- Surface Modification Techniques.
- Ultrasonic Agitation
- pH Control of Nanofluids.

1.6 Nanofluids Thermophysical Properties

Different types of fluids are usually used as heat carriers in heat transfer applications. Such applications where heat transfer fluids (HTF) have an important role are heat exchanging systems in power stations, cooling and heating systems in buildings, vehicles air conditioning (AC) system in transportation, and cooling systems of most of the processing plants. In all of the aforementioned applications, the HTF's thermal conductivity has a strong influence on the efficiency of the heat transfer process and with it the overall efficiency of the system. For such reason, researchers have continuously worked on developing advanced HTF's that have significantly higher thermal conductivities than conventionally used fluids.

Thermal fluids play very important role in removing excess heat from a system or assist heating process in industrial field such therefore thermal conductivity of fluids is the main properties to be considered in developing an energy efficient heat transfer equipment. However, commercial fluids have low thermal properties as compared to solids materials.

New type of fluid has been formed by addition on nanoparticles in base fluid with completely different thermophysical properties such as density, specific heat capacity, thermal conductivity, convective heat transfer, thermal diffusivity, and viscosity. Thus nanofluids are superior. The word "effective" is commonly used to describe the thermophysical properties of nanofluids (e.g., effective viscosity and effective density). This is done to differ between the thermophysical properties of the base fluid and the fabricated nanofluid.

In order to investigate the heat transfer performance of nanofluids and use them in practical applications, it is necessary first to study their thermophysical properties such as density, specific heat, viscosity, and thermal conductivity. In this study, to validate the numerical results, thermal properties of Al2O3/water nanofluid are determined by employing well- known empirical correlations.

1.12 CFD FLUENT

Nowadays, simulation has become an important tool for design and operation control. It helps to find the quick and accurate results throughout design and manufacturing as well as during end use.

Ansys FLUENT software contains the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications ranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants.This simulation software also allows you to predict, the impact of fluid flows and heat transfer on your product.

II. LITERATURE REVIEW

Wei Yu and Huaqing Xie[1] summarized the recent progress on the study of nanofluids, such as the preparation methods, the evaluation methods for the stability of nanofluids, and the ways to enhance the stability for nanofluids, the stability mechanisms of nanofluids, and presents the broad range of current and future applications in various fields including energy and mechanical and biomedical fields and the opportunities for future research.

Besides using nanofluid as a HTF in heat transfer applications, which was the main reason behind the development of such category of fluid, it is also used in sunscreen products, medicine, reducing buildings pollution, magnetic sealing, microbial fuel cells, antibacterial activity, and many other applications [2-4].

Akshay Kumar Surana and K. John Samuel [5] in their paper showed the effect of number of tubes, unequal baffle spacing and tube diameter on heat transfer and pressure drop characteristics of a typical shell and tube type heat exchanger. The second phase of their research work aimed at studying the influence of Al2O3 nanofluid of 0.5%, 0.75%, 1%, 1.25% and 1.5% concentrations by admitting water along the tubes and Al2O3 nanofluid along the shell side. They modelled the shell and tube heat exchangers of various geometrical configurations by using SOLIDWORKS 2015.

M Siva Eswara Rao, Dowluru Sreeramulu and D Asiri Naidu [6] stated that heat transfer rate increases with decreasing particle size. By performing an experiment based on Alumina nano particles of about 22 nm diameter with different concentrations (0.13%, 0.27%, 0.4%, and 0.53%) with water as a base fluid using ultra-sonicator. Experiment has been conducted on shell and tube heat exchanger for the above concentrations on parallel and counter flow conditions by keeping constant inlet temperatures and mass flow rate. The result showed that the heat transfer rate is good compared to conventional fluids.

The effect of number of baffles and mass flow rate on fluid flow in shell side has been studied by Ozden and Tari [7]. The heat transfer coefficient is found to vary in direct proportion to the mass flow rate and indirectly proportional to number of baffles. The pressure drop across the shell side is found to increase if baffle numbers and mass flow rate are increased.

