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Designing & Developing a Porous based Box-Type Heat Exchanger for Enhanced Heat Transfer Rate

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Abstract: The shell-and-tube heat exchanger's geometric configuration is optimized during the design development phase by taking into account various aspects like baffle spacing, tube arrangement, and overall system integration. Incorporating a blower into the system results in improved air circulation and effective heat transfer. By placing the band heater in a strategic location, air is heated precisely and locally, which helps to create a more responsive and controlled heating process. One essential tool for assessing the system's thermal and fluid dynamics is CFD analysis. The heat exchanger, blower, and band heater components' fluid flow patterns, temperature distributions, and pressure gradients are investigated through simulations. The CFD analysis provides valuable insights that guide design modifications aimed at optimizing heat transfer rates, minimizing pressure drops, and improving the integrated system's overall performance.
Keywords: Shell, Tube, Baffle, Band Heater & CFD analysis.

I. INTRODUCTION

The design and development of a shell-and-tube heat exchanger, coupled with a blower and band heater for hot air supply and a water motor for cold water supply, represent an innovative and versatile thermal system. This multifunctional design seeks to efficiently address diverse heating requirements by integrating a blower for enhanced air circulation, a band heater for localized water heating, and a water motor for controlled cold water supply.[2] The synergy of these components aims to optimize the heat exchange process, providing simultaneous hot air and water heating. The incorporation of Computational Fluid Dynamics (CFD) analysis into the design process further ensures a comprehensive understanding of fluid dynamics, thermal performance, and system efficiency. This integrated approach holds promise for applications across various industries, offering an adaptable and energy-efficient solution for the simultaneous provision of hot air and heated water.[1]

A. Problem Definition

The main difference between a normal heat exchanger and a porous-based heat exchanger lies in the nature of the heat transfer medium and how it affects heat exchange efficiency and other characteristics. In a normal heat exchanger, the heat transfer occurs through a solid wall or a direct contact interface between two fluids. The fluids do not mix, and the heat is conducted through the separating barrier. Heat transfer efficiency depends on the surface area of contact between the fluids and the thermal conductivity of the separating material. In general, normal heat exchangers are efficient for transferring heat between non-reacting fluids. Achieving higher heat transfer rate thorough porous & Nano particles. Normal heat exchangers may exhibit pressure drops due to changes in fluid direction, turbulence, and flow restrictions caused by the geometry of the heat exchange surfaces.

B. Objective

1) To design and CFD analyse the heat transfer effect using Catia v5 & Ansys Workbench before manufacturing the proposed system.
2) To purchase, Fabricate the required frames as per the design modulation.
3) To increase the heat transfer rate with the available porous & nano particles material.
4) To maximize the temperature distributions by capturing the heat in porous bed form.
5) To conduct an experiential setup and note the reading upon time dependent factor.

II. LITERATURE SURVEY

Yue Hu1, Per Kvols Heiselberg [1] In this paper, a new window application—a ventilated window with a Phase Change Material (PCM) heat exchanger—is proposed. When ventilation pre-cooled air is available, the summertime night ventilation mode is used to release energy stored in PCM by the surrounding cold air, which can then be reloaded. The PCM ventilation system is assessed using numerical models that are constructed and validated through large-scale experiments.[1]

Because of their high latent heat, phase change materials (PCM) can store thermal energy over a narrow temperature range. In addition to thermal conductivity, density, and phase change enthalpy, viscosity based on temperature must be characterized when designing a thermal energy storage (TES) system with PCMs in order to account for natural convection.

Utilizing the resources of various research groups operating within a global network, a series of cooperative experiments were conducted to ascertain the viscosity of two PCMs—octadecane and the commercial paraffin RT70 HC—based on their respective temperatures.[2]

Buildings use an astounding amount of electricity—up to 45% of all energy used globally. One passive cooling method used in buildings to lower indoor heat input, enhance heat absorption, and prevent heat buildup is phase change materials (PCM). The use of PCM for thermal energy storage can raise a building's overall heat capacity. PCMs with enormous energy densities have sparked strong interest in developing high thermal inertia structures with significant energy savings.[3]

The current study focuses on the thermal performance of a heat exchanger based on encapsulated phase change material (PCM) for building thermal management in Indian settings. Through experimental investigation, the encapsulated PCM-based heat exchanger's heat transfer characteristics are examined, and comparisons with radiant panel and thermally activated roof systems are made. The test chamber of an experiment is a small concrete cube with a window facing north. It is discovered that an enclosed PCM-based heat exchanger can lower the mean air temperature by more than 6 C and the test chamber's heat gain by about 50%.[4]

III.PROPOSED SYSTEM

A. Working & Proposed Design

In order to maximize thermal performance and versatility, a methodical process is employed in the design development of a shell-and-tube heat exchanger integrated with a blower and band heater for air supply and water heating. First, the heat exchanger's geometry is designed, taking into account elements like the configuration of the tubes, the distance between the baffles, and the placement of the blower and band heater. While the band heater precisely and locally heats the air, the blower promotes improved air circulation. Durability, thermal efficiency, and corrosion resistance are all dependent on the choice of material and integration of components. Iterative improvements are made to the system with the goal of reaching the best possible heat exchange performance for both water and air.

