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DEDICACE

We dedicate this humble work: to our mothers and fathers To our brothers and sisters and to all our families, each in his name.

To all the professors of the Mechanical Engineering Department, Especially Prof. Dr. Deghoum Khalil Head of the Mechanical Engineering Department

To all members of the evaluation committee, professors and doctors to My dearest friends and all my colleagues.

Thanks

First of all, we thank Allah, who helped us complete the memorandum and illuminated our path and success in our scientific thesis.

We thank the good parents who gave us all the incentives to complete this note we also thank Dr. Deghoum Khalil.

We thank all the professors and employees of EL-Oued University For what they have provided for education in our university, especially The dean, the professors of the Faculty of Science and Technology, Especially the Mechanics Department, and the head of the department For all. Masters.

Also, we cannot don't forget our sincere thanks to all of our classmates.

Abstract

Heat exchangers have gained significant economic importance. It is estimated that nearly all of the generated thermal energy passes through a heat exchanger at least once. The thermal-hydraulic properties of a double-pipe heat exchanger were analyzed with the aim of improving its performance.

This study aims to improve the performance of a heat exchanger by implementing conical elements inside the inner pipe and analyzing their effect using CFD simulations. The goal is to increase heat transfer while keeping pressure drop low. Conical elements create turbulence, which helps transfer heat more effectively. However, too much turbulence may create resistance, making the system less efficient. Using CFD software ANSYS Fluent, this study tests a heat exchanger with different designs (simple, 25°, 45°, 60°) to find the best balance between higher heat transfer and lower pressure drop. We have concluded that the heat exchanger with 60° conical elements angle and velocity of 0.3 m/s performed better in terms of heat transfer and overall efficiency.

The results will help design more efficient and cost-effective heat exchangers for industrial use.

Keywords: H-E (Heat Exchanger), Double-pipe, Conical Elements, Heat Transfer, Turbulence, Pressure Drop.

Résumé

Les échangeurs de chaleur ont acquis une importance économique considérable. On estime que la quasi-totalité de l'énergie thermique produite traverse un échangeur au moins une fois. Les propriétés thermohydrauliques d'un échangeur à double tube ont été analysées afin d'améliorer ses performances.

Cette étude vise à améliorer les performances d'un échangeur de chaleur en intégrant des éléments coniques dans le tube intérieur et en analysant leur effet à l'aide de simulations CFD. L'objectif est d'augmenter le transfert de chaleur tout en maintenant une faible perte de charge. Les éléments coniques créent des turbulences, ce qui favorise un transfert de chaleur plus efficace. Cependant, une turbulence excessive peut créer une résistance, réduisant ainsi l'efficacité du système. À l'aide du logiciel CFD ANSYS Fluent, cette étude a testé différents échangeurs de chaleur (simple, 25°, 45°, 60°) afin de trouver le meilleur équilibre entre un transfert de chaleur plus élevé et une perte de charge plus faible. Nous avons conclu que l'échangeur de chaleur avec des éléments coniques à 60° d'angle et une vitesse de 0,3 m/s offrait de meilleurs résultats en termes de transfert de chaleur et d'efficacité globale.

Les résultats contribueront à la conception d'échangeurs de chaleur plus efficaces et plus rentables pour un usage industriel.

Mots-clés : Échangeur de chaleur, Double tube, Éléments coniques, Transfert de chaleur, Turbulence, Perte de charge.

الملخص

اكتسبت المبادلات الحرارية أهمية اقتصادية كبيرة. تشير التقديرات إلى أن جميع الطاقة الحرارية المولدة تقريبًا تمر عبر المبادل الحراري مرة واحدة على الأقل. وقد تم تحليل الخصائص الحرارية الهيدروليكية لمبادل حراري مزدوج الأنبوب بهدف تحسين أدائه. تهدف هذه الدراسة إلى تحسين أداء المبادل الحراري من خلال تطبيق عناصر مخروطية داخل الأنبوب الداخلي وتحليل تأثيرها باستخدام محاكاة ديناميكا الموائع الحسابية. الهدف هو زيادة نقل الحرارة مع الحفاظ على انخفاض انخفاض الضغط. تُحدث العناصر المخروطية اضطرابًا، مما يساعد على نقل الحرارة بشكل أكثر فعالية. ومع ذلك، قد يؤدي الاضطراب الشديد إلى خلق مقاومة، مما يقلل من كفاءة النظام. باستخدام برنامج ديناميكا الموائع الحسابيةANSYS Fluent ، تختبر هذه الدراسة مبادلًا حراريًا بتصميمات مختلفة (بسيط، 25 درجة، 45 درجة، 60 درجة) لإيجاد أفضل توازن بين ارتفاع نقل الحرارة و اقل انخفاض في الضغط. لقد توصلنا إلى أن المبادل الحراري بزاوية عناصر مخروطية 60 درجة وسرعة 0.3 متر/ثانية كان أداؤه أفضل من حيث نقل الحرارة والكفاءة الكلية. وستساعد النتائج في تصميم مبادلات حرارية أكثر كفاءة وفعالية من حيث التكلفة للاستخدام الصناعي.

الكلمات المفتاحية: مبادل حراري(H-E) ، أنبوب مزدوج، عناصر مخروطية، انتقال الحرارة، اضطراب، انخفاض الضغط.

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List of Nomenclatures

φ	Heat Flux density (W/m^2)
ϕ	Heat Flux (W)
A	Isothermal Surface (m^2)
dQ	differential heat added (J)
dT	differential Temperature change (K or C°)
m	Mass (kg)
C_p	Specific Heat capacity (J/kg.K)
Rc	Thermal contact resistance (m^2.K/W)
h_c	Thermal contact conductance (W/m^2.K)
Re	Reynolds number.
U	Characteristic velocity of the flow (m/s)
L	Characteristic length (m)
υ	Kinematic viscosity (m^2/s)
ρ	Volumetric mass (kg/m^3)
μ	Dynamic viscosity (kg/m.s)
Nu	Nusselt number
h	Heat transfer coefficient (W/m^2.K)
λ	Thermal conductivity (W/m.K)
ϕ_{conv}	Convective Heat flux (W/m^2)
ϕ_{cond}	Conductive Heat flux (W/m^2)
Pr	Prandtl number
e	Thickness (m)
σ	Stefan-Boltzmann constant (N/m^2.K)

ΔT_{LM}	Log mean temperature difference (K or C°)
ΔT	Temperature difference (K or C°)
T_h	Hot fluid temperature (K or C°)
T_c	Cold fluid temperature (K or C°)
$\dot{m}_h$	Mass flow rate (hot) (kg/s)
$\dot{m}_c$	Mass flow rate (cold) (kg/s)
η	Efficiency (%)
q_{ideal}	Ideal heat transfer rate (W)
q_{act}	Actual heat transfer rate (W)
C	Heat capacity rate (W/K)
U	Global heat transfer coefficient ($W/m^2.K$)
NUT	Number of transfer units.
$T_{in.c}$	Inlet temperature of cold fluid (K)
$T_{out.c}$	Outlet temperature of cold fluid (K)
$T_{in.h}$	Inlet temperature of hot fluid (K)
$T_{out.h}$	Outlet temperature of hot fluid (K)
ε	Effectivness (%)

General Introduction

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more environments using a working fluid and a working surface having different temperatures. Heat transfer can occur between a solid surface and a liquid, between solid particles and a liquid, etc.

The heat-exchange (or heat-utilizing) apparatus is one of the most common and important elements of power, utility and technological installations. Any conversion of energy from one type to another, as well as the transfer of energy from one device to another, is accompanied by the transition of a certain part of the energy to heat. Therefore, in almost all machines and apparatuses, heat transfer is important.

Heat exchangers play an important role in technological processes, energy, oil refining, manufacturing, transportation, air conditioning, cryogenic and recovery systems. They also serve as key components of many industrial products available on the market. All heat exchangers can be classified according to various criteria.

Heat exchangers have evolved from the Roman hypocaust systems of ancient times that used hot air to warm baths to more advanced applications during the Industrial Revolution, such as James Watt's steam engine condensers. Early heat exchangers were installed in boilers and distillation by the late 19th century. The 20th century saw rapid developments, including shell-and-tube, plate, and finned-tube configurations, due to industrial, automotive, and HVAC needs. Contemporary heat exchangers utilize computational design techniques and Nano technology to advance efficiency in the fields of energy, aerospace, and manufacturing.

Problematic: Can we optimize double pipe heat exchanger’s performance using internal conical elements with different geometries?

This study includes three different chapters:

-Chapter One: Generalities about Heat Exchangers

-Chapter Two: Mathematical Modeling

-Chapter Three: Simulation and Interpretations

Chapter I:

Generalities about Heat Exchangers

I.1. Introduction:

Double-pipe heat exchangers (DPHEs) due to their modular structure and simplicity are among the widely used heat exchanger systems in both household and industrial fields. These heat exchangers consist of two concentric cylindrical pipes and the area between two pipes labeled as an annulus part. The main purpose of this configuration is to exchange the heat between two media flowing in the inner pipe and the annulus side. The amount of the heat transferred between two media significantly affects the system's thermal performance (Kakaç and Liu, 2002). To enhance the thermal performance of the system relative parameters (e.g., geometric factors) can be modified, but at the same time the total cost of the system is highly influenced by these modifications. Therefore, the economic investigation should be taken into account as well as thermal analysis. In order to maintain an admissible balance between these two concepts, the design process like similar engineering problems can be converted into an optimization problem.[1]

I.2. Classification of Heat Exchangers:

I.2.1. Pipe-in-pipe heat exchangers:

Equipment consisting of two pipes with different diameters inserted one into the other. With the help of clutch couplings, all parts of the pipes are assembled into a coil, which provides the necessary space for the heating and cooling medium. Sections are placed one above the other. The flows are directed counter-currently (towards each other). The cooling agent comes from below, and after heating rises up. The heated steam accumulates from above. After condensation, it goes to the bottom of the heat exchanger. This heat exchange equipment is used in the food industry. Heat exchangers of this design are characterized by a significant heat transfer coefficient and can operate at high pressure. The pipes are cleaned mechanically on level areas. The flow inside the two-pipe heat exchangers can be parallel or counter-current.[2]

- **The advantages:**

The main advantages of the device of this design include:

• High flow rate of the coolant: this is achieved through careful selection of water pipes of the desired diameter, which allows the medium to flow freely inside the pipe.

• Ease of maintenance. This property makes it possible to carry out regular cleaning of equipment, which allows to increase the duration of its operation.

• Versatility. In systems, it is permissible to use a coolant both in the liquid and in the vapor phase.[2]

- **The disadvantages:**

• Dimensions: due to the large size, difficulties arise during transportation and use of the device. Most of all this refers to individual use, where space is very limited.

• High cost: the price of external pipes that are not involved in heat exchange, and which are connected to the heat exchanger, is quite impressive.

• Difficulties in the design: when choosing this equipment, you must contact the professionals, which is associated with the complexity of the calculation. At the same time, the overall cost of manufacturing and installation work increases.[2]

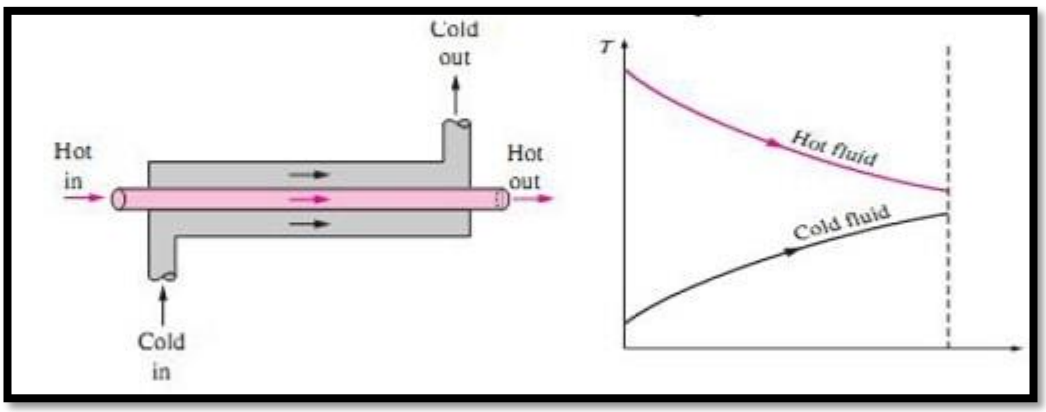


Figure I.1: Parallel Flow.[3]

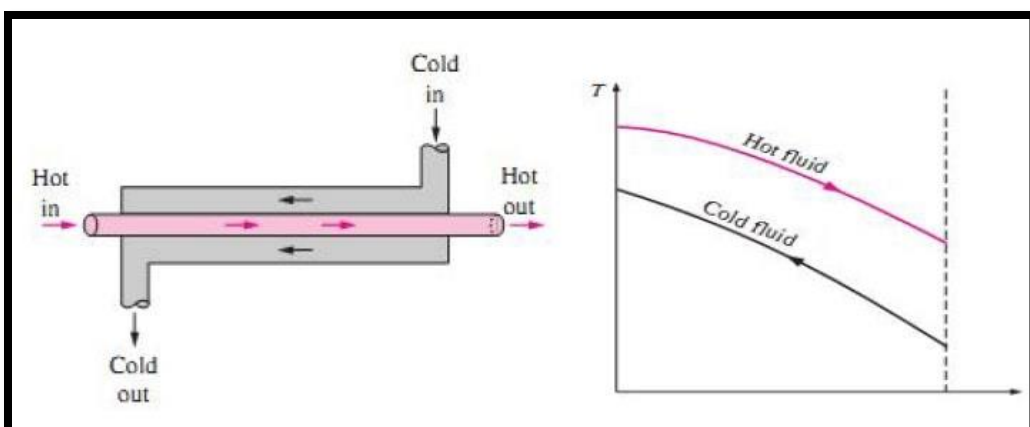


Figure I.2: The counter-current flow.[3]

I.2.2 Shell-and-Tube Heat Exchangers

The shell-and-tube heat exchanger includes a tubular tank and an integrated tubing section. The heat carriers in the heat exchanger are directed both parallel and towards each other. Shell-and-tube heat exchangers are used in the chemical, food, oil and gas, and other fields. They are used as evaporators and condensers. Depending on the operating conditions of the equipment, it is installed in a vertical or horizontal position.

In multi-way devices, it is necessary to firmly fix the base and pipe sections. Such modules function even with a small difference in temperature of the working environment. When choosing the material of the heat exchanger, it is necessary to take into account the aggressiveness of the environment. Due to the inaccessibility of the heat exchanger tubes, the formation of corrosion is highly undesirable. Cleaning is carried out exclusively by a chemical method.[4]

- **The advantages:**

• Internal reliability. Shell-and-tube heat exchangers are more resistant to scale formation, which implies that cleaning should be done less frequently than with other heat exchangers.

• Possibility of power regulation. If necessary, increase or decrease the power, adjust the number of sections, the length and diameter of the pipes.

• Long service life. Shell-and-tube heat exchangers have a long service life.[4]

- **Disadvantages:**

• Large dimensions. A heat exchanger weighing 120–150 kilograms and a length of 4 meters cannot always be fitted and installed at the facility.

• Vulnerability of the outer part of the case. Tube heat exchangers are made of electric welded pipe. After a short period of work, the outer coating begins to diverge along the seam, leaks appear, as a result of which oxygen begins to be released when the water is heated. This contributes to the development of metal corrosion.

