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Optimization of Procedure and Variables of a Double Pipe Composite Heat Exchanger with Protruding Surfaces

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Abstract

Under low heat duty conditions, double pipe heat exchangers are employed. When utilized for heavy-duty tasks, they show limitations. To use double pipe heat exchangers for heavy-duty applications, heat transmission needs to be increased. In this project, we are investigating the optimization process parameters of a twin pipe heat exchanger with and without protruding surfaces. In both cases, the inner and outer tubes are composed of steel, and the working fluid is water. Our goal is to increase the efficiency of the twin pipe heat exchanger, even if there are other configurations that may transfer the necessary quantity of heat. Optimal sizes where one of the process fluids is present can be calculated from the initial conditions. After comparing the outcomes of the two situations, we can choose the most effective model. The results of the investigation demonstrate that heat transfer rate values increase in tandem with flow rate values. We utilized the same number of boundary conditions and protruded the pipes to enhance the object's performance. Our calculations revealed that the heat transfer rate values were much higher than those of a typical double-pipe heat exchanger, with the cold domain heat transfer values increasing by nearly three times and the hot domain heat transfer rate values increasing by roughly five to six times. This suggests that the performance of the object in terms of heat transfer values can be enhanced by the addition of protrusions.

Keywords: Double pipe heat exchanger (DPHE), double pipe with protrusion heat exchanger, coefficient of heat transfer, length and diameter, heat transfer rate

INTRODUCTION

An apparatus that permits thermal energy (enthalpy) to be transmitted between two or more fluids at different temperatures, between a fluid and a solid surface, or between solid particles and a fluid in order to preserve thermal contact.. Heat exchangers usually don't interact with external heat sources or work. Figure 1 they are frequently used to condense or evaporate single or multiple component fluid streams, as well as to heat or cool a troublesome fluid stream. They can also be used for sterilizing, pasteurizing, fractionating, distilling, concentrating, crystallizing, recovering or rejecting heat, and controlling a process fluid. In certain heat exchangers, the fluids that transmit heat come into close contact with one another. Most heat exchangers use a dividing barrier to transfer heat between fluids. These exchangers are referred to as direct transfer kinds or recovery types. In contrast, indirect transfer type exchangers—also known as regenerators—allow for intermittent heat exchange between the hot and cold fluids by storing and releasing thermal energy through the exchanger surface or matrix. In these exchangers, leakage between the fluid streams are frequently observed

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due to factors such matrix rotation, valve switching, and pressure variations. Common heat exchanger types include shell-and-tube exchangers, cooling towers, condensers, evaporators, air pre-heaters, and car radiators. Sensible heat exchangers are those in which none of the fluids inside the exchanger change phase. These exchangers can incorporate internal thermal energy sources including powered heaters, fluidized-bed exchangers, and electric heating in boilers.

Winglet tabulators were used as vortex generators by Hatami et al. [1] to improve exhaust heat recovery from diesel engines. Rotating turbulators were used by Keat Goh et al. [2] to create entropy and enhance heat transmission in a heat exchanger. They found that the Nusselt number increased by 240% and 360%, respectively, for rotating and non-rotating tabulators. In a double-pipe heat exchanger, Vaisi et al. [3] used tabulators composed of twisted tape. In comparison to the continuous tabulator, they found that the discontinuous tabulator increased heat transmission by 8.2% and decreased the pressure drop coefficient by 9.8%. They also looked into how this discontinuous turbrulator was affected by various hole shapes. Ribeiro et al. [4] showed the improvements in heat transfer by using turbulators in unmixed cross-flow small heat exchangers for automotive applications. Liou et al. [5] employed wing-shaped turbulators, a different type of tabulator, for a serpentine heat exchanger's coolant route. Singh and Sarkar [6] employed tapered wire coil inserts to increase the Nusselt number by up to 84% in a double tube heat exchanger that was filled with an Al_2O_3 + MgO hybrid nanofluid. The similar kind of tubulator was also employed by Mashoofi et al. and Panahi and Zamzamian [7]. [8] For heat exchangers with shells, coiled tubes, and tube-in-tubes, respectively. Both verified that this kind of turbulator performs well for increases in Nusselt numbers. Adding nano particles to the working fluid is a powerful and effective method of improving the fluids' thermo physical characteristics in a variety of industrial equipment. [9–11]. Sheikholeslami et al. [12] investigated how Al_2O_3 nano powder affected solar collector performance enhancement in a turbulent flow condition. They found that thermal irreversibility can be considerably decreased by including nano particles into the working fluid. By employing four twisted turbulators, they discovered a 92.86% improvement in thermal performance. The effects of CMC/CuO nano powder on forced convection and heat transfer in a heat exchanger tube with twisted tapes were investigated by Bazdidi-Tehrani [13]. According to their findings, the nano particles may significantly improve the non-Newtonian fluid's performance in the heat exchanger tube. After analyzing the entropy creation of Cu powder-water flows via wavy channels, Esfahani et al. [14] concluded that thermal entropy generation was the dominant term in most of the tubes. Furthermore, they found that thermal entropy formation decreased as the volume proportion of the nano particles grew. Akbarzadeh et al. [15] investigated the two-phase nanofluid flow characteristics of solar heater corrugated absorber panels numerically. The SST model was used to numerically simulate the nanofluid flows inside the corrugated tubes. Perforated hollow cylinders were used as turbulators by Nakhchi and Esfahani [16], who discovered that they enhanced heat transmission and reduced flow resistance by 86.2%. Nakhchi et al. [17] made use of the heat exchanger's perforated louvered strips. Better fluid mixing between the tube walls and core region improved the Nusselt number and thermal performance, they discovered. They also used perforated conical rings (PCR) for heat exchangers and found that re-circulating flows via the holes enhance heat transfer and lower pressure loss. [18, 19] In addition to increasing turbulator efficiency, perforation also increases turbulator effectiveness through cutting or grooves. A new experimental investigation examined the impact of double-cut twisted tape on by Nakhchi et al. [20]. They discovered that the Nusselt number increased by 177.4% when the cut ratio was raised from 0.25 to 0.90.

PROBLEM DEFINATION

Double pipe designs are the most basic type of heat exchangers used in applications that need high temperatures and pressure. This was the problem with the double pipe heat exchanger: we can't reach the maximum heat transfer rate even though they are extensively used in many applications and are easy to fix. By developing a design with a protruding surface and process parameters, we were able to solve the twin pipe heat exchanger issue. Although these heat exchangers have many benefits, their inefficiency makes them challenging to use.

Figure 1. Heat exchanger.

Table 1. The AISI 1137 carbon steel's chemical composition.

Element	Content (%)
Iron, Fe	~98
Manganese, Mn	1.35-1.65
Carbon, C	0.32-0.39
Sulfur, S	0.08-0.13
Phosphorous, P	0.08-0.13

SELECTION OF COMPOSITE MATERIAL

The primary alloying element found in carbon steels is carbon. These steels, which have a manganese content of 1.2% and a silicon content of 0.4%, are categorized using four-digit AISI codes. Traces of molybdenum, chromium, nickel, copper, and aluminum are found. These steels may also contain trace impurities like sulfur and phosphorus. The datasheet for the AISI 1137 carbon steel provides an overview. It is shown in the following table, which shows the chemical composition of AISI 1137 carbon steel.