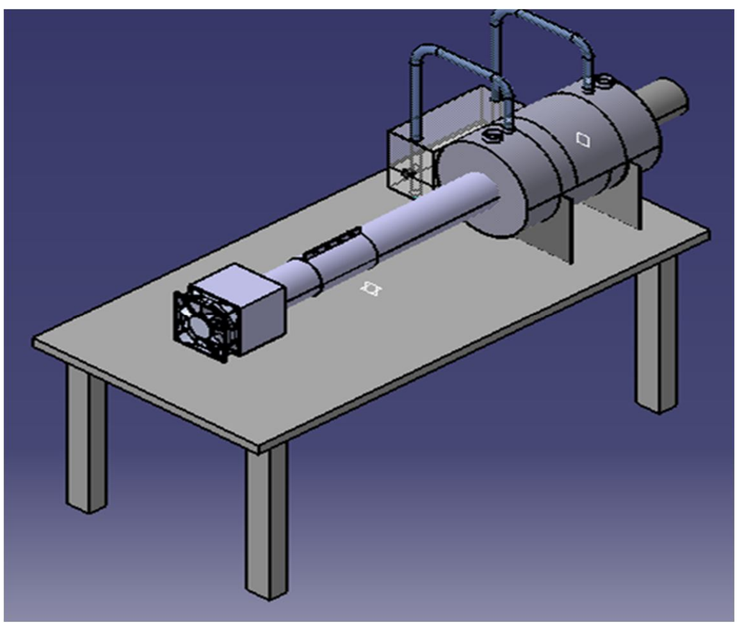

Figure 1. ISO View of Proposed system

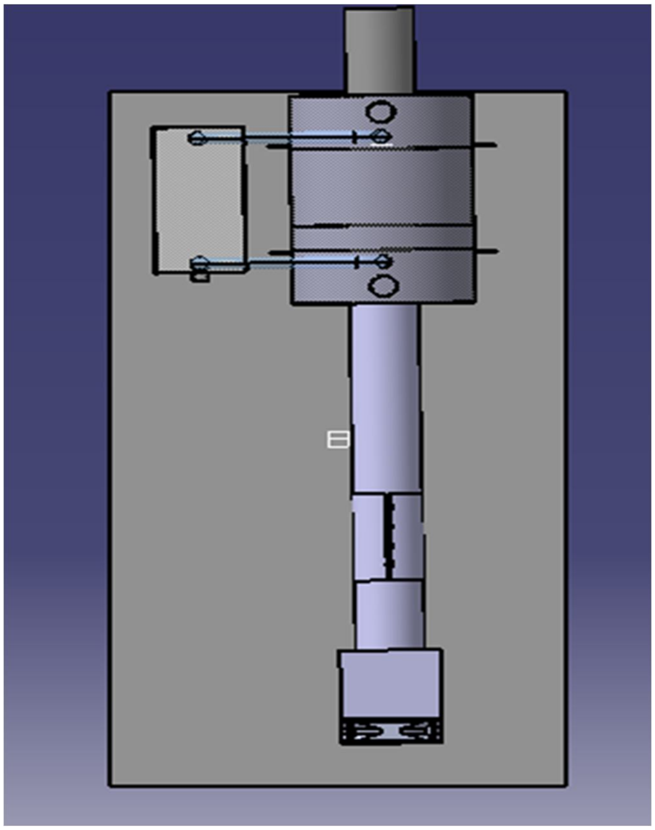

Figure 2. Top View of Proposed system from Catia v5 Software

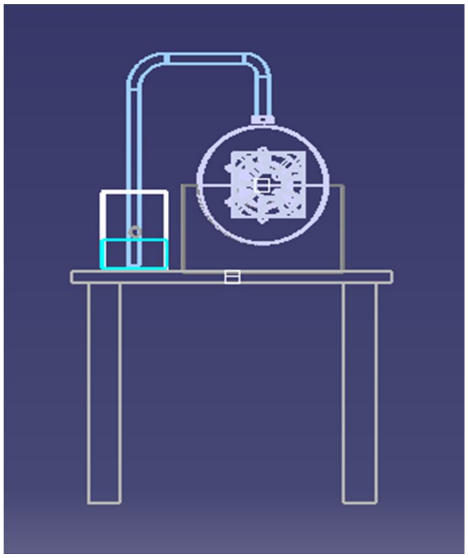

Figure 3. Side View of Proposed system from Cati V5 Software.

