COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF SHELL AND SINGLE TUBE HEAT EXCHANGER WITH NANOFLUIDS

Mr. N. MURALIDHAR [1], MARIDI BALA MURALI KRISHNA [2], PANTAM SATISH KUMAR [3], VARNAKAVI TILAK KUMAR [4], VARTHANAPALLI JAYASAI [5], YAMALA DURGA PRASAD [6]

[1] Asst. Professor, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING, Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: muralidharkankati@gmail.com

[2] B.Tech, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING, Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: balumaridi568@gmail.com

[3] B.Tech, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING, Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: Satish77025@gmail.com

[4] B.Tech, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING, Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: kumartilak160@gmail.com

[5] B.Tech, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING, Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: jayasai14243v@gmail.com

[6] B.Tech, Department Mechanical Engineering, WEST GODAVARI INSTITUTE OF SCIENCE AND ENGINEERING Prakasaraopalem, Avapadu, Nallajerla, East Godavari District, Andhra Pradesh, India
E-mail: crazyprasad28@gmail.com

ABSTRACT

The Shell and Tube Heat Exchangers are most commonly used in industries. The shell-and-tube heat exchanger which is the majority type of liquid-to-liquid heat exchanger is used as feed water cooler in process industries, refineries, chemical plants and power plants. It is necessary to operate heat exchanger at optimum condition which serves high thermal efficiency in allowable condition and low running cost

Nanofluids are engineered suspensions of nanoparticles in a base fluid, often water or oil. They exhibit enhanced thermal conductivity and other properties due to the high surface area and unique behaviour of nanoparticles, making them promising for various applications like electronics cooling, solar energy, and biomedical fields. Nano-fluids have diverse applications.

Applications:

Heat Transfer Enhancement: Used in cooling systems of electronics, engines, and industrial processes to improve efficiency and heat dissipation.

Solar Energy: Enhancing the heat transfer properties of heat transfer fluids in concentrated solar power systems.

Biomedical: Utilized in hyperthermia treatment for cancer, drug delivery systems, and

bioimaging due to their unique properties at the nanoscale.

Manufacturing: Enhancing lubricants and cutting fluids to improve machining processes in manufacturing industries.

HVAC Systems: Improving the efficiency of heating, ventilation, and air conditioning systems by enhancing the thermal conductivity of coolants.

Energy Storage: In thermal energy storage systems to improve efficiency and heat transfer rate

In this study, four nanofluids Al2O3, CCl2, CuO, and TiO2 are tested at varying velocities on five different geometries, shell and tube heat exchanger, shell and tube heat exchanger with discs, shell and heat exchanger with discs and horizontal plate, shell and tube heat exchanger with holed discs, shell and tube heat exchanger with discs and holed horizontal plates respectively. The experiments were conducted to determine the maximum surface heat transfer coefficient of outer tube wall at various flow velocities 1.36 m/s, 1.6 m/s, and 2.17m/s.

1. INTRODUCTION

Heat Exchangers

Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronics cooling, air-conditioning, refrigeration, and automotive applications. In this thesis we will examine the basic theory of heat exchangers and its applications. In addition, we will examine various aspects of heat exchanger design and analysis.

1.1 HEAT EXCHANGER CLASSIFICATION

Due to the large number of heat exchanger configurations, a classification system was devised based upon the basic operation, construction, heat transfer, and flow arrangements. The following classification as outlined by Kakac and Liu (1998) will be discussed:

Recuperators and Regenerators

Transfer processes: direct contact or indirect contact

Geometry of construction: tubes, plates, and extended surfaces

Heat transfer mechanisms: single phase or two-phase flow

Flow Arrangement: parallel flow, counter flow, or cross flow

1.2 TYPES OF HEAT EXCHANGERS

Heat exchangers are vital in various industrial applications, enabling efficient heat transfer between fluids or surfaces. They come in various designs and configurations, each with advantages and limitations. In this section, we will explore some of the most common types of heat exchangers.

Understanding the characteristics and capabilities of each type of heat exchanger is crucial in selecting the appropriate heat exchanger for specific industrial processes, ensuring efficient Heat transfer and overall system performance.