The influence of various geometrical parameters such as pitch of the tube, diameter of shell and tube, tube length, number of tubes, diameter of the nozzle and tube arrangements on the heat transfer in a shell and tube heat exchanger without any baffles is studied by Kim and Aicher [8].

Albadr et al [9] conducted several experiments using different concentrations of Al2O3 Nano fluid to see its effect on the heat transfer of a heat exchanger. It is perceived that the heat transfer coefficient is higher with Nanofluids rather than 100% water. The study revealed that with an increase in the volume concentration and mass flow rate of the Nanofluid the heat transfer coefficient is also found to be increased.

Kwon, Kim and Li C G [10] showed that the paper presents ZnO and Al2O3 Nano fluids are used and final results observed that heat transfer coefficient increased to 30% at 6% volume concentration of Al2O3 nanofluid.

One of the commonly used methods for synthesising nanofluids, known as the direct evaporation one-step approach, depends on solidifying nanoparticles that are originally in gaseous phase inside the base fluid itself. The method was developed by Akoh et al. [11] and was named the Vacuum Evaporation onto a Running Oil Substrate (VEROS) method.

Wagener et al. [12] proposed a modified VEROS process, where they used high pressure magnetron sputtering to synthesis dispersions containing Fe and Ag nanoparticles. Eastman et al. [13] also developed a modified VEROS process, where they directly condensed Cu vapour with a flowing low vapour-pressure EG to fabricate their Cu/EG nanofluid. Zhu et al.

[14]employed a one-step approach, through chemical reaction, to obtain Cu nanofuid. Tran and Soong [15] used a laser ablation one-step method to synthesize Al2O3 nanofluid. Another one-step approach also exists [16, 17], with all being favourable in minimizing the agglomeration of nanoparticles in the basefluid. However, the downside of using the one-step approach is the presence of contaminations that are difficult to dispose [20].

Eastman et al. [13], Wang and Xu [18], and Lee et al. [19] adopted two- step approach to form their Al2O3 nanofluids.

Some researchers claim that the two-step process is preferable for forming nanofluids containing oxide nanoparticles, while it is less effective toward nanoparticles of metallic origin [21]. The main disadvantage of the two-step approach is the large aggregation of particles that accompanies the process compared to the one-step method. Despite such disadvantages, this process is still the most popular route for producing nanofluids of large or small quantities and can be used to synthesize almost any kind of nanofluids [22].

Various commercial heat transfer oils such as thermal oil, engine oil, turbine oil and transformer oil possess low thermal conductivity. A slight improvement in the thermal properties of heat transfer oils can lead to a major economic and energy-efficient heat- transfer process.[23]

Intensive research studies are done on the preparation and physicochemical properties of water, ethylene glycol and propylene glycol-based nanofluids for different commercial applications [24-27].

The effective properties of nanofluids have significant impact on the convective heat transfer applications. Effective density and viscous transport properties of nanofluids are crucial for natural convection and forced convection applications. A slight increase in effective density or viscosity of nanofluids can give a negative impact on natural convection heat transfer process [27, 29].

The stability of nanofluids is one of the primary concerns for any industrial application [30]. The smaller size of nanomaterials exhibits large surface area and enhanced van der Waal's attractive forces. Also the electrical double layer repulsive force which tends to separate the particles from each other via steric and electrostatic repulsion mechanisms [31-33]. These attractive forces are the reason of agglomeration among nanomaterial's which causes settling issues. The extensive literature review revealed that different techniques were applied to stabilize nanoparticles in liquids such as ultra-sonication, surfactant addition, surface modification [28,29]. The thermal conductivity of nanofluids is highly dependent on the stability of dispersed nanoparticles in the base fluid. Investigations have confirmed the decrement in overall effective thermal conductivity of unstable nanofluids [24].