B. Analytical Formulas used in the projects

1) Log Mean Temperature Difference (LMTD)

$$LMTD = \frac{T1}{In\left(\frac{T1}{T2}\right)}$$

$$T1 = Thi - Tco$$

$$T2 = Tho - Tci$$

2) Effectiveness

$$e = \frac{Thi - Tho}{Thi - Tci}$$

3) NTU

$$NTU = \frac{(-In)\left(\frac{1-e}{1+e}\right)}{1-c}$$

The heat transfer area is a crucial parameter and is determined based on the heat transfer rate required for the specific application.

$$Q = U.A.\nabla Tlm$$

Where:
Q is the heat transfer rate,
U is the overall heat transfer coefficient,
A is the heat transfer area,
∇Tlm is the log mean temperature difference.

Overall heat transfer co efficient

$$U = \frac{1}{Rtotal}$$

$$Rtotal = total\ thermal\ resistance.$$

IV. COMPONENTS DESCRIPTION

Main Component of Proposed Heat Exchanger
1) Outer Shell
2) Copper Tubes
3) Baffles
4) Outer Tube
5) Blower
6) Band Heater
7) Temperature sensor
8) Water Motor

A. Outer Shell

In the field of thermal engineering, the outer shell and tube heat exchanger is a basic and often used apparatus that is essential to many industrial processes. This kind of heat exchanger has a bundle of tubes inside a cylindrical outer shell. Its principal function is to enable the effective transfer of heat between two fluids—one circulating through the tubes and the other encircling the tubes' exteriors inside the shell.

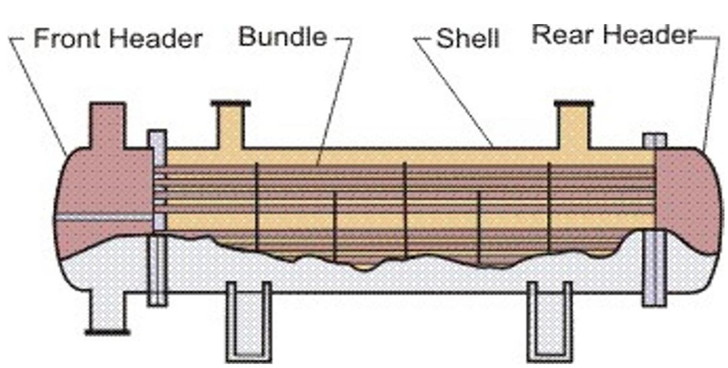

Figure 4. Shell & Tube Heat Exchanger (https://www.thermopedia.com/es/content/1121/)

Guage	Thickness mm	Weight kg/sq.m
8	4	31.4
9	3.55	27.9
10	3.15	24.75
11	2.8	22
12	2.5	19
13	2.25	17.6
14	2	15.7
15	1.8	14.15
16	1.6	12.55
17	1.4	11
18	1.25	9.8
19	1.12	8.8
20	1	7.85
21	0.9	7.05
22	0.8	6.3
24	0.63	4.95
26	0.5	3.9
28	0.4	3.15

Table 1 sheet metal STD thickness and weight

B. Copper Tube

Due to its many advantageous qualities, such as its high thermal conductivity, resistance to corrosion, and malleability, copper is a great material choice for the heat exchanger tubes.

Figure 5. Copper tube (https://www.indiamart.com/proddetail/copper-tubes-for-heat-exchanger-condensers-23256009530.html)

Figure 6. Copper tube with baffle plate (Manufactured)

Material Properties of copper tube

1) The accepted value of the specific heat of copper is 0.385 J/g·°C.
2) Thermal Conductivity of Copper – 398 W/m•K.
3) Copper (Cu) in pure form is a reddish-brown metal with high ductility and malleability. The atomic weight is 63.54, atomic number is 29, and the density is 8.94 g/cm3.

C. Baffle plate

A baffle plate is a type of plate used to control or limit fluid flow. In shell and tube heat exchangers, baffles are parts that hold the tubes in place and provide support. Drilling is the primary machining procedure used on baffle plates.

Figure 7. Baffle Plate (https://www.gzcladplates.com/products/clad-tube-sheet.html)

D. Blower

A blower is a mechanical device that creates a flow through a pipe, enclosure, or duct to move air or other gases. It supports operations like heating, cooling, ventilation, and pneumatic conveying and has numerous uses in a variety of industries. Blowers differ from fans in that they are frequently utilized in situations where it is necessary to overcome resistance in a duct system and are typically made to generate higher pressure.