Shell and tube heat exchanger

Plate heat exchanger

Finned tube heat exchanger

Double pipe heat exchanger

Spiral heat exchanger

1.2.1 SHELL AND TUBE HEAT EXCHANGER:

A shell-and-tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

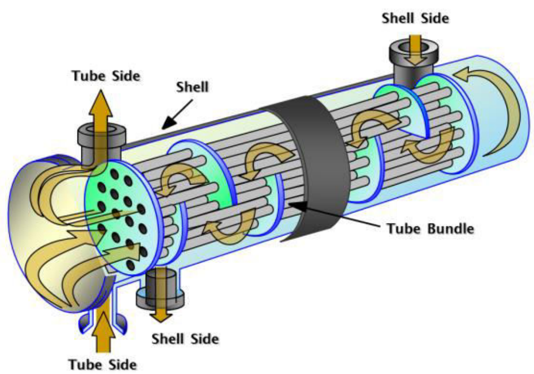

Fig.1.1 Shell and tube heat exchanger

1.2.2 PLATE HEAT EXCHANGER:

Plate heat exchangers consist of relatively few parts. Because plate heat exchangers are used for transferring heat, they require inlets and outlets where the flowing mediums -or fluids- can enter and leave the heat exchanger. A fluid may be a liquid or a gas. As fluids are often assumed to be liquid only, we will use the term flowing medium to avoid confusion.

Gaskets and plates are used to separate the flowing mediums and prevent them mixing; gaskets are adhered to one side of each plate only. The plates hang upon a carry bar and are pressed together using clamping bolts. When the plates are compressed together, they are referred to as a 'plate stack'. A guide bar ensures the plates are aligned correctly when the plate stack is opened and closed.

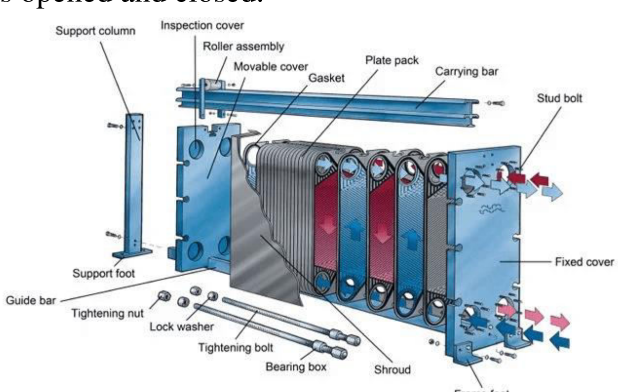

Fig.1.2 Plate heat exchanger

1.3 NANOFLUIDS

Nanofluids are used to increase the thermal conductivity of the base fluid because in pure form the liquids like water do not show good thermal conductivity. Nanofluids are gaining importance due to its applications in cooling and heating processes.

Nanofluids are constructed by the suspensions of nanoparticles. Generally, nanoparticles are made of metals, oxides, carbides, graphene and carbon nanotubes and the base liquids are glycol, engine oil, water etc. Among nanoparticles graphene is one of the most important nanomaterials.

Graphene has been envisaged as a highly promising material for various field emission devices, super-capacitors, photo catalysis, sensors, electro-analytical systems, fuel cells and photovoltaics. Graphene oxide nanosheets generates a thermal conductivity improvement of 30, 62 and 76% at a particle loading of 5 vol.% for the three different base fluids, distilled water, propylene glycol and liquid paraffin respectively which shows that the observed enhancement is higher than Effective Medium Theory (EMT).

Graphene shows continuous electrical conducting behaviour even at zero carrier concentration because the electrons motion in graphene is very high in contrast with other existing nanomaterials.