COMPOSITION OF WORKING FLUID

One common working fluid that works well at both high and low temperatures is water. Water cooling is one method of removing heat from industrial machinery and parts. Water is inexpensive and safe for human consumption. There is a plentiful supply of inexpensive, safe water that covers most of the earth. The thermal conductivity of liquid cooling is superior to that of air cooling. Table 1 at room temperature and atmospheric pressure, water has an unusually high specific heat capacity, which makes it possible to move heat effectively across long distances at low mass transfer rates. Cooling water can be used in a once-through cooling (OTC) system that only needs one pass or reused through a recalculating system. Water works well as an evaporative cooling method to remove surplus heat from cooling towers or ponds because of its high enthalpy of vaporization. Depending on whether they use heat extraction through heat exchangers with low evaporation losses or evaporative cooling, recirculation systems can be classified as either open or closed. While indirect cooling water can be separated from a fluid being cooled via a heat exchanger or condenser, direct cooling water can be used on objects like saw blades, where phase separation is straightforward. Environmental standards place a high value on lower waste product concentrations in indirect cooling water. Working fluid properties are Density-998.2kg/m^3, Specific heat-4182j/kg-k, Thermal conductivity-0.6w/m-k, Viscosity-0.001003kg/m-s.

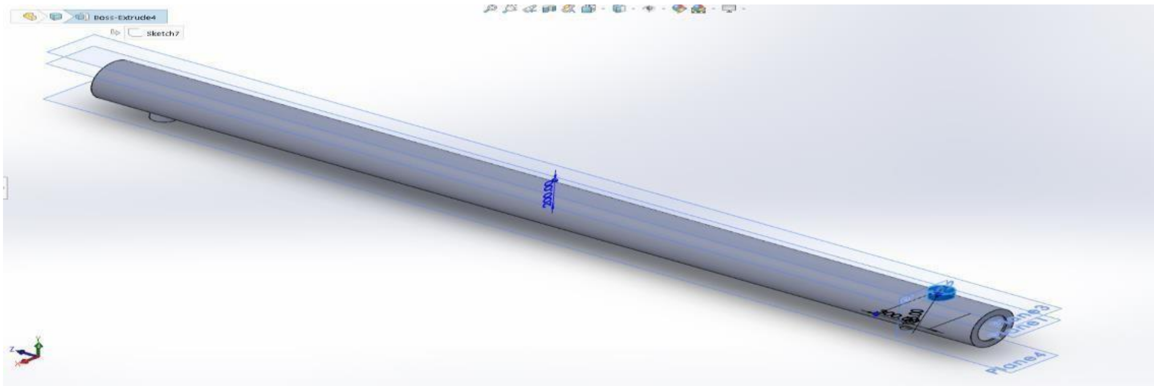

Figure 2. Double Pipe Heat Exchanger with dimension.

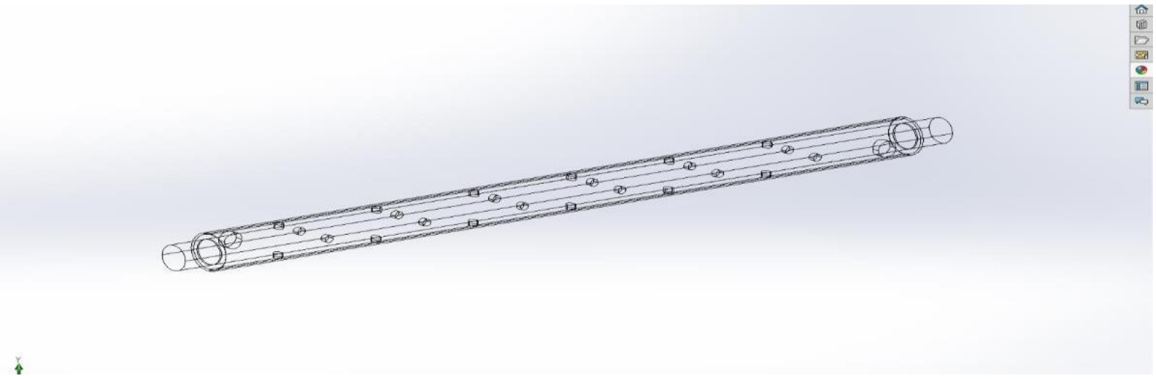

Figure 3. Double pipe heat exchanger with protrusions final assembly model.

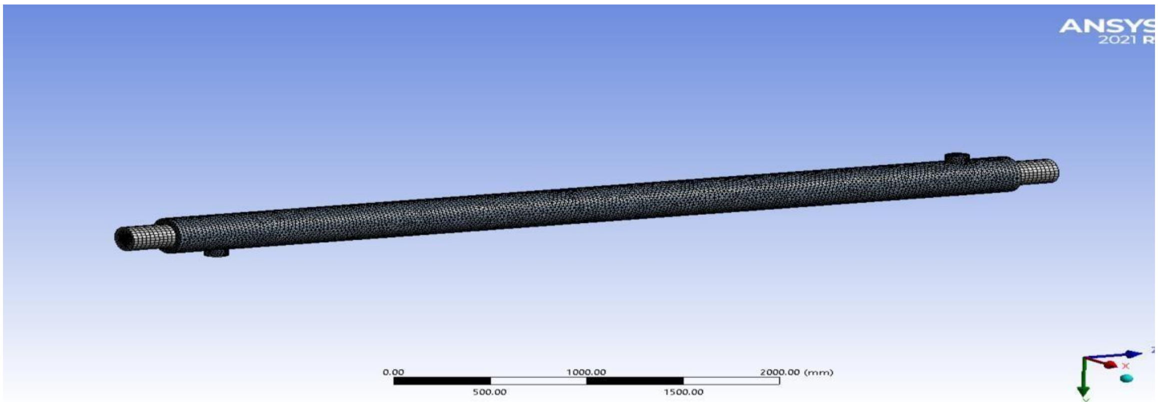

Figure 4. Grid generation along the conjugated tube wall.

SOLID WORKS MODEL

A final assembly model, also known as a double-pipe heat exchanger with protrusions, is a comprehensive 3D computer-aided design (CAD) or simulation-ready model of a double-pipe heat exchanger that has been improved with internal surface alterations (protrusions) to boost heat transfer performance. For numerical simulations, the method of generating a computational mesh or grid is shown in Figures. 2, 3, and 4 along the conjugated tube wall.

FLUENT ANALYSIS RESULTS

Boundary Conditions

- Cold domain inlet temperature→303k
- Hot domain inlet temperature→333k
- Hot inlet flow rate→0.072kg/s or 6Lpm (constant in each case)

- Cold inlet flow values varies from 3lpm to 15lpm and those values are given below,
- Cold inlet flow rate→0.036, 0.11, 0.18 kg/s or 3LPM, 9LPM, 15LPM