Figure 8. Blower for air Supply (https://www.mouser.in/ProductDetail/Delta-Electronics/BFB0724H?qs=%2FW4LtXOBxKvyNCiuJ6oyaw%3D%3D)

E. Band Heater

An electric heating element known as a band heater is usually made to fit around a cylindrical or spherical object, like pipes, barrels, or containers, in order to provide precise and effective heat. When precise heating of particular tools or materials is needed, industrial and manufacturing processes frequently use these heaters.

Figure 9. Band Heater (https://www.indiamart.com/proddetail/mica-band-heaters-4630704288.html)

Temperature Range(C)	-50 to +110
Temperature Display Resolution	0.1
Temperature Measurement Accuracy(C)	1
Display Dimensions(mm)	48x29x16
Cable Length (Meter)	1

Table 2. Specification of band heater

F. Temperature Sensor

It has a probe for temperature measurement in specific locations. To measure the water temperature in the fish tank, submerge the probe; the LCD will show HC (higher than 110C) or LC (lower than -50C) depending on the temperature.

Figure 10. Digital temperature (Amazon)

V. CFD ANALYSIS

A. Steps in creating CFD analysis

1) Import 3D Model:
2) Setup Geometry
3) Mesh Configuration
4) Defining Physics & Named Selections.
5) Material application
6) Boundary Conditions
7) Solver Setup
8) Extract all required results