Different evaluation methods for the stability of nanofluids were discussed by different researchers [34, 35].

The zeta potential analysis evaluates the stability of nanofluids through the observation of electrophoretic behaviour of the fluid [36]. Adding surfactants, also referred to as dispersant, is an effective stability enhancement method that prevents the agglomeration of nanoparticles within the nanofluid [37].

III. Design

We have done the analysis of shell and tube heat exchanger by taking the following dimensions into consideration.

Parameters	Notation	Unit	Value
Length of heat exchanger	L	mm	1000
Shell inside diameter	Di	mm	254
Shell outside diameter	Do	mm	270
Number of tubes	NT	-	7
Tube outer diameter	do	mm	38.1
Tube inner diameter	di	mm	31.3
Tube pitch	P	mm	50.8
Shell inlet tube inner dia	di(iss)	mm	57
Shell inlet tube outer dia	do(iss)	mm	50
Shell outlet tube inner dia	di(oss)	mm	57
Shell outlet tube outer dia	do(oss)	mm	50
Baffle number	Nb	-	6
Pitch of the baffle	B	mm	100
Thickness of the baffle	Bt	mm	4
Baffle cut	Bc	%	25

We have created 3D model of our heat exchanger in ANSYS on Space claim direct modeller platform as per dimensions mentioned earlier.

Steps for modelling heat exchanger:-

1.Prepare 3D model in ANSYS 2019 R3

2.Mesh the geometry

3.Import the model in fluent

In our geometry shell and outer volume of heat exchanger are having tetrahedral meshing, whereas tubes and inner volume are having hexahedron meshing.

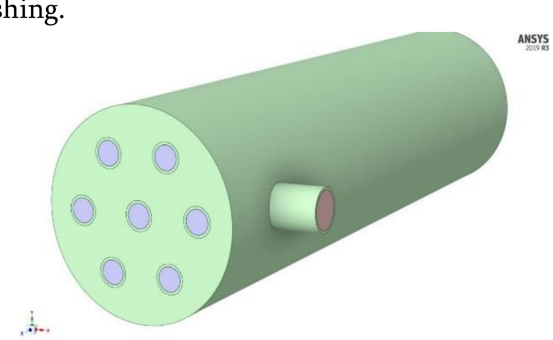

Fig 3.1-ANSYS model of shell and tube heat exchanger with internal volume generated.

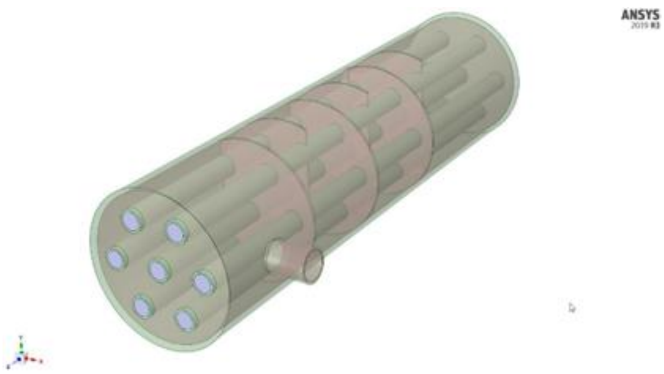

Fig 3.2 - Baffle and tube view

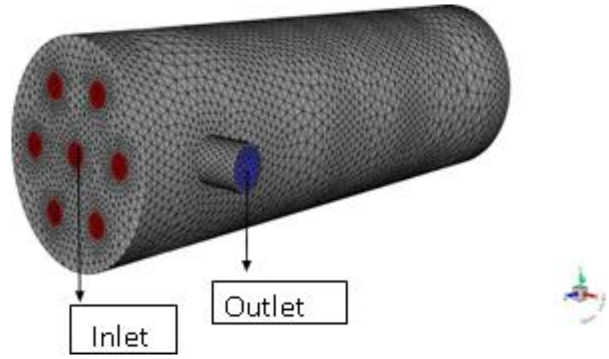

Fig 3.3- Meshed geometry

- Meshed geometry to visualize the internal pipe fluid volume with 50mm max element size for pipe fluid and 150mm max element size for shell fluid volume.
- It also shows fluid flow boundary conditions where red is for inlet flow and blue is for outlet flow.

