

People's Democratic Republic of Algeria  
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Mohamed Boudiaf University of M'sila  
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## END OF STUDY MEMORY

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### MASTER

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**Option:** Energetic

**Presented by:**

Bella Dea Manara

### Theme

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**Influence of the perpendicular corrugation of the  
combustion chamber on the flame in a hot water boiler**

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### BOARD OF EXAMINERS:

Last name and first name	Grade	Quality
Boudilmi Aissa	Professeur	President
Berkache Amar	MCA	Examiner
Zergane Said	MCA	Supervisor
Djerad Abdelkader	MCA	Co-supervisor

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# Thanks

Before all, it would not know how to undertake the thanks without Having thanked the

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As well as MY PARENTS for their help, their patience, their tenderness.

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## ملخص

في مشروع نهاية التخرج هذا، نقدم عملاً يتناول تصميمًا جديدًا لغرفة الاحتراق للمراجل الحرارية. يتمثل هذا التصميم الجديد في إنشاء سطح متموج لغرفة الاحتراق، مما يعزز من جهة التبادل الحراري بين المائع ووسط الاحتراق، ومن جهة أخرى يساعد على تجنب اضطرابات تدفق المائع أثناء السيلان. دراسة و تصميم الشكل الجديد تم عن طريق البرمجية انسيس **Ansys** حيث يمكن متابعة تطور درجة الحرارة و الضغط على سطح و وسط غرفة الاحتراق. هذا العمل الجديد يسمح بزيادة مردود المرجل الحراري لنفس كمية غاز الميثان المستعملة.

## Abstract

In this graduation project, we present a work that involves a new design for the combustion chamber of thermal boilers. This new design features a wavy surface for the combustion chamber, which enhances heat exchange between the fluid and the combustion medium on one hand, and helps to avoid fluid flow disturbances during the process on the other. The study and design of the new shape were conducted using **Ansys** software, allowing for the monitoring of temperature and pressure developments on the surface and within the combustion chamber. This new approach enables an increase in the efficiency of the thermal boiler using the same amount of methane gas.

## Résumé

Dans ce projet de fin d'études, nous présentons un travail qui porte sur un nouveau design pour la chambre de combustion des chaudières thermiques. Ce nouveau design se caractérise par une surface ondulée pour la chambre de combustion, ce qui améliore d'une part l'échange thermique entre le fluide et le milieu de combustion, et aide d'autre part à éviter les perturbations du flux de fluide pendant le processus. L'étude et la conception de cette nouvelle forme ont été réalisées en utilisant le logiciel **Ansys**, permettant de suivre l'évolution de la température et de la pression sur la surface et à l'intérieur de la chambre de combustion. Cette nouvelle approche permet d'augmenter l'efficacité de la chaudière thermique en utilisant la même quantité de gaz méthane.

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# General introduction

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The intensification of installations in energy-intensive sectors, both domestic and industrial, in recent years has justified the rapid development of technologies. This growing demand for energy particularly concerns boilers. A boiler is a machine that transfers the energy from methane into heat for heating water or producing steam.

The main objective of this final year project is to propose and study a new design for the combustion chamber of an industrial boiler. In traditional boilers, the combustion chamber is simple in shape, generally a cylindrical sheet with an inlet for air and methane, and an outlet for the gases produced by the chemical reaction, thus generating an amount of energy used for heating, evaporation, or superheating. To improve the efficiency of these boilers, we propose in this work a wavy-shaped combustion chamber. This design has two main objectives:

- Increase the contact surface for heat transfer.
- Avoid turbulence in the flow during boiler operation.

All these points are addressed in this final year project, which consists of three chapters:

- The first chapter presents general information about boilers, their history, their operating principle, their overall construction, and their classification.
- The second chapter discusses the modes of heat transfer within a boiler.
- The third chapter deals with the numerical simulation of a boiler's combustion chamber using Ansys Fluent, where we analyze and compare the results obtained for different combustion chamber designs: simple and wavy.

We conclude this study with a conclusion that highlights the innovations and strengths of this research.

# ***Chapter One***

# ***General of steam Boiler***

## **I.1. Description of boiler**

### **I.1.1. History of steam boiler**

In summary, the history of boiler technology traces back to Heron's innovations in 120 BC, but the modern era began in the 18th century with advancements by Savary, Newcomen, and Watt. Fire-tube and water-tube boilers were developed in the early 19th century. Throughout the 20th century, significant progress occurred in water treatment, metallurgy, and manufacturing techniques, alongside advancements in combustion methods and steam turbine technology. Key developments included pulverized coal combustion, reheat systems, membrane walls, forced water circulation, and sliding pressure operation, all introduced between 1920 and 1970. Presently, steam generators in coal-fired power plants utilize either "pulverized coal" or "circulating fluidized bed" combustion, with a focus on forced water-steam circulation. Gas-fired power plants employ combined cycles with gas turbines and steam turbines [1]. Steam generators feature economizers, evaporators, and multi-level pressure superheaters, with increasing adoption of forced circulation boilers.

### **I.1.2. What is steam boiler**

A steam boiler is a steam producing heating system. It creates energy by heating water to get steam. A heat exchanger makes steam for outside usage and has a combustion chamber and water container. The several varieties of steam boilers include those that are very small and those that are large for more demanding jobs.

### **I.1.3. Application of steam boiler**

In industry, steam generators, or steam boilers, are used to produce saturated steam that can be used for different purposes, depending on the field of application. They are normally used when direct and indirect heating must be produced simultaneously; where heat transfer is required at a constant temperature, with high heat transfer rates; when heating large quantities of hot process water is required; and finally, where very high working pressures are required.

## **I.2. Operation**

### **I.2.1. Working principle of steam boiler**

Understanding the working of the boiler is very simple. The boiler is a closed vessel in which the water is stored. Hot gases are produced by burning fuel in the furnace. These hot gases are made to come in contact with the water vessel where the heat transfer takes place between steams by using heat energy. There are different types of boilers used for different purposes [1].

### **I.2.2. Main components of steam boiler**

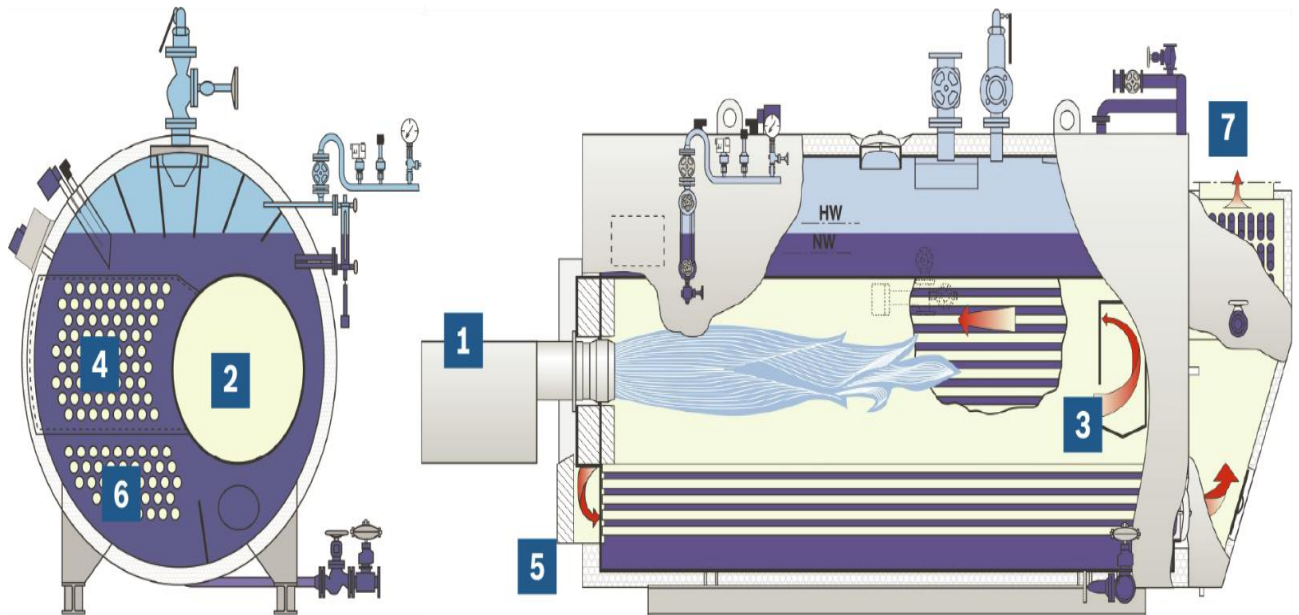
The three main components of all boilers are the burner, combustion chamber and heat exchanger:

#### **I.2.2.1. Burner**

One of the most important parts of a boiler is the burner. This is where the mixing of the air with the fuel source happens, resulting in the combustion which provides the necessary heat to heat up the fluid. The burner provides heat input by combustion of a heat source. In other words, it initiates the combustion reaction within the boiler. The way this particular component operates is that thermostats will send messages to the burner electronically when the system needs to produce heat. Then, fuel will pump, by a filter mechanism, to the boiler from an outside source — usually an adjacent fuel tank. A nozzle on the burner turns this fuel into a fine spray and ignites it, which creates the reaction in the combustion chamber.