• Efficiency. The coefficient is only 70%, which increases energy losses.[4]

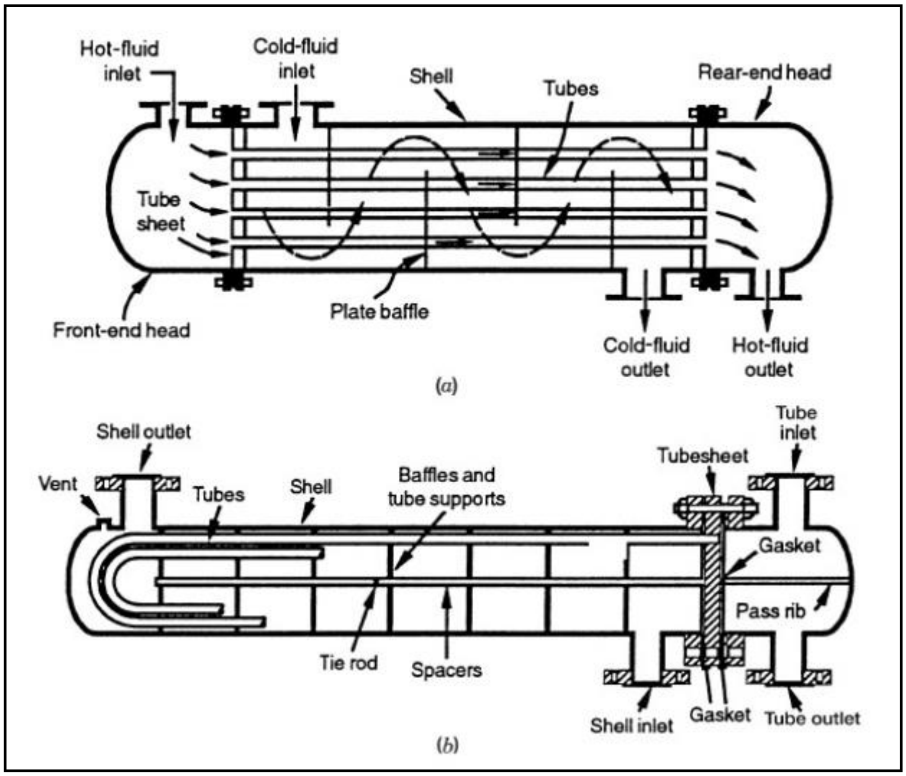


Figure I.3: a). shell-and-tube heat exchanger with one outer shell and one pipe passage.

b). shell-and-tube heat exchanger with one outer shell and two pipe passages.[5]

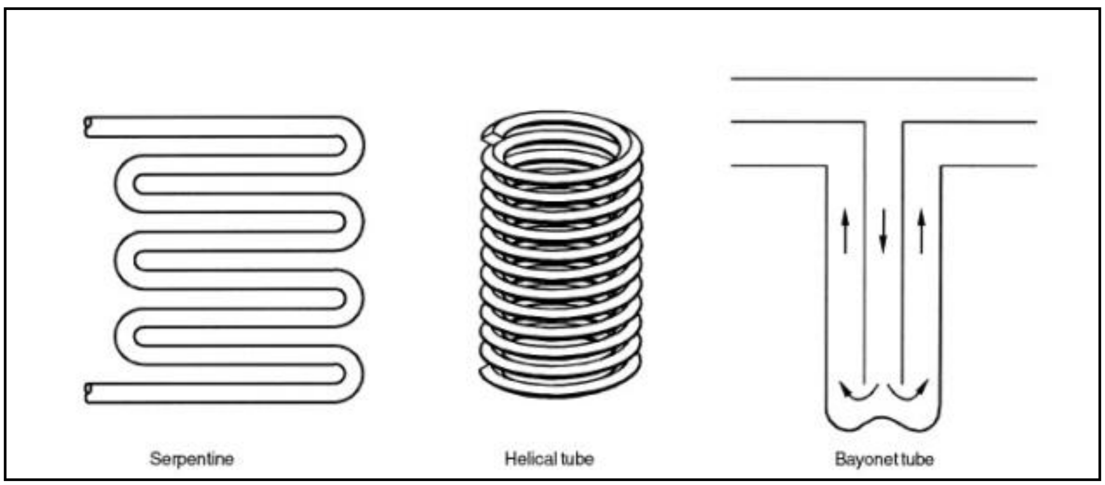


Figure I.4: Various configurations of pipes used in shell and tube heat exchangers.[6]

I.2.3. Plate Heat Exchanger:

They consist of a large number of corrugated plates made of stainless steel. They are separated by seals that are installed without the use of adhesive mixtures, but allow tight fit to each other. Gaskets provide absolute tightness and do not allow mixing of media. The direction of flow is counter-current. The power of the heat exchanger is determined by the number of plates installed inside. Service, cleaning and repair of the device is done by disassembling it. Areas of use: housing and public utilities, shipbuilding, metallurgy, oil and gas, pharmaceutical industries and so on. The choice of material of the heat exchanger must be carried out depending on the technological process, the type of coolants in the system, temperature load and pressure. The most universal in application: plate heat exchangers made of stainless steel with copper pipes.[7]

- **The advantages:**

• High efficiency. Due to the large area of the heat exchange surface, the efficiency reaches 95%, which is much higher than that of tubular apparatuses.

• Compactness. The device is selected in accordance with the required heat consumption. With a small number of plates, the differences will be less, respectively, with a larger number of plates, the differences will increase.

• Multifunctionality. Plate heat exchangers are used in many areas of life, have a wide range of capacities.

• The cost of the device depends on the number of plates installed in it. There is the possibility of selecting the right number of plates. Repair costs replacing a worn (damaged) plate, and not the entire system.[7]

- **Disadvantages:**

• Short service life. Plate heat exchangers are quickly clogged. The maximum service life without cleaning is 3 years.[7]

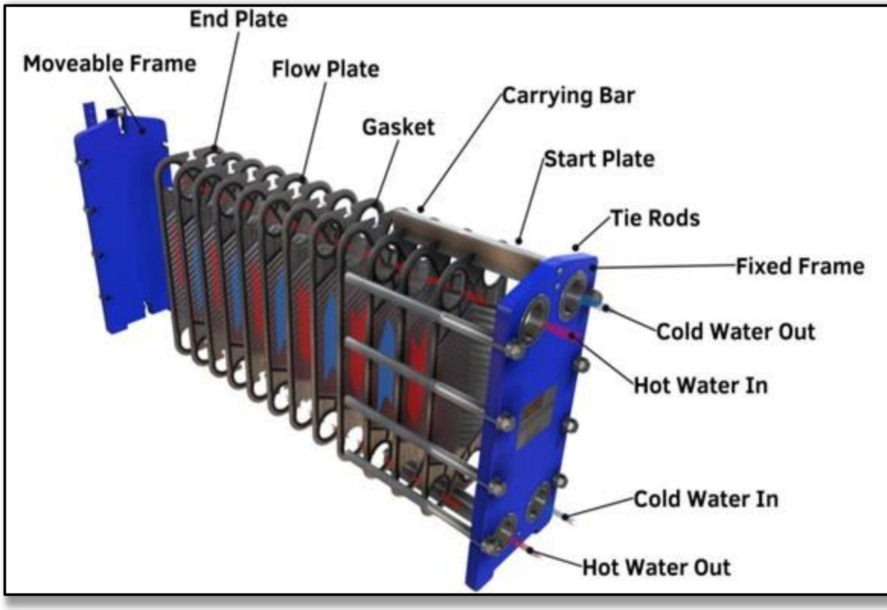


Figure I.5: Components of Plate Heat Exchanger.[8]

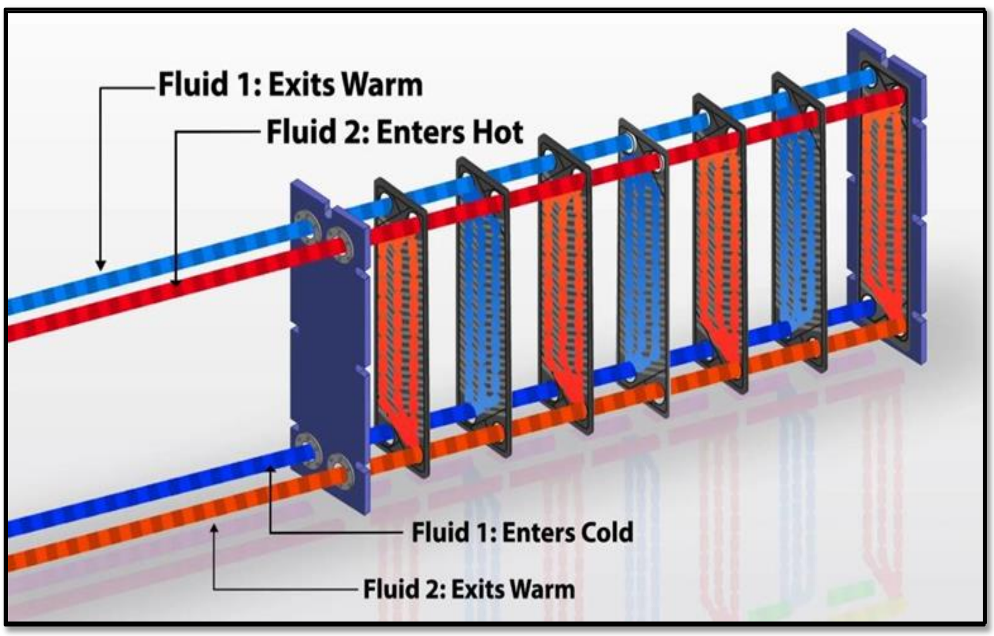


Figure I.6: Concept of Plate Heat Exchanger.[9]

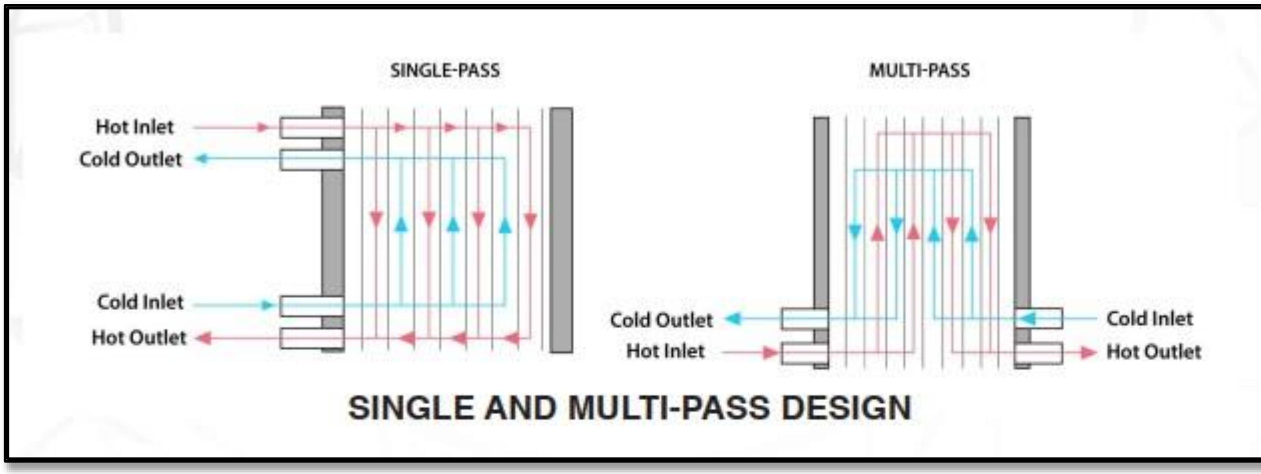


Figure I.7: Single and Muliti-Pass Design.[9]

I.3. Some of the previous experiments on H-E:

- **[M. Sheikholeslami , D.D. Ganji]: [10]**

- **Study tiltle:** Experimental Investigation of Perforated Turbulators in Dual-Pipe Thermal Exchange Systems.
- **Goal:**

  This study examines how perforated turbulence promoters affect heat exchange rates and pressure differentials in liquid-to-gas thermal transfer systems, employing computational modeling and multi-objective evolutionary optimization techniques.
- **Methodology:**
  - It contains a copper pipe, which is encased in a transparent acrylic shell.
  - Thermal energy transfers as the hot fluid travels through the central pipe, heating up the surrounding gas.
  - Disruptors with an opening were introduced in the gas flow to enhance heat transfer.
  - Precise instruments monitored temperature and pressure changes, with the flow of gas regulated by a variable-speed blower.
- **Results:**
  - Disruptors incorporated in the flow bettered heat transfer by 159% over standard conduit designs.
  - Larger holes made it simpler for the movement of the flow and made additional heat transfer possible simultaneously.

- Greater distances between flow disruptors diminished flow resistance at the cost of reduced thermal exchange capability due to attenuated vortex generation patterns

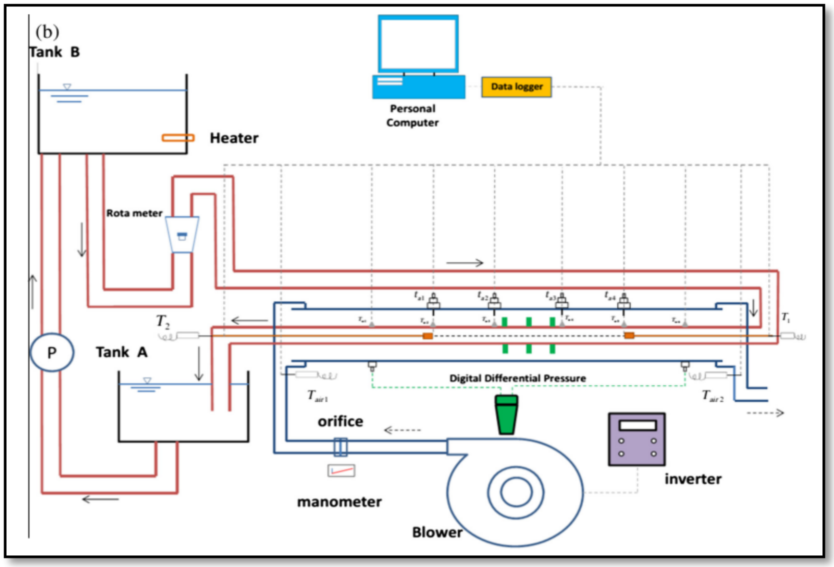


Figure I.8: Schematic diagram of the experimental setup.[10]

❖ **[Timothy J. Rennie, Vijaya G.S. Raghavan]: [11]**

➢ **Study title:** Experimental Studies of a Double-Pipe Helical Heat Exchanger

➢ **Goal:**

To experimentally analyze the heat transfer characteristics of a double-pipe helical heat exchanger, comparing parallel flow and counterflow configurations.

➢ **Methodology:**

- Two heat exchangers with inner tubes of varying sizes were constructed and experimented upon.
- The outer tube was 15.9 mm in width, with either 9.5 mm or 6.4 mm widths for the inner tube.
- They consisted of copper coils with a radius of curvature of 235.9 mm.
- It employed hot water inside the inner tube and cold water outside in the annulus with regulated rates of flow.

➢ **Results:**

- Counterflow had greater heat transfer rates due to a greater difference between temperatures.
- A larger coil had a constant rate of heat transfer at a smaller Dean number than did a smaller coil.
- Comparison with other studies with different boundary conditions revealed good agreement with the inner Nusselt number.

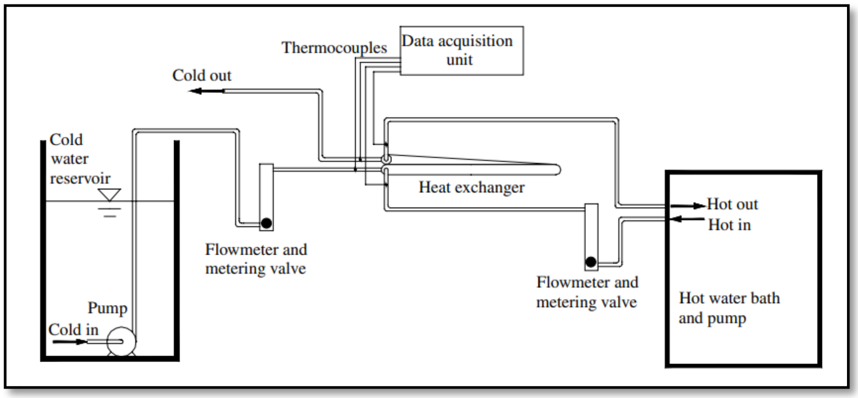


Figure I.9: Schematic of the experimental setup.[11]

❖ **[B. Venkatesh , Mudassir Khan]:[12]**

➢ **Study title:** Design Optimization of Counter-Flow Double-Pipe Heat Exchanger Using Hybrid Optimization Algorithm.

➢ **Goal:**

To optimize the design and performance of a counter-flow double-pipe heat exchanger using a hybrid optimization algorithm, integrating Gray Relational Analysis (GRA), Artificial Neural Networks (ANN), and Genetic Algorithms (GA).

➢ **Methodology:**

- There are two pipes nested inside one another.
- Inner tube: Copper, 9.5 mm width
- Outer tube: Zinc-coated iron, 28.5 mm inner diameter
- Hot water flows through the inner tube, and cold water flows through outer space in the reverse direction.