IV. Procedure

4.1 Replacement of Base fluid

The demand for energy is increasing but the reserves of energy are limited. There is an urgent need for the conservation of energy. One way is to reduce the losses encountered in different types of thermal devices such as heat exchanger and another way is to find a suitable base fluid which will enhance heat transfer.

As heat transfer will increase with the increase in contact surface area so nano particle will provide the better contact surface area than water using nanofluid.

As thermo-physical properties are one of the important parameter for identification of suitable nanofluid we derived the values from the standard formulas. The four main properties are as follows

- Thermal conductivity
- Specific heat
- Density
- Viscosity

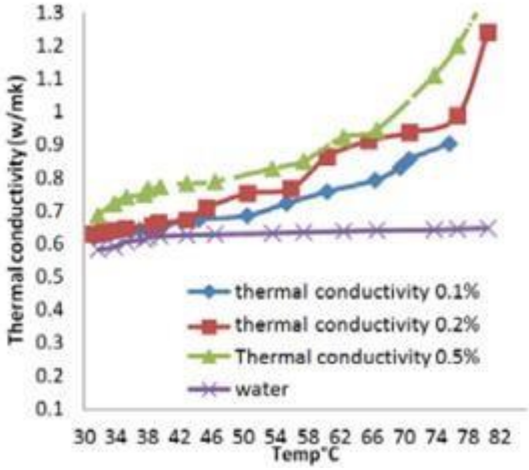

Fig 4.1- Thermal conductivity Vs Temp.

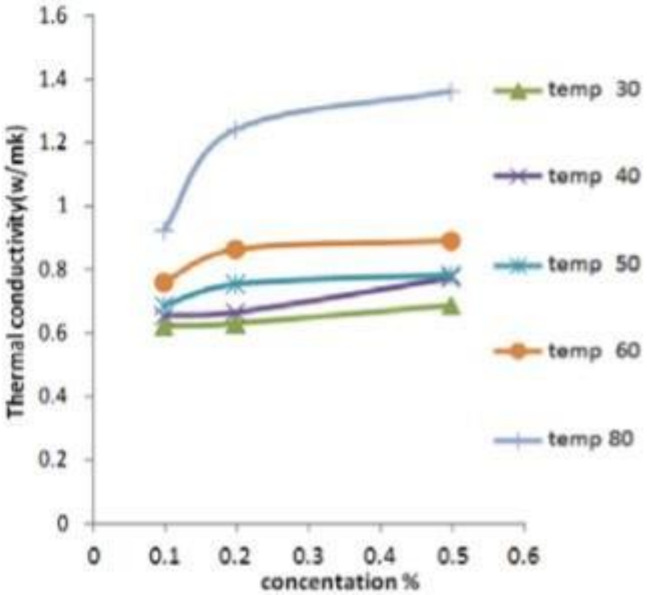

Fig 4.2- Thermal Conductivity Vs Conc.

