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## "CFD SIMULATION AND THERMAL-HYDRAULIC PERFORMANCE EVALUATION OF PLATE HEAT EXCHANGERS WITH MODIFIED PLATE GEOMETRIES"

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## ABSTRACT

***This research investigates the thermal and hydraulic behavior of plate heat exchangers (PHEs) with varied plate geometries using Computational Fluid Dynamics (CFD). The study evaluates pressure drop, velocity distribution, and heat transfer coefficient for different plate profiles including smooth, wavy, dimpled, bubbled, and tapered designs. Using ANSYS Fluent for simulation and SolidWorks for geometry creation, results show that optimized geometries significantly enhance thermal efficiency while maintaining manageable pressure losses. The bubbled plate configuration yields the highest performance in terms of effectiveness and pressure drop minimization. The findings serve as a design reference for compact heat exchanger applications.***

***Plate heat exchangers (PHEs) are integral components in a wide range of industrial applications due to their high thermal efficiency, compact structure, and ease of maintenance. However, optimizing their design to maximize heat transfer while minimizing pressure drop remains a complex engineering challenge. This study presents a comprehensive Computational Fluid Dynamics (CFD)-based investigation into the thermal and hydraulic performance of PHEs with varied plate geometries—including smooth, wavy, dimpled, tapered, and bubbled configurations—under different fluid temperatures and Reynolds number conditions. Using SolidWorks for geometric modeling and ANSYS Fluent for simulation, each design was evaluated based on key parameters such as frictional pressure drop, heat transfer coefficient, temperature distribution, and flow velocity. The simulation results reveal that non-smooth geometries induce favorable turbulence and secondary flows that enhance convective heat transfer. Among all designs, the bubbled plate geometry demonstrated the best performance, offering the lowest pressure drop (799 Pa) and the highest effectiveness (0.89), with a substantial temperature uniformity. Contour plots provided insights into internal flow dynamics, validating the design superiority of modified plates. This research contributes to the development of advanced PHEs by quantifying the relationship between plate geometry and thermal-hydraulic performance, offering a practical pathway for optimizing compact heat exchangers used in HVAC, power generation, refrigeration, and chemical processing industries.***

***Key Words:*** *Plate heat exchanger, CFD analysis, pressure drop, thermal performance, ANSYS Fluent, plate geometry, heat transfer coefficient, compact heat exchangers..*

## I. INTRODUCTION

Plate heat exchangers (PHEs) are compact, efficient devices used for heat transfer between fluid streams. Compared to traditional shell-and-tube exchangers, PHEs offer superior thermal performance due to their larger surface-to-volume ratios and turbulent flow channels. Recent advancements have explored the impact of plate surface modifications—such as dimpling, tapering, and bubbling—on flow disruption and heat transfer enhancement.

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This paper extends the current understanding by simulating and comparing multiple PHE geometries under similar boundary conditions. It uses numerical methods to predict thermal performance and hydraulic resistance across configurations, guiding the development of next-generation high-efficiency exchangers.

## II. Methodology

### 3.1 Overview

The methodology employed in this research is centered on a comprehensive Computational Fluid Dynamics (CFD) simulation to evaluate the thermal and hydraulic performance of various plate geometries used in Plate Heat Exchangers (PHEs). The steps included geometry modeling, meshing, defining boundary conditions, numerical simulation using ANSYS Fluent, and post-processing for result interpretation. Five different geometries—smooth, wavy, dimpled, bubbled, and tapered plates—were analyzed to determine the influence of surface topology on pressure drop, heat transfer coefficient, and overall effectiveness.

### 3.2 Geometry Modeling

The geometries of the five distinct plate configurations were modeled using **SolidWorks 2021**, considering two-dimensional cross-sectional views to reduce computational load while maintaining simulation accuracy. Each geometry included channels representing fluid flow paths and incorporated design features such as:

- **Smooth Plate**: Flat walls with uniform channel height.
- **Wavy Plate**: Periodic sinusoidal curves to induce turbulence.
- **Dimpled Plate**: Spherical indentations on the plate surface to generate vortices.
- **Tapered Plate**: Gradually narrowing or widening channels to alter flow acceleration.
- **Bubbled Plate**: Dome-shaped protrusions designed to promote secondary flows and breakup of boundary layers.

The geometries were then exported in IGES format for further processing.

### 3.3 Meshing and Grid Independence Study

Meshing was performed using **ANSYS Workbench 15.0**, generating structured meshes with quadrilateral elements. A mesh density of approximately 185,442 elements and 213,699 nodes was used after a **grid independence study**, which ensured simulation results did not vary significantly with further mesh refinement.

Mesh metrics:

- **Element type**: Quadrilateral
- **Skewness**: < 0.25 (average)
- **Aspect ratio**: < 5 for majority elements

The chosen mesh configuration ensured an optimal balance between computational time and numerical accuracy.

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**3.4 Simulation Setup in ANSYS Fluent**

The CFD simulations were conducted using **ANSYS Fluent**, applying a pressure-based steady-state solver with double precision. The finite volume method was employed to discretize the domain. The following physical models and settings were used:

- **Solver Type**: Pressure-based
- **Time**: Steady-state
- **Viscous Model**: Realizable *k–ε* turbulence model with standard wall functions
- **Energy Equation**: Enabled
- **Material**: Water as working fluid (temperature-dependent properties)
- **Flow Regime**: Incompressible, turbulent
- **Wall Conditions**: No-slip, adiabatic or constant wall temperature depending on the boundary

**Boundary Conditions:**

- **Inlet Velocity**: Defined using Reynolds numbers (Re = 200–350)
- **Inlet Temperature**: 100°C, 150°C, and 200°C (in different cases)
- **Outlet**: Pressure outlet at atmospheric conditions
- **Wall**: Thermally active or adiabatic depending on simulation case

## III. Result and Discussion

The subsequent table displays the findings of a study examining the influence of channel quantity in a plate heat exchanger and the Reynolds number (Re) on the inlet and outlet port pressure drop (Pa) and frictional pressure drop (Pa) characteristics for supercritical CO2 flow within a plate heat exchanger. To analyze the rise in the friction factor parameter of the plate heat exchanger, the findings have been juxtaposed with previously published experimental study on the same parameter in the literature [11]. Furthermore, the results have been juxtaposed with a numerical model created in this investigation, which functions under analogous operational circumstances.