- **Results:**
  - Increased with higher mass flow rates.
  - Higher for counterflow than parallel flow due to increased temperature difference.
  - Best performance was achieved at higher cold fluid flow rates.
  - Lower resistance indicates better heat exchange efficiency.

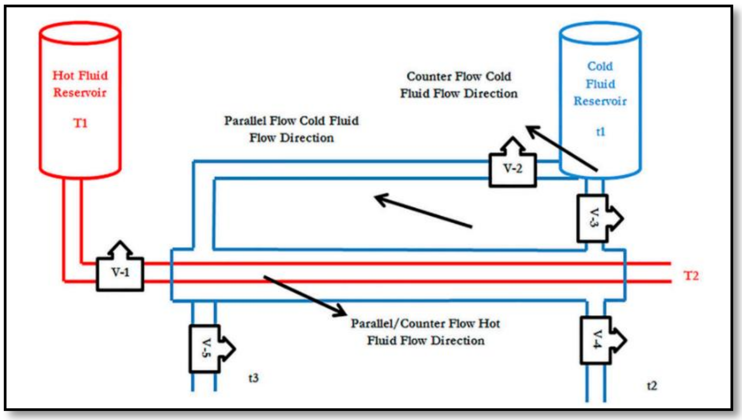


Figure I.10: Schematic layout of double-pipe heat exchanger.[12]

- **[Kunal G Kamble, Babaso N Naik]:[13]**

- **Study title:** CFD Analysis of Double Pipe Heat Exchanger Using Perforated Pipe
- **Goal:**

  To investigate the effect of a perforated pipe in the annulus region of a double-pipe heat exchanger, using Computational Fluid Dynamics (CFD) simulations, to improve heat transfer rate and effectiveness without significantly increasing pressure drop.
- **Methodology:**
  - The double-pipe heat exchanger consists of:
  - Outer pipe: 40 mm diameter
  - Inner pipe: 25 mm diameter (copper)
  - Perforated pipe: 29 mm diameter, 1 mm thickness, with 10 mm perforations arranged in linear and circular patterns.

- 3 configurations were tested**:**
  - Simple double-pipe heat exchanger (baseline case).
  - Double-pipe heat exchanger with a concentric perforated pipe.
  - Double-pipe heat exchanger with an eccentric perforated pipe.
  - Simulations were conducted at five different mass flow rates (0.036 to 0.11 kg/s) with water as the working fluid.

➢ **Results:**

  - Concentric perforated pipe showed a 438% increase in heat transfer compared to the simple heat exchanger.
  - Eccentric perforated pipe also improved heat transfer but was slightly less effective than the concentric design.
  - Highest for lower Reynolds numbers (Re = 4000) and decreased as flow rate increased.
  - Concentric perforated pipe had the best overall performance.
  - Eccentric perforated pipe resulted in a 95.8% pressure drop increase, slightly lower than the concentric case.

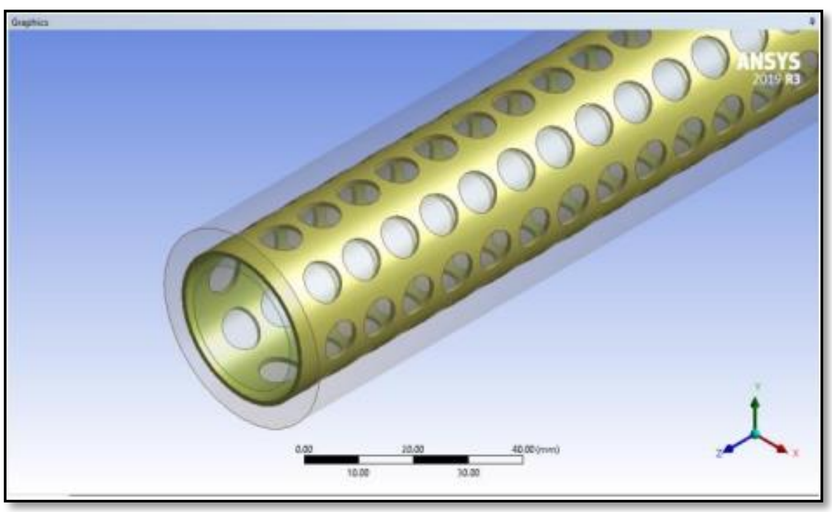


Figure I.11: 3D view of heat exchanger with perforated pipe.[13]

❖ **[H.-Z. Han, B.-X. Li, H. Wu and W. Shao]:[14]**

➢ **Study title:** Multi-Objective Shape Optimization of Double Pipe Heat Exchanger with Inner Corrugated Tube Using RSM Method.

➢ **Goal:**

To optimize the geometric design of a double-pipe heat exchanger with an inner corrugated tube using the Response Surface Methodology (RSM). The experiment emphasizes improving heat transfer performance.

➢ **Methodology:**

- Heat Exchanger Type**:** Double-pipe heat exchanger with a corrugated inner tube.
  - Simulated using Computational Fluid Dynamics (CFD).
  - Optimization performed with Response Surface Methodology (RSM) and Pareto optimal solutions.

➢ **Results:**

- Heat transfer increased with optimized design parameters.
- Maximum efficiency (h = 1.12) was achieved under specific conditions.

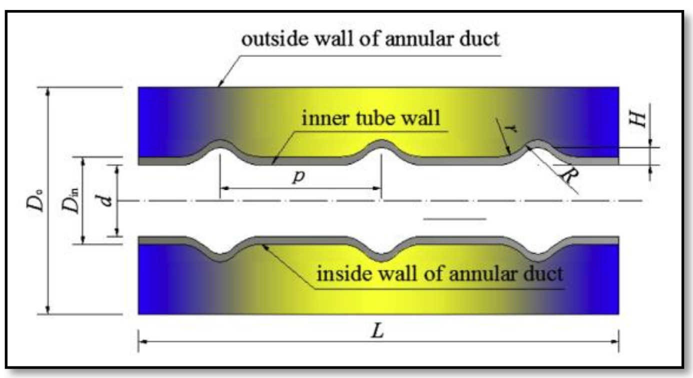


Figure I.12: Structural parameters of the corrugated tube.[14]

❖ **[P.V.K.V.Kola,S. K. Pisipaty, S.S. Mendu and R.Ghosh]:[15]**

➢ **Study title:** Optimization of Performance Parameters of a Double-Pipe Heat Exchanger with Cut Twisted Tapes Using CFD and RSM.

➢ **Goal:**

To optimize the design of a double-pipe heat exchanger with cut twisted tapes using Computational Fluid Dynamics (CFD) and Response Surface Methodology (RSM). The study aims to enhance heat transfer while minimizing friction factor.

➢ **Methodology:**

- Heat Exchanger Type**:** Double-pipe heat exchanger with cut twisted tapes.
- Design Parameters:
  - Mass flow 0.05–0.25 kg/s
  - Cut radius 2–6 mm
  - Cut angle 15°–45°
- Simulated using ANSYS fluent.

➢ **Results:**

- Improved with increased cut radius and angle of cut.
- Maximum heat transfer at mass flow rate = 0.05 kg/s, radius of cut = 5.464 mm, angle of cut = 45°.

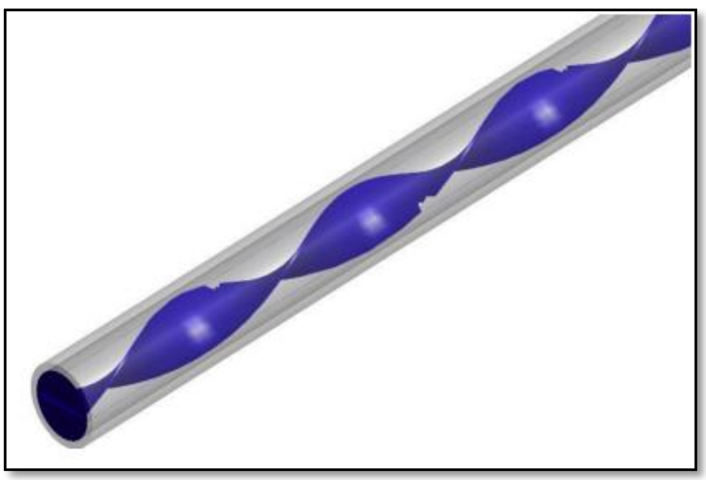


Figure I.13: Model of Plain Tube with VCSCTT.[15]

Chapter II:

Mathematical modeling

II.1. Introduction:

Heat exchangers are devices that aim to accomplish the process of thermal energy transfer from one fluid to another by means of radiation, convection, or conduction. They constitute key elements in industrial plants, playing a very important role in efficiency improvement. Fulfilling this task requires applying efficient calculation and sizing methods for the devices. Such an activity requires using correlations that are relevant to thermal and hydraulic calculations. In this chapter, we present a mathematical model.

II.2. Thermal quantities:

To be able to correctly describe the phenomena of heat transfer among different media, and the overall principles of conservation of heat in closed systems, one must define several fundamental physical quantities. For any body of matter, the addition of a certain amount of heat results in a change in its temperature or a change in its state. Temperature is a physical quantity characterizing the degree of matter's energy. These different notions will be explained further below.

II.2.1. The temperature:

The temperature sense is examined through sensory perceptions that may bring about an unreasonable judgment of such measurements. Temperature dictates the amount of thermal energy contained in an object, which allows for comparisons that determine whether an object is warmer or cooler in relation to another.[16]

II.2.2. Temperature distribution:

At every point in space where matter exists, we can define a scalar temperature function as a function of the point's coordinates and elapsed time. The collection of instantaneous temperatures dispersed throughout space is referred to as the "temperature field,", $T(x; y; z; t)$

II.2.3. Heat:

Heat is a special type of energy, which can be defined as the energy of movement and vibration of molecules in a material. It is the transfer of this sort of energy in one direction, that is, the direction of movement is always from a hotter, or higher-temperature, region to a colder, or lower-temperature, region.[17]

II.2.4. Heat flow:

Heat transfer is caused by a temperature gradient, from regions of higher temperatures to regions of lower temperatures. Heat flux density, symbolized as $\boldsymbol{\varphi}$, is the amount of heat transferred per unit time and per unit of an isothermal surface.[17]

$$\boldsymbol{\varphi = \frac{1}{A}\frac{dQ}{dt}} \tag{II.1}$$

The quantity of heat transmitted to surface S per unit time is called the heat flux ϕ:

$$\boldsymbol{\phi = \frac{dQ}{dt}} \tag{II.2}$$

II.2.5. The specific heat:

By definition, the specific heat, which is denoted by the letter $\boldsymbol{C_p}$**,** is the exact amount of heat energy that is needed for a given material of a specified mass to raise its temperature by just one degree. That is, this exact amount is a fundamental measure of the amount of heat that is exchanged between two different bodies that are at different levels of temperature, which can be mathematically represented using the symbols $\boldsymbol{T_1}$ and $\boldsymbol{T_2}$, for each body, respectively. It is important to note that, in this very context, it is assumed that is indeed greater than ($\boldsymbol{T1>T2}$). This kind of relationship can be stated mathematically as follows:

$$\boldsymbol{C_p = \frac{1}{m} \cdot \frac{dQ}{dt}} \tag{II.3}$$

II.2.6. Heat conductance:

Thermal conductance is a physical property that describes how materials behave in response to heat transfers by conduction. It is included in the constant of Fourier's law. It is the measure of the quantity of heat transmitted per unit area per unit of time in a state of a temperature gradient. Conductivity depends greatly upon:

- The inherent qualities of the material.
- The temperature.
- Other contributing factors were atmospheric pressure and humidity.

So thermal conductivity **λ** characterizes the material's ability to transmit heat.[18]

II.2.7. Contact resistance:

Contact between two solids is macroscopically uniform. At a smaller scale, at the roughness scale, for example, contact is discontinuous. This thermal conductivity discontinuity at the cross-sectional scale creates a temperature profile discontinuity. This may be represented by the introduction of the contact resistance $\boldsymbol{Rc}$, with the relation:

$$R_C = \frac{1}{h_C} \tag{II.4}$$

Where $\boldsymbol{hc}$ is the heat transfer coefficients

II.3. Physical magnitudes:

II.3.1. Density (ρ):

The ratio of the mass of a material per unit volume. Also known as mass-volume.[19]

II.3.2. Viscosity (μ):

Viscosity is a property of a liquid that tends to resist the flow of the liquid when the liquid is applied with a force. The more viscous the liquid (high viscosity), the harder it flows.[19]

II.3.3. Flow rate:

This is the amount of fluid that passes or is carried through in a period of time. Flow has been divided into two primary categories: mass flow and volume flow. The mass flow rate, given as Qm $[Kg/S]$, and the volumetric flow rate $m^{\cdot}$ $[m/s]$

II.3.4. Reynolds number:

Reynold's number quantifies the equilibrium between inertial forces and viscous forces in liquids. Boundary layer signifies the change in these forces in a pipe. It is where fast and slow liquids interact, resulting in turbulence and friction. Viscosity opposes turbulence, and Reynold's number measures the point of its occurrence.

Given by the following formula:

$$Re = \frac{UL}{v} = \frac{\rho UL}{\mu} \tag{II.5}$$

The REYNOLDS experiment on fluid dynamics in a cylindrical pipe discovers two different regimes of flow, characterized by a dimensionless quantity known as the Reynolds number.

At low flow rates, the regime is laminar, while at high flow rates, the regime is turbulent.

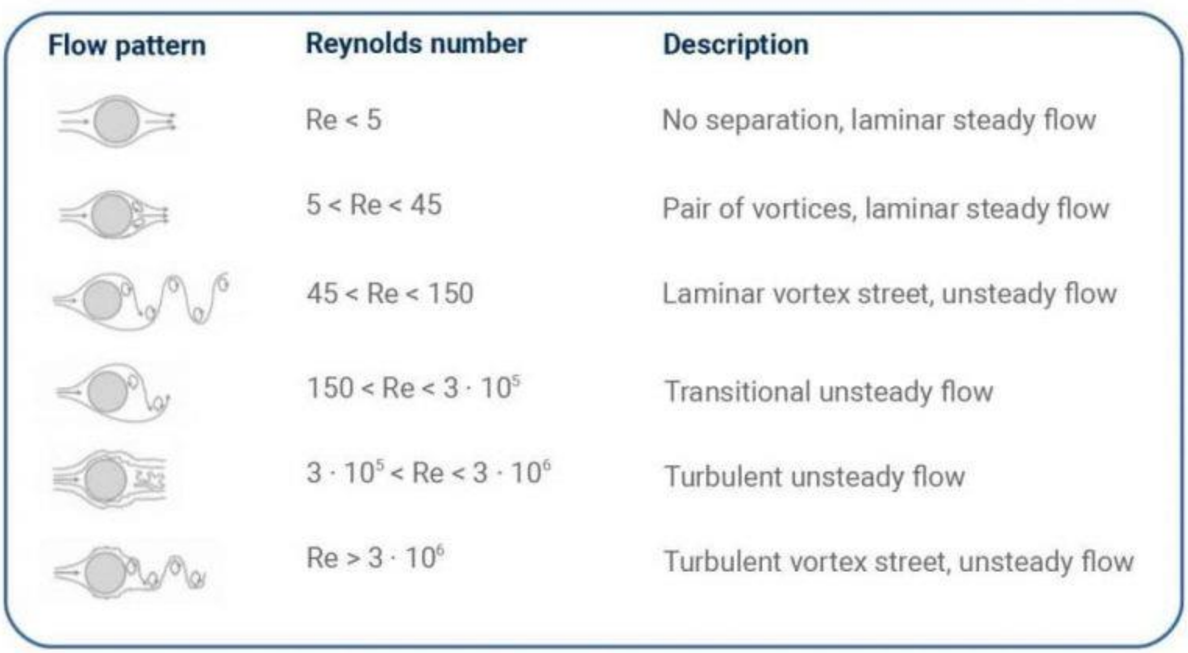
- **Laminar regime:**

The structure of fluid threads is defined by a parallel orientation, where molecular dynamics, or conduction, allows for interactions between layers.

The flow will remain laminar if the REYNOLDS number is kept below the critical value of 2300.