#### **I.2.2.2. Combustion Chamber**

As the name suggests, a combustion chamber is the part of a boiler in which the fuel/air mix burns. For this reason, the combustion chamber is usually cast iron, and the temperatures inside will rise to several hundred degrees. This process usually occurs in a very short amount of time. After the combustion, the heat generated in this chamber transfers to the boiler's heat exchanger (Fig. I.1).



**Fig. I.1 Combustion Chamber**

The combustion chamber is composed as follows:

- 1- Burner
- 2- Flame tube
- 3- Internal chamber
- 4- Smoke tube pass
- 5- Front reversing chamber
- 6- Smoke tube pass
- 7- Flue gas connection for economiser

### **I.2.2.3. Heat Exchanger**

A heat exchanger is a component of a boiler that allows heat to be exchanged between two fluids or substances, usually water and gas, without letting the substances mix. The heat exchanger of boiler allows the heat from the burner to heat the water in system. The job of the heat exchanger is to carry the heat from the burner to the water without having direct contact with the water. The heat exchanger transfers the heat produced by the burners within the combustion chamber to the water in the boiler. Heat exchangers can be made up of a variety of elements,

including bundles of steel tubes, cast iron or copper lines. The elements need to be made of very sturdy material that is able to withstand high temperatures, last a long time and transfer heat efficiently (Fig. I.2). The process begins with hot gas and cold water, but because of the heat exchanger, the process ends with cooler gas and hotter water. All this transformation happens without the two substances even having to meet [2].

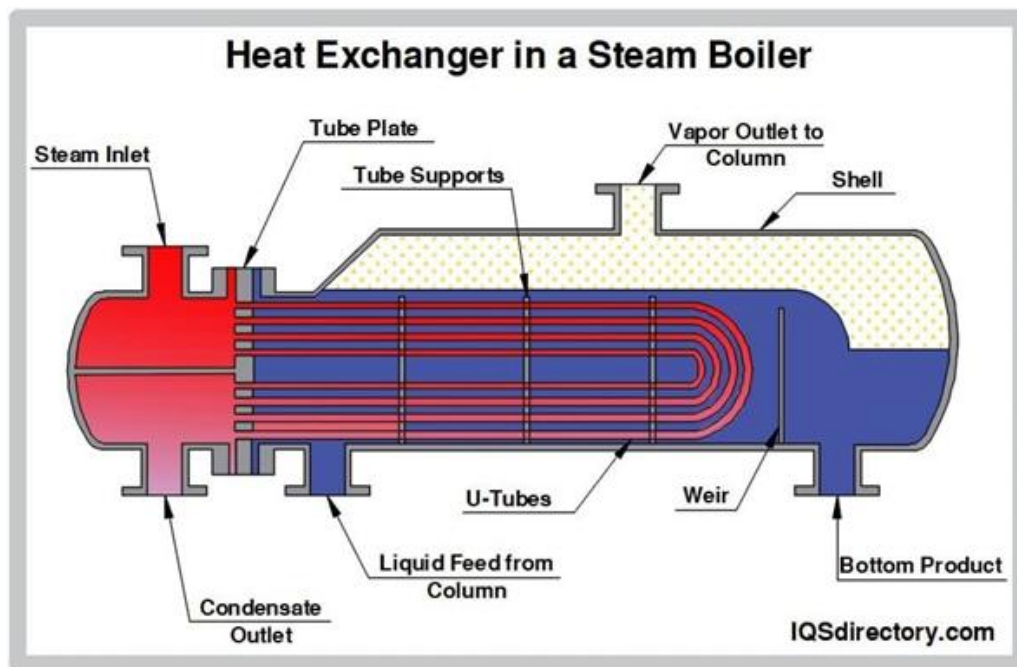


Fig. I.2 Heat Exchanger

#### I.2.2.4. Aquastats

Aquastats are the components in the boiler responsible to send the right signal to the burner about when to stop or when to start the process. They know the right time based on the temperature of the fluid in the boiler.

#### I.2.2.5. Backflow valve

Backflow valve acts as a safety unit, allowing the flow of the fluid only in a single direction

### **I.2.2.6. Circulator Pumps**

The circulator pump is the component that pushes the hot water out through the supply lines to the radiators or other distribution lines. The circulation pump plays a crucial role in the functioning of your boiler and must be well maintained to ensure the system is working as efficiently as possible

### **I.2.2.7. Controls**

The system controls allow the user to set water temperature, air and fuel supply mixtures, internal pressure and ignition. The controls regulate how often the burner fires, the quality of the mixture of fuel and oxygen, the rate at which it uses the fuel, and how hot the water will get. The controls are also an important part of the safety system of your boiler. Uncontrolled, high-pressure steam can be incredibly dangerous. Well-maintained system controls help to keep your boiler completely safe. By making sure that the internal pressures within it don't go too high, the water stays within a safe temperature range and the system continues to operate properly [3].

### **I.2.2.8. Deaerators/Condensers**

A deaerator is a device that removes oxygen and other dissolved gases from liquids. Meanwhile, a condenser is a heat exchanger that removes the latent heat from the exhaust so that it condenses and can be pumped back into the boiler. Deaerator and condenser tanks are only used in steam boiler systems and not in hot water and hot oil boilers because, in these tanks, the fluid is always in on the liquid form. The construction of these two types of tanks is almost identical. However, the tanks serve different purposes. There are two primary principles for this form of tank design are: thermal and vacuum [2] [4].

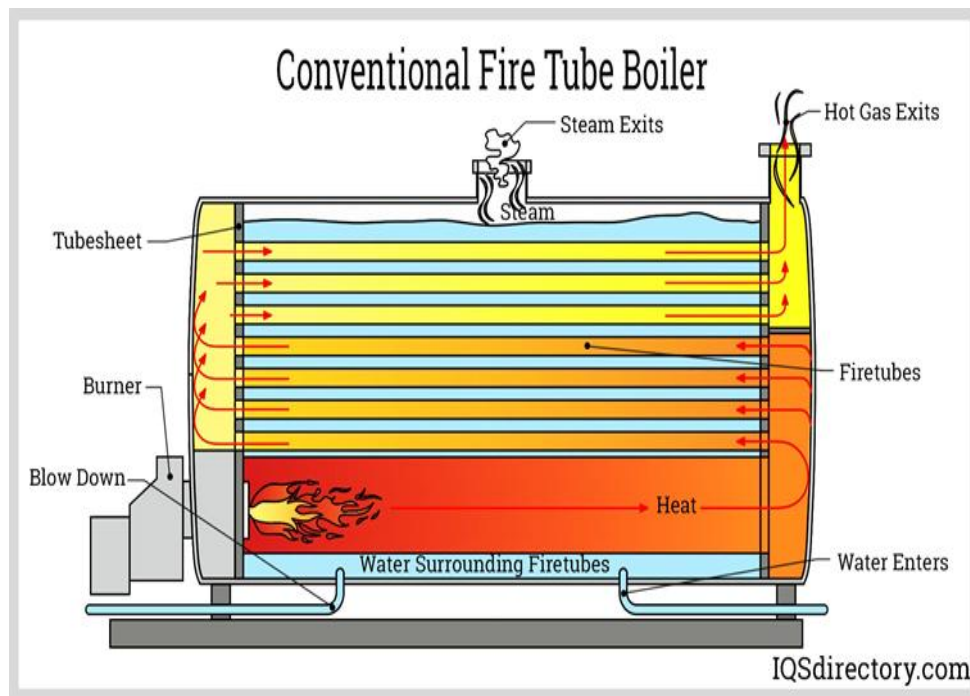
## **I.3.Types of boiler**

### **I.3.1. According to the position of water and hot gasses**

#### **I.3.1.1. Fire tube boiler**

A fire tube boiler is a boiler variant that employs the heat from combustion gases to warm

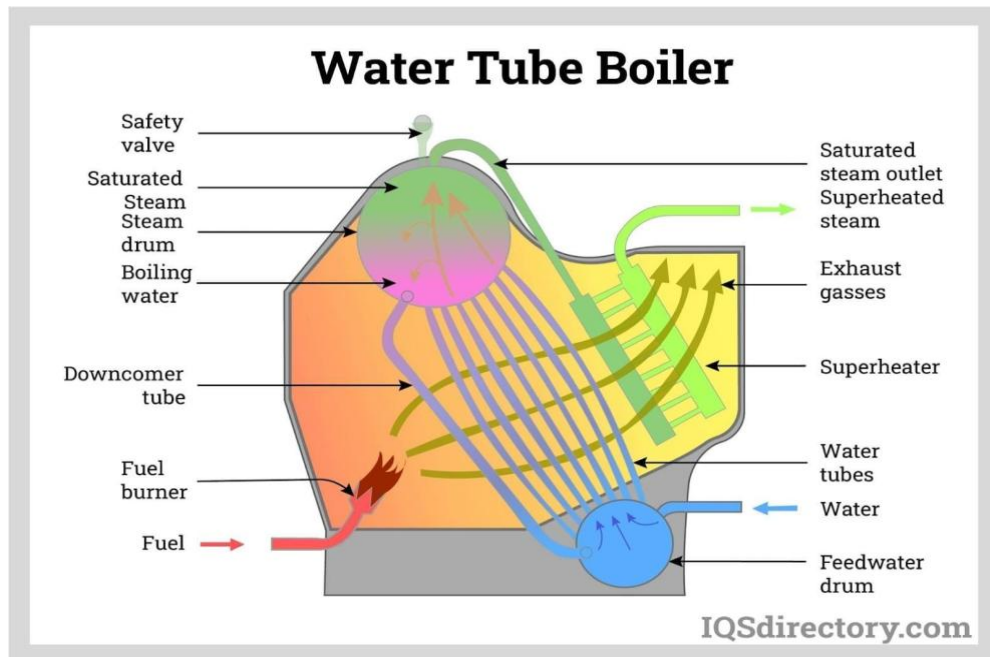
water within a network of tubes. Enclosed in a sealed vessel, these tubes are immersed in water. Thermal conduction facilitates the transfer of heat from the gases to the water through the tube walls, generating steam applicable for diverse uses (Fig. I.3) [5].