**3.1 Traits Characteristic of Pressure Drop (Frictional Pressure Drop)**

The heat transfer coefficient, denoted by hc, may be determined using the formula that is provided below. The difference in temperature, denoted by dT, is derived using the FLUENT solver. It is assumed that the mass flow rate of water remains the same.

$$q = mC_p\,dT$$

CFD was used to determine the values of the heat transfer coefficient that are shown in the table below. The influence of pressure drop and heat transfer coefficient is cited in reference [25].

Frictional Pressure Drop (Pa) - The frictional pressure drop is calculated by taking the pressure differential from the FLUENT solver at the flow zone between the plates. The density of the water is then computed by using the formula that is provided below.

$$f = \frac{\rho D_h}{2G^2 L}\,\Delta P_{fric}$$

The values of frictional Pressure Drop (Pa) for smooth plate derived through numerical simulation are presented in the table below. These values were found for a variety of various choices of the operating temperature of the fluid and the Reynolds number (Re).

**Effectiveness calculation for plate heat exchanger -**

The desired effectiveness of heat exchanger is given by the formula:

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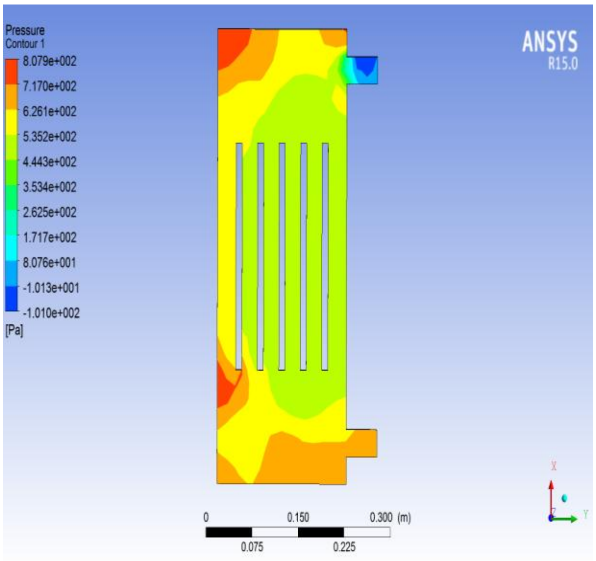
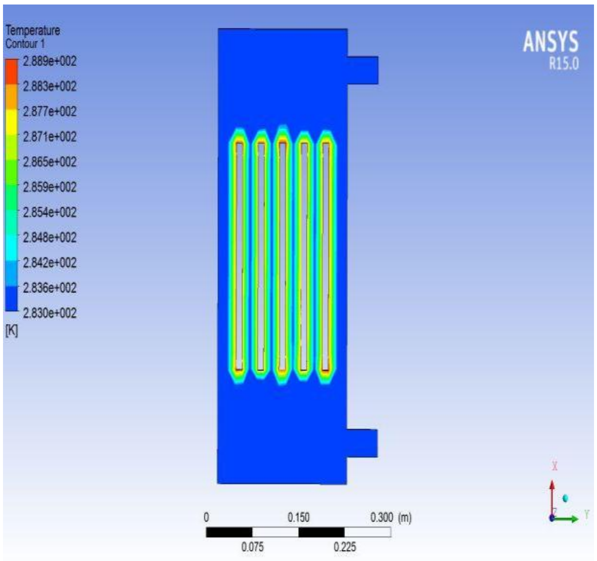
$$\varepsilon = \frac{C_h(T_{hi}-T_{ho})}{C_{min}(T_{hi}-T_{co})} = \frac{25.9875(80-76)}{25.8835(80-49)} = 0.12$$

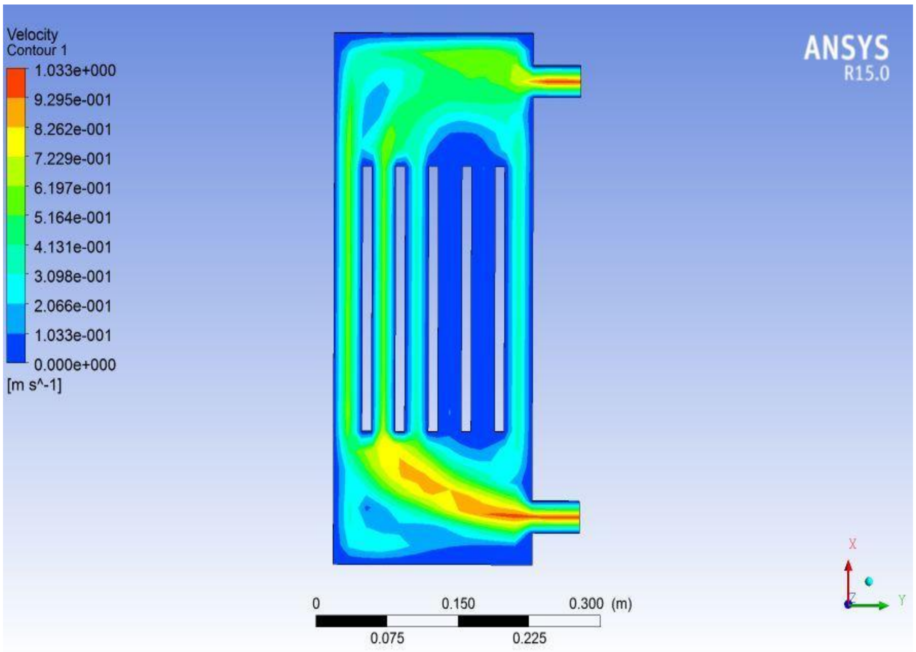
### 3.2 Contour plots obtained from numerical simulation for $10^0$ C