RESULTS AND DISCUSSIONS

Double pipe heat exchanger results Cold flow rate 3lpm & hot flow rate 6lpm

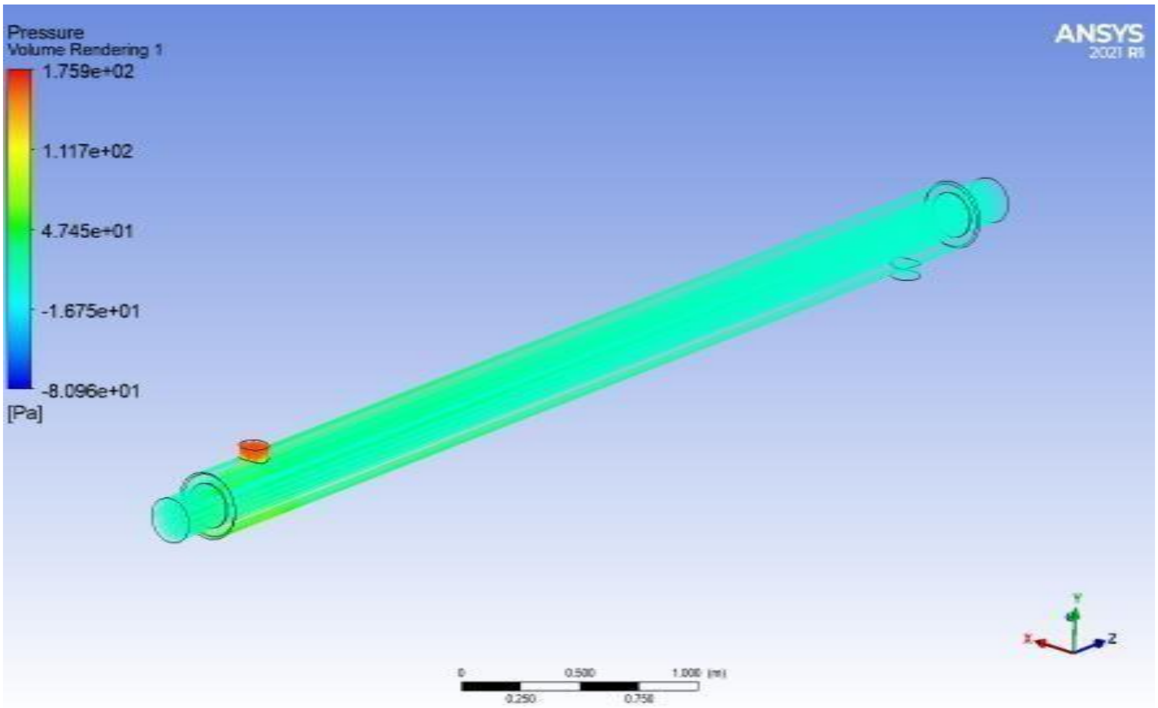

Figure 5. Pressure analysis.

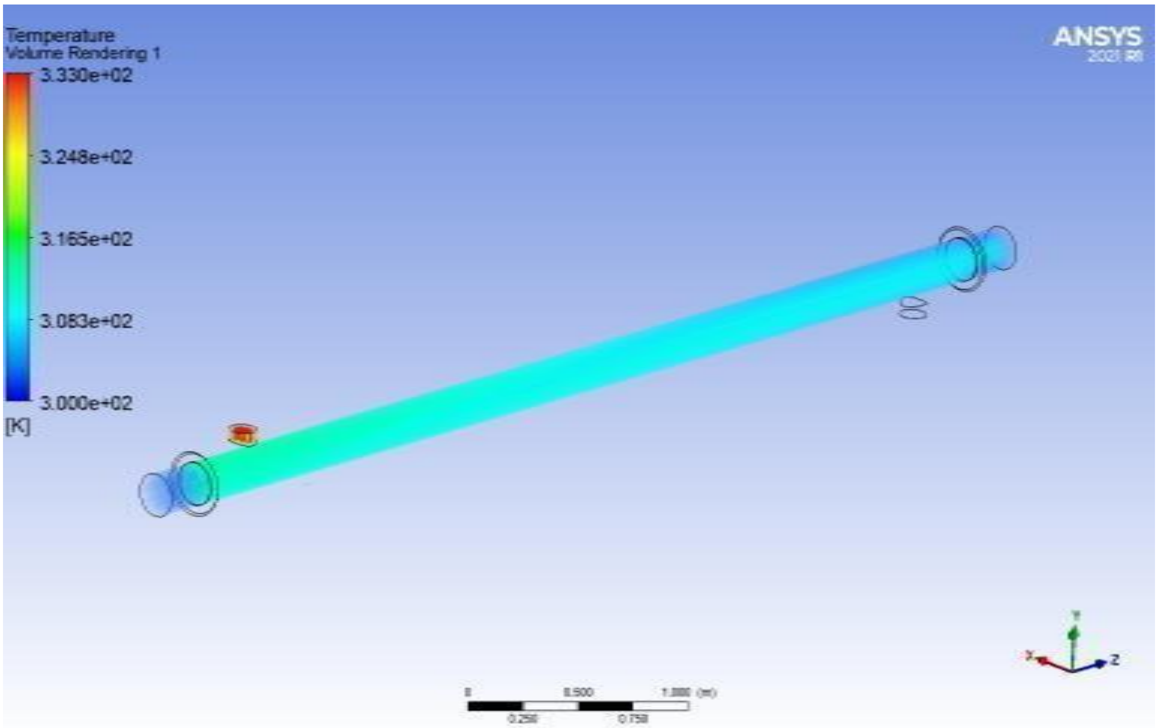

Figure 6. Temperature analysis.

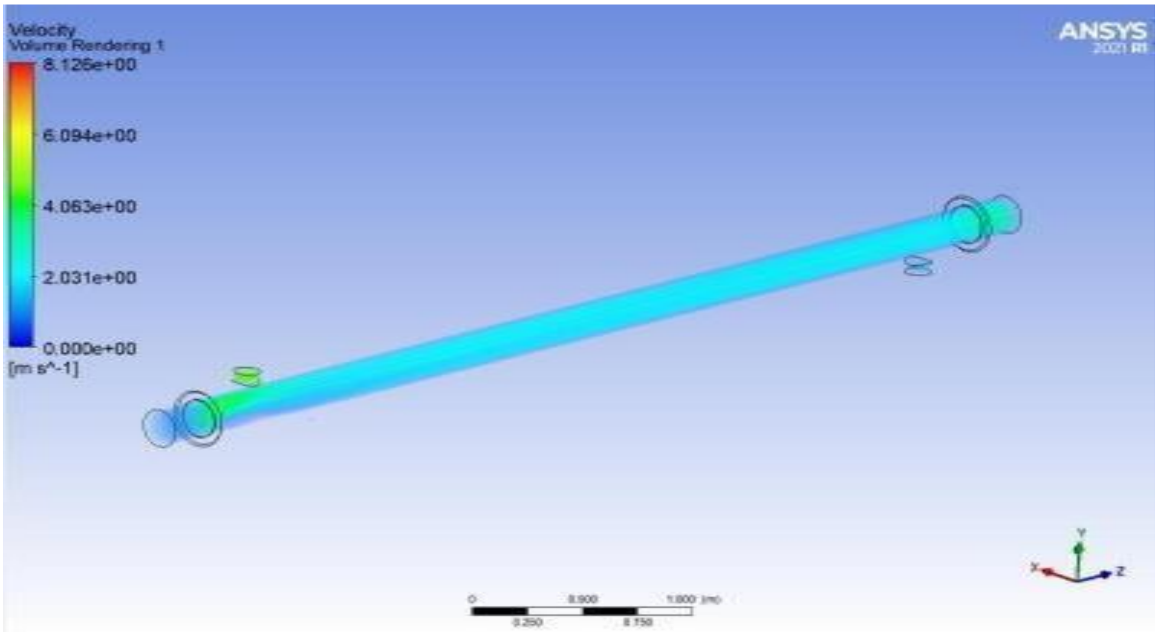

Figure 7. Velocity analysis.

Table 2. Average Static Temperature and Average wall adjacent Heat Transfer Coefficient Protrusion double pipe heat exchanger results Cold flow rate 3lpm & hot flow rate 6lpm.