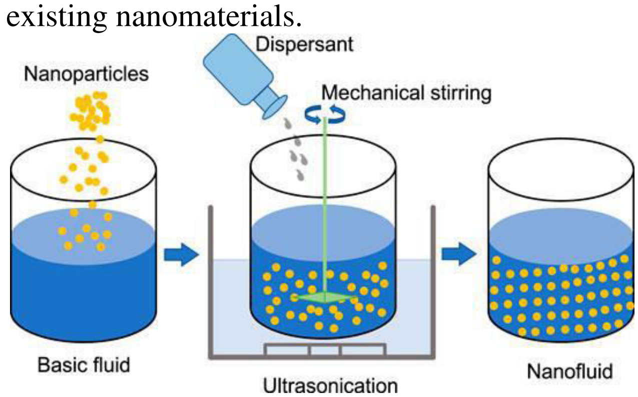

Fig.1.3 Nano Fluids

2. LITERATURE SURVEY

Literature on nanofluids reviews their thermal properties, applications across industries, challenges such as stability, and opportunities for modelling and simulation to optimize their performance.

2.1 THERMAL PROPERTIES

Numerous studies investigate the thermal conductivity, convective heat transfer, and viscosity of nanofluids, exploring the effects of nanoparticle concentration, size, and shape.

2.2 APPLICATIONS

Research delves into the application of nanofluids across industries, including electronics cooling, solar energy systems, automotive cooling, and biomedical engineering, highlighting their potential for enhancing heat transfer efficiency.

2.3 STABILITY AND DISPERSION

Investigations focus on methods for stabilizing nanoparticles within the fluid matrix and improving their dispersion to prevent aggregation and sedimentation, crucial for practical applications.

2.4 MODELLING AND SIMULATION

Computational studies develop models and simulations to predict the thermal and rheological behaviour of nanofluids, aiding in the design and optimization of nanofluid-based systems.

2.5 CHALLENGES AND OPPORTUNITIES

Literature addresses challenges such as cost-effectiveness, long-term stability, and environmental impact, while also identifying emerging opportunities for further research and technological advancements in nanofluid science.

By synthesizing findings from these studies, researchers aim to advance our understanding of nanofluid behaviour and facilitate the development of innovative applications with practical significance.

3. PROPOSED SYSTEM

3.1 CFD SIMULATION

CFD simulation employs numerical methods to analyse fluid flow, heat transfer, and other phenomena within a specified domain. It's widely used in engineering for optimizing designs, predicting performance, and understanding complex fluid dynamics. Key steps involve domain discretization, solving governing equations, and post-processing results for insights into flow behaviour and performance characteristics.

3.2 INTRODUCTION

Computational Fluid Dynamics (CFD) is a powerful numerical tool for analysing fluid flow, heat transfer, and related phenomena. It involves discretizing the governing equations of fluid motion into a set of algebraic equations, which are then solved using numerical methods. CFD has diverse applications in industries such as aerospace, automotive, environmental engineering, and biomedical engineering. By simulating fluid flow and heat transfer processes, CFD enables engineers and scientists to optimize designs, predict performance, and understand complex fluid behaviour. Key advantages of CFD include its ability to explore a wide range of operating conditions and geometries, often at a fraction of the cost and time of experimental methods. However, accurate CFD simulations require careful consideration of factors such as mesh quality, turbulence modelling, and boundary conditions. Overall, CFD plays a crucial role in advancing engineering knowledge and innovation by providing insights into fluid dynamics that are difficult or impossible to obtain through traditional experimental techniques alone.

3.3 BASIC GOVERNING EQUATIONS

The Reynolds Averaged Navier-Stokes equations (also known as RANS equations) are equations used to predict the fluid flow using a time averaged formulation. The primary concept applied is Reynolds decomposition which involves decomposing an instantaneous quantity into its time averaged and fluctuating quantities. The time averaged nature of its equations makes it an attractive choice while simulating turbulent flows. Considering certain approximations based on the knowledge of properties of turbulent flows, these equations can be used to give time averaged solutions to the Navier– Stokes.

3.4 LAMINAR VISCOUS MODEL

In ANSYS, particularly within its CFD (Computational Fluid Dynamics) software like ANSYS Fluent and CFX, the Laminar Viscous model is a specific setting used to simulate fluid flow that exhibits laminar characteristics.