(a)




(b)




(c)

Figure 3.1– (a) Pressure determined using numerical modelling of a plate heat exchanger, (b) Temperature distribution, and (c) Velocity distribution at 10 degrees Celsius

The phenomena of temperature, pressure, and velocity may be analyzed and elucidated through the configuration of a plate heat exchanger including five plates. Figure 5.4 presents a contour map of the pressure (a). The contour map of pressure and temperature can be utilized to analyze and elucidate processes such as thermal conduction and pressure reduction (Pa). The contour map of velocity illustrates the fluid flow pattern between the plates, incorporating the flow at the input and output ports.

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### 3.3 Contour plots obtained from numerical simulation for 15$^0$ C

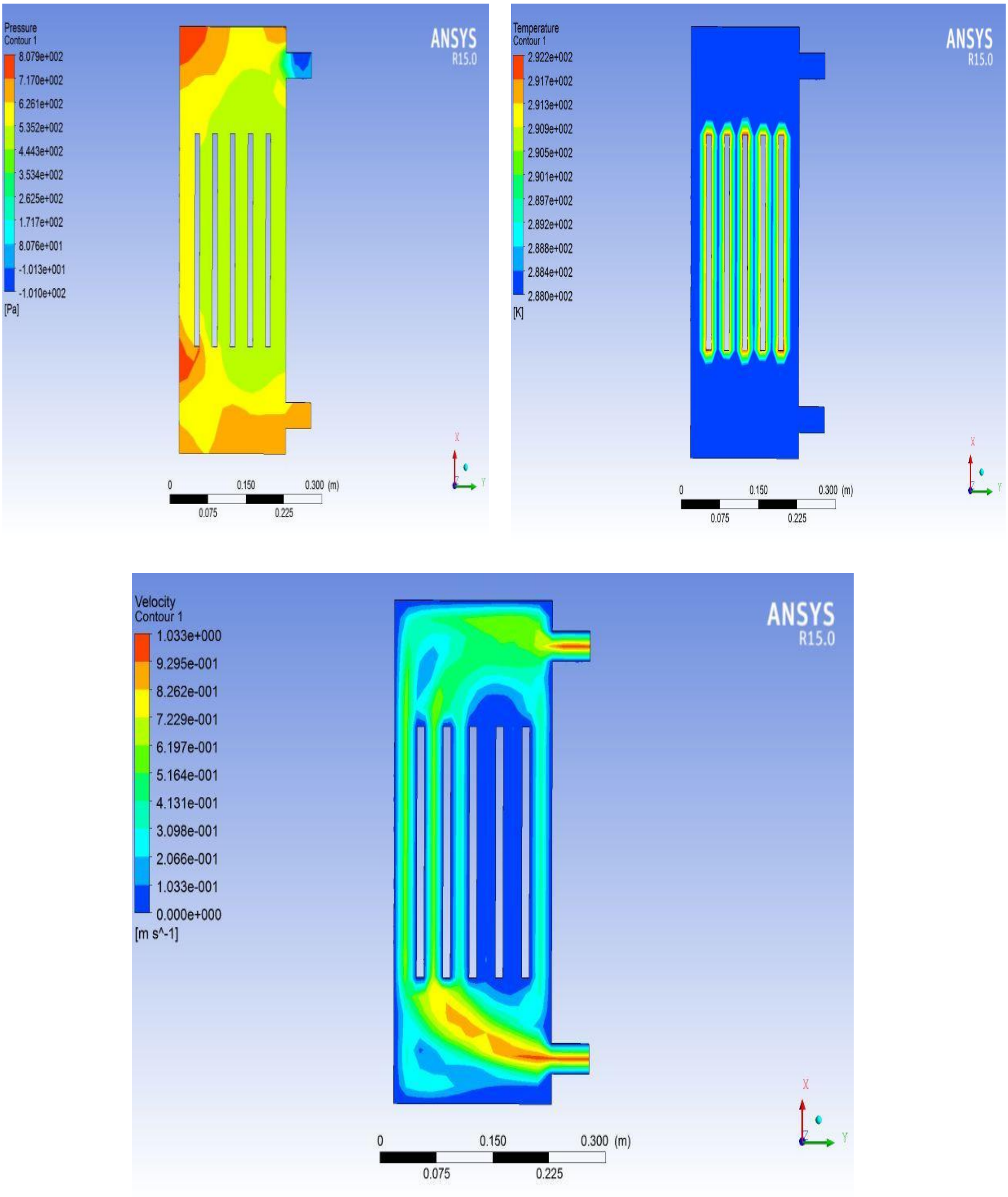


Figure 5.2 – (a) Pressure determined using numerical modelling of plate heat exchanger, (b) Temperature distribution, and (c) Velocity distribution at a temperature of 15 degrees Celsius.

The phenomena of temperature, pressure, and velocity may be analyzed and elucidated through the configuration of a plate heat exchanger including five plates. Figure 5.2 (a) illustrates the contour map of the pressure. The contour map of pressure and temperature can be utilized to analyze and elucidate processes such as thermal conduction and pressure

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reduction (Pa). The contour map of velocity illustrates the fluid flow pattern between the plates, incorporating the flow at the input and output ports.