- **Turbulent regime:**

Flow is disturbed, and fluid particle motion is random and three dimensional. The flow regime is considered turbulent if the REYNOLDS number reaches or exceeds 10000. The regime corresponding to a REYNOLDS number between 2300 and 10000 is said to be transient.[20]



Flow pattern	Reynolds number	Description
	$Re < 5$	No separation, laminar steady flow
	$5 < Re < 45$	Pair of vortices, laminar steady flow
	$45 < Re < 150$	Laminar vortex street, unsteady flow
	$150 < Re < 3 \cdot 10^5$	Transitional unsteady flow
	$3 \cdot 10^5 < Re < 3 \cdot 10^6$	Turbulent unsteady flow
	$Re > 3 \cdot 10^6$	Turbulent vortex street, unsteady flow

Figure II.1: Flow regimes.[21]

II.3.5. Nusselt number:

This dimensionless number specifies the relative importance of the heat flux actually transmitted by convection compared with a reference conductive heat flux for the problem.

$$Nu = \frac{h \cdot L}{\lambda_F} = \frac{\phi_{conv}}{\phi_{cond}} \tag{II.6}$$

h **:** Local or global exchange coefficient, depending on the case.

In forced convection, the Nusselt number is linked to the Reynolds number and the Prandtl number.[22]

II.3.6. Prandtl number:

It characterizes the influence of the nature of the fluid on heat transfer by convection:

$$P_r = \frac{\mu C_p}{\lambda} \tag{II.7}$$

II.4. Heat transfer modes:

II.4.1. Heat conduction:

Conduction mainly describes the transfer of heat energy from the hotter parts to the colder parts of the same body, or alternatively, from one independent body to another. This process takes place without any considerable parallel motion of the substances involved in the process. This mode of heat transfer may take place in any state of matter, including solid substances and fluid materials. The manner and properties of conduction are controlled by the laws provided in Fourier's law: **[18]**

$$\vec{\phi} = -\lambda \vec{\nabla} T \tag{II.8}$$

When a body at temperature T_1 is connected to another body at temperature T_2 by a thermal conductor with a cross-sectional area **A** and a thickness e, the resulting heat transfer between the two bodies may be written as: **[18]**

$$\phi = \lambda . A . \frac{(T_1 - T_2)}{e} \tag{II.9}$$

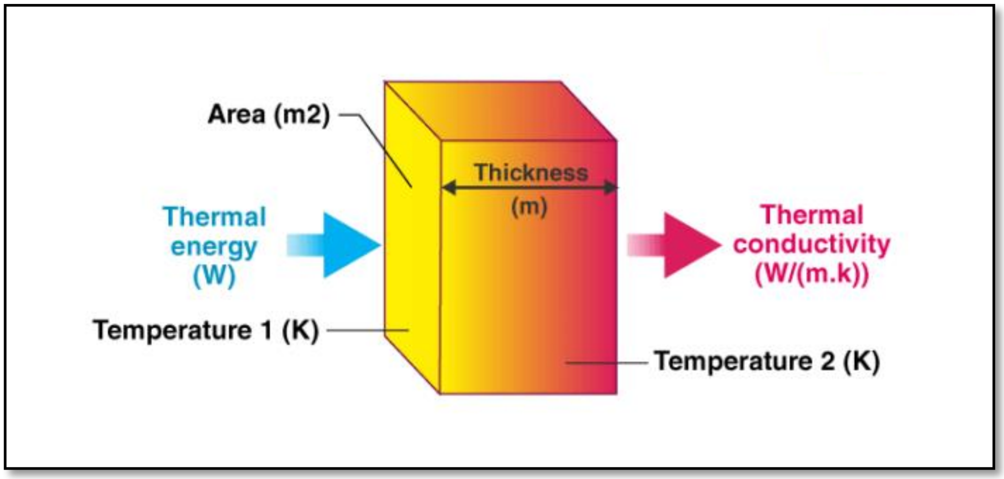


Figure II.2: Heat conduction through a wall.[23]

II.4.2. Heat convection:

Convection is defined as the process by which energy interacts with a fluid that is moving in relation to an interface. Although there is an inevitable conduction that takes place during this phenomenon, the major mode of energy transfer is made possible by the movement of fluid particles. **[18]**

$$\phi = h.A.(T_1 - T_2) \tag{II.10}$$

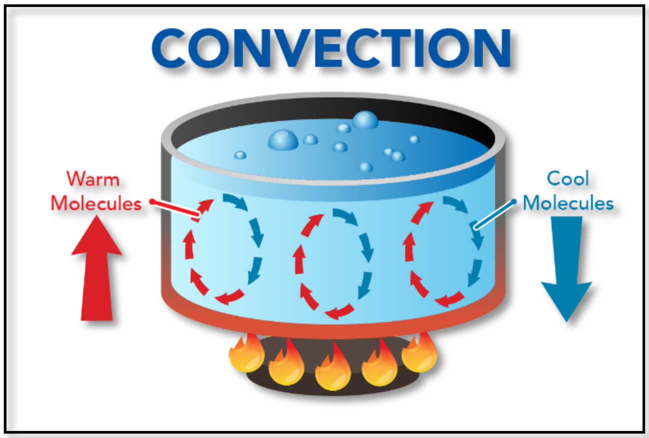


Figure II.3: Heat convection phenomena.[24]

II.4.2.1. Types of Convection:

There are two types of convection, and they are:

- Natural convection
- Forced convection

➢ **Natural convection:** When convection takes place due to buoyant force as there is a difference in densities caused by the difference in temperatures it is known as natural convection.

Examples of natural convection are oceanic winds.

➢ **Forced convection*:*** When external sources such as fans and pumps are used for creating induced convection, it is known as forced convection.

Examples of forced convection are using water heaters or geysers for instant heating of water and using a fan on a hot summer day.

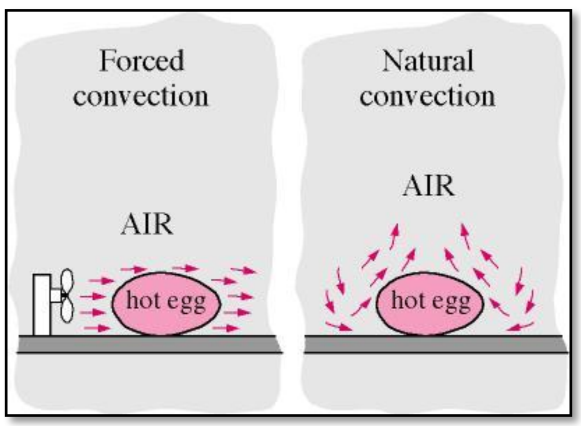


Figure II.4: Types of convection.[25]

II.4.3. Radiation:

Thermal radiation is the third mode of heat transfer anyone with a temperature above 0 K releases along with conduction and convection. Heat transfer by radiation occurs in the form of electromagnetic waves and can be seen between two bodies placed in a vacuum unlike conduction and convection, in which case energy is transferred by the presence of matter (in fluid or solid form). Its characteristic is Stephan-Boltzmann law:[18]

$$\boldsymbol{\phi = \sigma . A . T^4} \tag{II.11}$$

$\boldsymbol{\sigma}$ **:** Stephan Boltzmann's constant. It equals ($5{,}67.\ 10^{-8}[N.\ m^{-2}.\ K]$)

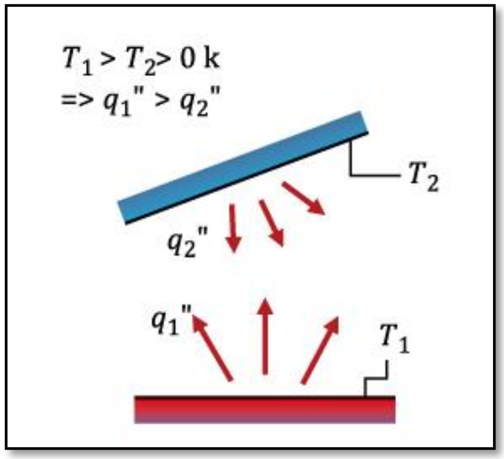


Figure II.5: Radiation phenomenon.[26]

II.5. Study of a Heat Exchanger:

In the construction of a heat exchanger, we always try for a given exchange capacity with a minimum exchange surface and with a minimum drop in pressure, that is with a minimum investment and operational costs. Size, weight, corrosion, and restrictions due to standardization play their part so that the number of disposable parameters will in most cases be much higher than the number of equations with some of them being of technological or economic nature. Full design of a heat exchanger therefore involves several disciplines (thermal, hydraulic, technology, etc.)[27]

II.5.1. Total heat transfer coefficient:

Heat transfer coefficient is one measure of the extent to which energy gets transferred from the wall to the fluid. If the coefficient is low, there is poor heat transfer. A very high value, on the other hand, suggests efficient transmission of the heat. **[28]**
The physical properties of the fluids have a direct effect on it:

$$\boldsymbol{\phi = h.A.(T_h - T_c)} \quad \text{(II.12)}$$

The methods used to design and calculate heat exchangers are either analytical or numerical.

II.5.2. Analytical methods:

II.5.2.1. DTLM method:

Calculation of the mean logarithmic temperature difference between the two fluids (DTLM) based on their flow mode for a heat exchanger. Example of a practical use of this calculation. **[17]**

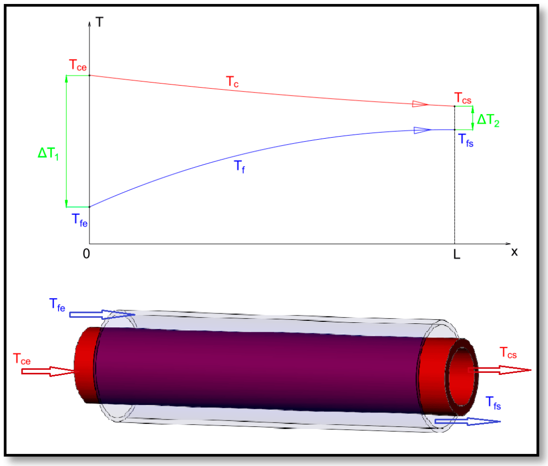


Figure II.6: An example for Hot and cold fluid temperature changes for a co-current exchanger.[29]

The mean logarithmic temperature difference ΔT_{LM}(DTLM) is defined as follows: **[17]**

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \tag{II.13}$$

With:

$$\Delta T_1 = T_{h1} - T_{c1} \ ;$$

$$\Delta T_2 = T_{h2} - T_{c2}$$

A simple shell-and-tube heat exchanger is defined by two concentric tubes. The hot fluid, which is the primary fluid, flows through the inner tube, whereas secondary fluid flows through the annulus between the tubes. Heat transfer between the cold and hot fluids takes place through the inner cylinder wall. The hot fluid enters with an initial temperature labeled as T_{h1} and exits with a temperature labeled as T_{h2}. The cold fluid enters with T_{c1} and leaves at T_{c2} .Heat flow can be evaluated in different ways.[29]

- For full exchanger length:

$$\phi = \mathrm{h.A.}(\mathrm{T_h} - \mathrm{T_c}) \tag{II.14}$$

- Heat transfer in anexchanger section of length dx and cross section:

$$d\phi = \mathrm{h.}(\mathrm{T_h} - \mathrm{T_c})\mathrm{.ds} \tag{II.15}$$

- Heat loss through hot fluid:

$$d\phi = -\dot{m}_h\ .Cp_h.dT_h \tag{II.16}$$

- Heat gain through cold fluid:

$$d\phi = \dot{m}_c\ .Cp_c.dT_c \tag{II.17}$$

II.5.2.2. Heat exchanger efficiency:

In general, the efficiency of heat exchange is defined as the ratio of the amount of heat transferred in the actual case to the amount of heat in the ideal case, in the optimal case (equation below): **[30]**

$$\eta = \frac{q_{ideal}}{q_{act}} \tag{II.18}$$

The heat transfer rate in the actual state is defined as the basis of the rate of change of cold or hot fluid temperature:

$$q_{act} = C_{hot}(T_{h1} - T_{h2}) \tag{II.19}$$

Or:

$$q_{act} = C_{cold}(T_{c2} - T_{c1}) \tag{II.20}$$

Also, the optimal heat transfer can be calculated as the following equation:

$$q_{ideal} = U.A.(T_a - T_b) \quad \text{(II.21)}$$

We denote the surface at which heat exchange takes place by A. Also, the overall average heat transfer coefficient is equal to U.

$$T_a - T_b = \frac{T_{h1} - T_{h2}}{2} - \frac{T_{c2} - T_{c1}}{2} \quad \text{(II.22)}$$

Heat exchanger efficiency is a convenient approach for heat exchanger analysis, and can be used to solve rating and sizing problems, as well as network of heat exchangers without the need for charts, or complicated performance expressions. The efficiency of all heat exchangers is determined from a single algebraic expression.

II.5.2.3. Heat capacity ratio:

The ratio of heat capacities R in the expressions relating the number of transfer units and the efficiency of the exchanger for the different types of exchangers is taken as 0 ≤ R ≤ 1.

Depending on the case of the fluid that controls the transfer, the expressions for the ratios of heat capacities are given by:

$$R_1 = \frac{\min(\dot{m}_{N1}Cp_{N1}, \dot{m}_C Cp_C)}{\max(\dot{m}_{N1}Cp_{N1}, \dot{m}_C Cp_C)} = \frac{\min(\Delta T_{N1}, \Delta T_C)}{\max(\Delta T_{N1}, \Delta T_C)} \quad \text{(II.23)}$$

$$R_2 = \frac{\min(\dot{m}_{N2}Cp_{N2}, \dot{m}_C Cp_C)}{\max(\dot{m}_{N2}Cp_{N2}, \dot{m}_C Cp_C)} = \frac{\min(\Delta T_{N2}, \Delta T_C)}{\max(\Delta T_{N2}, \Delta T_C)} \quad \text{(II.24)}$$

II.5.2.3. NUT method:

The NUT technique provides a swift and elegant solution to most of the challenges of exchanger engineering investigation. Such problems fall into two principal classes:[17]

A design problem in which inlet temperatures and an outlet temperature is imposed, the flow rates being given. The issue consists of identifying the most appropriate exchanger model, and then the size of the heat exchanger, the heat transfer surface area required in order to produce the specified outlet temperature.[17]

The methodology to be followed consists in: determining the NUT, then the efficiency and calculating the required heat transfer surface. The method can look as follows:[17]

- Estimate outlet temperatures.
- Calculate overall heat transfer coefficient.
- Determine NUT and exchanger efficiency
- Calculate output temperatures.

The number of transfer units is the dimensionless number given by:

$$NUT = \frac{h.A}{\dot{m}C_p} \quad \text{(II.25)}$$

The number of transfer units on the cold side is given by:

$$NUT_c = \frac{h.A}{\dot{m}C_{pc}} \quad \text{(II.26)}$$

The number of transfer units on the hot side is given by:

$$NUT_h = \frac{h.A}{\dot{m}C_{ph}} \quad \text{(II.27)}$$

II.5.3: Expression of efficiency (E) as a function of (R and NUT):

This concept of efficiency is particularly interesting because it allows direct access to power while only considering fluid inlet temperatures. Expressions for efficiency based on heat capacity ratios and the number of transfer units are given in the following table:[31]

Table II.1: Efficiency and NUT for the four arrangements.[31]

	Circulation 1	**Circulation 2**
Contre-courant	$NUT_1 = \frac{1}{1-R_1} Ln \frac{1-R_1E_1}{1-E_1}$	$NUT_2 = \frac{1}{1-R_2} Ln \frac{1-R_2E_2}{1-E_2}$
	$E_1 = \frac{1-\exp[-(1-R_1)NUT_1]}{1-R_1\exp[-(1-R_1)NUT_1]}$	$E_2 = \frac{1-\exp[-(1-R_2)NUT_2]}{1-R_2\exp[-(1-R_2)NUT_2]}$
Co-courant	$NUT_1 = \frac{1}{1-R_1} Ln \frac{1}{1-E_1(1+R_1)}$	$NUT_2 = \frac{1}{1-R_2} Ln \frac{1}{1-E_2(1+R_2)}$
	$E_1 = \frac{1-\exp[-(1+R_1)NUT_1]}{1+R_1}$	$E_2 = \frac{1-\exp[-(1+R_2)NUT_2]}{1+R_2}$
Co-courant/ Contre-courant	$NUT_1 = \frac{1}{1-R_1} Ln \frac{1}{1-E_1(1+R_1)}$	$NUT_2 = \frac{1}{1-R_2} Ln \frac{1-R_2E_2}{1-E_2}$
	$E_1 = \frac{1-\exp[-(1+R_1)NUT_1]}{1+R_1}$	$E_2 = \frac{1-\exp[-(1-R_2)NUT_2]}{1-R_2\exp[-(1-R_2)NUT_2]}$
Contre-courant/ Co-courant	$NUT_1 = \frac{1}{1-R_1} Ln \frac{1-R_1E_1}{1-E_1}$	$NUT_2 = \frac{1}{1-R_2} Ln \frac{1}{1-E_2(1+R_2)}$
	$E_2 = \frac{1-\exp[-(1-R_2)NUT_2]}{1-R_2\exp[-(1-R_2)NUT_2]}$	$E_2 = \frac{1-\exp[-(1+R_2)NUT_2]}{1+R_2}$

Chapter III :

Simulation and Interpretations

III.1 Introduction:

The aim of this chapter is to study a simulation on a double pipe heat exchanger with different geometries to optimize the heat transfer in the heat exchanger for better efficiency by Ansys fluent.