3.4.1 LAMINAR VISCOUS MODEL IN ANSYS

ANSYS offers various flow models within its CFD software. The Laminar Viscous model is selected when the flow conditions are expected to be laminar, neglecting turbulence effects. By activating this model, ANSYS solves the governing equations of fluid mechanics considering the viscous forces within the fluid. These equations account for the interaction between fluid layers due to viscosity.

The Laminar Viscous model is computationally simpler compared to turbulence models, leading to faster simulation times.

However, it's crucial to ensure the flow is indeed laminar for accurate results. You can estimate the flow regime using the Reynolds number, a dimensionless quantity that indicates the transition from laminar to turbulent flow.

3.5 INTRODUCTION TO ANSYS SPACE CLAIM

When it comes to modelling, Ansys Space Claim is perfect for engineers seeking 3D answers but lack the time or desire to grasp the traditional CAD systems. It gives you the resources you need to expedite geometry preparation, leap straight into simulation, and cut short the design-related delays.

1.Edit, repair and create any geometry

2.De-feature CAD models, extract fluid domains or simplify models for simulation

3.Leverage scan data to reverse engineer new parts

4.Prepare models for manufacturing steps and maximise machining time

5.Create, import, or repair sheet metal designs

6.STL prep for 3D printing

3.5.1 LEARNING OUTCOMES

Following completion of this course, you will be able to:

1.Create a new geometry from scratch in Ansys Space Claim.

2.Repair an imported geometry in Ansys Space Claim.

3.Extract the fluid volume from solid bodies

4.Create and edit an enclosure around a body.

5.Create Named Selections and parameters in Ansys Space Claim.

6.Import the geometry to Ansys Workbench with the Named Selections and the Parameters.

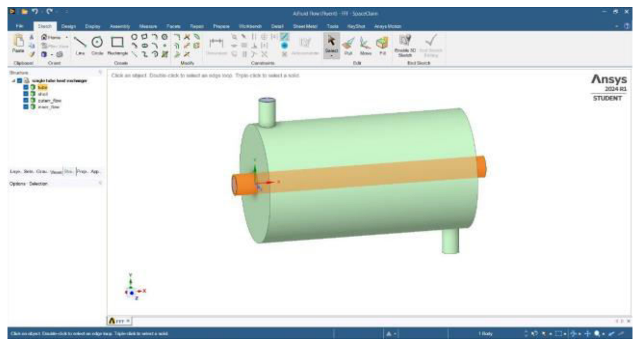

Fig.3.1 Shell and single tube heat exchanger geometry

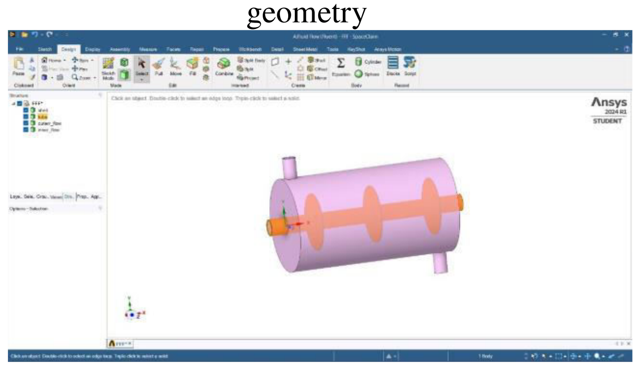

Fig.3.2 Shell and single tube heat exchanger with discs geometry

The results can be analysed both numerically and graphically. The postprocessor takes the numerical results and displays them as a visual representation. It displays a visual image of the physical geometry through which the fluid flows, with the option of printing a hard copy of all the results as tables of numbers and other means. It is possible to superimpose the velocity, pressure, and temperature distributions within the fluid. The format of this display is a graphical contour with the option of displaying scaled arrows for vector quantities. The output file can contain all sorts of information, including the spatial coordinates of all of the cells in the computational mesh and the solved transport variables for each cell. ANSYS WORKBENCH is the most popular commercial software package used to solve complex fluid flow and heat transfer problems using CFD program. ANSYSWORKBENCH is a graphical user interface that allows the user to use the tools from a single place. To solve the engineering problem the necessary steps are:

1.Geometry
2.Mesh
3.Physical setup
4.Numerical solution
5.Result verification

4. RESULTS

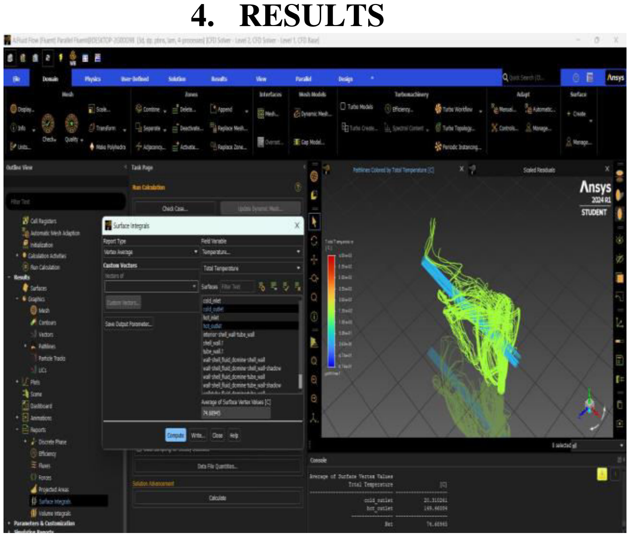

Fig.4.1 Hot and cold outlet temperature of shell and single tube heat exchanger by using TiO2 nanofluid at 1.6 cold fluid inlet velocity

In our CFD analysis of the heat exchangers consisting of shells and tubes, we used Al2O3 as the working nanofluid with an intake velocity of 2.7 m/s. In this case, heated water runs through the shell of the heat exchanger, while the nanofluid Al2O3 flows through the tube. Finally, temperature and surface heat transfer coefficients are determined. In this scenario, the temperature ranges from 20.54199C to 148.93817oC.

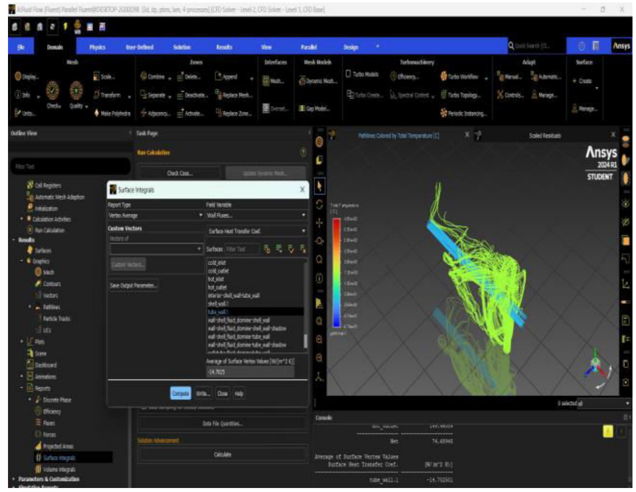

Fig.4.2 Surface heat transfer coefficient of outer tube wall of shell and single tube heat exchanger by TiO2 nanofluid at 1.6m/s cold inlet velocity

The surface heat transfer coefficient value of the tube exterior wall profile is 83.182341 W/m2k due to the obstruction caused by the discs and horizontal plate on the tube profile, the hot fluid circulates more uniformly than in other circumstances

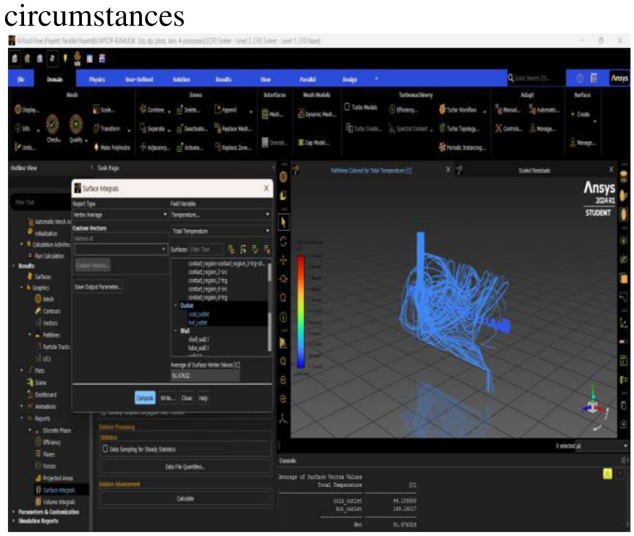

Fig.4.3 Hot and cold outlet temperature of shell and single tube heat exchanger with discs by using ClC2 nanofluid at 1.36 cold fluid inlet velocity