### 3.4 Contour plots obtained from numerical simulation for 20$^0$ C

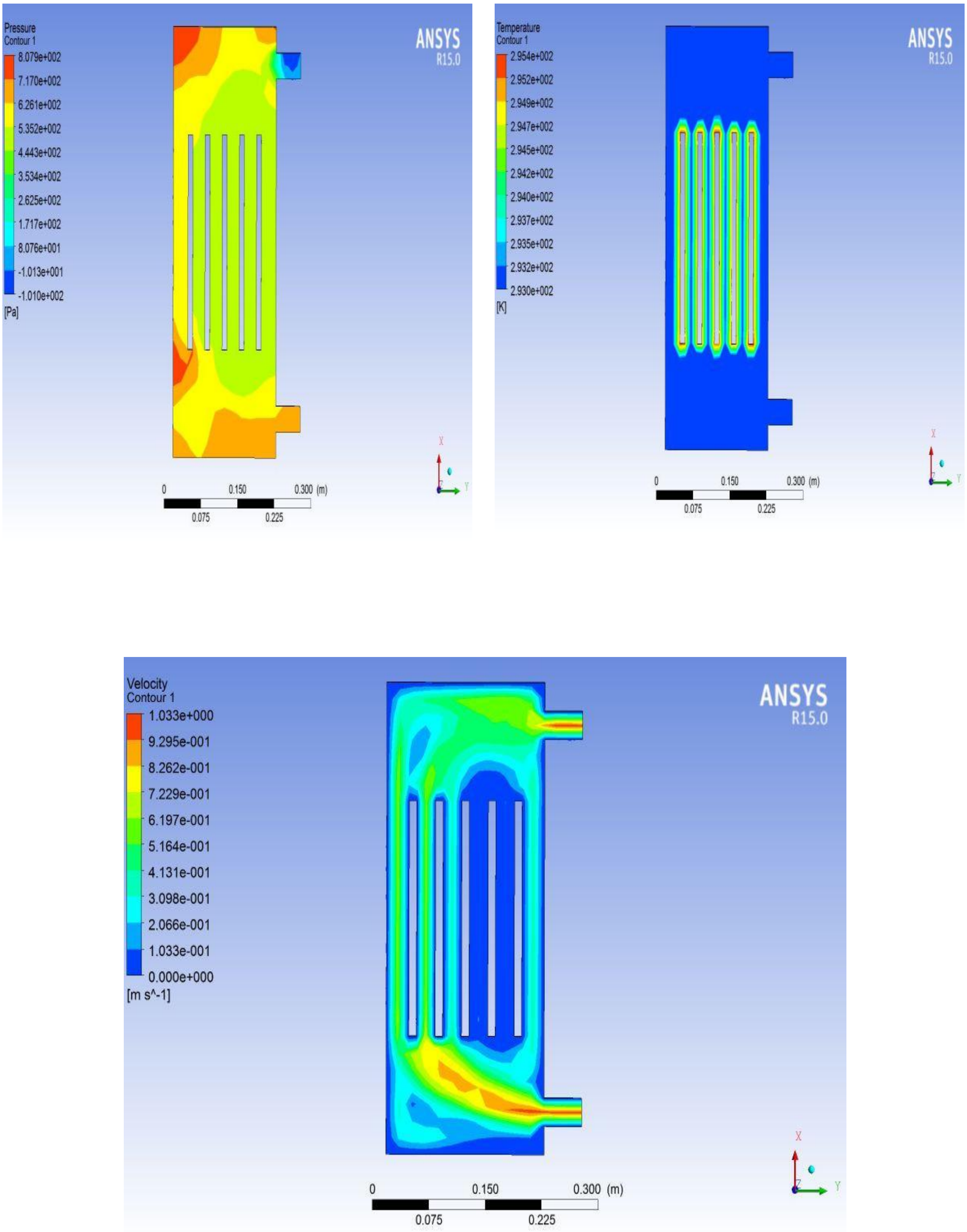


Figure 3.3 – (a) Pressure determined using numerical modelling of plate heat exchanger, (b) Temperature distribution, and (c) Velocity distribution at a temperature of 20 degrees Celsius.

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### 3.5 Contour plots obtained from numerical simulation for wavy plate for $10^0$ C