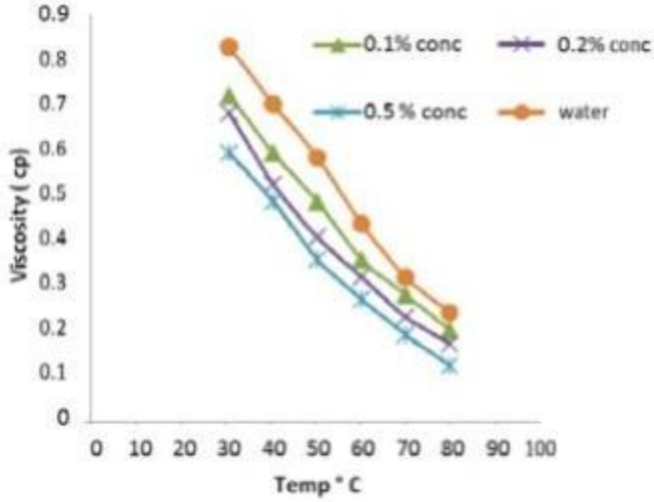

Fig 4.3 – Viscosity Vs Temp.

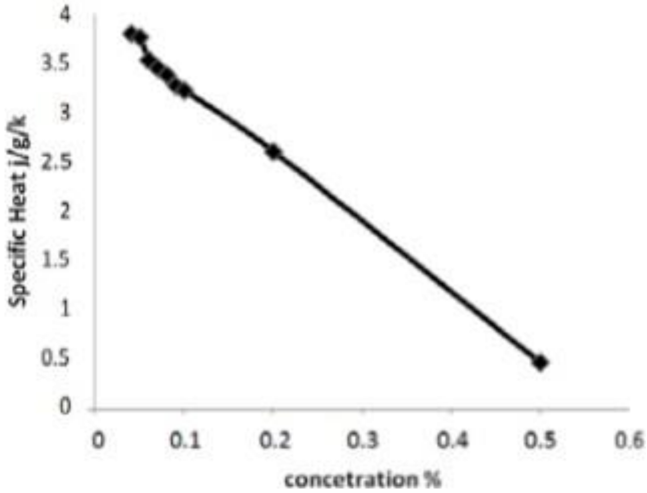

Fig 4.4 – Specific Heat Vs Conc.

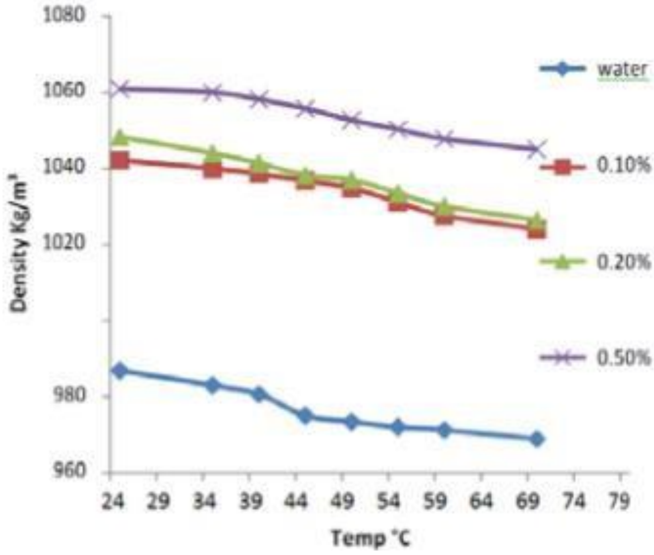

Fig 4.5- Density Vs Temp.

As we can conclude that Al2O3 nanofluid have better properties than water as base fluid so it will improve heat transfer efficiency.

Theoretical calculation

We have performed two experiments, first one by taking water as base fluid and another one by taking Al2O3 nanofluid as base fluid and concluded our theoretical results by keeping inlet temperatures and mass flowrate as constant.

1. Water as basefluid :- In this, water as working fluid is passed along the shell side of heat exchanger as well as inside the tube as basefluid.
2. Al2O3 as basefluid :- In this, water as working fluid is passed along the shell side of heat exchanger and Al2O3 nanofluid in tube side as basefluid.

We have taken thermal properties of Al2O3nanofluid and water into consideration and performed experiment in counter flow condition.

Reynolds number is defined as the product of density time's velocity time's length divided by viscosity coefficient; it is used to predict if the flow will be laminar or turbulent.