III.2 Geometry of the Heat Exchanger:

Table III.1: Geometric parameters.

SN.	PARAMETER	DESCRIPTION
1	Inner dia. of inner pipe	60.00 mm
2	Outer dia. of inner pipe	62.00 mm
3	Inner dia. of outer pipe	200.00 mm
4	Outer dia. of outer pipe	210.00 mm
5	Length of both pipes	3000.00 mm
6	Angles of the conical elements	(25°, 45°, 60°)
7	Length of the conical element	40.00 mm
8	Number of the conical elements	15

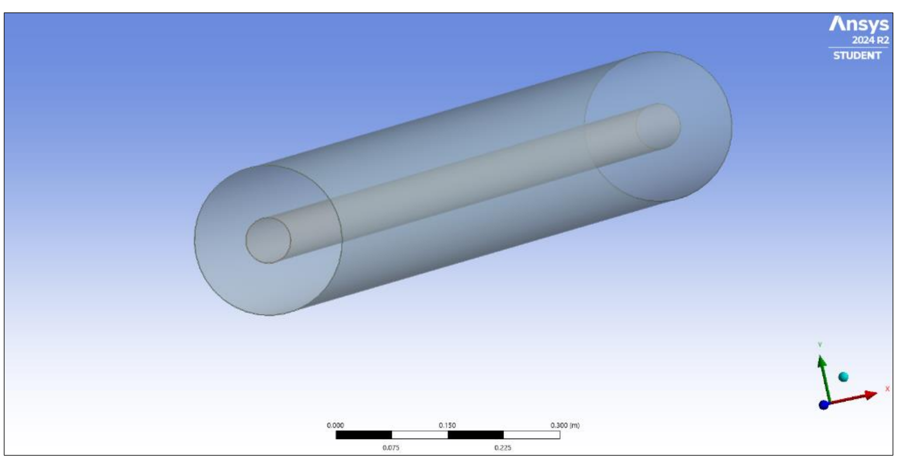


Figure III.1: Geometry of double pipe heat exchanger simple.

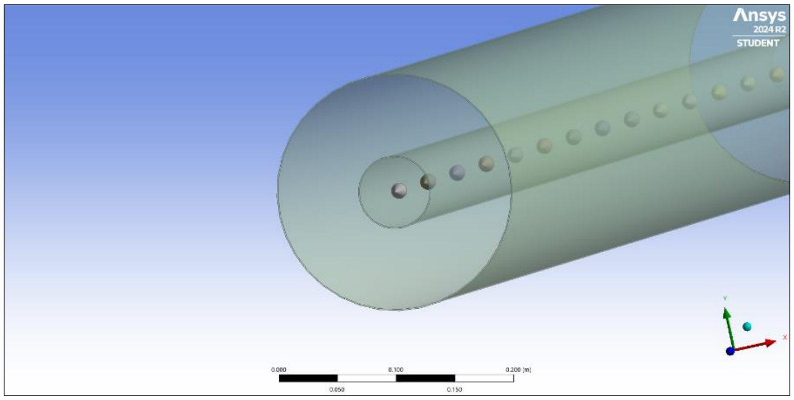


Figure III.2: Geometry of double pipe heat exchanger with conical elements.

Named Selections - The different surfaces of the solid are named as per required inlets and outlets for inner and outer fluids.

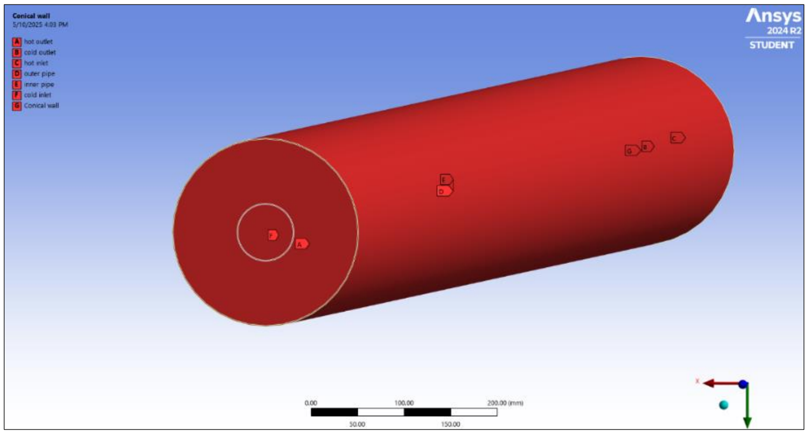


Figure III.3: Named selections for the geometry

III.3 Mesh:

Table III.2: Mesh report

Domain	Nodes	Elements
Cold fluid	34100	24200
Hot fluid	31220	27140
Inner pipe	17830	9700
Outer pipe	22710	11345
Total	105901	73205

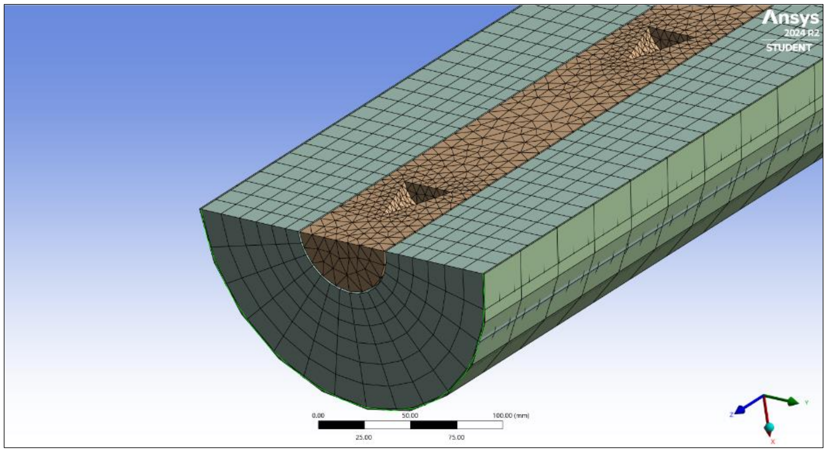


Figure III.4: Meshing obtained.

III.4. Setup and Solution:

- **Problem setup:**

The mesh is checked and quality is obtained. The analysis type is changed to (pressure-based) type. The velocity formulation is changed to (absolute) and time to (Ready) state.

- **Models:**

Energy is set to ON. Viscous model is selected as (k-epsilon model) and it is kept as standard.

- **Materials:**

We've chosen the inner fluid to be air from (the fluent database) by clicking (create/edit) option, moreover for the pipe's material we've chosen aluminum. This selection ensures optimal thermal conductivity and durability, making it suitable for different applications.

- **Cell zone condition:**

Inner fluid assigned as air and outer fluid assigned as water inner and outer solid pipes assigned as material aluminum.

- **Boundary Conditions**:

Boundary condition is used according to the need of the model. The inlet and outlet conditions are defined as velocity-inlet and pressure-outlet.

- **Measure of convergence:**

In order to have an accurate result, the criteria are set tight in an attempt to have a decent convergence throughout the simulation. For this reason, residuals are provided in the following table 3.

Table III.3: Boundary conditions

Sr. No.	Boundary Conditions type	Velocity (m/sec)	Temperature (kelvin)
Cold inlet	Velocity inlet	0.3, 0.5, 0.7, 0.9	288K
Hot inlet	Velocity inlet	0.3	300K
Cold outlet	Pressure outlet	_	_
Hot outlet	Pressure outlet	_	300K

Table III.4: Measure of convergence.

Variable	Residual
X – Velocity	10^{-6}
Y – Velocity	10^{-6}
Z - Velocity	10^{-6}
Continuity	10^{-6}
Turbulent Kinetic Energy	10^{-6}
Energy	10^{-6}

- **Run Calculations:**

The number of iterations is set to 300 and the solution is calculated.

III.5. Results and discussion:

III.5.1. Definition of ANSYS software:

ANSYS, an abbreviation for "Analysis System," is a collection of engineering simulation software created by ANSYS Inc. This software is utilized for finite element analysis (FEA) and computational fluid dynamics (CFD). It enables engineers and designers across different industries to simulate the performance of their products under real-world conditions before they are physically constructed or manufactured. ANSYS achieves this by analyzing a variety of issues related to mechanical product design and civil structure design using numerical techniques.

III.5.2. Computational Fluid Dynamics (CFD):

Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to analyze and solve problems involving fluid flows, heat transfer, and related phenomena. CFD involves the simulation of fluid behavior by solving the equations of fluid motion (typically the Navier-Stokes equations) on a computer, allowing engineers and scientists to predict how fluids will behave in a variety of real-world scenarios, such as in aerodynamics, weather forecasting, and industrial processes.

III.5.3. Fluid Fluent:

Fluid Fluent (or ANSYS Fluent) is a specific CFD software within the ANSYS suite. It is one of the tools engineers and researchers use to perform CFD simulations. Fluent allows users to model fluid flow, heat transfer, and related phenomena in a wide range of engineering applications.

There are many indicators that we rely on to judge the effectiveness of heat exchangers, some of the most important of which are:

III.5.4. The temperature:

Temperature directly affects the efficiency of heat transfer in heat exchangers. The greater the temperature difference between the two mediums (such as the fluids exchanging heat), the more heat is transferred, thus improving the heat exchanger's performance.

III.5.5. Analyzing and discussing results:

- **Velocity (0.3 m/s):**
  - **Temperature contours:**

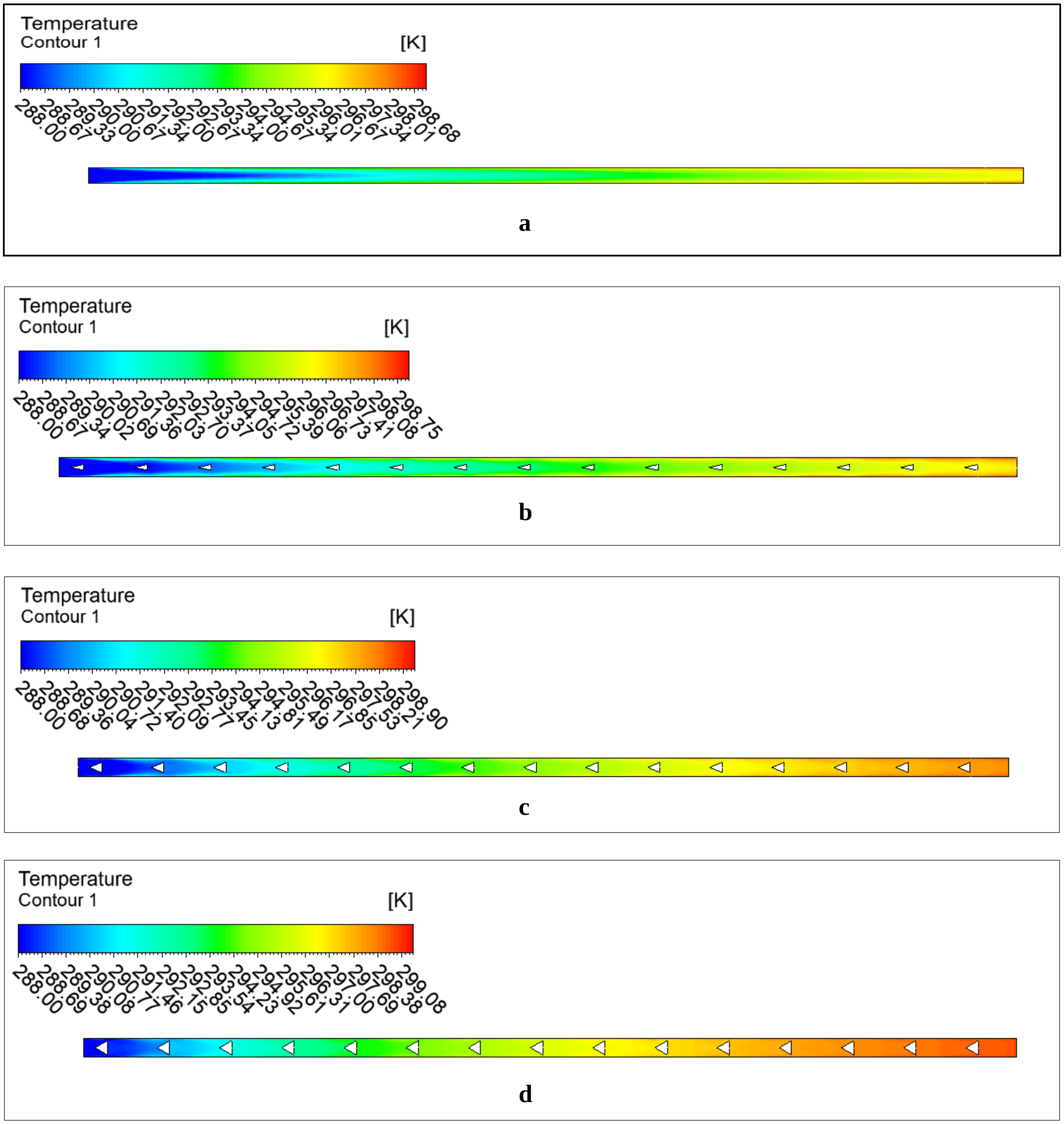


Figure III.5: H-E temperature contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Pressure contours:**

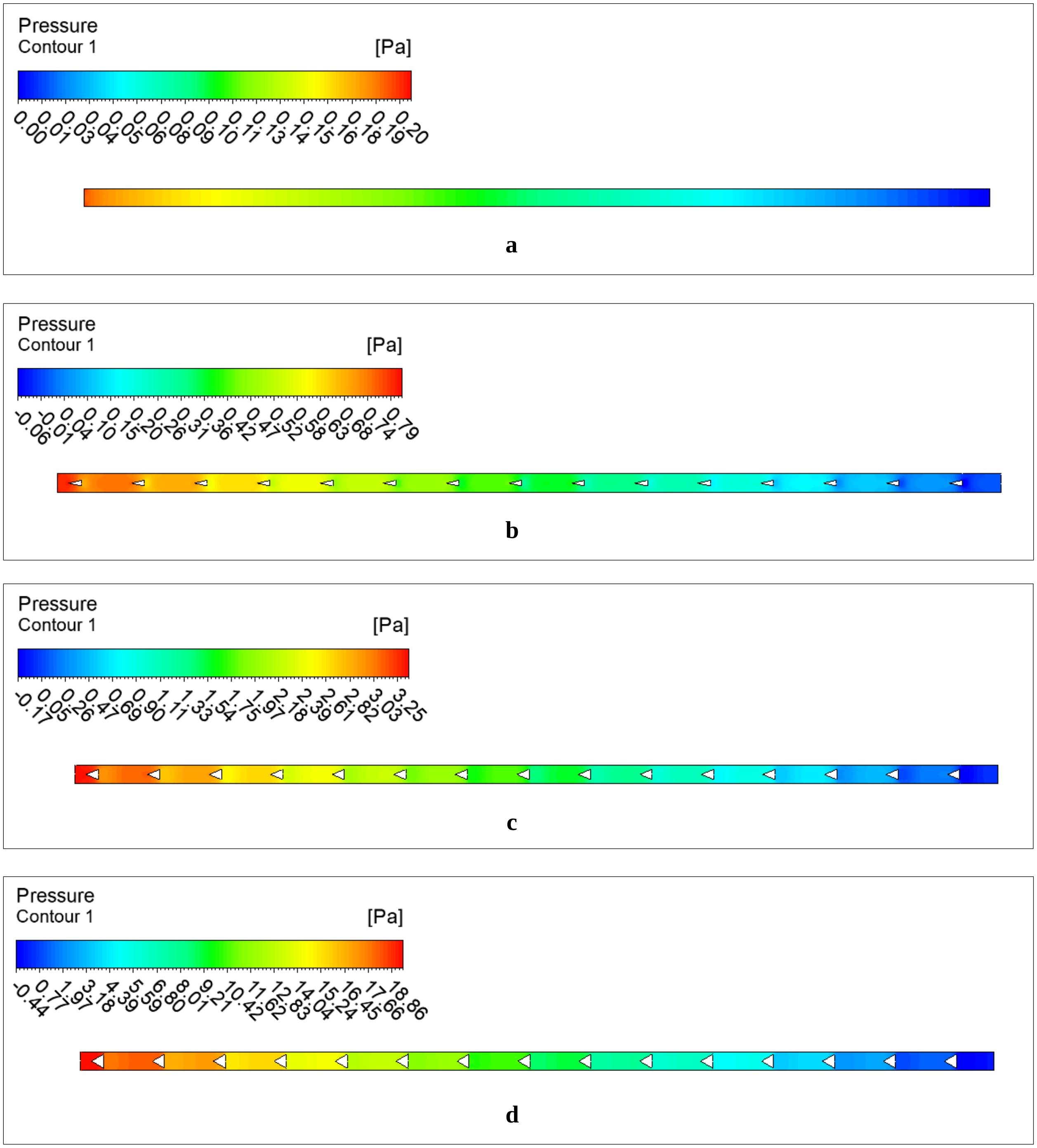


Figure III.6: H-E pressure contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Velocity contours:**