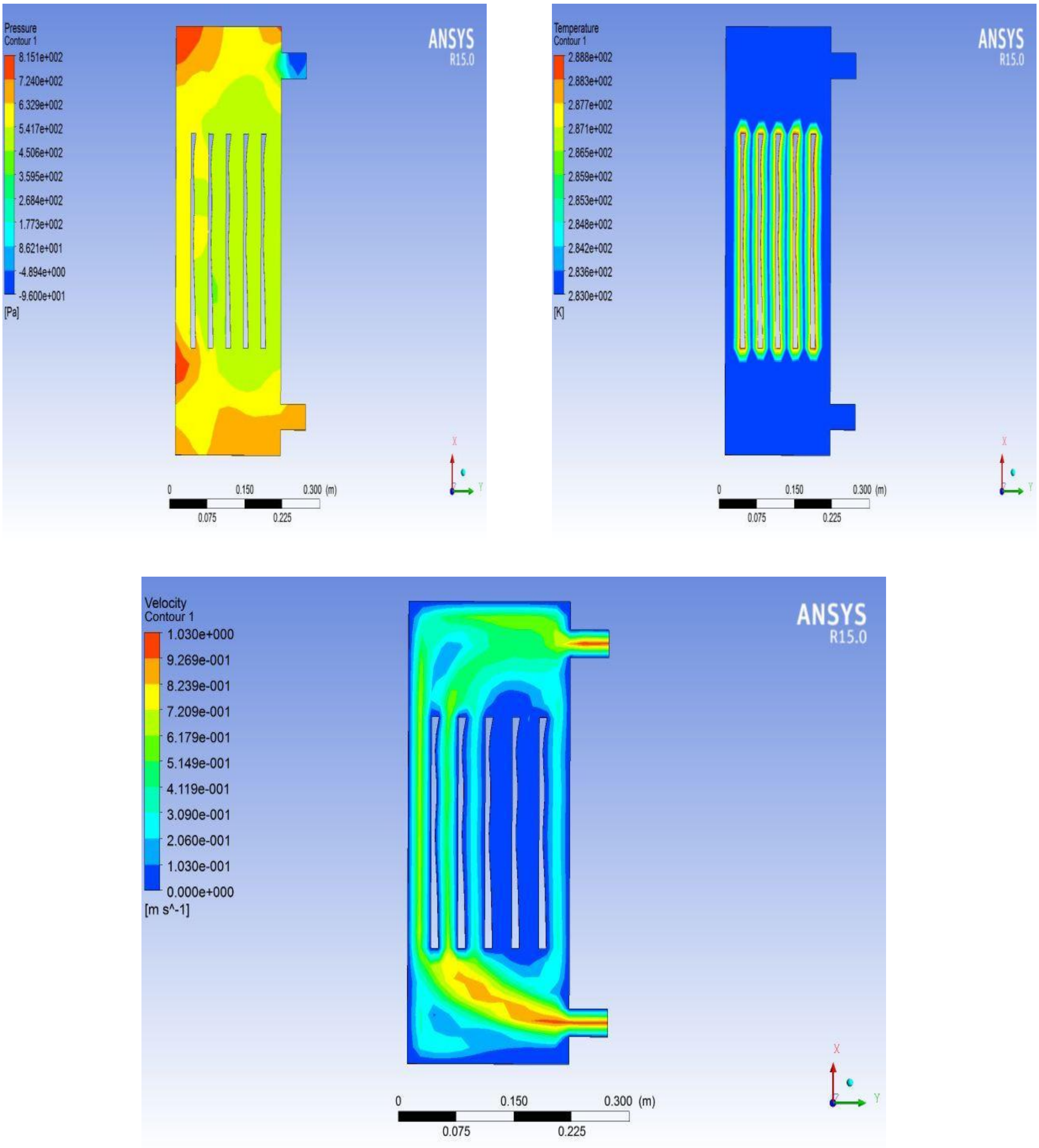


Figure 3.4 – (a) Pressure determined using numerical modelling of a plate heat exchanger, (b) Temperature distribution, and (c) Velocity distribution at a temperature of 10 degrees Celsius in a wavy plate heat exchanger

The phenomena of temperature, pressure, and velocity may be analyzed and elucidated through the configuration of a plate heat exchanger including five plates. Figure 5.4 (a) illustrates the contour map of the pressure. The contour map of pressure and temperature can be utilized to analyze and elucidate processes such as thermal conduction and pressure reduction (Pa). The contour map of velocity illustrates the fluid flow pattern between the plates, incorporating the flow at the input and output ports.

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### 3.6 Contour plots obtained from numerical simulation for 15⁰ C