**Fig. I.3 Fire tube boiler**

### **I.3.1.2. Water tube boiler**

A Water Tube Boiler is a specific type of boiler where water flows inside the tubes while the combustion chamber produces hot gases that surround the tubes. This arrangement allows the boiler to be utilized for electricity generation purposes (Fig. I.4).

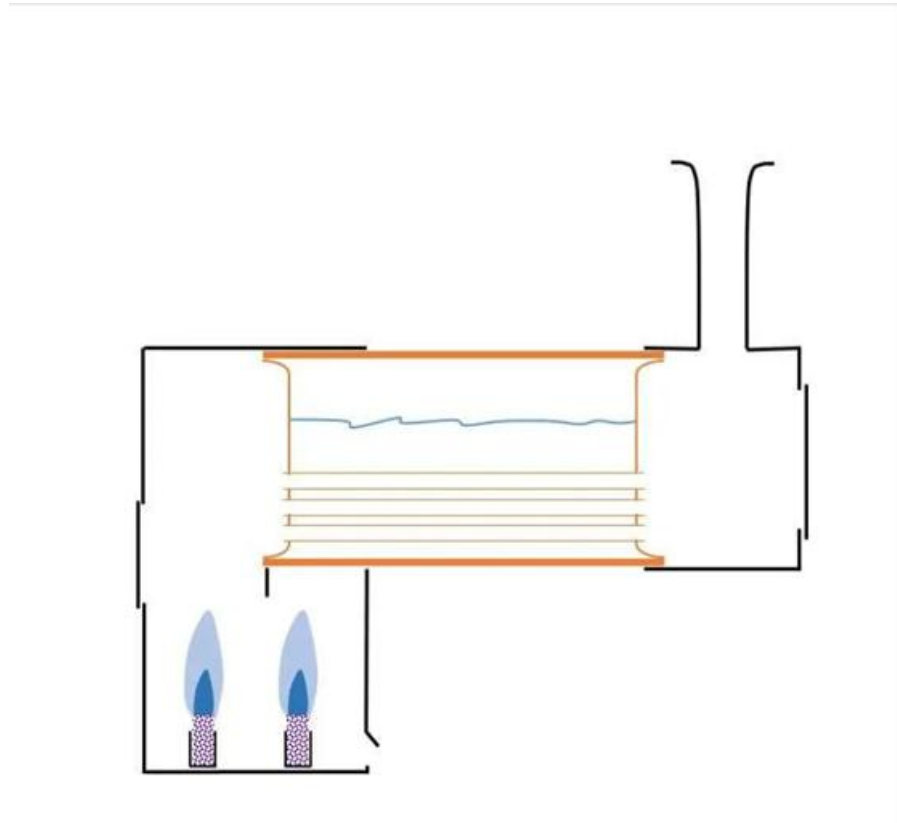


**Fig. I.4 Water tube boiler**

### **I.3.2. According to Axis of shell**

#### **I.3.2.1. Horizontal boiler**

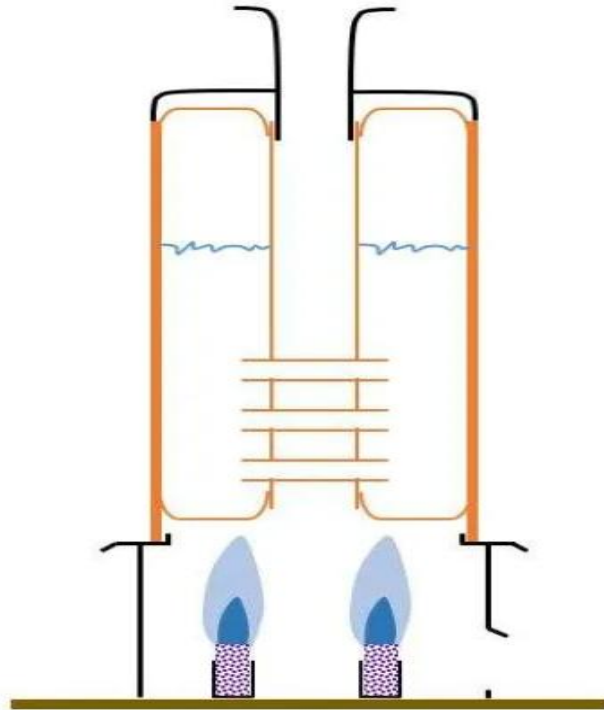
A horizontal fire tube boiler is a type of boiler with a cylindrical shell filled with water and a combustion chamber located in the lower part. Fuel or gas is burned in the combustion chamber, generating hot gas, which transfers heat through the fire tube (Fig. I.5). This design is efficient for smaller applications like heating homes or businesses, while water-tube boilers are preferred for larger applications such as power plants [6].



**Fig. I.5 Horizontal boiler**

### **I.3.2.2. Vertical boiler**

A vertical boiler is a type of steam boiler that is designed with a vertical cylinder shape. Vertical boilers are often used in small- to medium-sized facilities, such as schools, hospitals, and small industrial plants, where space is at a premium. This is the simplest type of fire tube boiler. A simple vertical boiler produces (Fig. I.6) [6] [7].



**Fig.I.6: Vertical boiler**

### **I.3.3. According to the position of the boiler**

#### **I.3.3.1. External fired boiler**

An externally fired boiler is a type of steam boiler where the combustion of fuel takes place outside of the boiler shell. In this type of boiler, the furnace or firebox is located outside the boiler shell, and the hot gases produced by the combustion of fuel are then passed through tubes or flues that are immersed in water inside the boiler shell. The external firing of the boiler provides several advantages over internal firing, such as the ability to use a wide range of solid, liquid, or gaseous fuels, improved combustion efficiency, and easier maintenance of the combustion system. However, the design of an externally fired boiler is more complex and requires additional components such as an external furnace, fuel supply system, and a system for delivering the hot gases to the boiler tubes [7].

**I.3.4. According to the pressure****I.3.4.1. Low-pressure boiler**

In a low-pressure boiler the pressure does not go beyond 15 psi, and hot water heating boilers are not designed to go beyond 260 psi. The temperature in a low-pressure boiler will not rise above 250° F. Because these types of boilers operate at lower pressures, they do not need to be checked regularly and only have to be checked when the appliance begins to break down.

**I.3.4.2. High-pressure boiler**

A high-pressure boiler is a type of boiler that operates at 80 bars or higher and is used in thermal power plants to generate power. Using water-filled tubes in a metal tank or enclosure, they create power by converting water into steam through thermal energy, which is used to power equipment.

***Chapter Two***

***Heat transfer in steam***  
***boiler***

## Introduction

A thermal transfer, commonly known as heat, is one of the modes of internal energy exchange between two systems. Generally, there are three modes of thermal energy transfer between two bodies at different temperatures (Fig. II.1):

- Conduction
- Convection
- Thermal radiation.

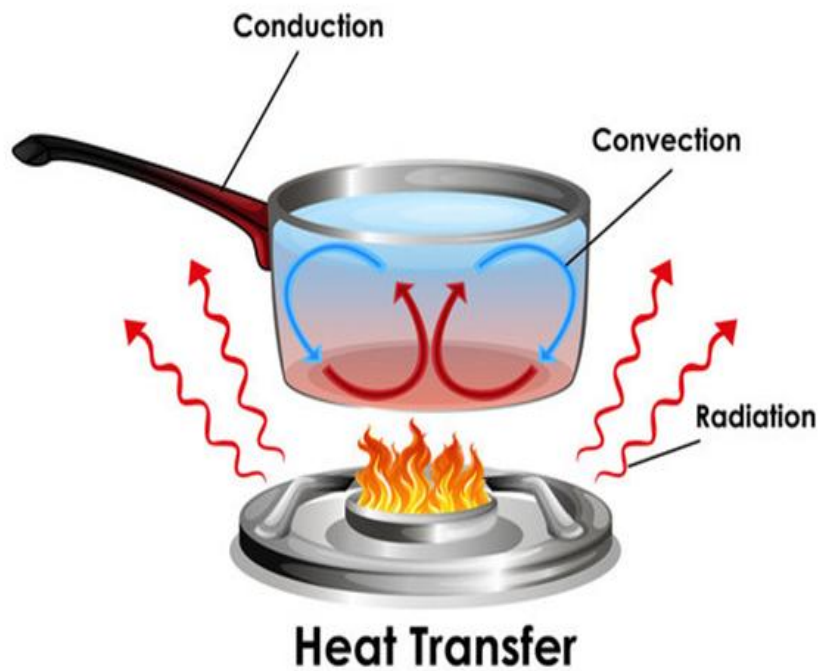


Fig. II.1 modes of thermal energy transfer

### II.1. Heat transfer in steam boiler

A steam boiler is engineered to capture the utmost heat generated during the combustion process. Heat transfer within a steam boiler occurs through three mechanisms: radiation, conduction, and convection. The proportion of heat transferred by each method varies depending on the type of steam boiler in question [8].