Reh =ρhuhDi/μh

Prandtl number is the ratio of kinematic viscosity to thermal diffusivity; it signifies the thickness of thermal boundary layer.

Prh = Cp.h μh/kh

The Nusselt number is the ratio of convective to conductive heat transfer across a boundary; it shows how much is the heat transferred due to fluid motion as compared to heat transfer by fluid by the process of conduction.

Nu= 0.023(Reh) 0.8(Prh) 0.4

The heat transfer coefficient is the heat transferred per unit area per kelvin; it is used to calculate heat transfer.

It is concluded from theoretical calculation that the value of heat transfer coefficient is increased by using nanofluid as compared to water as base fluid.

4.2 CFD Analysis

Theoretical calculation was followed by CFD Analysis, where a model of heat exchanger was prepared in ANSYS and two simulations were done one as water and another as Al2O3nanofluid then results were compared. We did the simulation in ANSYS FLUENT platform with energy equation and k-epsilon Omega model to capture heat transfer and turbulence accurately.

Steps for CFD Analysis:
STEP 1: Prepare 3D Model in Ansys 2019 R3. STEP 2: Mesh the geometry
STEP 3: Generate name selection for inlet, outlet, interface and wall boundary conditions.
STEP 4: Import the mesh in fluent.
STEP 5: In fluent turn on the energy equation for heat transfer calculate.
STEP 6: Turn ON the VISCOUS (SST k-omega) for turbulence.
STEP 7: Define fluid properties according to the calculated properties.
STEP 8: Assign the material to specific cell zones.
STEP 9: Give mass flow input as inlet boundary and pressure output as outlet conditions.
STEP 10: Initialize the simulation.
STEP 11: Run the simulation for 1000 iterations to achieve convergence.

V. RESULTS

In the validation by using CFD Analysis we achieved nearby results with the theoretical results

- In the analysis while using water as base fluid, the shell side outlet temperature was reduced to 73o C from 80o C and in tube side the outlet temperature was increased to 42o C from 35o C.
- Similar analysis by using 0.2% Al2O3 Nanofluid, the shell side outlet temperature was reduced to 71o C from 80o C and in tube side the outlet temperature was increased to 44o C from 35o C.
- Results show that heat transfer coefficient was increased by 7.6% by the use nanofluid compare to water.
- It also shows that pressure drop in tube side inlet while using water as base fluid is 7.15941 Pa and while using nanofluid as base fluid is 6.33122 Pa.

Water as basefluid	Al_2O_3 as basefluid
Dynamic Viscosity:-7.2497 x 10^{-4} kg/ms	Dynamic Viscosity:- 0.6 x 10^{-3}kg/ms
Specific heat:-4.0956 KJ/KgK	Specific heat:- 3.901 KJ/KgK
Conductivity:- 0.621 w/mK	Conductivity:- 0.64w/mK
Density:- 994.03 kg/m^3	Density:- 1043 kg/m^3
M_S:- 0.5 kg/s	M_S:- 0.5 kg/s
M_T:- 0.5 kg/s	M_T:- 0.5 kg/s
T_{Sin}:-80 deg C	T_{Sin}:-80 deg C
T_{Tin}:-35 deg C	T_{Tin}:- 35 deg C
Re:- 4082.05	Re:- 4932.277
Pr:- 4.77	Pr:-3.657
Nu:- 33.25	Nu:- 34.7869
h:- 20.667 w/Km^2	h:- 22.264 w/Km^2