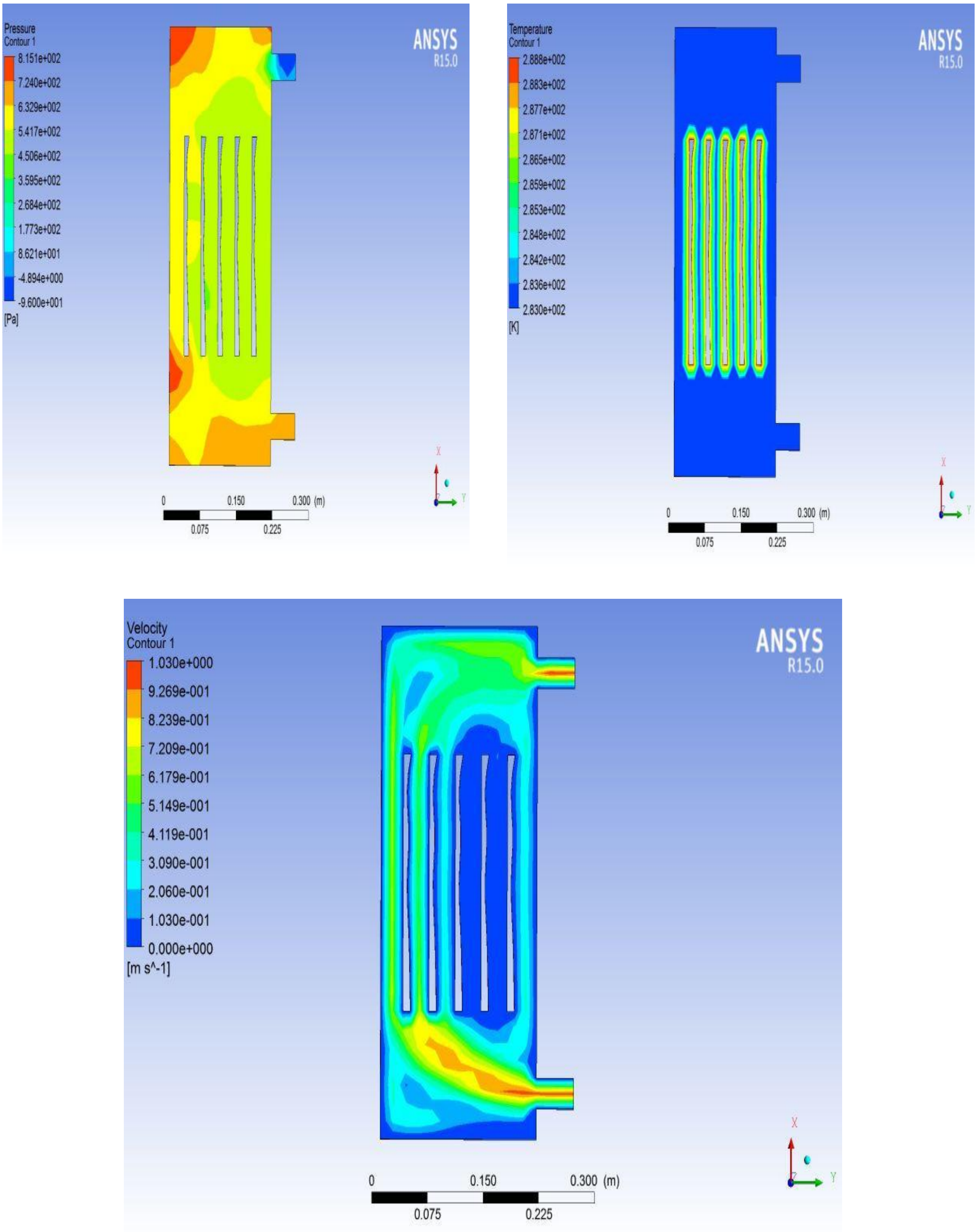


Figure 5.5 – (a) Pressure obtained from numerical simulation of plate heat exchanger, (b) Temperature distribution, (c) Velocity distribution at 15 C in wavy plate heat exchanger

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### 3.7 Contour plots obtained from numerical simulation for 20$^0$ C

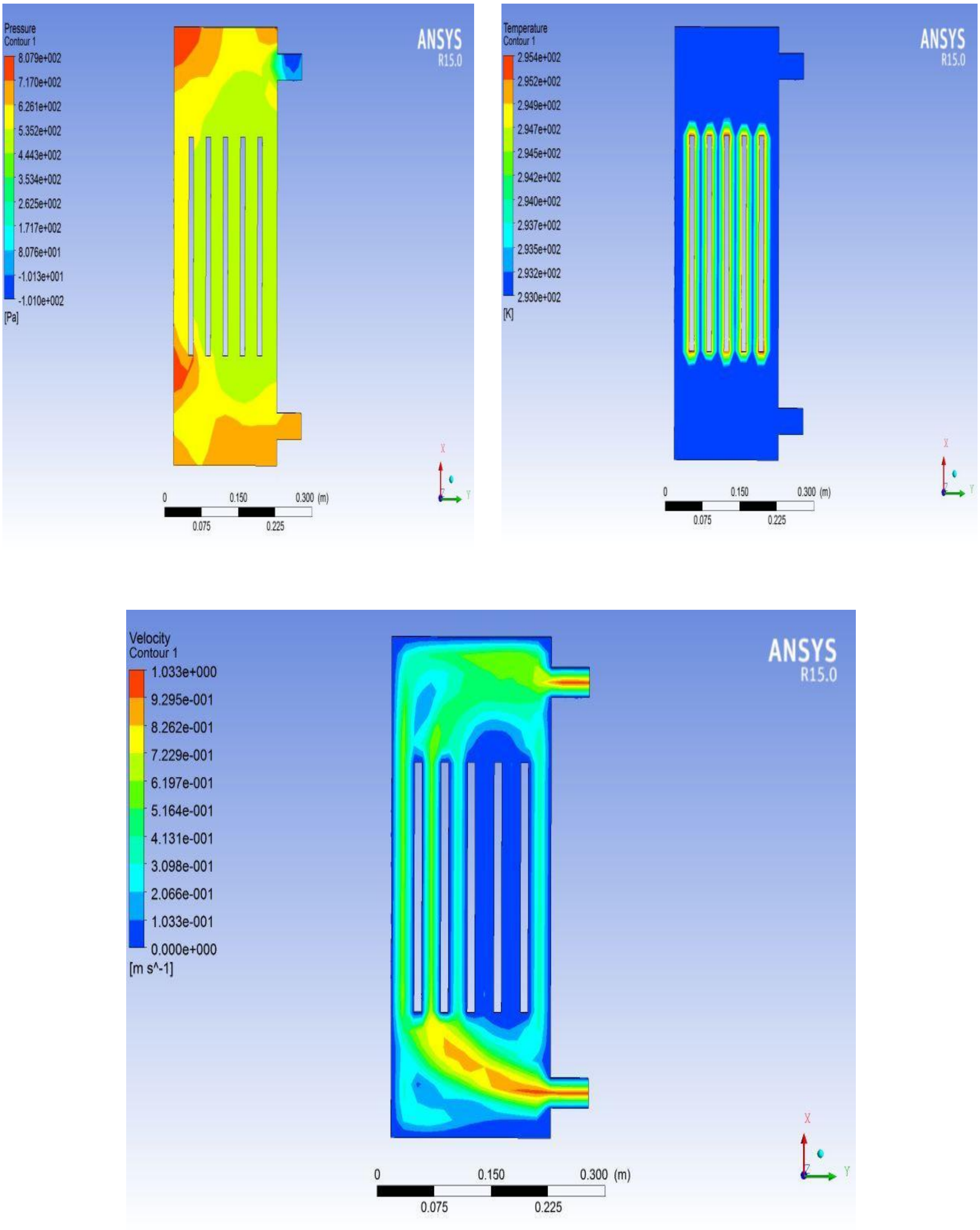


Figure 3.6 – (a) Pressure obtained from numerical simulation of plate heat exchanger, (b) Temperature distribution, (c) Velocity distribution at 20 degree C in wavy plate heat exchanger.