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain [W/(m²k)]	Heat transfer coefficient hot domain [W/(m²k)]
303	305.45	333	300.028	5.070493	16.065502
Net amount		307.61418		7.4199359	

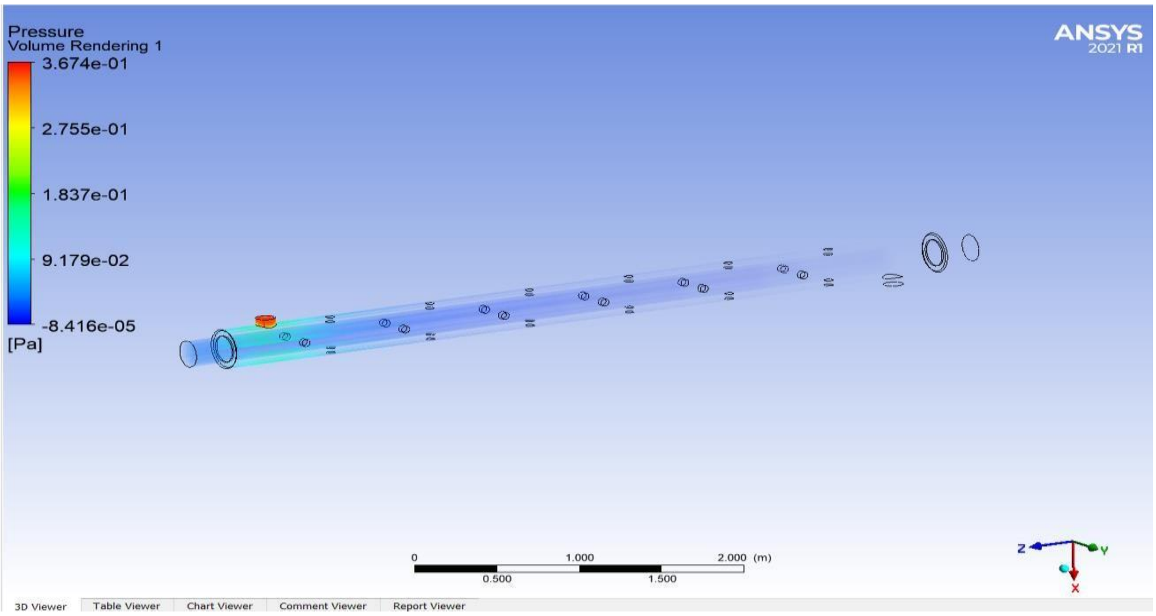

Figure 8. Pressure analysis.

Figures 5, 6, and 7 Performance measurements are usually obtained from CFD models or investigations of temperature profiles, pressure drops, and velocity distributions. The typical temperature, pressure, and velocity distributions for such a system are determined by the counter flow arrangement, water as the working fluid, and conventional analysis

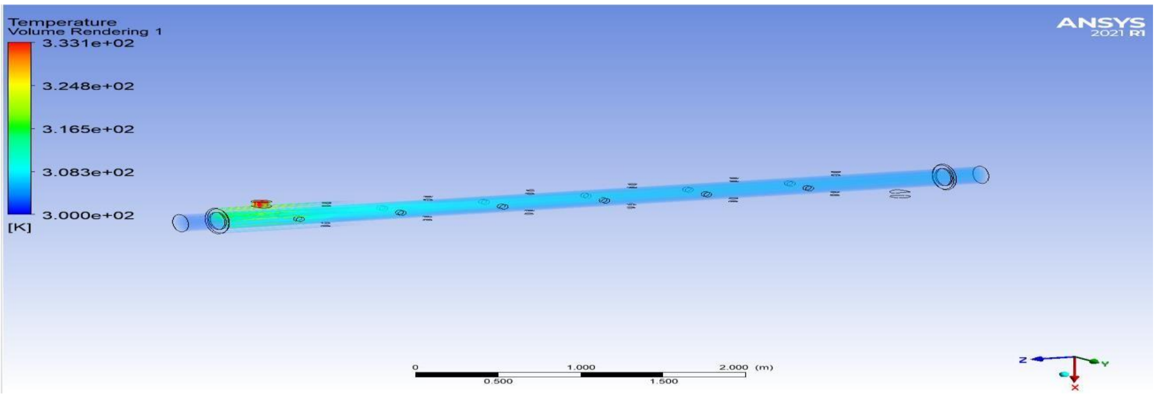

Figure 9. Temperature Analysis.

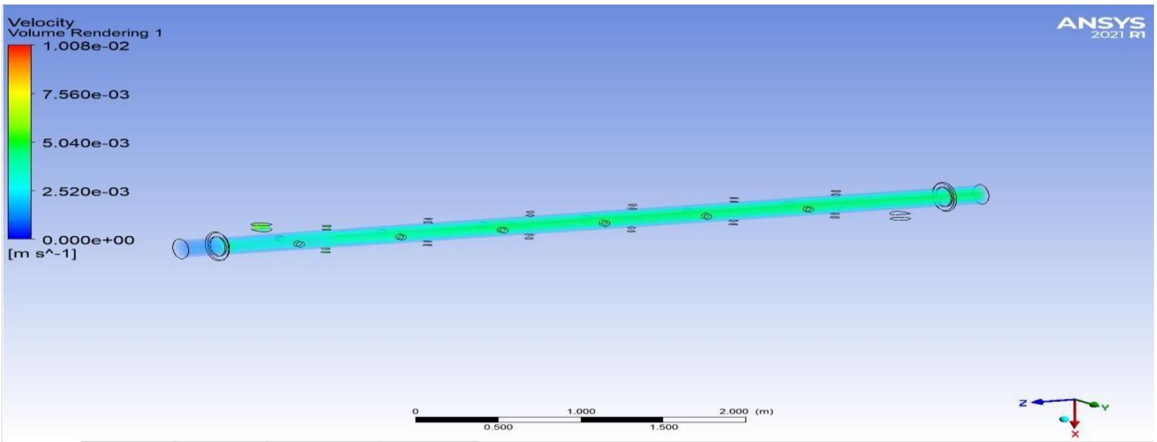

Figure 10. Velocity analysis.

The usual distributions of temperature, pressure, and velocity for such a system are shown in Figures 8, 9, and 10 and Table 2 based on standard analyses.

Table 3. Average Static Temperature and Average wall adjacent Heat Transfer Coefficient Double pipe heat exchanger results Cold flow rate 9lpm & hot flow rate 6lpm

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain[W/(m^{2}k)]	Heat transfer coefficient hot domain [W/(m^{2}k)]
303	304.34532	333	300.00002	15.993422	92.670166
Net amount		307.20718		32.563268	

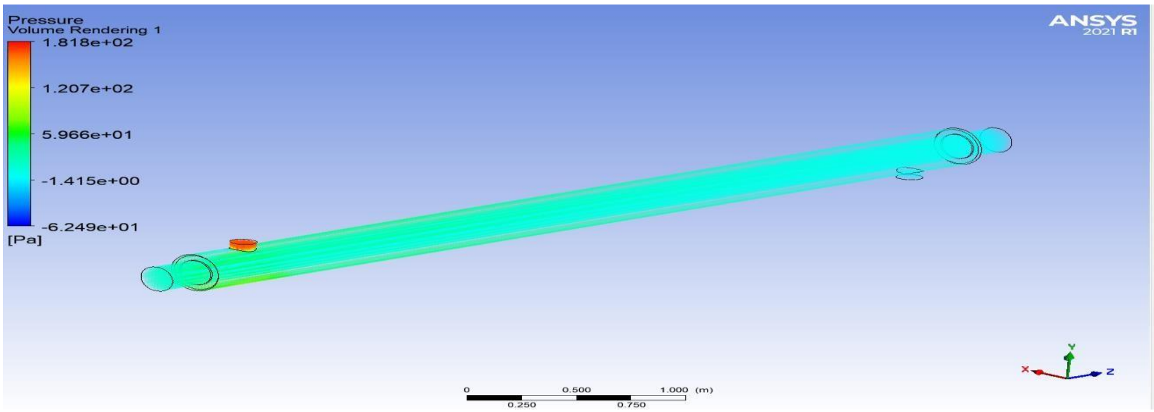

Figure 11. Pressure analysis.