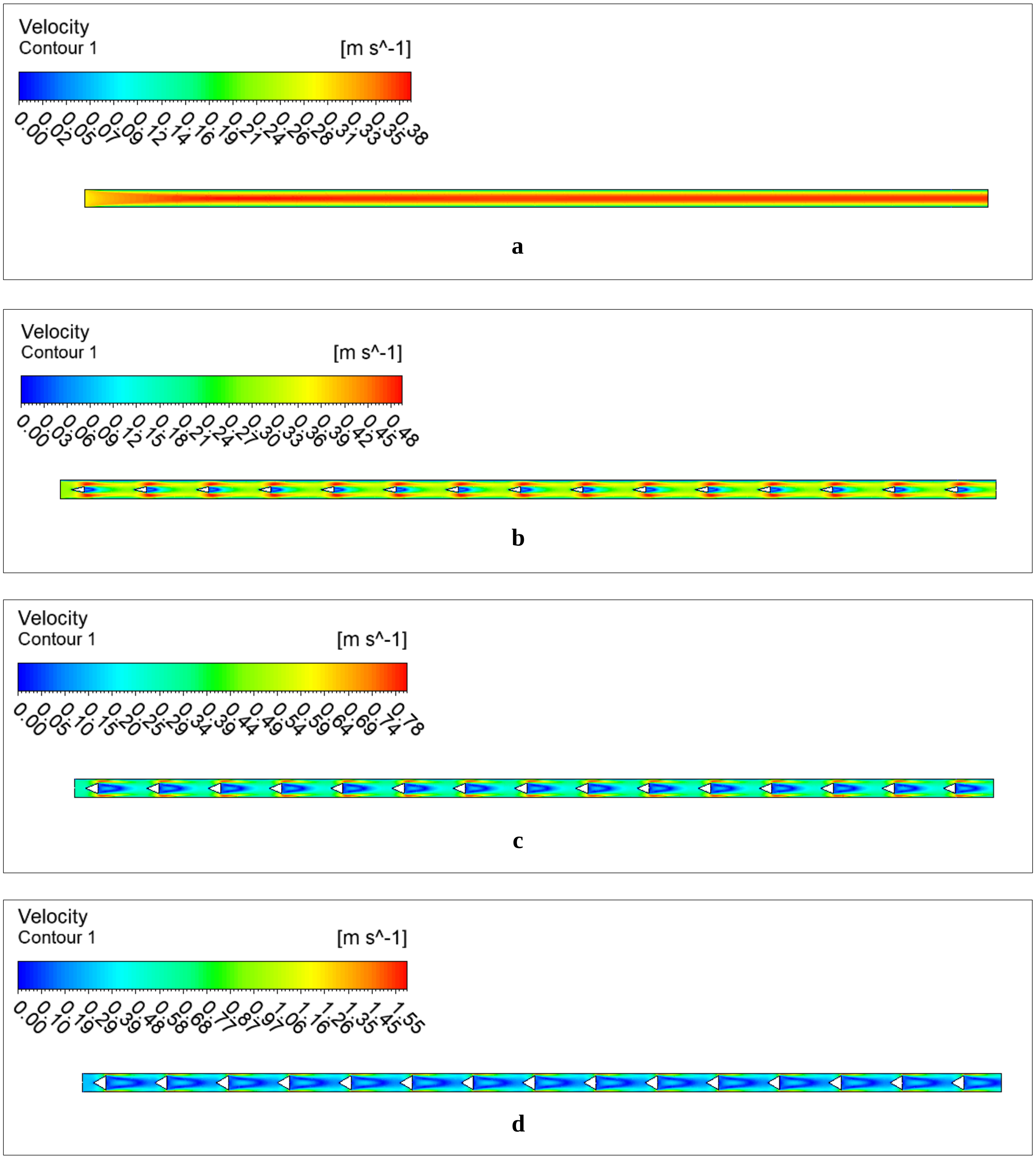


Figure III.7: H-E velocity contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Velocity (0.5 m/s):**
  - **Temperature contours:**

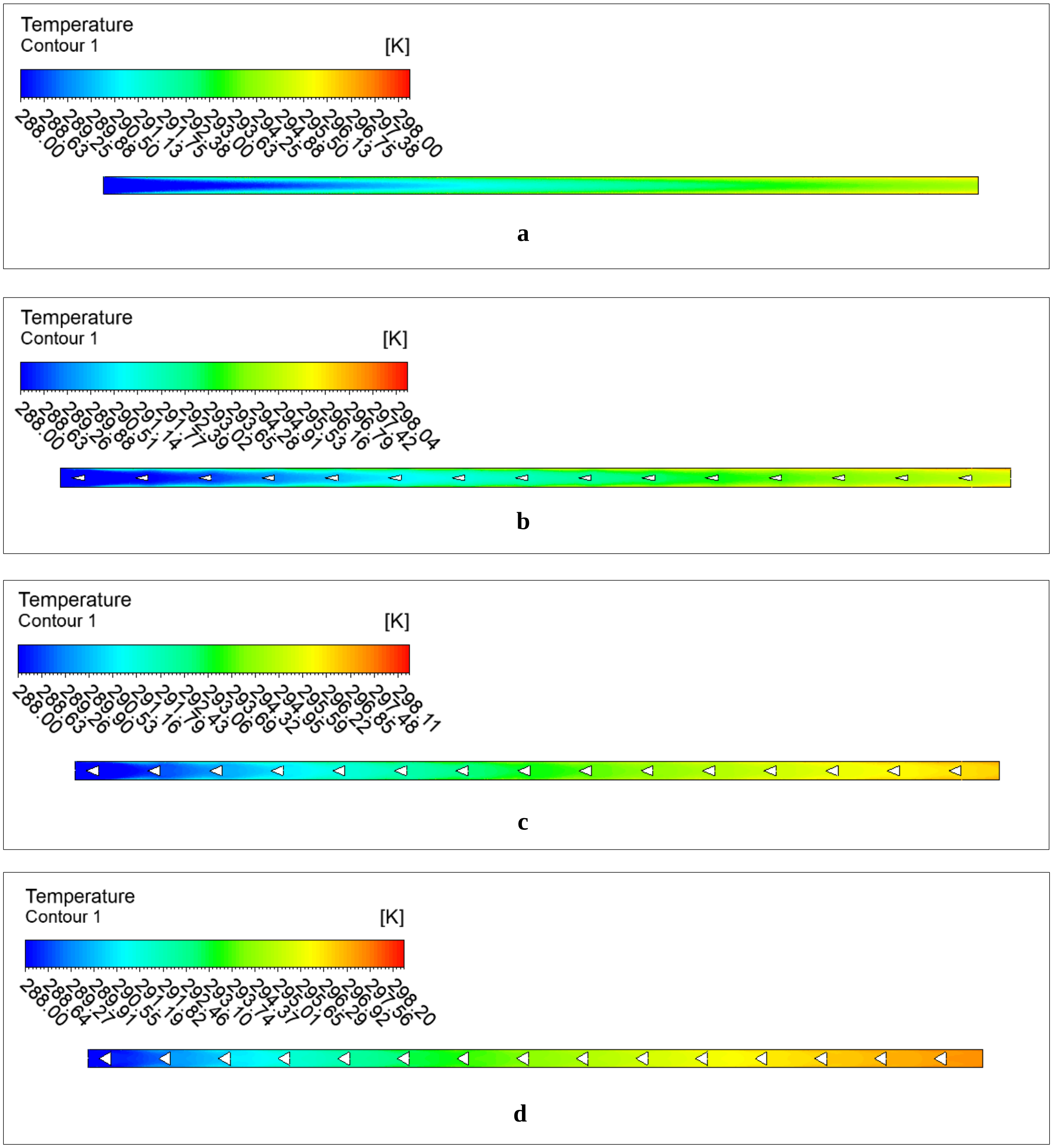


Figure III.8: H-E temperature contour for (a) simple, (b) 25°, (c) 45°, (d) 60°

- **Pressure contours:**

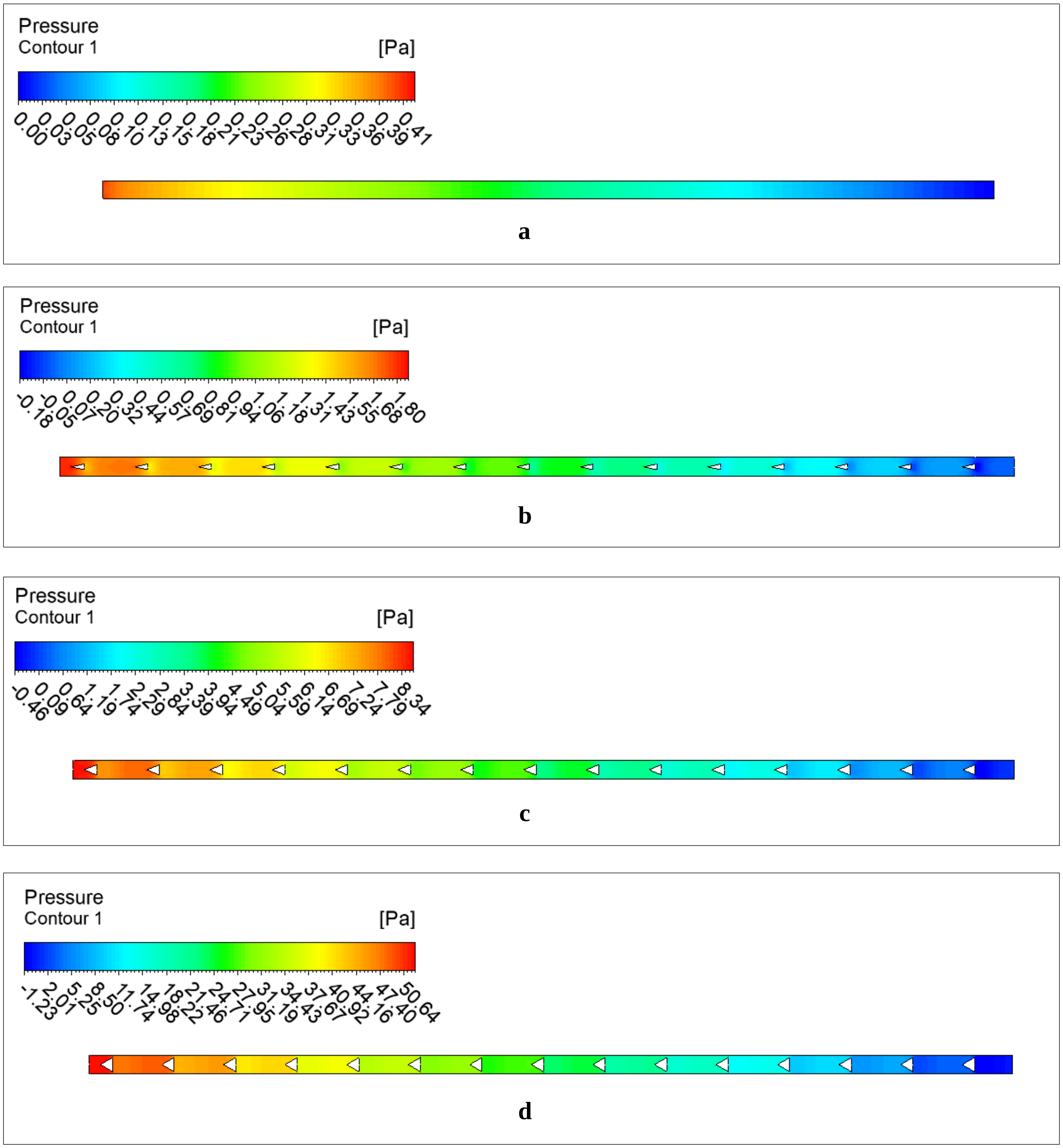


Figure III.9: H-E pressure contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Velocity contours:**

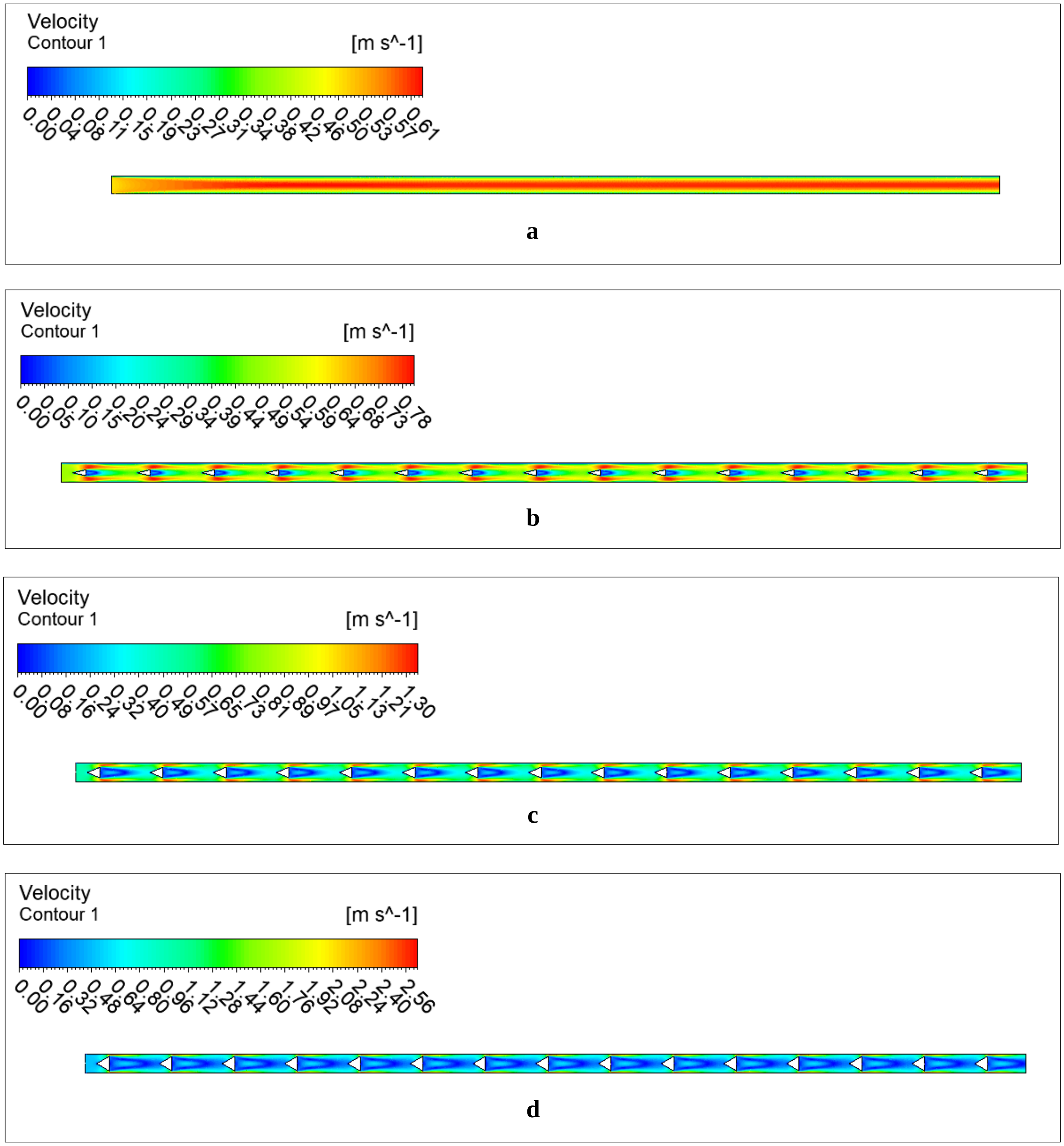


Figure III.10: H-E velocity contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