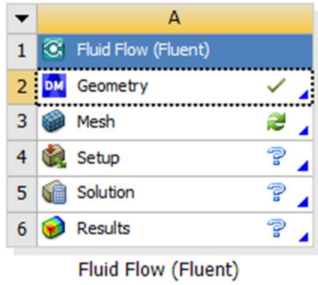

Figure 11. Geometry Importation to Setup

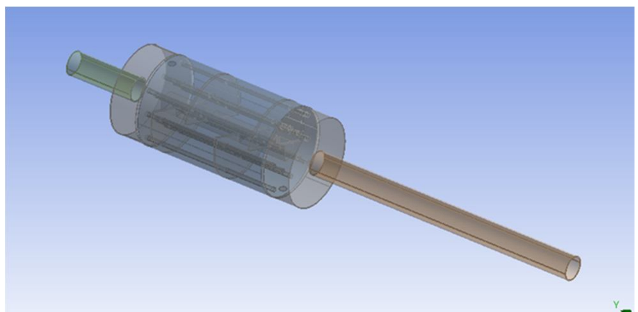

Figure 12. Imported geometry Modification in design Modeler

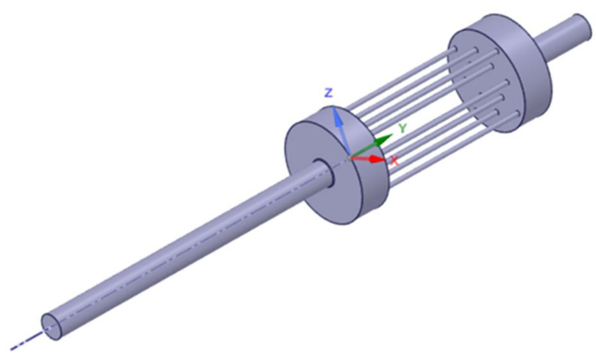

Figure Air Domain Created in the Heat Exchanger modal

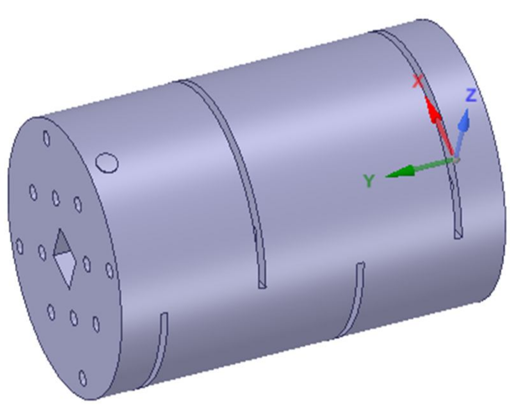

Figure 14. Water Domain

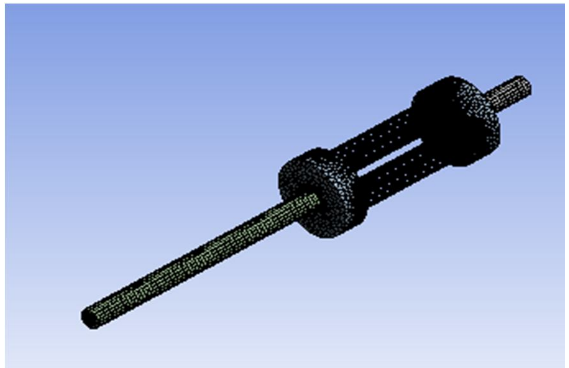

Figure 15. Mesh Configuration

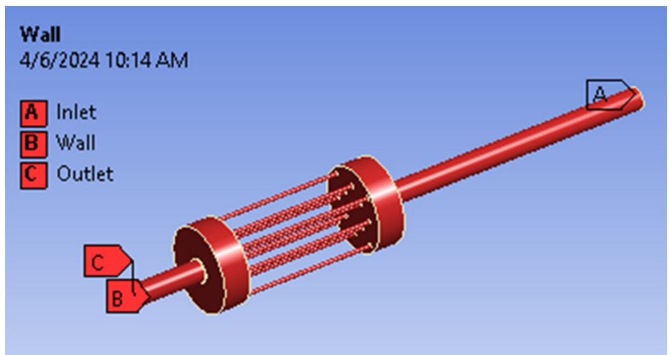

Figure 16. Named Selection for Air Domain Inlet & Outlet

B. *Solver Output & Boundary's*

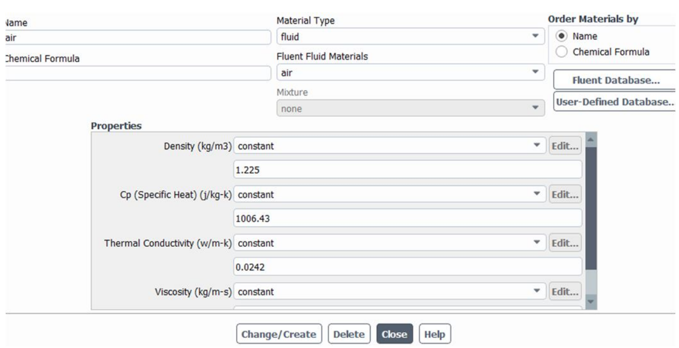

Figure 17. Air Properties

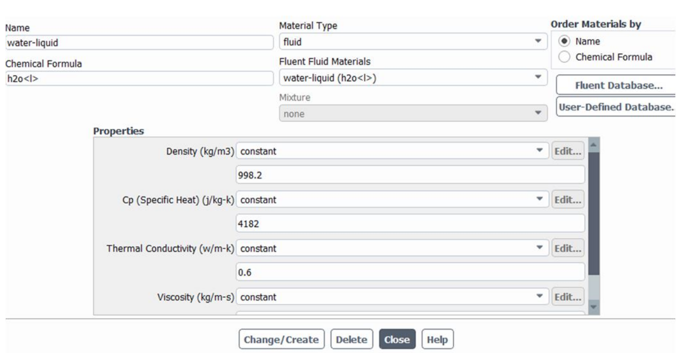

Figure 18. Water Properties

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C. Boundary Conditions

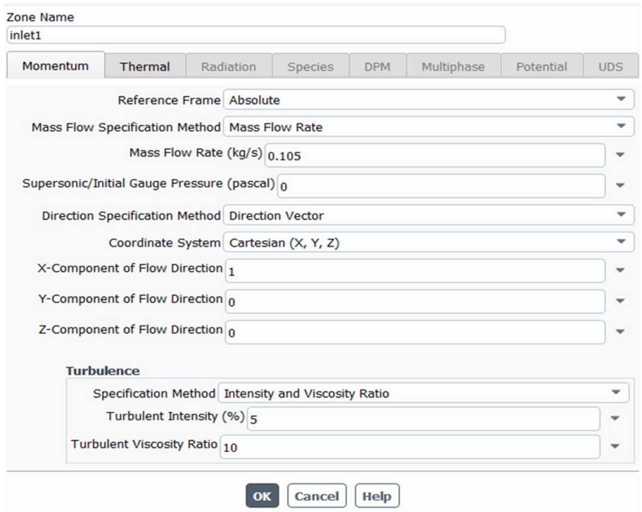

Figure 19. Inlet boundary condition of air

D. Results

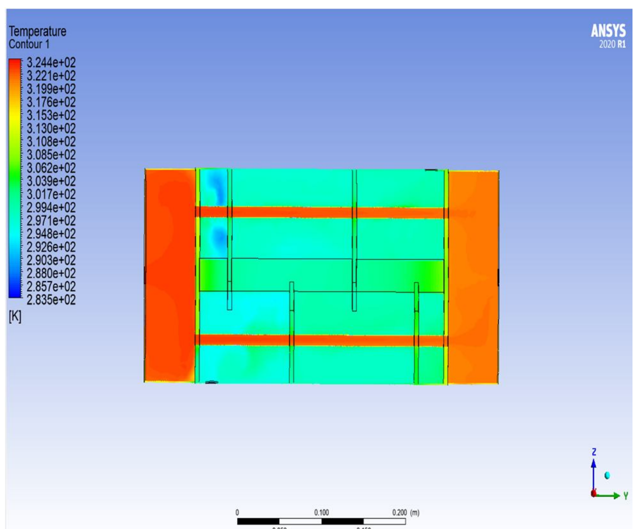

Figure 20. result Temperature counter from min to maximum

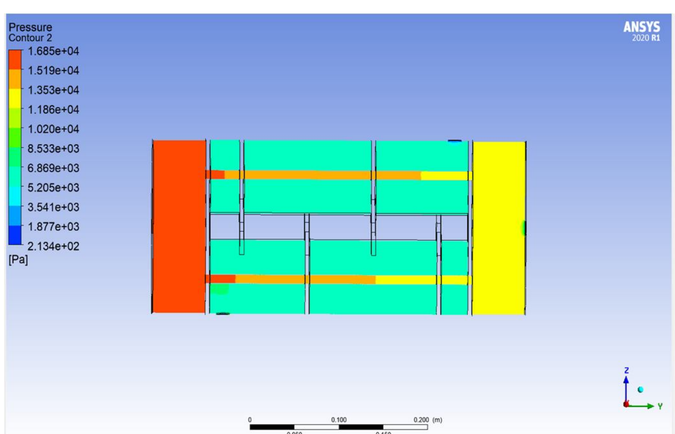

Figure 21. result Pressure counter from min to maximum

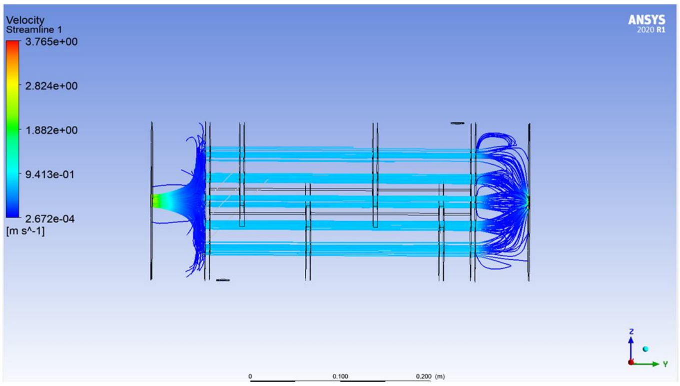

Figure 22. result Velocity counter of air from min to maximum

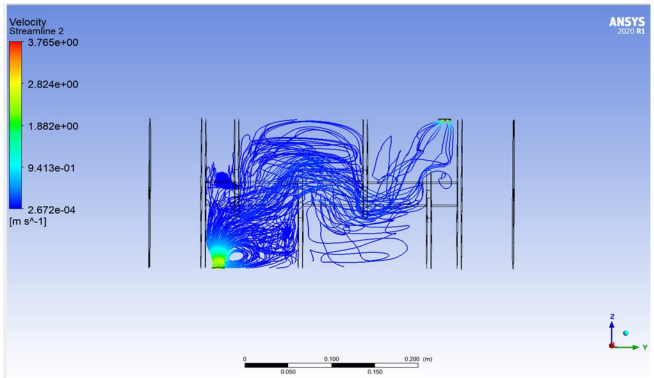

Figure 23. result Velocity counter of water from min to maximum

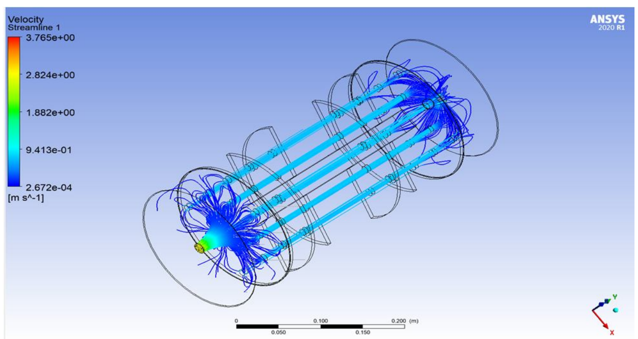

Figure 24. result Velocity 3D counter of air

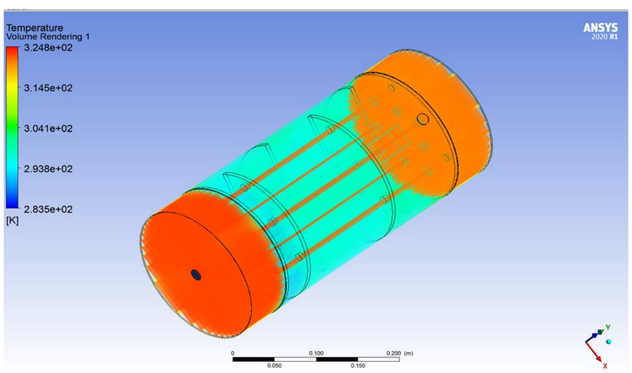

Figure 25. result Temperature counter from min to maximum

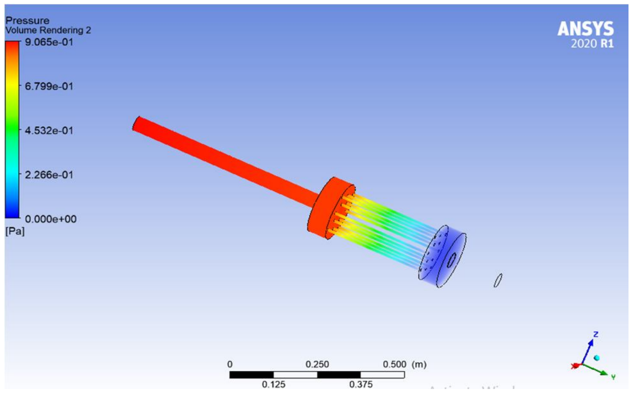

Figure 26. Pressure contour

E. Ansys Results