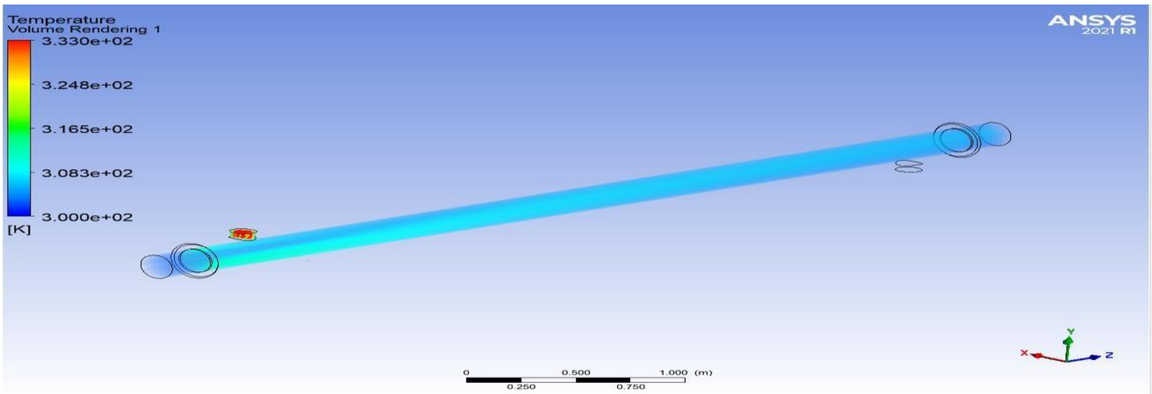

Figure 12. Temperature analysis.

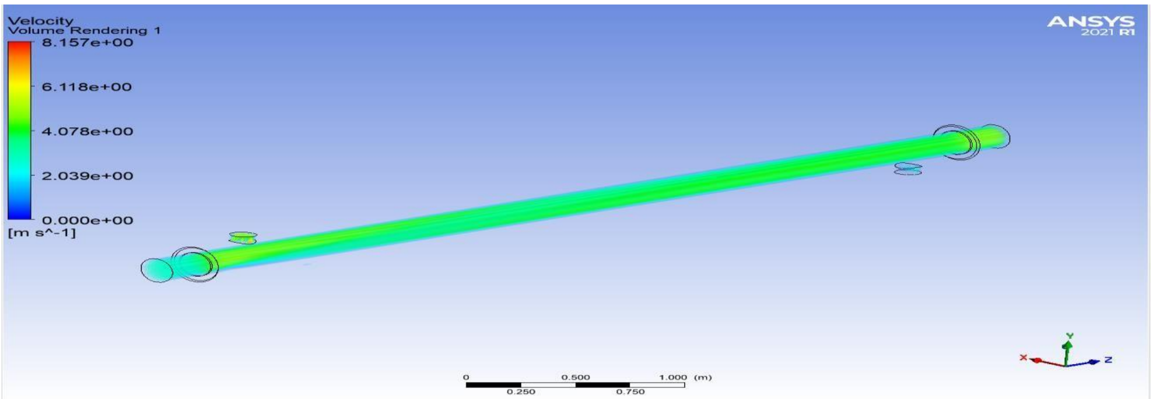

Figure 13. Velocity analysis.

The usual distributions of temperature, pressure, and velocity for such a system are shown in Figures 11, 12, and 13and table 3 based on standard analyses.

Table 4. Average Static Temperature and Average wall adjacent Heat Transfer Coefficient Protrusion double pipe heat exchanger Cold flow rate 9lpm & hot flow rate 6lpm.

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain[W/(m^{2}k)]	Heat transfer coefficient hot domain [W/(m^{2}k)]
303	304.44894	333	300.04004	6.9962783	16.567974
Net amount		307.25023		9.0415838	

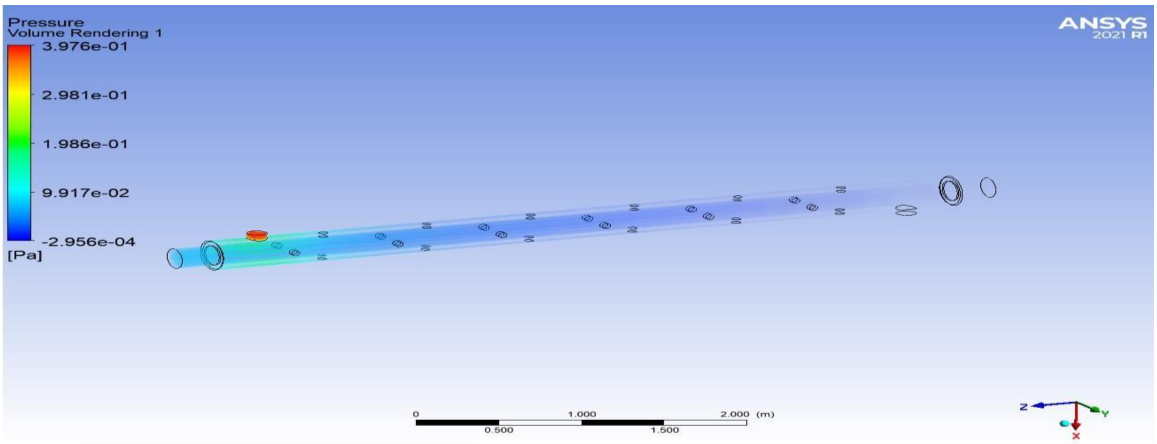

Figure 14. Pressure analysis.

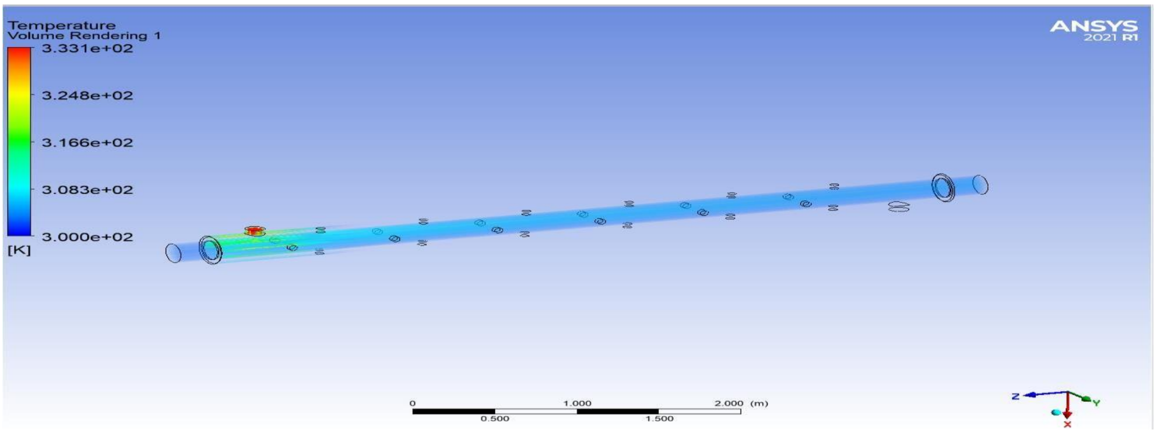

Figure 15. Temperature analysis.