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3.1 Table Comparison table with overall parameters of all four different plate geometries

| | | (Simple Plate) CASE -I | | | (Wavy Plate) CASE -II | | | (Tapered Plate) CASE -III | | | (Dimpled Plate) CASE -IV | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10°C | 15°C | 20°C | 10° | 15°C | 20°C | 10°C | 15°C | 20°C | 10°C | 15°C | 20°C |
| Temperature (K) | MIN | 283 | 288 | 293 | 283 | 283 | 293 | 283 | 283 | 283 | 283 | 288 | 293 |
| | MAX | 288.9 | 292.2 | 295.4 | 288.8 | 288.8 | 295 | 289.9 | 289.9 | 289.9 | 288.8 | 292.1 | **295.4** |
| Pressure (Pa) | MIN | -1.01E+02 | -1.01E+02 | -1.01E+02 | -9.62E+01 | -9.62E+01 | -1.01E+02 | -1.07E+02 | -1.07E+02 | -1.07E+02 | -9.67E+01 | -9.67E+01 | -9.67E+01 |
| | MAX | 8.07E+02 | 8.07E+02 | 8.07E+02 | 8.15E+02 | 8.15E+02 | 8.08E+02 | 8.00E+02 | 8.00E+02 | 8.00E+02 | 7.99E+02 | 7.99E+02 | **7.99E+02** |
| Velocity (m/s) | MAX | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |

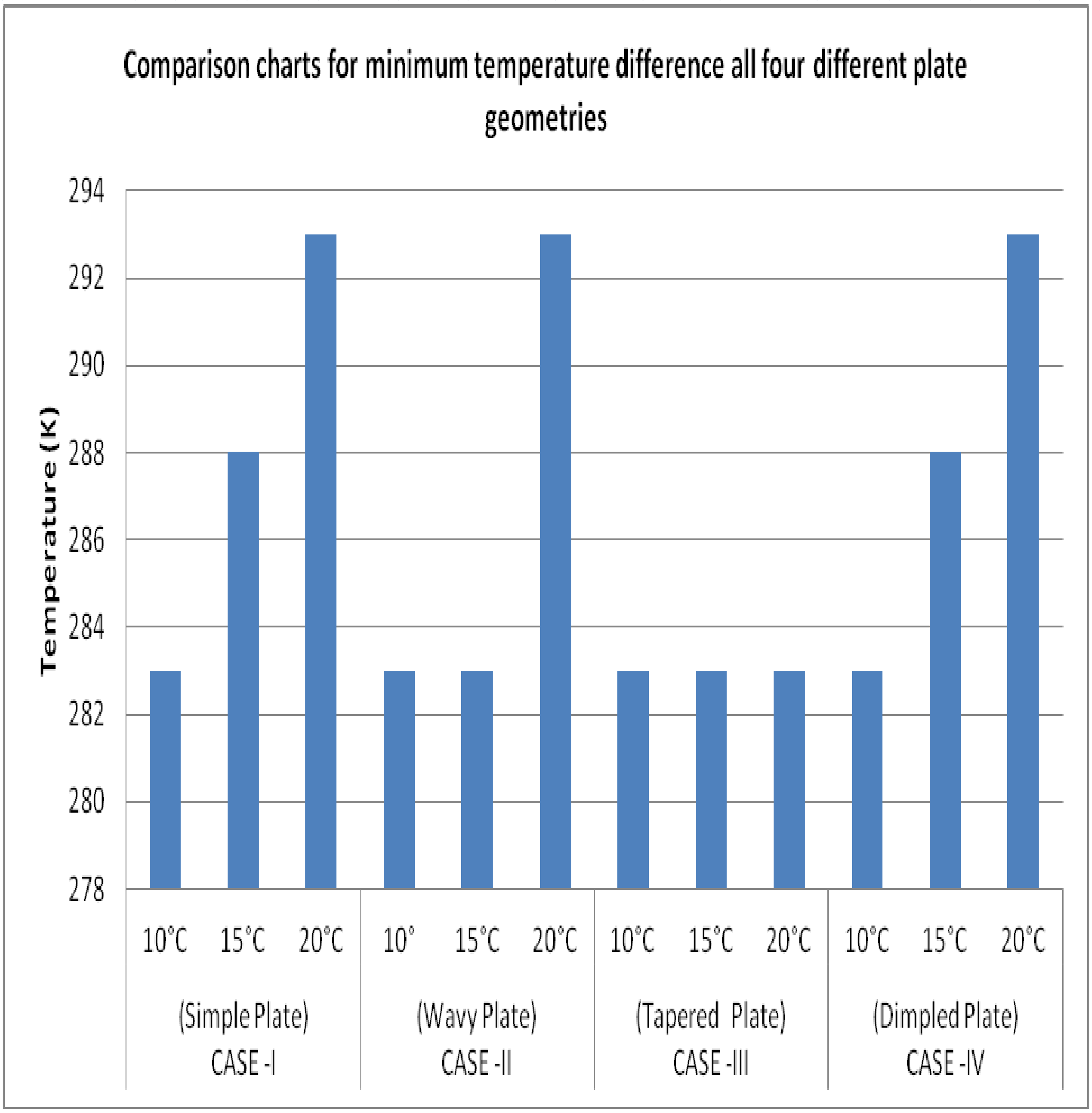


Fig.3. C7omparison charts for minimum temperature difference all four different plate geometries