➢ **Velocity (0.7 m/s):**

- **Temperature contours:**

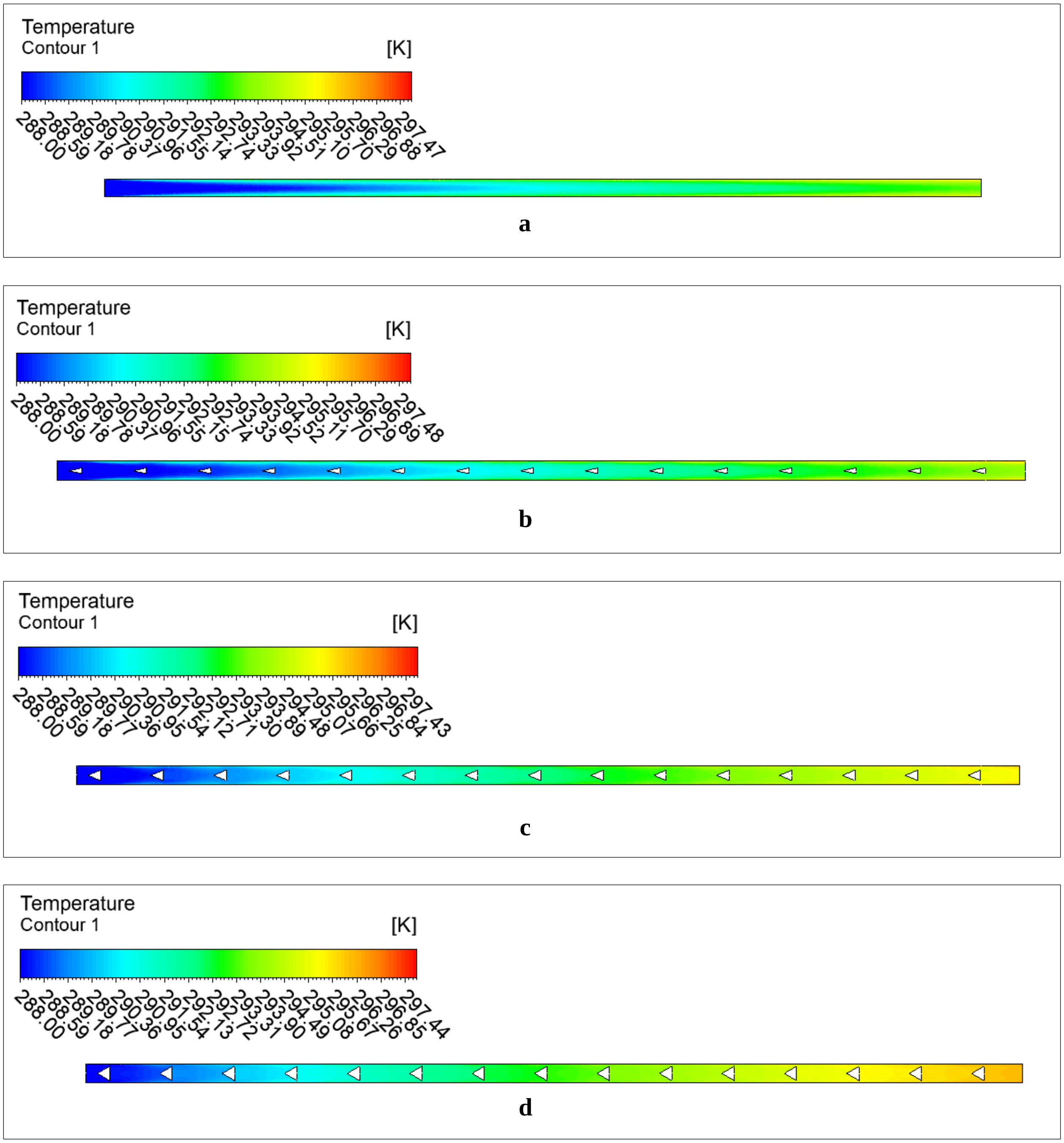


Figure III.11: H-E temperature contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Pressure contours:**

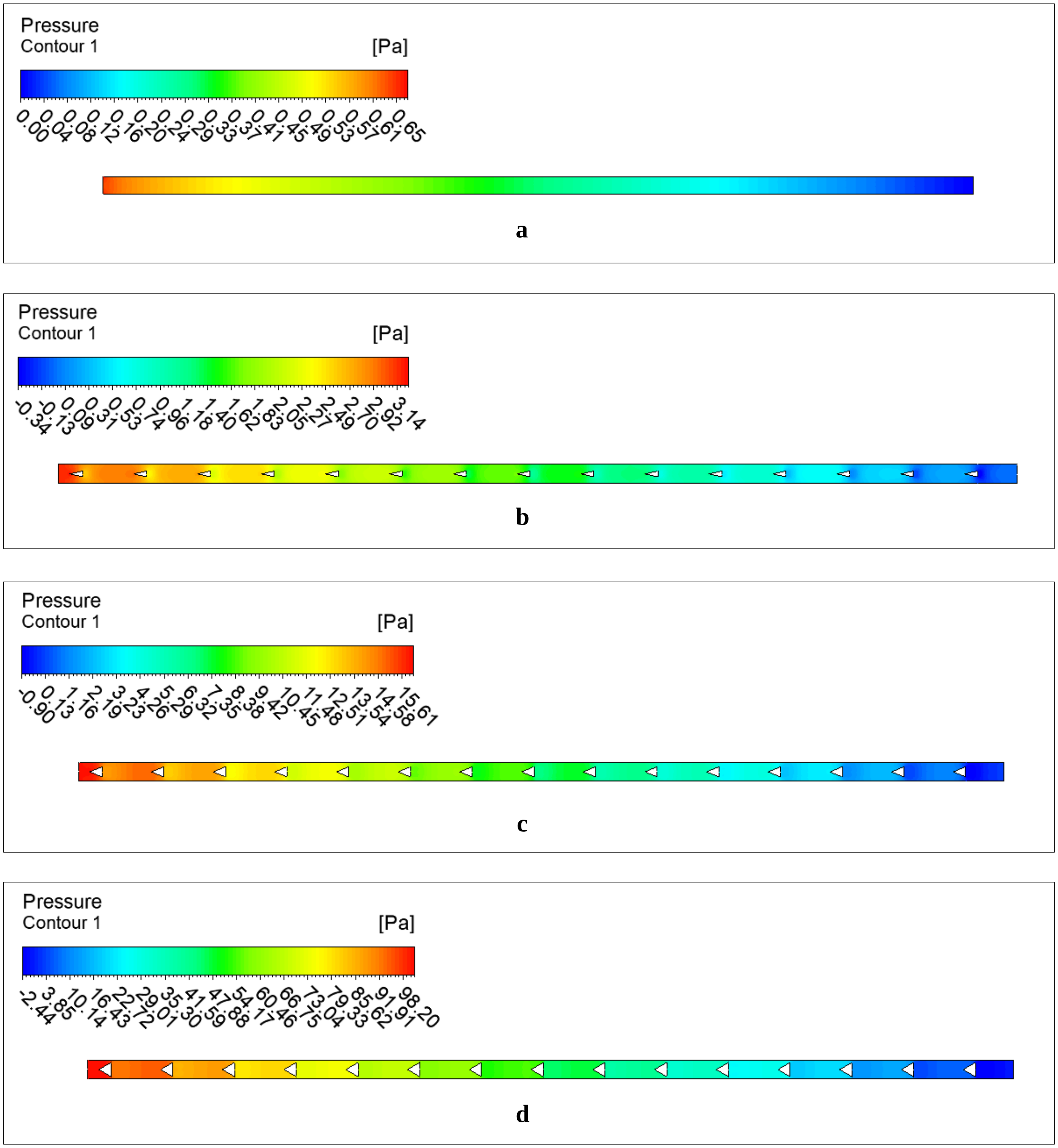


Figure III.12: H-E pressure contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Velocity contours:**

Figure III.13: H-E velocity contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

➢ **Velocity (0.9 m/s):**

- **Temperature contours:**

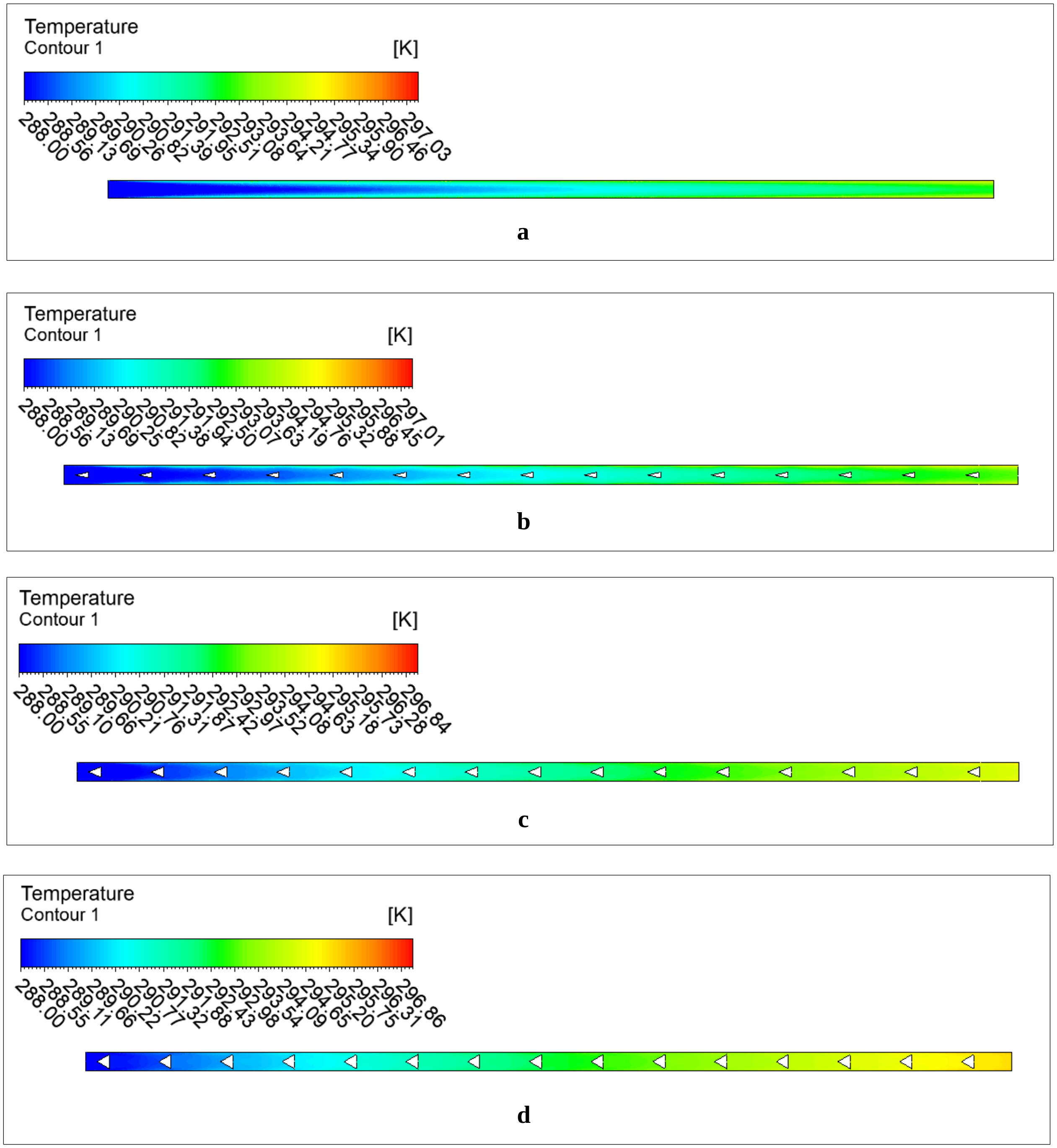


Figure III.14: H-E temperature contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Pressure contours:**

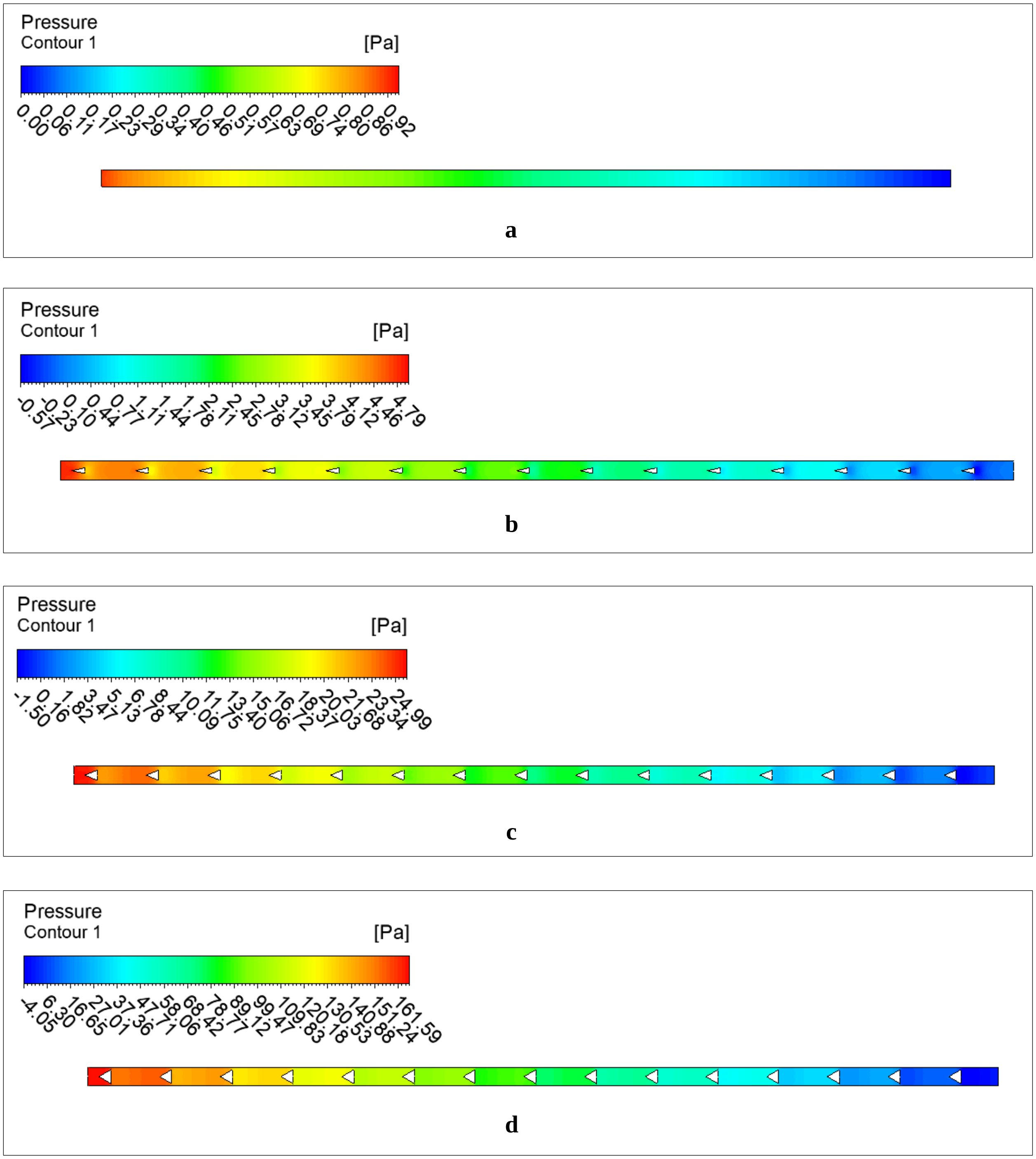


Figure III.15: H-E pressure contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