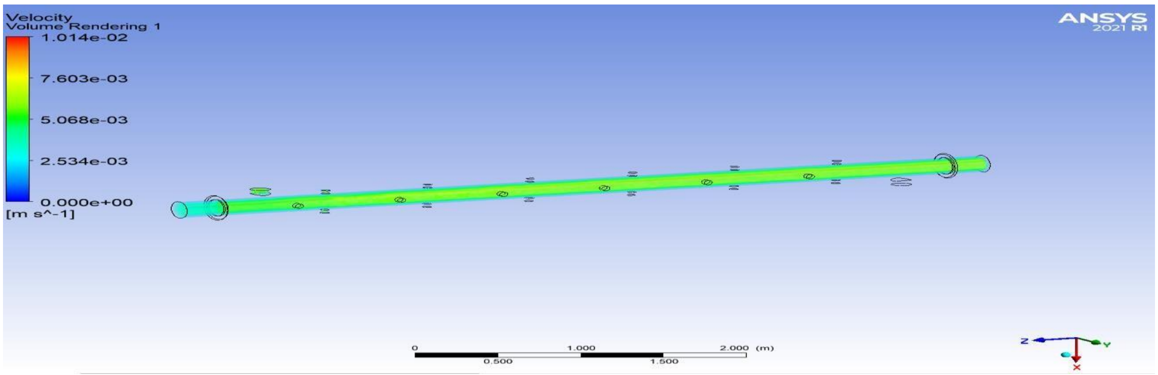

Figure 16. Velocity analysis.

Based on conventional analysis, Figures 14, 15, and 16 and table 4 display the typical temperature, pressure, and velocity distributions for such a system.

Table 5. Average Static Temperature and Average wall adjacent Heat Transfer Coefficient Double pipe heat exchanger Cold flow rate 15lpm & hot flow rate 6lpm

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain[W/(m^{2}k)]	Heat transfer coefficient hot domain[W/(m^{2}k)]
303	303.90236	333	300	15.99102	98.778063
Net amount		307.04673		33.881302	

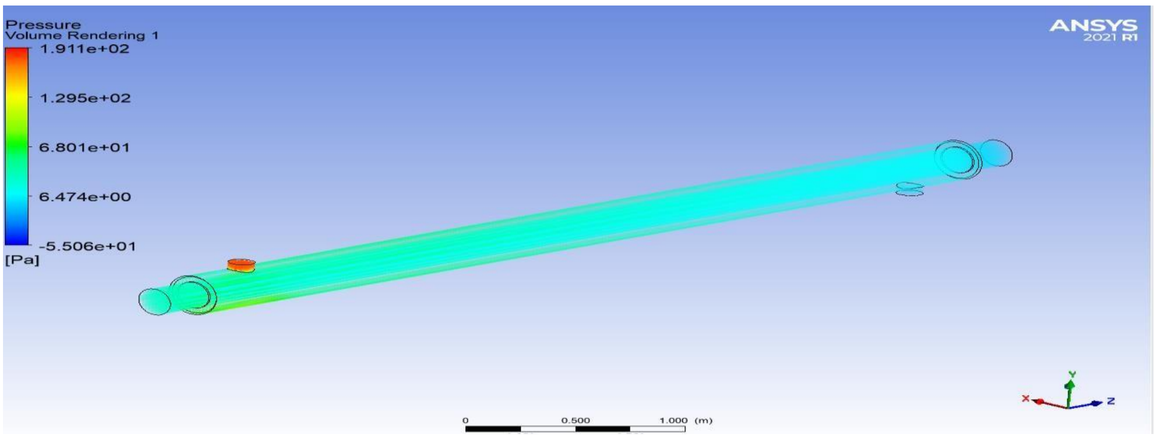

Figure 17. Pressure analysis.

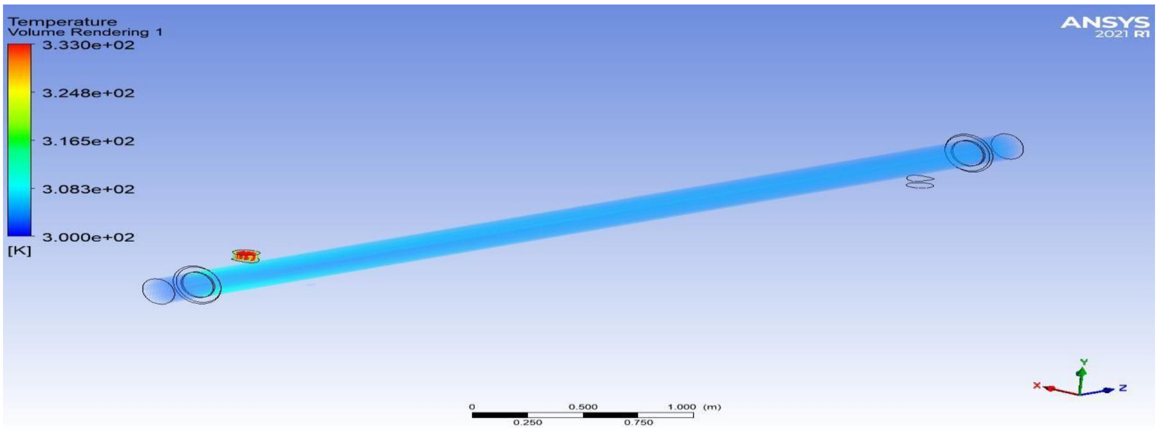

Figure 18. Temperature analysis.

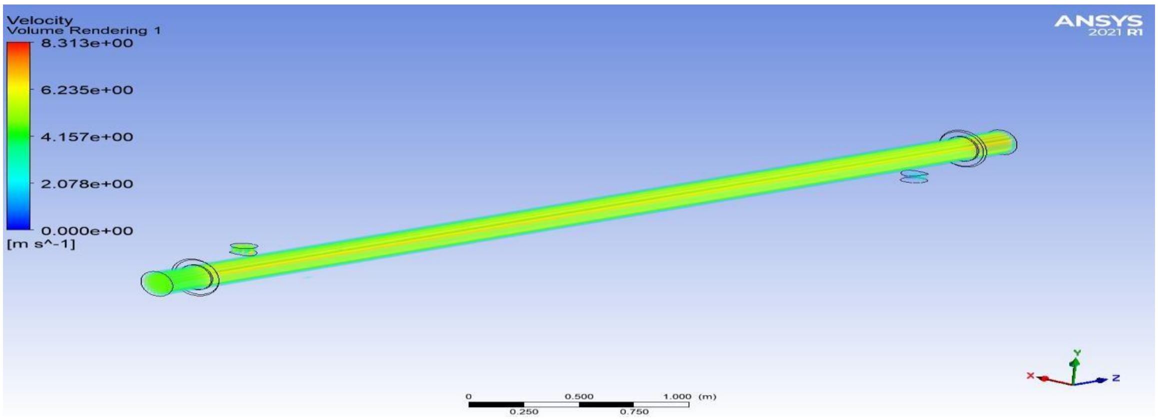

Figure 19. Velocity analysis.

The usual temperature, pressure, and velocity distributions for such a system are shown in table 5 and Figures 17, 18, and 19, which are based on traditional analysis.

Table 6. Average static temperature and average wall adjacent Heat Transfer Coefficient Protrusion double pipe heat exchanger Cold flow rate15lpm & hot flow rate 6lpm.