Table 5.1 Calculations of water and Al2O3

5.1 Shell results for water

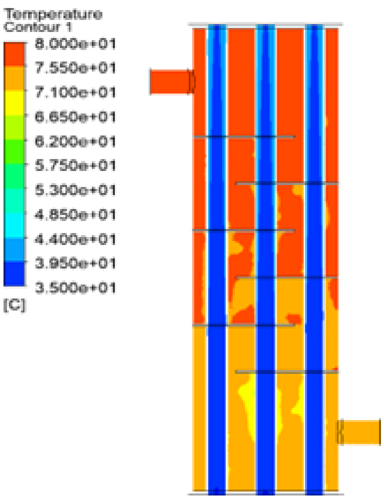

Fig 5.1- Shell result 1 for water

It shows the global contour of temperature for fluid on both sides

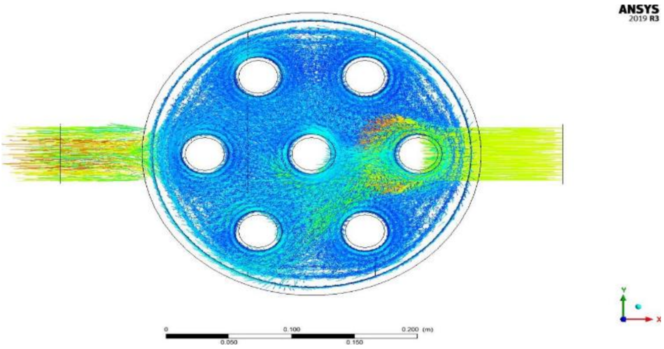

Fig 5.2- Velocity Vector for water

5.2 Shell results for Al2O3:

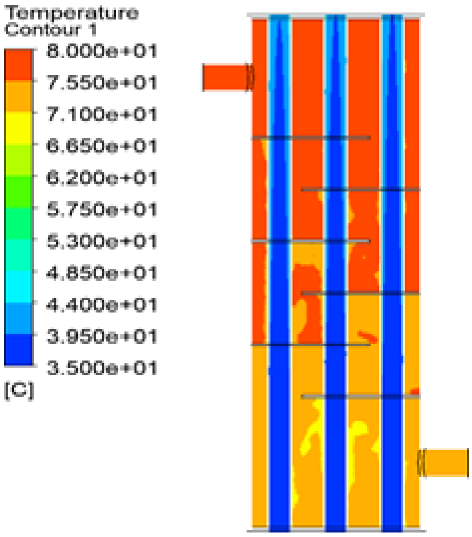

Fig 5.3 - Shell result 1 for nanofluid

It shows temperature contour on local side on section plane for the shell side fluid volume.

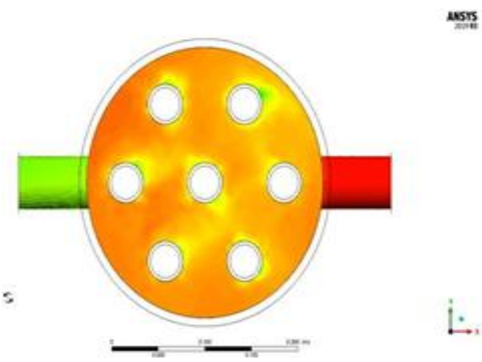

Fig 5.4- Shell result 4 for nanofluid

VI. CONCLUSION

- Analysis shows that if we will use the nanofluid by neglecting the losses and finding the solution of challenges we will get the best fluid for heat transfer which will have good heat transfer coefficient and thermal conductivity.
- Validation shows the possibility of using nanofluid for enhancing the heat exchanger efficiency.
- Analysis shows that the performance of heat exchanger will improve by using suitable nanofluid instead of water as base fluid.
- The heat transfer coefficient of nanofluid is 7.6% more than water only at 0.2% volume concentration.
- By using proper surfactant and method of synthesis, long term stability can be achieved.
- The research also shows that with the increase of concentration and by reducing size of nanoparticle we would get more heat transfer coefficient change.

The prospect of using nanofluids in different applications is related to their thermal and flow properties. Measurement of these properties will be performed in near future in order to access the total improvement in energy efficiency where these fluids are being used.

Despite some undesirable changes such as rising viscosity or decreasing specific heat, we can consider nanofluids as good thermal fluids.

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