## II.2. Modes of heat transfer

### II.2.1. Conduction

Thermal conduction, also known as thermal diffusion, is a mode of heat transfer that occurs due to a temperature difference between two regions within the same medium or between two contacting media, without the macroscopic movement of matter, unlike convection which is another mode of heat transfer. It can be interpreted as the progressive transmission of thermal agitation: an atom or molecule transfers part of its kinetic energy to its neighbor.

Thermal conduction is a process of internal energy transport related to molecular agitation and caused by macroscopic heterogeneity of the medium. It is an irreversible phenomenon similar to diffusion. In fluids (liquids and gases), this energy transport results, at the microscopic level, from the anisotropy of the velocity distribution of particles. In solids, thermal conduction is jointly ensured by conduction electrons and by the vibrations of the crystal lattice, called phonons.

In boilers, conduction heat transfer takes place from outer surface of the boiler tubes through with water and steam flow takes place to the inner surface of the tubes [7].

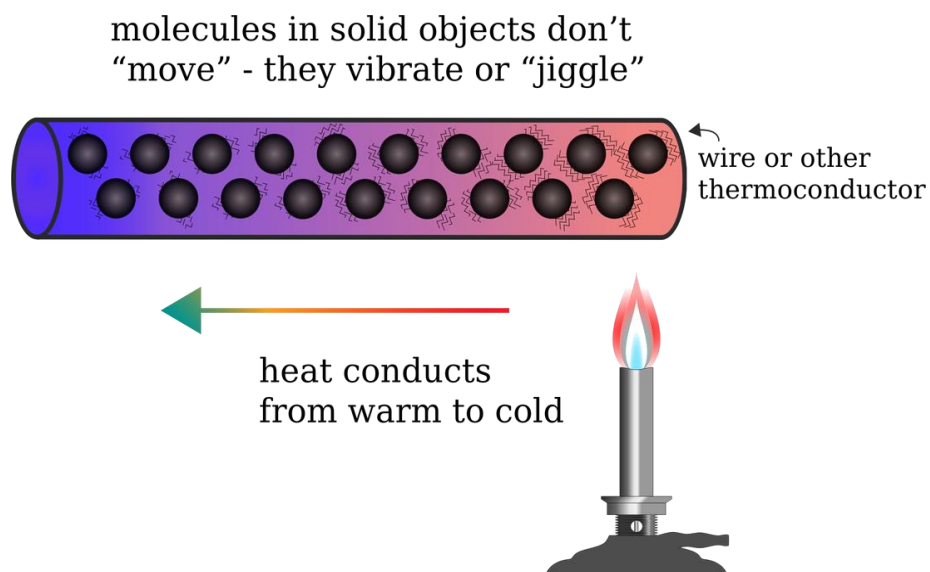


Fig. II.2 Heat conduction

**II.2.1.1. Laws of thermal conduction**

The laws of thermal conduction describe the fundamental principles governing the transfer of heat by conduction through different mediums. Here are the main aspects of the laws of thermal conduction:

**a- Fourier's Law (or the law of thermal conduction):**

This law establishes that the amount of heat  $Q$  transferred through a material is proportional to the contact area  $A$ , to the temperature difference  $\Delta T$  between the two ends of the material, and inversely proportional to the distance  $L$  separating these two ends. Mathematically, it is expressed as:

$$Q = -k \cdot A \cdot \frac{\Delta T}{L} \quad (\text{II.1})$$

where  $k$  is the thermal conductivity of the material.

**b- Law of thermal resistance:**

This law considers that the heat flux  $Q$  through a material can be analyzed as the heat flux passing through a series of thermal resistances in series. It is often used to analyze systems composed of multiple materials with different thermal conductivities.

**c- Law of conservation of energy**

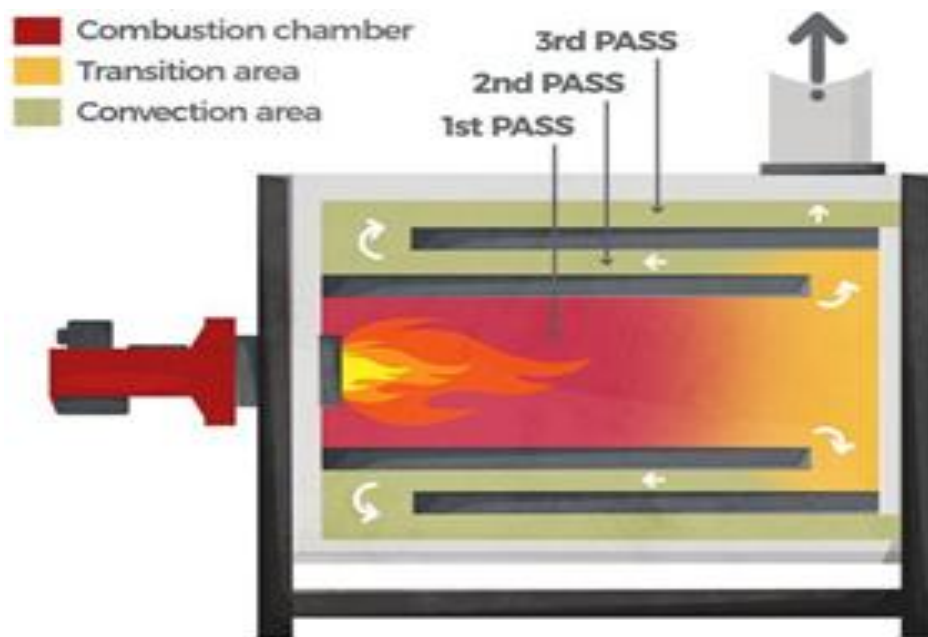
This fundamental law of thermodynamics states that the total energy within a closed system remains constant. It is applied to describe how heat moves through materials while maintaining energy balance.

These laws provide an essential theoretical framework for understanding and modeling thermal conduction in various contexts, whether at the macroscopic scale of building structures or at the microscopic scale of conductive materials.

### II.2.2. Convection

Convection heat transfer takes place when the heated medium displaces. In boilers, when water is heated, its density becomes less hence it is displaced by the high density cold water. This movement takes place continuously. If the convection flow is caused naturally because of the density difference it is called natural circulation. If this movement is assisted by a fan or pump it is called forced convection [9].

In a boiler, mostly the tubes receive the heat from the convective flow of hot gases from combustion chamber (furnace). Also within the tubes, the water or steam picks up the heat from inner surface of the tubes by convection (Fig. II.2).



**Fig. II.2 Heat convection**

There are two main types of convection: natural (or free) convection and forced convection.

#### **a- Natural Convection**

This occurs due to density differences in the fluid caused by temperature variations. When the fluid is heated, it becomes less dense and rises, while the cooler, denser fluid descends. This movement creates convection currents that promote heat transfer. For

example, heating the air above a radiator creates ascending currents of warm air and descending currents of cool air [9].

### b- Forced Convection

This type of convection involves the use of external forces to cause the movement of the fluid. Devices such as fans, pumps, or blowers are used to move the fluid and thereby transfer heat. For example, a fan in a heating or cooling system forces air to circulate, improving heat transfer [9] [10].

#### II.2.2.1. Convection Equations

The basic equation for heat transfer by convection is given by Newton's law of cooling:

$$Q = h \cdot A \cdot (T_s - T_f) \quad (\text{II.2})$$

Where :

- $Q$  is the amount of heat transferred per unit time,
- $h$  is the convective heat transfer coefficient,
- $A$  is the contact surface area,
- $T_s$  is the surface temperature,
- $T_f$  is the fluid temperature.

#### II.2.2.2. Applications of convection

Convection plays a crucial role in many natural and artificial systems:

- **Earth's Atmosphere:** Convection is responsible for air currents, weather systems, and cloud formation.
- **Oceans:** Ocean currents are partly the result of convection, influencing the global climate.
- **Thermal Engineering:** Heating, ventilation, and air conditioning (HVAC) systems use forced convection to regulate temperature in buildings and vehicles.

- **Cooking:** Convection ovens use fans to distribute heat evenly, ensuring more uniform cooking of food.

In summary, convection is an effective heat transfer mechanism in fluids, influencing many natural and technological processes [10].

### II.2.3. Radiation

Radiation heat transfer is a common phenomenon that takes place in all the heater bodies as they radiate the heat energy. There is no requirement for any medium for the radiation to take place. The amount of radiation energy depends on the size and the quantum of heat energy a body have. In boilers, radiation heat transfer takes place in the combustion chamber from the hot gases to the boiler tubes surrounding the combustion chamber (Fig. II.3) [11].