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain [W/(m^{2}k)]	Heat transfer coefficient hot domain[W/(m^{2}k)]
303	303.76577	333	300.04833	8.9208248	16.948378
Net amount		307.00391		10.636174	

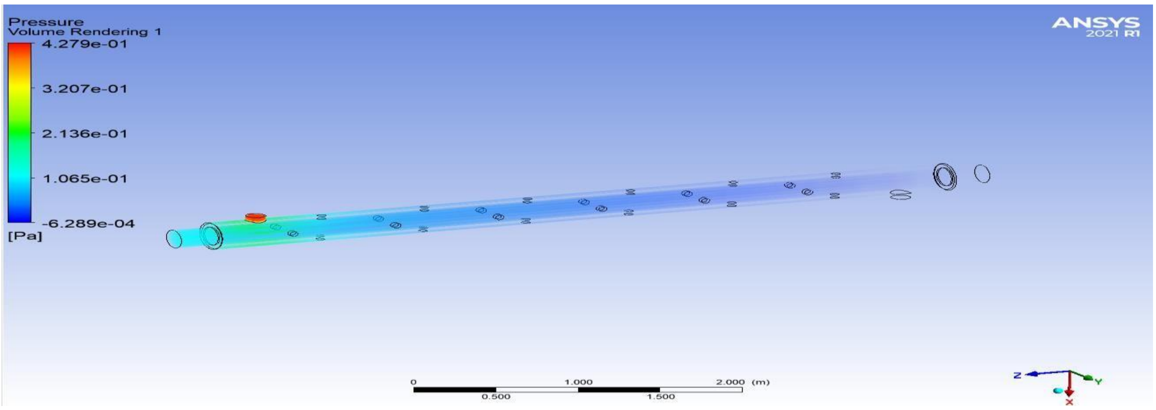

Figure 20. Pressure analysis.

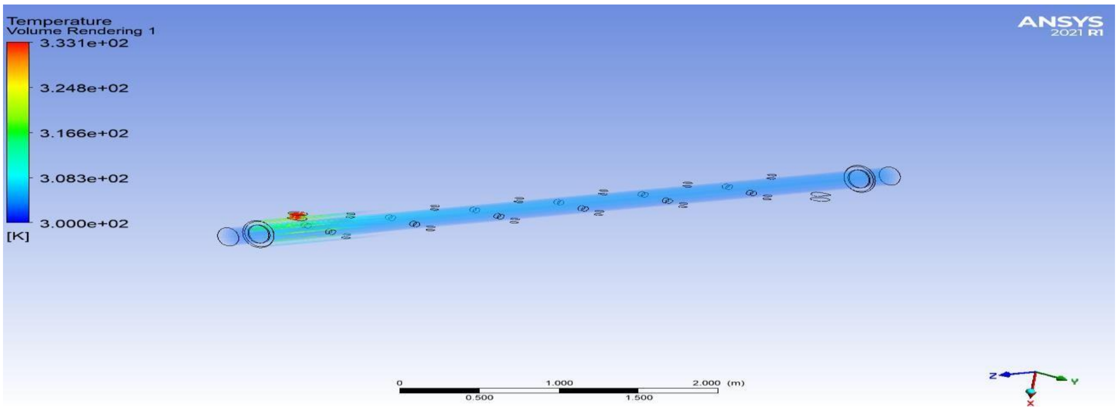

Figure 21. Temperature analysis.

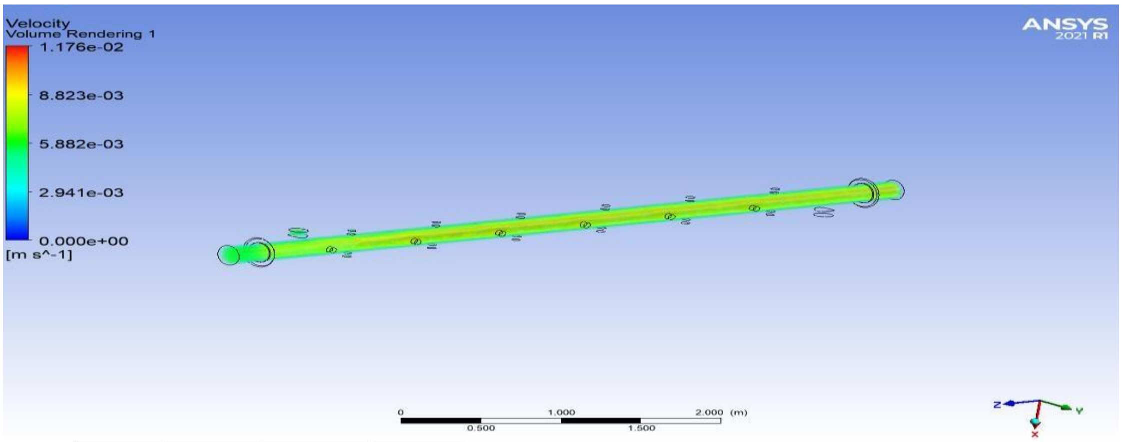

Figure 22. Velocity analysis.

Based on traditional analysis, Figures 20, 21, and 22 and table 6 display the typical temperature, pressure, and velocity distributions for such a system.

Table 7. Average Static Temperature and Average wall adjacent Heat Transfer Coefficient.

Cold in (K)	Cold out (K)	Hot in (K)	Hot out (K)	Heat transfer coefficient cold domain [W/(m^{2}k)]	Heat transfer coefficient hot domain [W/(m^{2}k)]
303	303.68424	333	300.00001	15.991763	105.44472
Net amount		306.96772		35.32255	

Table 8. Double pipe heat exchanger comparison results double pipe heat exchanger comparison results.

Double pipe heat exchanger results	3LPM & 6LPM	9LPM & 6LPM	15LPM & 6LPM
Pressure (pa)	1.759e2	1.818e2	1.911e2
Temperature (k)	330	330	330
Velocity (m/s)	8.126	8.157	8.313
Cold In let temperature (k)	303	303	303
Cold Out let temperature (k)	305.45	304.44	303.765
Hot In let temperature (k)	333	334	335
Hot Out let temperature (k)	300.029	300.04	300.048
Cold domain Heat transfer rate coefficient(w/m^{2}k)	5.07	6.996	8.920
Hot domain Heat transfer rate Coefficient (w/m^{2}k)	16.06	16.567	16.948

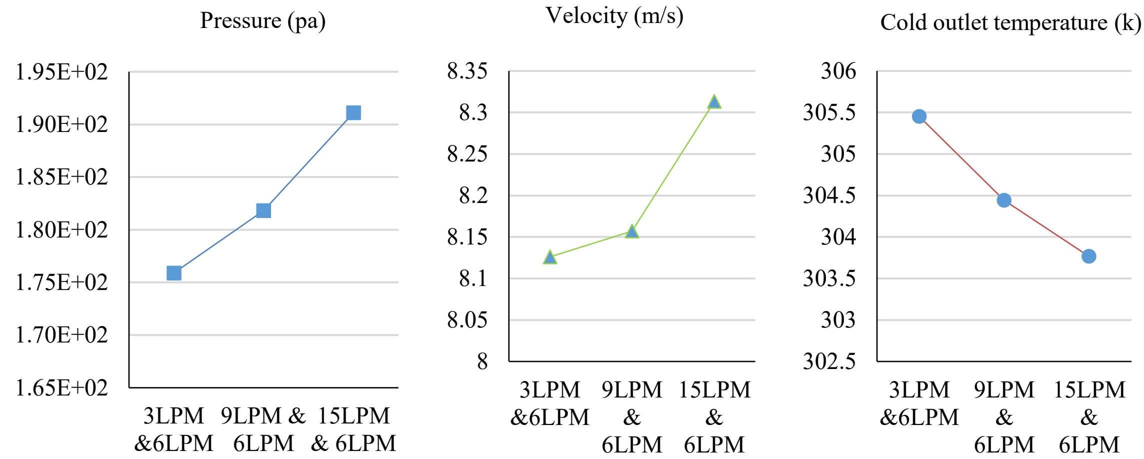

Figure 23. Cold pressure, cold velocity, cold outlet temperature analysis.