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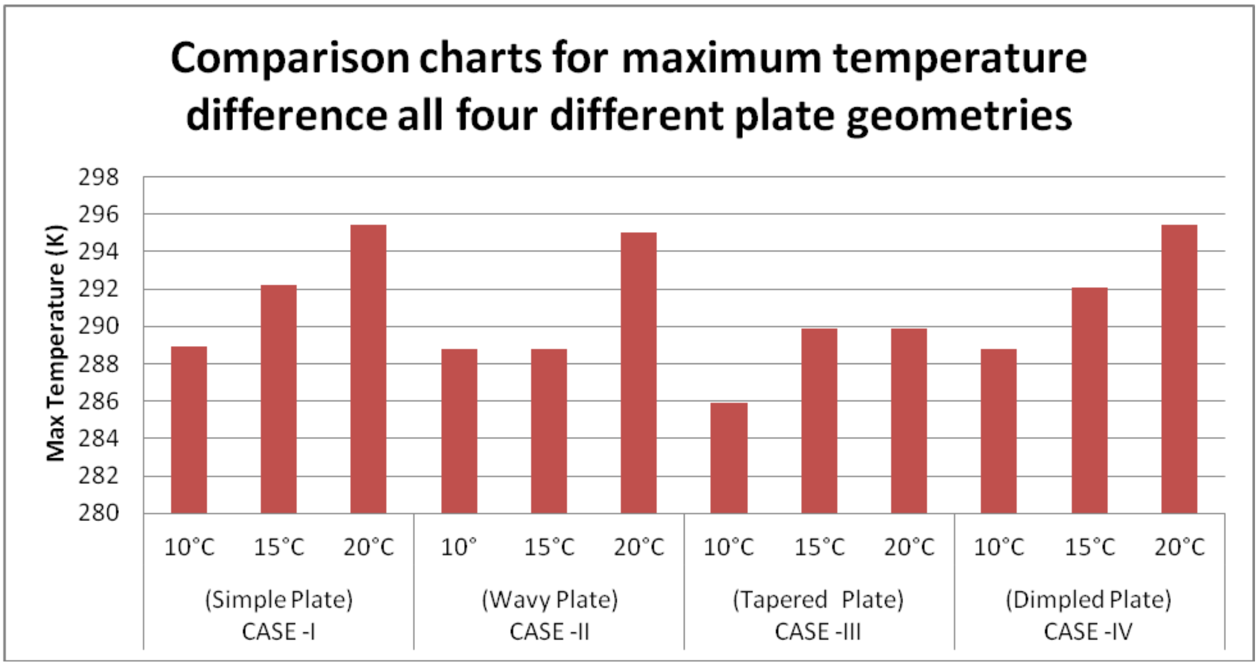


Fig.3.8 Comparison charts for maximum temperature difference all four different plate geometries

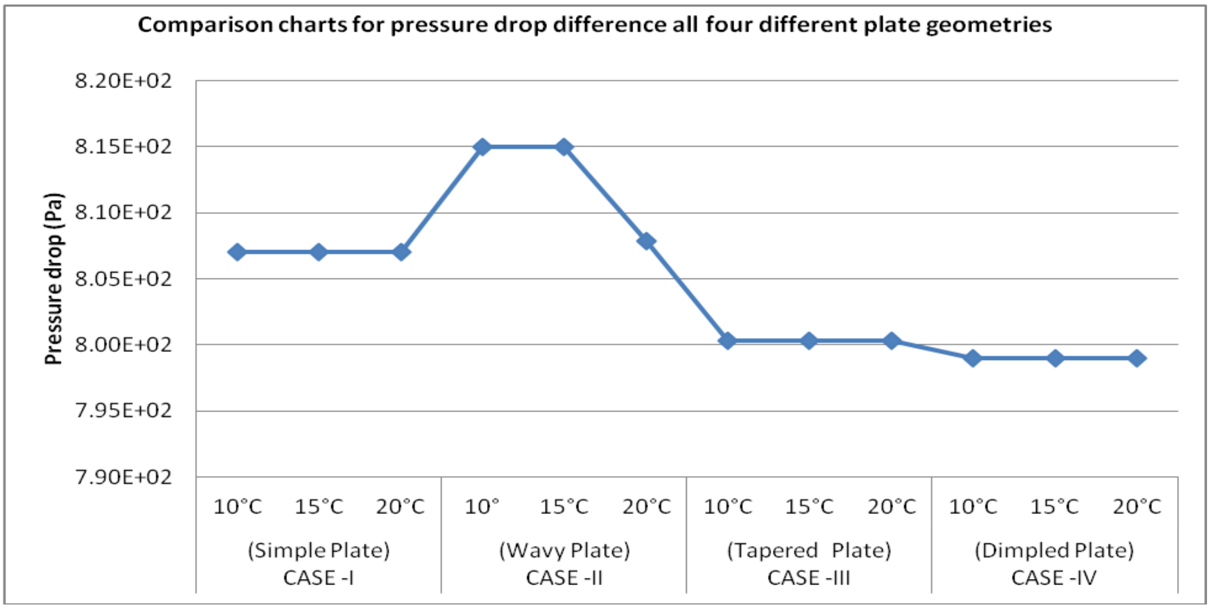


Fig. 3.9 Comparison charts for pressure drop difference all four different plate geometries

## IV. CONCLUSION

Expanding the surface area of the liquid flow route in a plate heat exchanger enhances temperature dispersion but results in an increase in pressure drop, shown by the symbol Pa. The variation in temperature distribution is observed with distinct fluid temperatures, namely 100°C, 150°C, and 200°C, which correspond to the inlet liquid temperatures. The Frictional Pressure Drop (Pa) increases by 200 C in every configuration of the plate heat exchanger; hence, the configuration with the lowest value of the bubbling plate heat exchanger demonstrates superior performance. The results exhibit the minimal achievable frictional pressure drop (Pa) and temperature in the plate heat exchanger featuring a bubbling-shaped structure. The values are -799 Pa and 295.4 K, respectively. Utilizing diverse geometries inside the plate-to-plate heat exchanger might reduce the frictional pressure drop (Pa) to an acceptable level. Consequently, the plates will possess an extended longevity.

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