- **Velocity contours:**

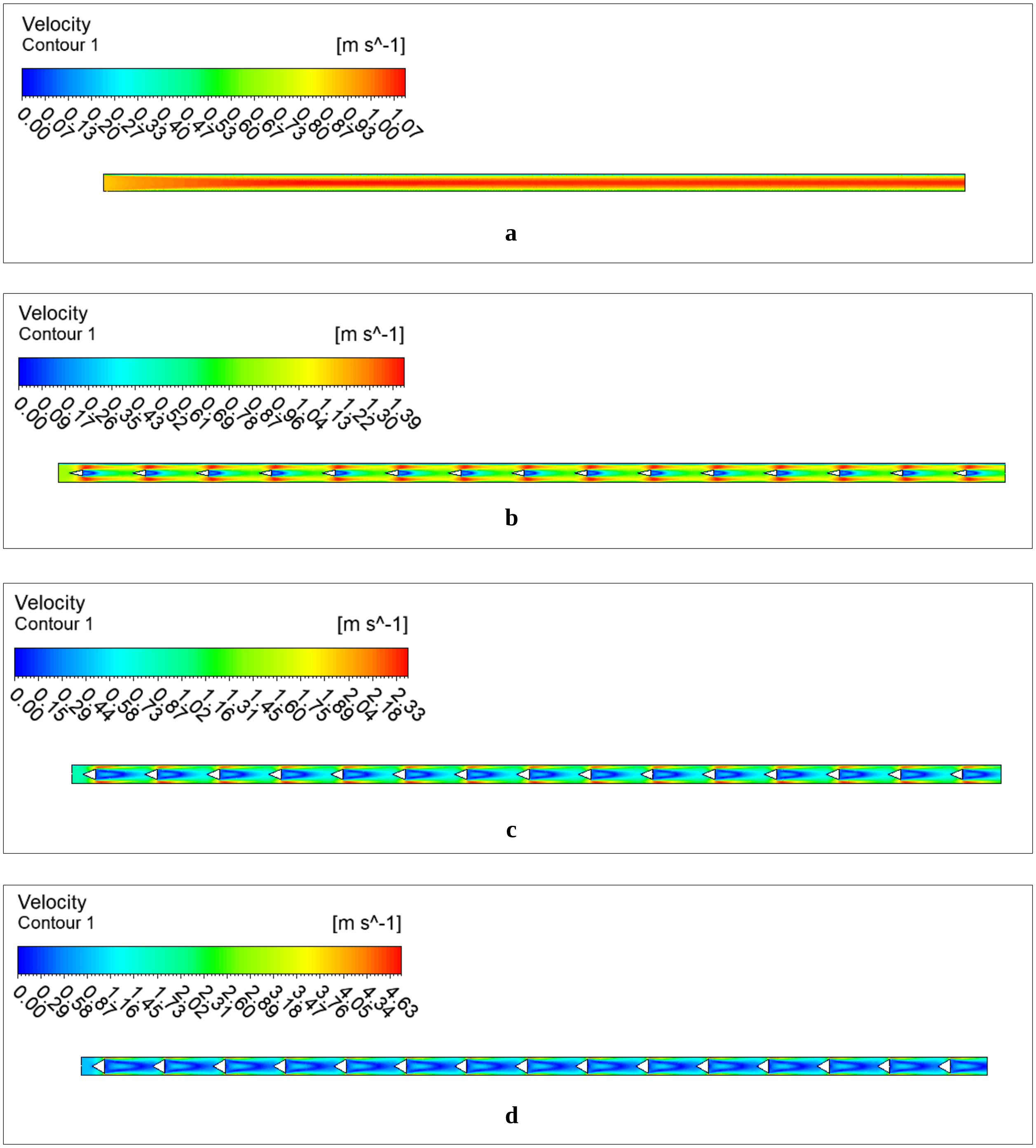


Figure III.16: H-E velocity contour for (a) simple, (b) 25°, (c) 45°, (d) 60°.

III.5.5.1. Analyze and comparing results:

From the results above we observed that the best Rynolds number is (Re=1233) or (V= 0.3 m/s) because it has shown the best results compared to the other Reynolds numbers.

As shown on (Figure III.5) we notice the highest heat transfer is on the 60° conical elements angle compared to the other designs (simple, 25°, 45°), the temperature difference is quite noticeable it has reached 11.5 K as the inlet temperature is 288 K and at the outlet is 299.5 K, thus that's a high heat transfer.

The optimum pressure results (lowest pressure drop) are shown with (Re=1233) and 25° conical elements angle (b), we can observe that the pressure value at the inlet is (0.79 Pa) while at the outlet is (0.06 Pa), the pressure drop gets higher with 45° and 60°. The pressure drop is a result of the flow turbulence due to the conical elements design.

Moreover, the optimum velocity for the highest turbulence is shown on (Figure III.16) with (Re=3698) and 60° conical elements angle (d), therefore, higher turbulence means higher heat transfer.

Finally, after calculating the Heat Flux for every configuration and every Reynolds Number we observed that the best Heat Flux is at (Re=3698) or (V= 0.9 m/s) and 60° conical element angle which equals ($\dot{q}$= 21.333 w).

We have compared the results in the graphs below:

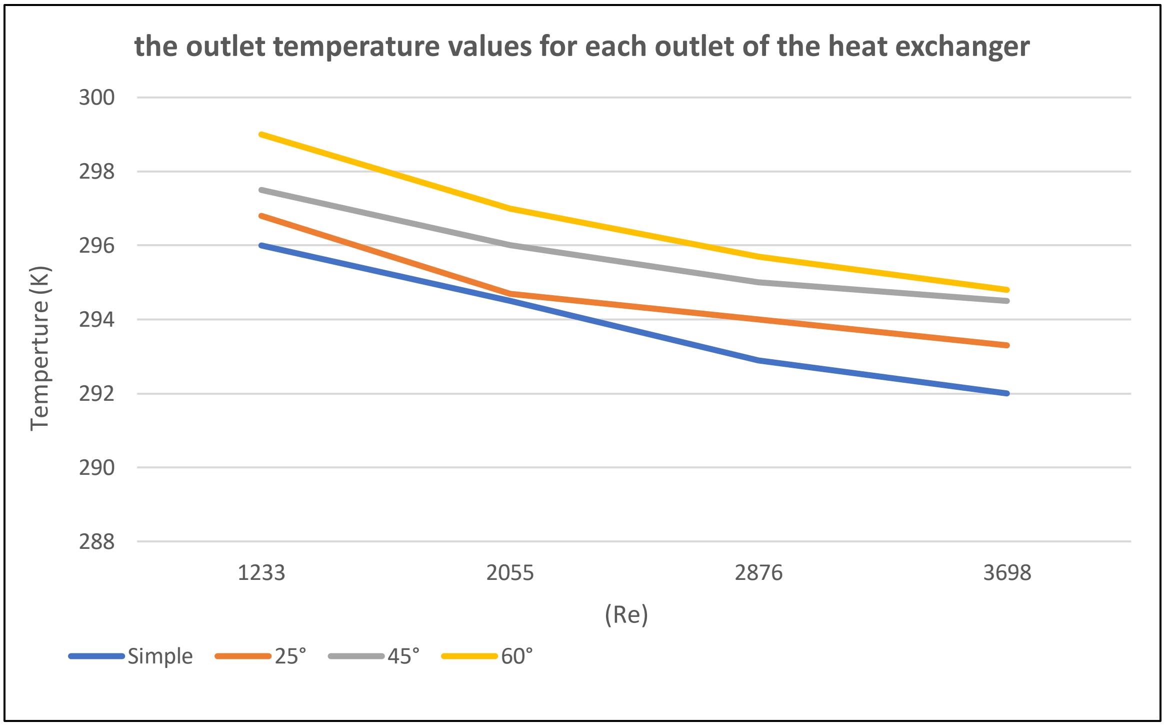


Figure III.17: Graphic curve representing temperature changes as a function of Reynolds Number for the four configurations of heat exchanger.

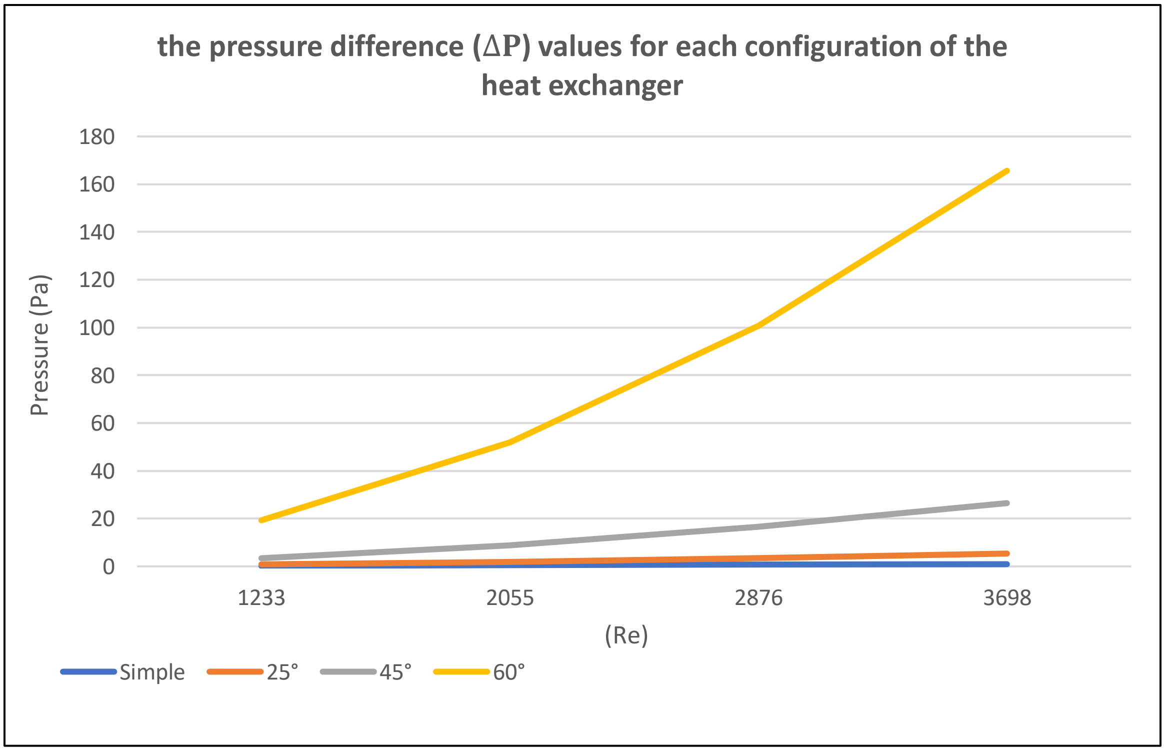


Figure III.18: Graphic curve representing pressure difference as a function of Reynolds Number for the four configurations of heat exchanger.

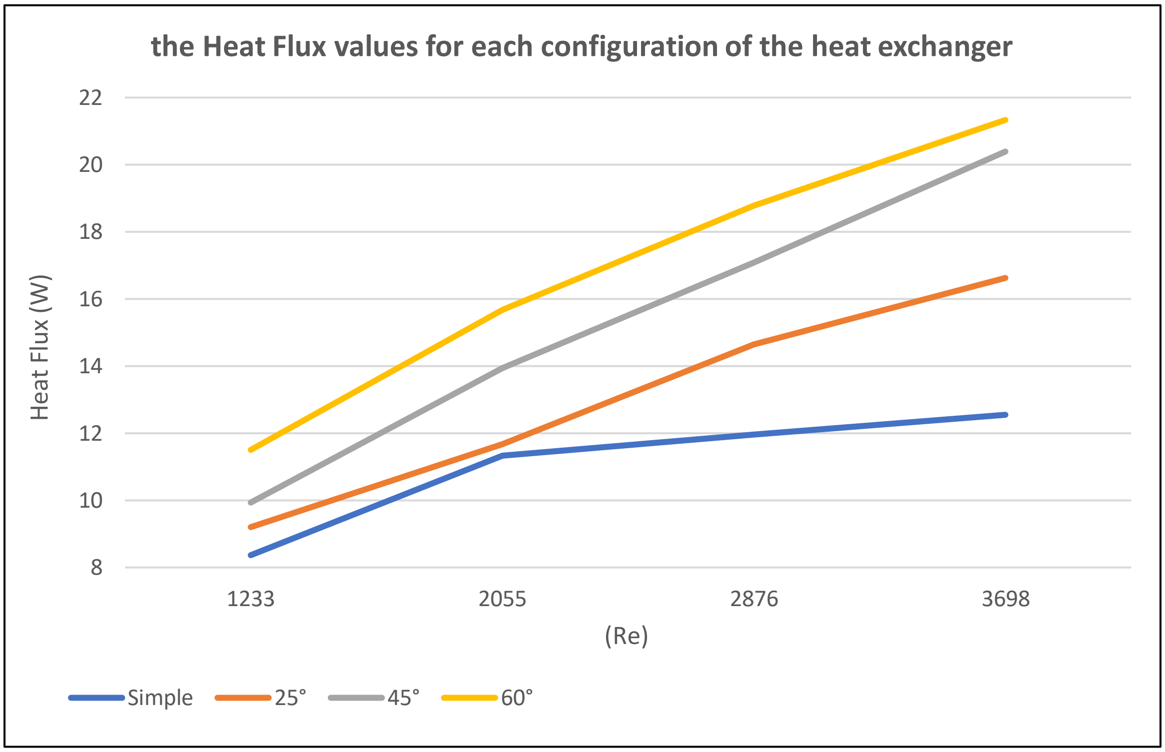


Figure III.19: Graphic curve representing Heat Flux values as a function of Reynolds Number for the four configurations of heat exchanger.

III.6. Study the efficiency of heat exchangers:

We have used two different Efficiency methods:

$$\varepsilon = \frac{T_{in.c} - T_{out.c}}{T_{in.c} - T_h} \times 100$$

$$\dot{q}_{max} = C_{min}(T_{h.in} - T_{c.in})$$

$$\varepsilon = \frac{\dot{q}}{\dot{q}_{max}}$$

After applying the equations above, we got the following results:

$$\varepsilon_{simple} = \frac{288-296}{288-300} \times 100 = 60\%$$

$$\varepsilon_{25^\circ} = \frac{288-296.8}{288-300} \times 100 = 73\%$$

$$\varepsilon_{45^\circ} = \frac{288-297.5}{288-300} \times 100 = 79\%$$

$$\varepsilon_{60^\circ} = \frac{288-299}{288-300} \times 100 = 91.6\%$$

From this we can conclude that the Heat Exchanger with 60° conical elements angle and (Re=1233 or V= 0.3 m/s) has better efficiency than a simple Heat Exchanger.

III.7. Conclusion:

In this chapter, we have presented the dynamic and thermal behaviors of the flow of two hot and cold fluids, in forced convection, in turbulent mode in a simple and 25°, 45°, and 60° conical element angles heat exchanger. The numerical results presented in this study prove that the use of conical elements contributes to the heat exchange and hence, despite the resulting pressure loss. The effects of this improvement are:

The geometric shape of conical elements plays a very important role in improving the heat transfer where the 60° conical angle was better in our study.

General conclusion

General conclusion

In conclusion, by using different conical elements geometry under different flow circumstances, this thesis has significantly advanced the optimization of heat transfer in a heat exchanger. three different conical angles (25°, 45°, and 60°) and a simple heat exchanger have been thoroughly compared, with an emphasis on how each affects important variables like temperature, pressure, and velocity.

The simulation showed an increase in the temperature difference (Δt) and the heat flux. (Δt) was significantly higher at velocity of 0.3m/s and 60° conical angle, the heat flux was at its highest at velocity 0.7m/s and 60° conical angle. These results show that 60° conical angle is the best angle for heat transfer regardless of the inlet velocity. In general, this depends on how the heat exchanger is used. However, it is worth noting that the pressure drop is quite large, which leads to the appearance of a vacuum or fluid stagnation in various locations inside the heat exchanger (behind the conical elements as shown in the velocity contours). However, this does not mean that the flow has completely stopped. It would be better to use a high-efficiency pump to compensate for the pressure drop. We suggest that in the future researches, we will have to focus on the pump efficiency and perhaps change some settings and dimensions that we did not change, such as the length of the conical elements, and that the length of the heat exchanger should be larger in order to show a better efficiency, thus the results will be better and closer to reality.

All things considered, this work has made a substantial contribution to our knowledge of heat exchanger efficiency and the function of conical elements engineering in improving thermal system performance, opening the door for future innovation and advancement in this important area.

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