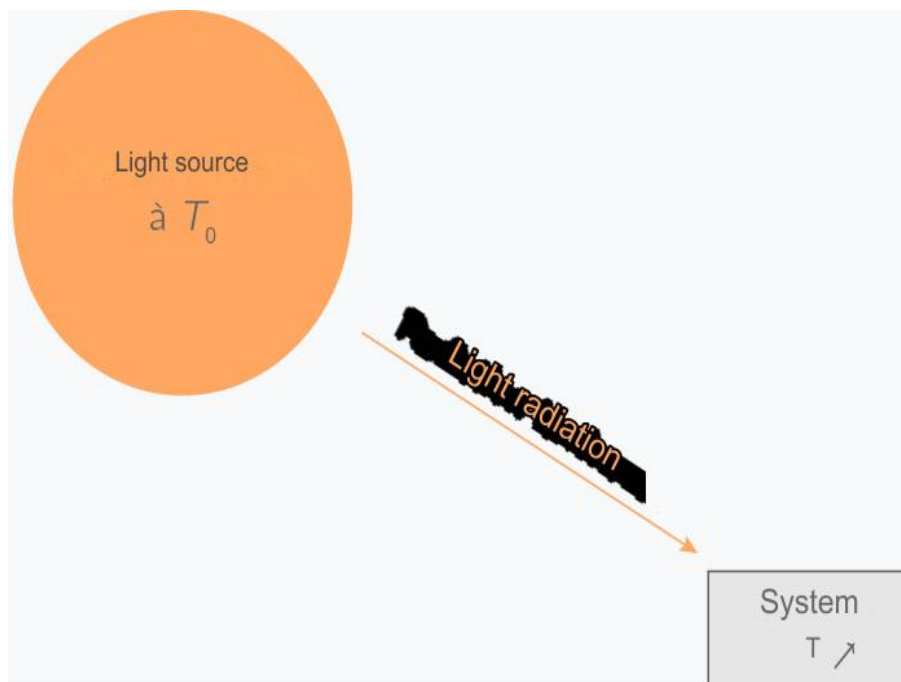


Fig. II.3 Radiation

#### II.2.3.1. Principle of thermal radiation

Thermal radiation is the result of the emission of photons by the atoms and molecules of a body. All objects with a temperature above absolute zero (-273.15°C or 0 K) emit thermal radiation. This radiation can be absorbed, reflected, or transmitted when it encounters another object [11].

### II.2.3.2. Laws of thermal radiation

#### a- Planck's Law

This law describes the spectral distribution of energy emitted by a black body (an ideal object that absorbs all incident energy) as a function of temperature. Planck's equation gives the intensity of the radiation as a function of wavelength and the temperature of the body.

#### b- Stefan-Boltzmann Law:

This law states that the total radiative power emitted by a black body is proportional to the fourth power of its absolute temperature  $T$ . It is expressed by the equation:

$$P = \sigma \cdot e^T \quad (\text{II.3})$$

where  $P$  is the power emitted per unit area,  $\sigma$  is the Stefan-Boltzmann constant, and  $T$  is the absolute temperature in kelvins.

#### c- Wien's Law

This law indicates that the wavelength at which a black body's emission is maximal is inversely proportional to the temperature of the body. It is given by:

$$\lambda_{max} = \frac{b}{T} \quad (\text{II.4})$$

$\lambda_{max}$  is the wavelength of maximum emission,  $b$  is the Wien's displacement constant, and  $T$  is the absolute temperature.

### II.2.3.3. Applications of thermal radiation

Thermal radiation plays a crucial role in many natural and artificial domains:

- **Climate and Meteorology:** Solar radiation heats the Earth's surface, and terrestrial thermal radiation to space regulates the planet's temperature.
- **Astrophysics:** Studying the radiation of stars and other celestial bodies helps determine their temperature and composition.
- **Technology:** Solar panels convert solar radiation into electrical energy. Thermal cameras detect infrared radiation to visualize the temperature of objects.
- **Construction:** Thermal insulation of buildings aims to reduce heat loss by radiation, conduction, and convection.
- **Health:** Radiators and infrared lamps use thermal radiation for heating and medical treatments.

***Chapter three***

***Results and discussions***

**Introduction**

To improve the boiler efficiency, we try to revamp the combustion chamber design by increasing the heat contact area, and we designed a vertical combustion chamber and performed a numerical simulation.

In this chapter, we will focus on the numerical simulation of a boiler combustion chamber using ANSYS Workbench, a comprehensive simulation environment that provides advanced functionality. It provides all the functions required to analyze layered structures, making it a powerful tool for studying the behavior of composite materials

**III.1. Simulation by Ansys software**

Ansys is an analyzing software that provides its users an understanding of how their product will work or not work in real conditions. It is also called engineering simulation software and FEA or finite element analysis software. It analyzes a wide range of problems related to mechanical product design and civil structure design by using numerical techniques. These design models can be further tested for strength, elasticity, toughness, distribution, and temperature.

Through Ansys, engineers innovate freely and in a more experimental environment. It saves both time and manufacturing costs, along with reducing the risks involved in the process from designing to manufacturing. Ansys also has software for data management and backup along with academic research and teaching.

ANSYS offers a wide range of simulation tools for various fields, such as structural mechanics, fluid dynamics, electromagnetism, acoustics, optics, thermic, etc. It enables engineers to predict the behavior of a product or system before it is manufactured, saving time and resources.

ANSYS software uses the finite element method, a numerical technique for solving complex mathematical equations that describe the physical behavior of a system. It features a user-friendly graphical interface for creating models, defining material properties, setting boundary conditions and loads, and analyzing results.

ANSYS Fluent is a widely used computational fluid dynamics (CFD) software developed by ANSYS Inc. It is a powerful tool for the simulation and analysis of fluid flow and heat transfer phenomena.

ANSYS Fluent is used in a variety of industries, aerospace, automotive, energy, chemical processing and many others.

Here are some of ANSYS Fluent's key features and capabilities

- **Fluid flow simulation:** ANSYS Fluent enables you to model and simulate a wide range of fluid flow scenarios, including laminar and turbulent flows, compressible and incompressible flows, multiphase flows, and much more.
- **Heat transfer analysis:** The software lets you analyze different heat transfer mechanisms, such as conduction, convection and radiation. It can be used to study temperature distributions, heat transfer rates and thermal effects in systems.
- **Multiphysics simulations:** ANSYS Fluent supports simulations that are coupled with other physical phenomena, such as fluid-structure interaction (FSI), conjugate heat transfer (CHT) and combustion modeling. This feature enables a more comprehensive analysis of complex engineering problems.
- **Pre-processing tools:** The software offers a comprehensive set of pre-processing tools for geometry creation, meshing and simulation parameter configuration. . It offers 2D and 3D modeling capabilities and supports the import and export of various file formats.
- **Solver technology:** ANSYS Fluent uses advanced numerical methods methods and solvers to solve the equations governing fluid flow and heat transfer. It includes options for steady state and transient simulations, as well as turbulence modeling using different turbulence models (e.g. k- $\epsilon$ , k- $\omega$ , large-scale simulation).
- **Post-processing and visualization:** ANSYS Fluent offers a range of tools for post-processing tools for analyzing and visualizing simulation results. It includes options for generating contour plots, vector plots, and animations and extract specific quantities of interest from simulation data.

### III.2. Applications of Ansys

To know better what is Ansys software, one needs to know where it can be used. Here is a Table II.1 explaining some of the applications of the software:

**Table III.1 Applications of Ansys**

<b>NB</b>	<b>Application</b>	<b>Function</b>
1.	Autonomous Sensor Development	This helps in the development of autonomous vehicle sensor capabilities include Lidar, Radar, and Camera.
2.	Battery Simulation	Ansys helps in improving the battery design while maintaining the state of its performance, size, cost, reliability, and above all safety.
3.	3D Design	3D prototypes can be developed to make faster decisions by reducing development costs.
4.	Multiphysics	Through Ansys, we can study complex interactions between fluid, electromagnetic, thermal, and other forces to improve product design.
5.	Antenna Design and Placement	Antennas are used for a wide variety of fields ranging from smartphones to defense purposes. Electromagnetic simulation of antenna design and its interaction with the system allows one to analyze its work in real-life situations.
6.	Avionics and Flight Controls	Through Ansys, avionics that are engine controls, flight control systems, cockpit display systems, and others are analyzed. This is to ensure functional safety, and cybersecurity and develop certified embedded software.
7.	Battery Pack and Module Thermal Management	This is for finding solutions to make cost-effective cooling devices within the space of a product and safer batteries.
8.	Autonomous System development	It focuses on model-based safety and cybersecurity solutions to develop autonomous systems and their certification.

### **III.3. ANSYS Workbench**

When it comes to numerical simulation, ANSYS Workbench offers a range of tools and functions to facilitate the process of modeling, analysis and interpretation of results. Here are some important points to know about ANSYS Workbench.

#### **III.3.1. User-friendly interface**

ANSYS Workbench features a graphical user interface graphical user interface, enabling users to navigate easily between different simulation. The various ANSYS applications and add-on modules can be can be integrated into Workbench, providing a seamless, streamlined working experience.

#### **III.3.2. Geometry and meshing**

Workbench lets you import geometries from a variety of file formats, such as CAD files, and offers modeling tools for create and modify geometries. It also offers advanced functions to generate and control meshes, allowing structured or unstructured meshing, adaptive and high-quality meshing.

#### **III.3.3. Boundary conditions**

Workbench makes it easy to define bending test boundary conditions, such as imposed stresses or displacements, supports and applied loads. Users can also define contact conditions between different parts of the model, if required.

#### **III.3.4. Advanced analysis tools**

ANSYS Workbench offers a wide range of options, including static and dynamic analysis, material and geometric non-linearity analysis, contact analysis, etc. Users can choose the appropriate analysis types according to the characteristics of their model.