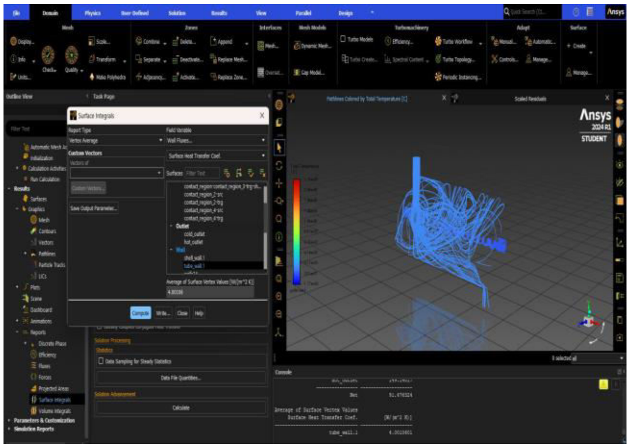

Fig.4.4 Surface heat transfer coefficient of outer tube wall of shell and single tube heat exchanger with discs by ClC2 Nanofluid at 1.36m/s cold inlet velocity

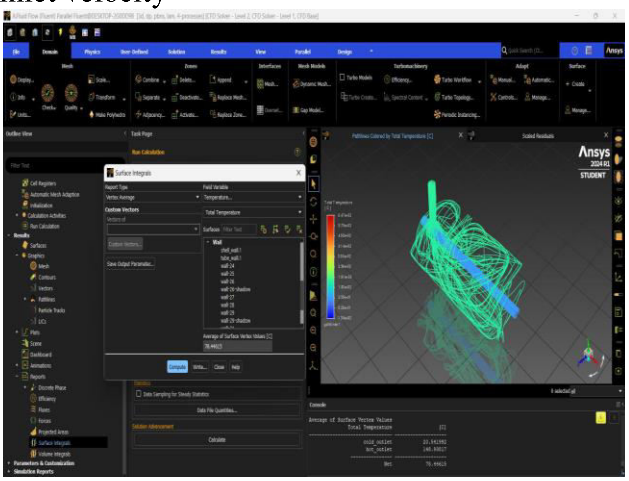

Fig.4.5 Hot and cold outlet temperature of shell and single tube heat exchanger with discs and horizontal plate by using Al2O3 nanofluid 2.17m/s cold fluid inlet velocity

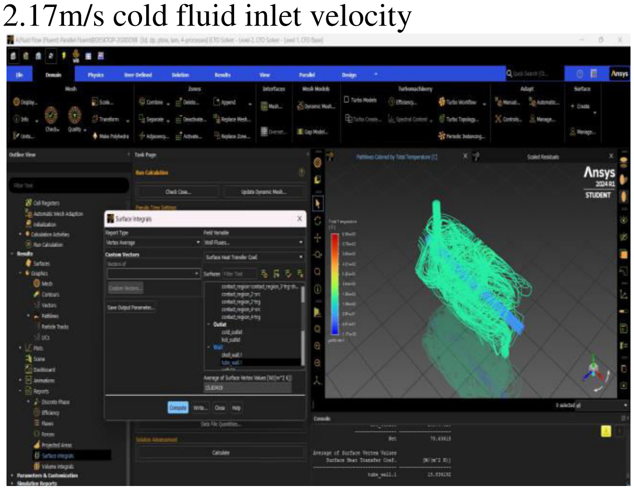

Fig.46 Surface heat transfer coefficient of outer tube wall of shell and single tube heat exchanger with discs and holed horizontal plate by CuO nanofluid at 2.17m/s cold inlet velocity

5. CONCLUSION

In this study, four nanofluids Al2O3, CCl2, CuO, and TiO2 are tested at varying velocities on five different geometries, shell and tube heat exchanger, shell and tube heat exchanger with discs, shell and heat exchanger with discs and horizontal plate, shell and tube heat exchanger with holed discs, shell and tube heat exchanger with discs and holed horizontal plates respectively. The experiments were conducted to determine the maximum surface heat transfer coefficient of outer tube wall at various flow velocities 1.36 m/s, 1.6 m/s, and 2.17 m/s. Based on the preceding experiments, the following conclusions are made.