Ultimately, the integrated design development and CFD analysis process can yield a well-optimized shell-and-tube heat exchanger design that meets or exceeds performance expectations, is energy-efficient, and is capable of withstanding the rigors of real-world applications. This iterative approach, where design modifications are informed by simulation results, contributes to the development of heat exchangers that align closely with the intended engineering specifications and operational requirements.

- Air inlet temperature = 49 degree Celsius
- Air Outlet temperature = 36 degree Celsius
- Water inlet temperature = 26 degree Celsius
- Water outlet temperature = 37 degree Celsius

F. Fabrication

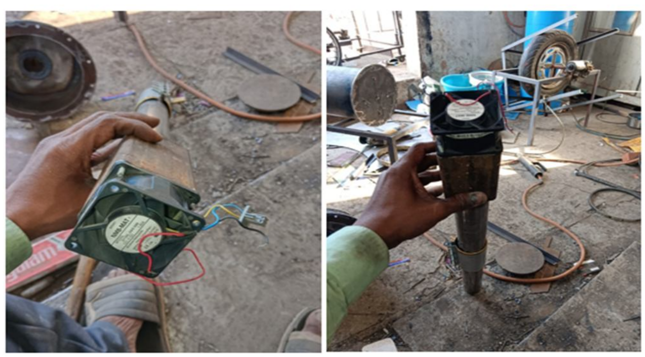

Figure 27 Fabrication of blower with tube

Figure Heater air flow part body

Figure 28 Fabrication of Shell

Figure Shell Cap & Frame with shell assembly

Figure 29 Image of fabricated

VI. CONCLUSION

The design development and Computational Fluid Dynamics (CFD) analysis of a shell-and-tube heat exchanger can lead to several possible outcomes, impacting its efficiency, performance, and overall suitability for a given application. There are several possible results from the design, development, and computational fluid dynamics (CFD) study of a porous-based shell and tube heat exchanger with an air blower and band heater. Improved fluid distribution and surface area may lead to higher heat transfer rates when porous materials are used in the heat exchanger. An air blower improves heat exchange processes by facilitating effective air circulation. Furthermore, the band heater offers accurate temperature control, guaranteeing the appropriate air heating levels. The design may be fine-tuned for best performance by carefully studying several characteristics, including fluid flow patterns, temperature distributions, and pressure drops, using rigorous CFD research. In the end, this integrated system has the ability to effectively heat air and cool water at the same time, with potential uses in environmental control systems, industrial processes, and HVAC systems.

A. Future Scope

Future versions of the band heater and air blower-equipped porous-based shell and tube heat exchanger may investigate several options for improvement and modification. The use of sophisticated materials with enhanced thermal conductivity has the potential to enhance heat transfer efficiency and minimize energy usage. Smart sensor and feedback mechanism integration might allow for real-time control and monitoring, allowing performance to be optimized in response to changing operating circumstances. Further chances for even larger efficiency increases may arise from investigating alternate designs, such as multi-stage heat exchange or unique geometric layouts. Furthermore, improvements in computer power and CFD modeling methods may make it possible to conduct more thorough and precise assessments, exploring intricate fluid dynamics processes and optimizing design parameters. All things considered, the key to realizing the full potential of this integrated system for heating and cooling applications in many sectors is ongoing innovation and refinement in design, development, and CFD analysis.