#### **III.3.5. Visualization and interpretation of results**

Workbench offers advanced to display and interpret simulation results. The generate graphs, tables, animations, stress contours, and other visualizations.

### III.4. Simulation on Ansys

We need to simulate two combustion chamber scenarios: one is straightforward (without ripples), and the other includes ripples.

#### III.4.1. Simple case without ripple

Numerical simulation, of a boiler combustion chamber with a simple design

##### III.4.1.1. Geometry

The model was created using Design Modeler and imported into ANSYS as we shown in figure III.1.

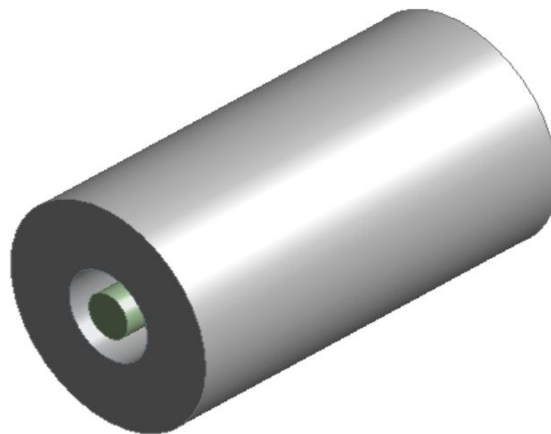


Fig. III.1. Geometry of simple geometry

##### III.4.1.2. Mesh

The meshing process is an essential step in ANSYS, aimed at achieving accurate simulation using the finite element method (FEM). The mesh is composed of elements containing nodes representing the shape of the geometry, and can vary according to the type of element. By using the principle of calculation on a finite number of elements and interpolating the results over the entire structure, the finite element method makes it possible to reduce the infinite number of degrees of freedom of a continuous object to a limited number, thus facilitating numerical resolution. In ANSYS Workbench, various meshing methods are available, including the mechanical, tetrahedral and hexahedral dominance methods (Fig. III.2, III.3).



Fig. III.2. Mesh of simple case

Details of "Mesh"	
<b>Display</b>	
Display Style	Use Geometry Setting
<b>Defaults</b>	
Physics Preference	CFD
Solver Preference	Fluent
<input type="checkbox"/> Element Size	1, cm
Export Format	Standard
Export Preview Surface Mesh	No
<b>Sizing</b>	
Use Adaptive Sizing	No
<input type="checkbox"/> Growth Rate	Default (1,2)
<input type="checkbox"/> Max Size	Default (2, cm)
Mesh Defeaturing	Yes
<input type="checkbox"/> Defeature Size	Default (5, e-003 cm)
Capture Curvature	Yes
<input type="checkbox"/> Curvature Min Size	Default (1, e-002 cm)
<input type="checkbox"/> Curvature Normal Angle	Default (18,°)
Capture Proximity	No
Bounding Box Diagonal	114,46 cm
Average Surface Area	3179, cm <sup>2</sup>
Minimum Edge Length	31,416 cm
<b>Quality</b>	
<b>Inflation</b>	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
<input type="checkbox"/> Transition Ratio	0,272
<input type="checkbox"/> Maximum Layers	5
<input type="checkbox"/> Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
<b>Advanced</b>	
<b>Statistics</b>	
<input type="checkbox"/> Nodes	289432
<input type="checkbox"/> Elements	279461
Show Detailed Statistics	No

Fig III.3 shows the measurements

### - Models

Models" encompass the numerical representations of diverse physical interactions within the simulated system. The choices and configurations within the "models" section are contingent

upon the simulation's context and the phenomena under examination. These mathematical constructs span across multiple domains, including fluid dynamics, thermal behavior, combustion, chemical equilibrium, corrosion, ionization, mass transfer, and various other physical and chemical processes. Parameters within these models provide avenues for selecting appropriate simulation models, fine-tuning their parameters, and specifying the principles and assumptions guiding model computations (Fig. III.3).

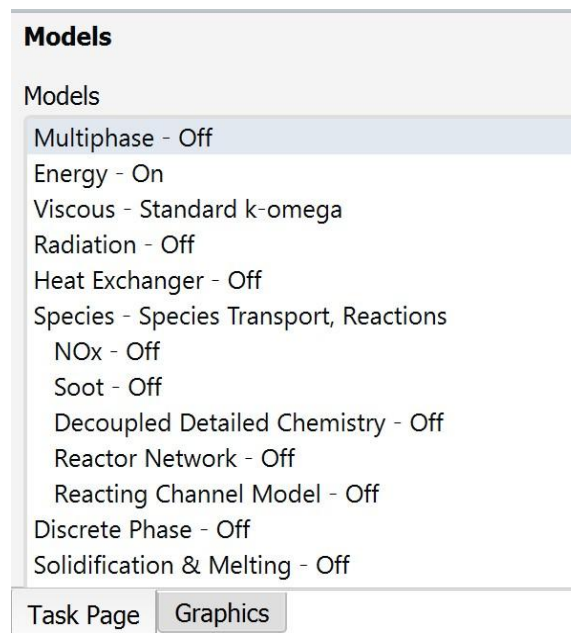


Fig. III.4. Models

#### - Materials

"Materials" pertains to the inherent characteristics of the substances utilized within the simulation. The careful selection and characterization of these materials, including their physical and chemical attributes, are crucial for ensuring the fidelity of the simulation by accurately depicting the physical interactions and effects within the simulated environment. Through the "Materials" parameters, properties such as density, viscosity, thermal conductivity, electrical conductivity, thermal expansion coefficients, resistivity, and other pertinent material traits can be defined. The selection of materials within these parameters facilitates the precise portrayal of material behaviors and interactions within the simulation, thereby enhancing the accuracy and reliability of results pertaining to fluid dynamics, temperature distribution, and various other

interactions within the simulated system (Fig. III5).

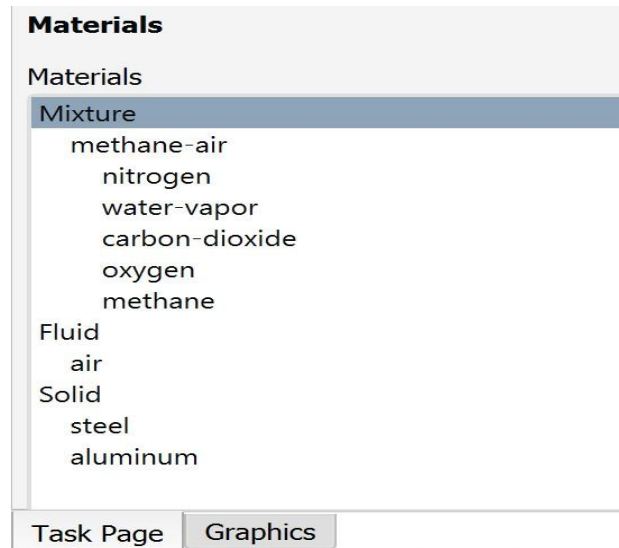


Fig. III.5 Materials

#### - Boundary conditions

“Boundary conditions refer to the conditions imposed on the external barriers of the simulated system. These conditions determine how the system interacts with the external environment, and govern flow, temperature combustion and other related factors. The determination of the appropriate boundary conditions is crucial in the simulation to ensure accurate representation of actual conditions (Tale III.1).

**Table III.1 Boundary conditions**

	<b>Velocity</b>	<b>Temperature</b>	<b>Species Mass Fraction</b>
<b>Air</b>	2 m/s	400°k	0.23
<b>Ch4</b>	1m/s	300°k	1

#### - Solution Methods

"Solution methods" encompass the strategies and methodologies employed for resolving mathematical equations and models within the simulation procedure. These methods play a crucial role in achieving both precision and efficiency in simulation calculations. Selecting suitable solution methods within the designated parameters aids in enhancing calculation accuracy, reducing analysis time, and mitigating the consumption of computational resources.

The choice of solution methods is contingent upon the type of simulation being conducted and the physical considerations inherent in the simulated system. Broadly speaking, the solution methods specified in the "Solution methods" parameter aim to strike a harmonious balance between accuracy and efficiency throughout the simulation process, resulting in precise outcomes and streamlined computational time within numerical modeling endeavors (Fig. III.6)