1. Increasing the cold fluid inlet velocity leads to higher surface heat transfer coefficients of the exterior tube wall.
2. Nanofluids exhibit strong surface heat transfer coefficients in shell and single tube heat exchangers using disc and horizontal plates when compared to other geometries
3. Al2O3 nanofluid has the highest heat transfer coefficient among all nanofluids, regardless of geometry.

Future Scope:

The demand for high heat transfer rates with little pressure drop has remained constant throughout the years, while technological improvements strive to reduce energy consumption and prices for these units. Innovations in heat transfer enhancement techniques are now moving toward the use of fluid additives such as nanofluids (NFs), which are colloidal distributions of nanoparticles (e.g. metals, oxides, CNTs, or carbon nanotubes) in base fluids commonly used as coolants, such as oil, water, and ethylene glycol. These additives, which are typically less than 5 volume (vol%)

percent, were found to improve the thermophysical properties of the working fluid, making them excellent options for satisfying high heat transfer requirements because nanotechnology is a relatively young field, the open literature cannot provide a concrete and unified judgment about the amount of the overall enhancement provided by nanofluids on heat transfer systems. Studies that used such fluids as coolants for plate and tube heat exchangers discovered a range of improvements in heat transfer.

Shell and single tube heat exchangers lie in improving efficiency, reducing size and weight, enhancing materials for better heat transfer, and integrating advanced technologies like nanotechnology or additive manufacturing. Additionally, exploring applications in sustainable energy systems, such as geothermal or solar thermal, could open up new avenues for innovation. Finally, considering the growing demand for compact and efficient heat exchangers in various industries, there's potential for research in optimization algorithms and computational modelling to further enhance performance.

This project helps in attaining the useful knowledge about surface heat transfer coefficient of Shell and tube heat exchangers. As the project is a part of research and learning project, students can carry forward the project and gain the knowledge of CFD and Heat Exchangers. Our project can also be carried by our juniors for learning and research.

REFERENCES

[1] W. Duangthongsuk
An experimental study on the heat transfer performance and pressure drop of TiO2-water nanofluids flowing under a turbulent flow regime
Int. J. Heat Mass Transf. (2010)

[2] J. Albadr
Heat transfer through heat exchanger using Al2O3 nanofluid at different concentrations
Case Stud. Therm. Eng. (2013)

[3] Y. He
Numerical investigation into the convective heat transfer of TiO2 nanofluids flowing through a straight tube under the laminar flow conditions
Appl. Therm. Eng. (2009)

[4] P. Selvakumar
Convective performance of CuO/water nanofluid in an electronic heat sink
Exp. Therm. Fluid Sci. (2012)

[5] S.M. Fotukian
Experimental study of turbulent convective heat transfer and pressure drop of dilute CuO/water nanofluid inside a circular tube
Int. Commun. Heat Mass Trans. (2010)

[6] C.T. Nguyen
Heat transfer enhancement using Al2O3–water nanofluid for an electronic liquid cooling system
Appl. Therm. Eng. (2007)

[7] S. Zeinali Heris, M. Nasr Esfahany, S.G. Etemad
Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube
Int. J. Heat Fluid Flow, 28 (2) (2007)

[8] W. Williams, J. Buongiorno, L.-W. Hu
Experimental investigation of turbulent convective heat transfer and pressure loss of alumina/water and zirconia/water nanoparticle colloids (nanofluids) in horizontal tubes
J. Heat Transfer, 130 (4) (2008)

[9] D.H. Fax, R.R. Mills
Generalized optimal heat exchanger design
ASME Trans., 79 (1957)