SR NO	PART NAME	MAT	QTY	COST
1	SHEEL	MS	1	1500
2	TUBE	MS	1	200
3	INLET PIPE	MS	2	450
4	OUTLET PIPE	MS	2	450
5	FRAME	MS	1	2500
6	TEMP INDICATOR	STD	4	2800
7	END CAP	MS	2	900
8	DRAIN PIPE	PVC	2M	200
9	BALL VALVE	SS	3	375
10	ADAPTOR	MS	3	45
11	NOZZEL	BRASS	6	240
12	SPRAY PAINT	STD	2	400
13	HEATER 1500 WATT	STD	1	450
14.	BLOWER	STD	1	115
15.	HEATER CLAMP	STD	1	345
16.	STEEL PIPE	STD	1	645
17.	WATER MOTOR	STD	1	375
18.	BATTERY	6V	1	475
19.	NANO CHIPS	STD	200 grms	200
20.	OTHERS	-	-	1000
			TOTAL	13665

Figure 30 Cost Estimation

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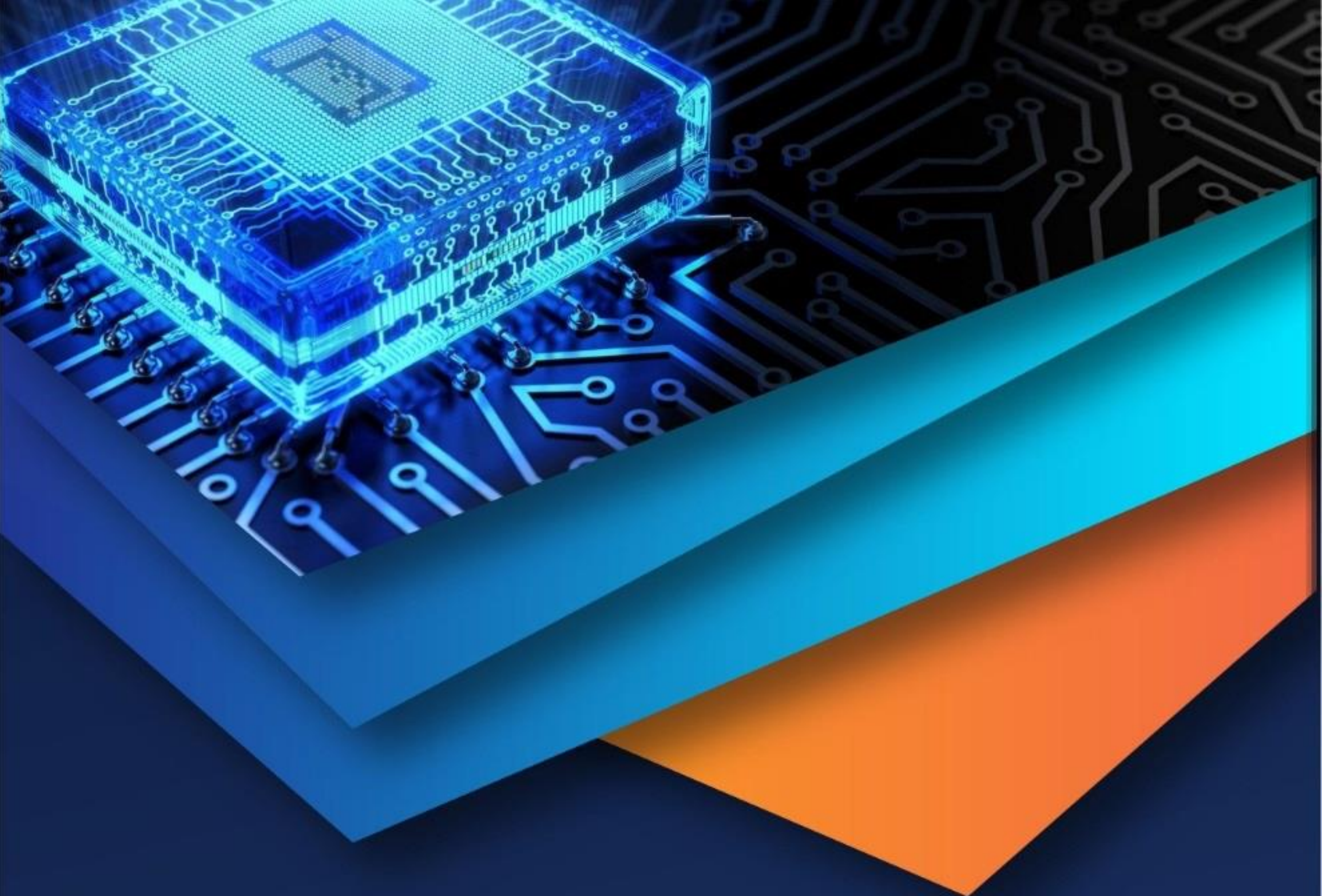

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