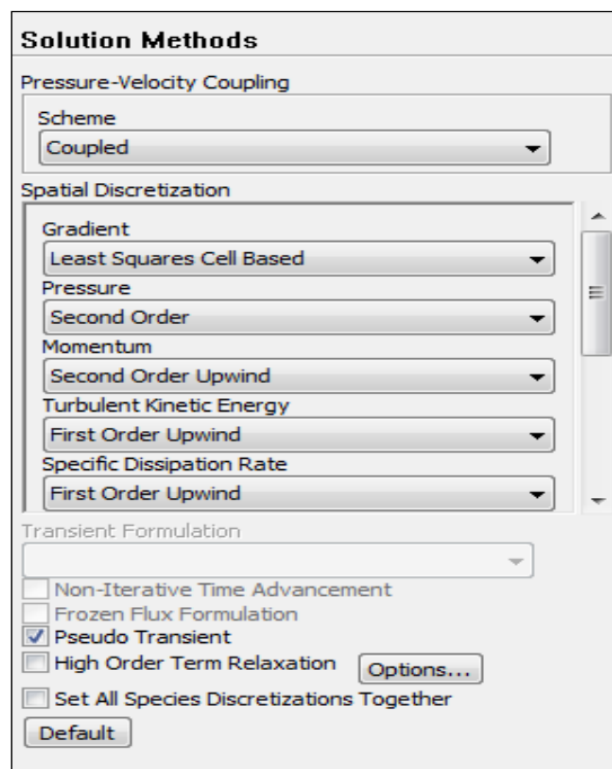
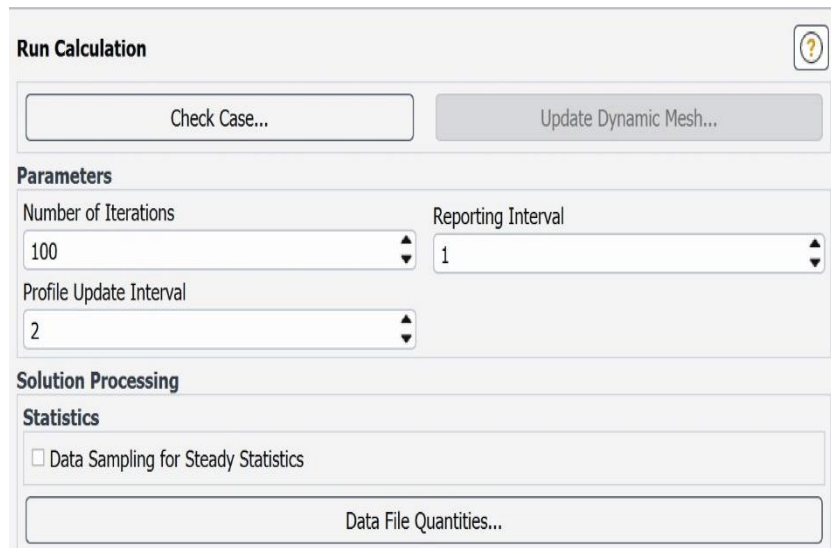


Fig. III.6 Solution methods

### - Run Calculation

"Run calculation" indicates that the simulation will carry out the actual mathematical operations. Once all necessary configurations are set up, the calculation process is initiated to generate the desired outcomes. This step is pivotal as it bridges the simulation model with physical variables, yielding the necessary results. The accuracy and efficiency of resolution methods significantly influence the quality of the calculation. Following the completion of the calculation, the simulated outcomes are scrutinized and assessed to comprehend the behavior, performance, and interactions within the studied system.



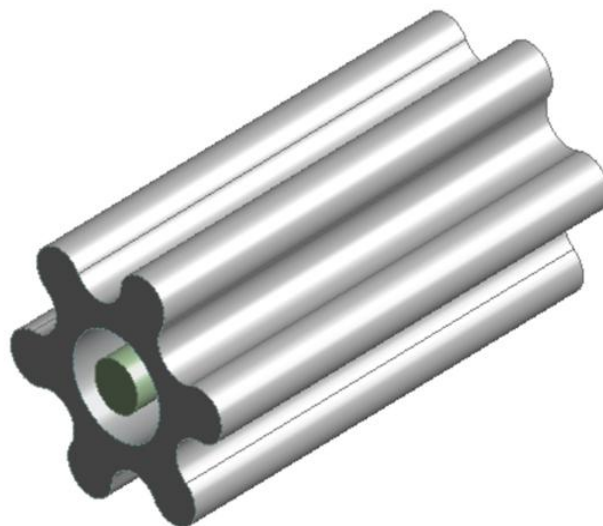
**Fig. III.7 Run calculation**

### III.4.2. Case with ripple (Wavy geometry)

Numerical simulation of a boiler combustion chamber with a vertical design

#### III.4.2.1. Geometry

The new geometry is represented in figure III.8



**Fig. III.8. New geometry**

### III.4.2.2. Mesh

The mesh of the combustion chamber in this case is represented in figure III.9. The rest of the steps are similar to those in the simple case. These steps are shown in the figures; III.10, III.11, III.12 and III.13



Fig.III.9. Mesh

Details of "Mesh"	
<input type="checkbox"/> Display	
Display Style	Use Geometry Setting
<input type="checkbox"/> Defaults	
Physics Preference	CFD
Solver Preference	Fluent
<input type="checkbox"/> Element Size	0,7 cm
Export Format	Standard
Export Preview Surface Mesh	No
<input type="checkbox"/> Sizing	
Use Adaptive Sizing	No
<input type="checkbox"/> Growth Rate	Default (1,2)
<input type="checkbox"/> Max Size	Default (1,4 cm)
Mesh Defeaturing	Yes
<input type="checkbox"/> Defeature Size	Default (3,5e-003 cm)
Capture Curvature	Yes
<input type="checkbox"/> Curvature Min Size	Default (7,e-003 cm)
<input type="checkbox"/> Curvature Normal Angle	Default (18,°)
Capture Proximity	No
Bounding Box Diagonal	113,12 cm
Average Surface Area	1663,1 cm <sup>2</sup>
Minimum Edge Length	13,301 cm
<input type="checkbox"/> Quality	
Check Mesh Quality	Yes, Errors
<input type="checkbox"/> Target Skewness	Default (0,9)
Smoothing	Medium
Mesh Metric	None
<input type="checkbox"/> Inflation	
<input type="checkbox"/> Advanced	
<input type="checkbox"/> Statistics	
<input type="checkbox"/> Nodes	482820
<input type="checkbox"/> Elements	464787
Show Detailed Statistics	No

Fig. III.10 Measurement

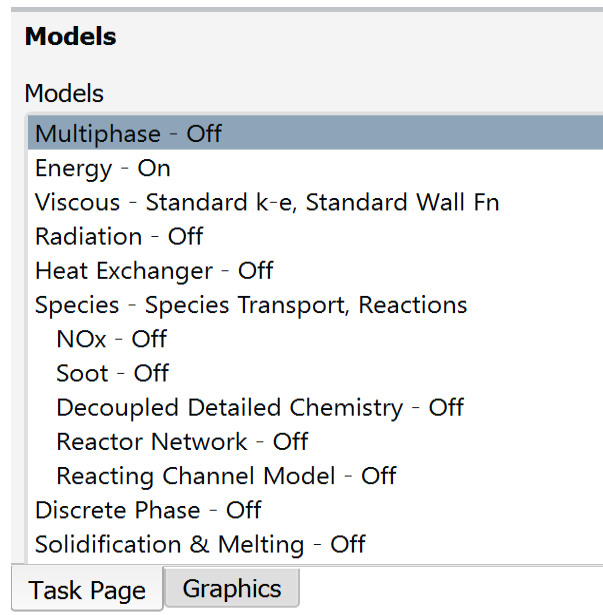


Fig. III.11 Models

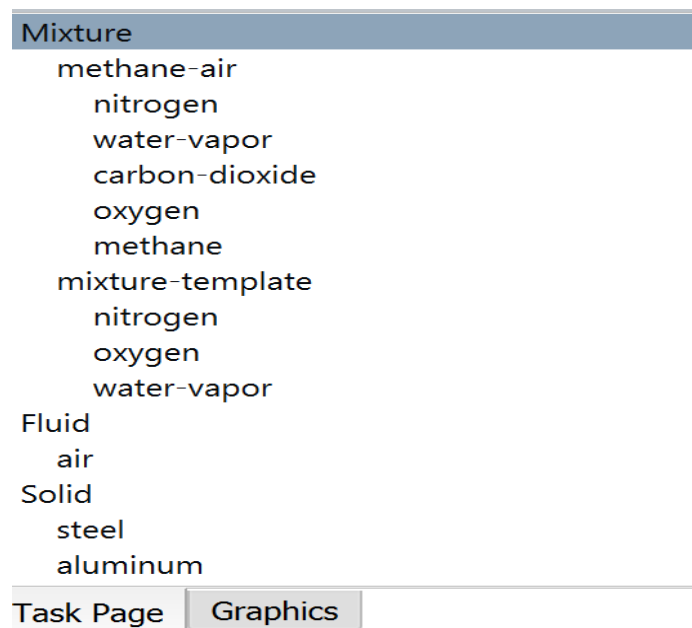


Fig. III.12 Materials

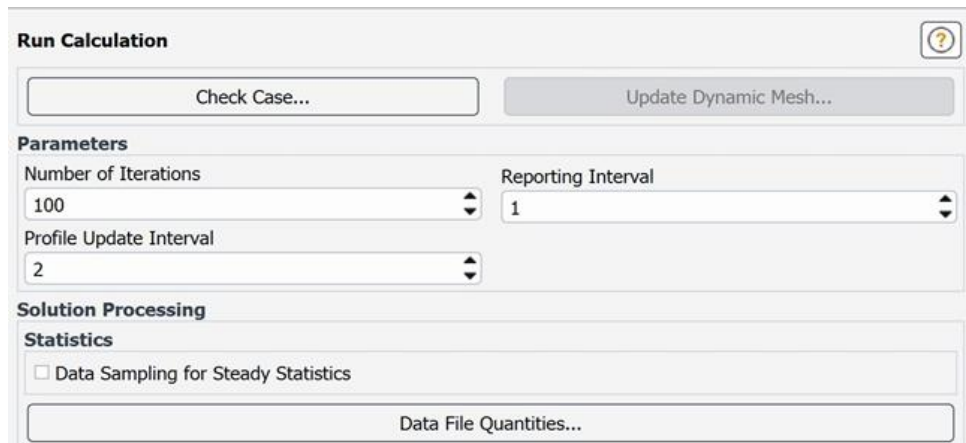


Fig. III.13 Run calculation

### III.5. Results and discussions

#### III.5.1. Simple geometry

##### III.5.1.1. Temperature

Without ripples, the temperature distribution over the entire surface of the combustion chamber is clear. At the inlet of methane gas and air, the temperature is the lowest, reaching 300 K. After the chemical reaction, the temperature increases to the value 2900 K (Fig. III.14).