Table 7, 8 and Figure 23, a lower flow rate is better for the cold fluid's maximal temperature increase. The concomitant rise in pressure drop and possible decrease in efficacy, a higher flow rate is preferable for maximal heat transfer rate. A Double Pipe Heat Exchanger (DPHE) running at three distinct cold water flow rates—3 LPM, 9 LPM, and 15 LPM, while maintaining a steady hot water flow rate of 6 LPM is compared here. Outlet temperatures, heat transfer rates, overall heat transfer coefficients (U), and effectiveness are the main performance measures that are evaluated. These observations are predicated on common water characteristics and heat exchanger principles.

Figure 24 shows Cold Pressure, Cold Velocity, Cold outlet Temperature Analysis Hot domain heat transfer rate, cold domain heat transfer rate, and hot out let temperature Analysis of Double pipe with protrusion heat exchanger results.

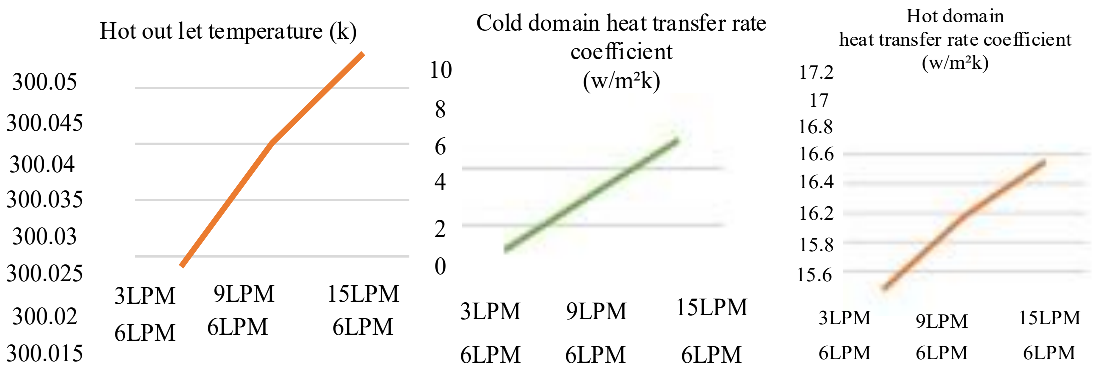

Figure 24. Cold pressure, cold velocity, cold outlet temperature analysis.

Table 9. Double pipe with protrusion heat exchanger comparison results.

Double pipe with protrusion heat exchanger	**3LPM & 6LPM**	**9LPM & 6LPM**	**15LPM & 6LPM**
Pressure (pa)	3.674e-1	3.976e-1	4.279e-1
Temperature (k)	333.1	333.1	333.1
Velocity (m/s)	1.008e-2	1.014e-2	1.176e-2
Cold In let temperature (k)	303	303	303
Cold Out let temperature (k)	304.345	303.902	303.684
Hot In let temperature (k)	333	333	333
Hot Out let temperature (k)	300	300	300
Cold Heat transfer rate coefficient (w/m^{2}k)	15.993	15.991	15.991763
Hot Heat transfer rate coefficient (w/m^{2}k)	92.670	98.77	105.444

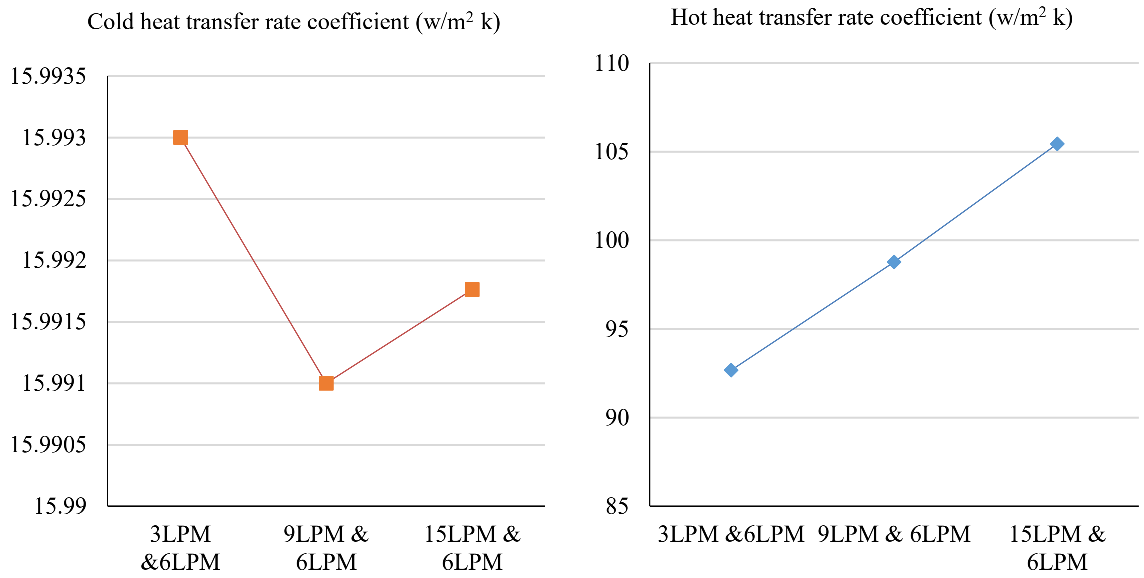

Figure 25. Cold and hot heat transfer rate coefficient analysis.

Table 9 and Figure 24, higher convective heat transfer coefficients on both the cold and hot sides result from enhanced thermal gradients caused by increased turbulence within the annulus caused by increasing the cold water flow rate. Protrusions cause the thermal boundary layer to be disrupted, which encourages secondary flows and increases the heat transfer coefficients even more than smooth tubes can. Higher protrusions and cold flow rates enhance heat transmission, but they also raise pressure drops, thus it's important to strike a balance between pumping power needs and thermal performance.

Figures 24, a double pipe heat exchanger's heat transfer coefficients for the hot and cold domains are greatly improved by the addition of protrusions. The thermal performance can be controlled by varying the cold water flow rate. 3 lpm ideal for uses that call for lower total heat transfer rates but higher temperature gains in the cold fluid. 9 lpm provide a well-rounded strategy that enhances heat transfer coefficients while preserving controllable pressure drops.15 lpm Increased pressure drop concerns are necessary for operations that require high heat transfer rates, however maximizing heat transfer coefficients is ideal.

CONCLUSION

This thesis investigates a double-pipe heat exchanger designed using Solid Works and analyzed through Ansys Workbench. The system was tested with both hot and cold water at varying flow rates. Specifically, cold water flow rates were tested between 3 and 15 liters per minute, while the hot water flow rate was maintained constant at 6 liters per minute. The analysis revealed that the heat transfer rate increases as the flow rate of the cold water rises. Protrusions were added inside the pipes to enhance system performance even more. After applying the same boundary conditions, the results showed a substantial enhancement in heat transfer rates compared to a standard double-pipe heat exchanger. In particular, the heat transfer rate in the hot water domain increased by 5 to 6 times, while the cold water domain saw an increase of nearly 3 times. These findings indicate that the inclusion of protrusions can significantly improve the heat exchanger's efficiency by boosting heat transfer performance.

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