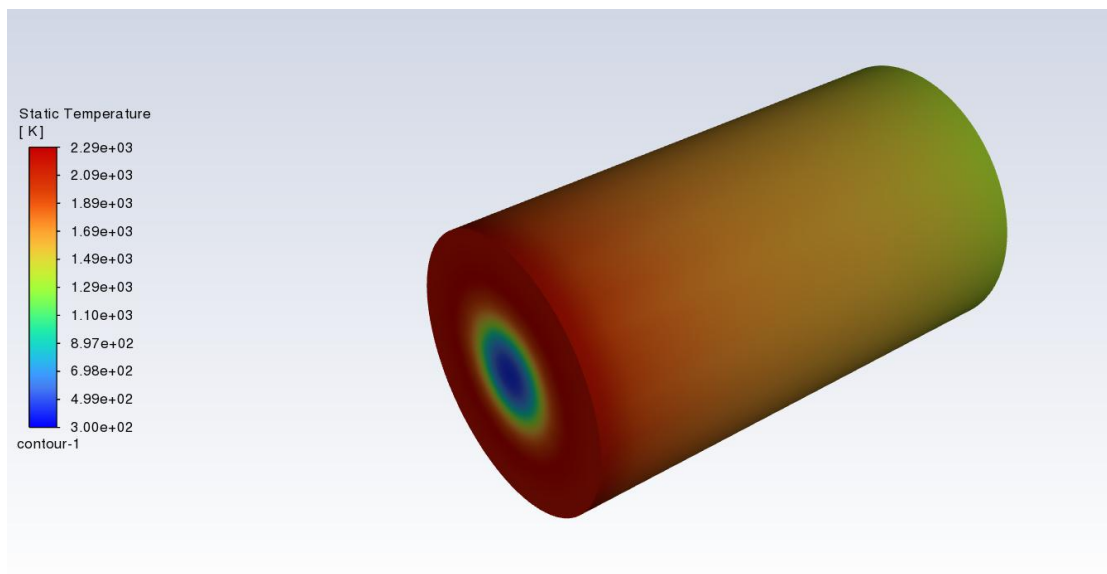


Fig. III.14. Combustion chamber temperature

### III.5.1.2. Velocity

The flow velocity is higher at the entrance of the combustion chamber, then gradually decreases until it reaches zero at the surface of the chamber as can be seen in the figure III.15.

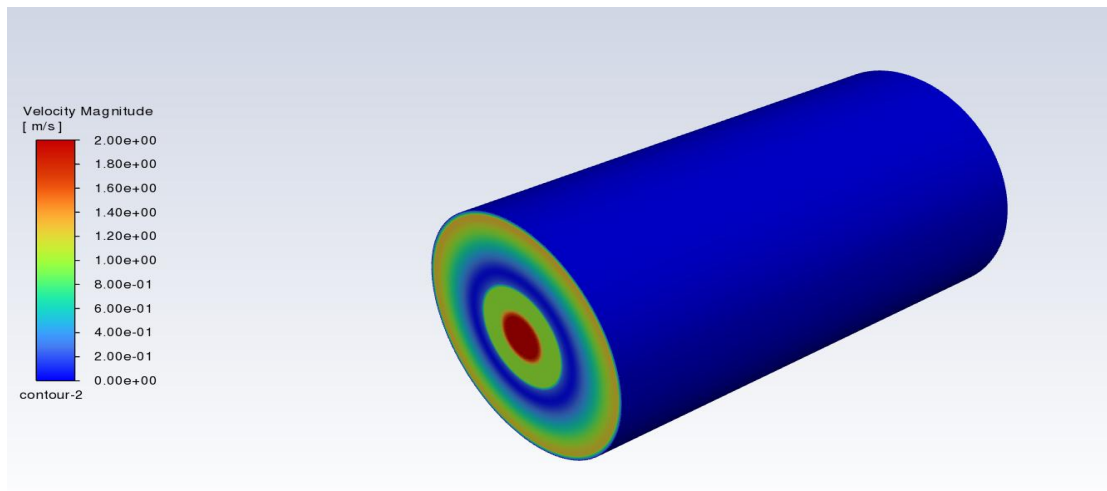


Fig. III.15. Combustion chamber velocity

### III.5.1.3. Pressure

As shown in Figure III.16 in the simple case, the pressure is higher in the combustion chamber at the inlet. This importance is due to the speed of the flow of air and methane.

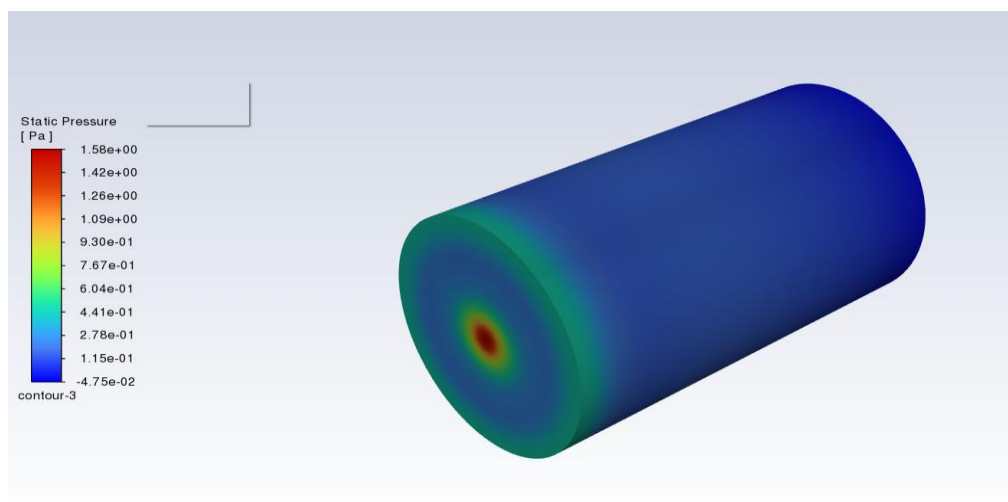


Fig.III.16. Combustion chamber pressure

### **III.5.2. Wavy geometry**

The surface of the combustion chamber is corrugated, as illustrated in Figure III.9. This corrugated shape aims to:

- Increase the contact surface between the boiler's combustion chamber and the fluid.
- Prevent flow turbulence.

The increase in this contact surface improves heat transfer, thereby enhancing the boiler's efficiency while using the same amount of methane gas. One of the consequences of this geometric shape is that the combustion flame is deformed between the positive and negative alternations.

#### **III.5.2.1. Temperature**

The temperature distribution on the surface of the combustion chamber is illustrated in Figure III.17. It clearly shows that:

- The temperature is higher at the bottom and in the peaks of the corrugations, reaching up to 2260 K.
- At the entrance of the combustion chamber and in the troughs of the corrugations, the temperature is significantly lower.

This difference can be explained by the deformation of the flame due to the corrugations.

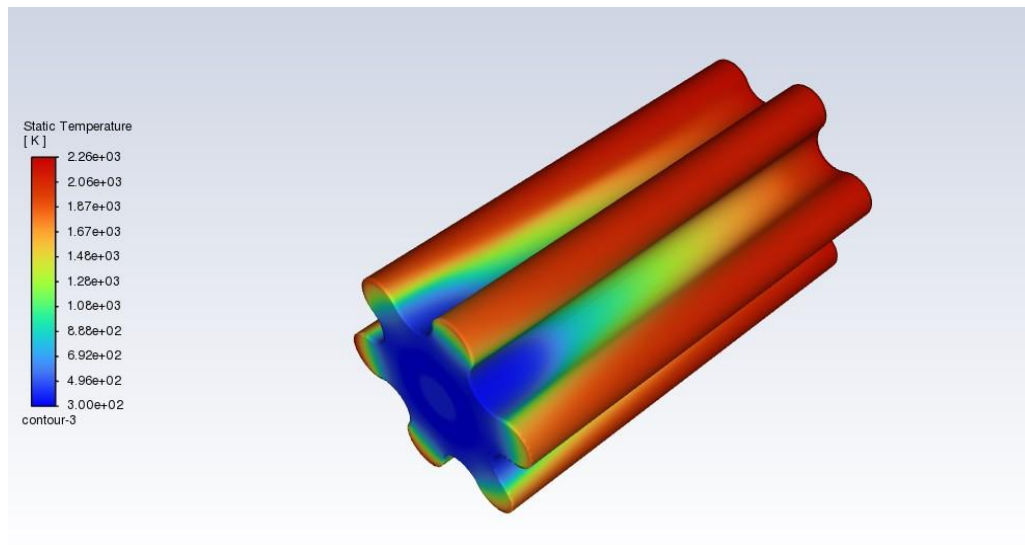


Fig.III.17. Combustion chamber Temperature

### III.5.2.2. Velocity

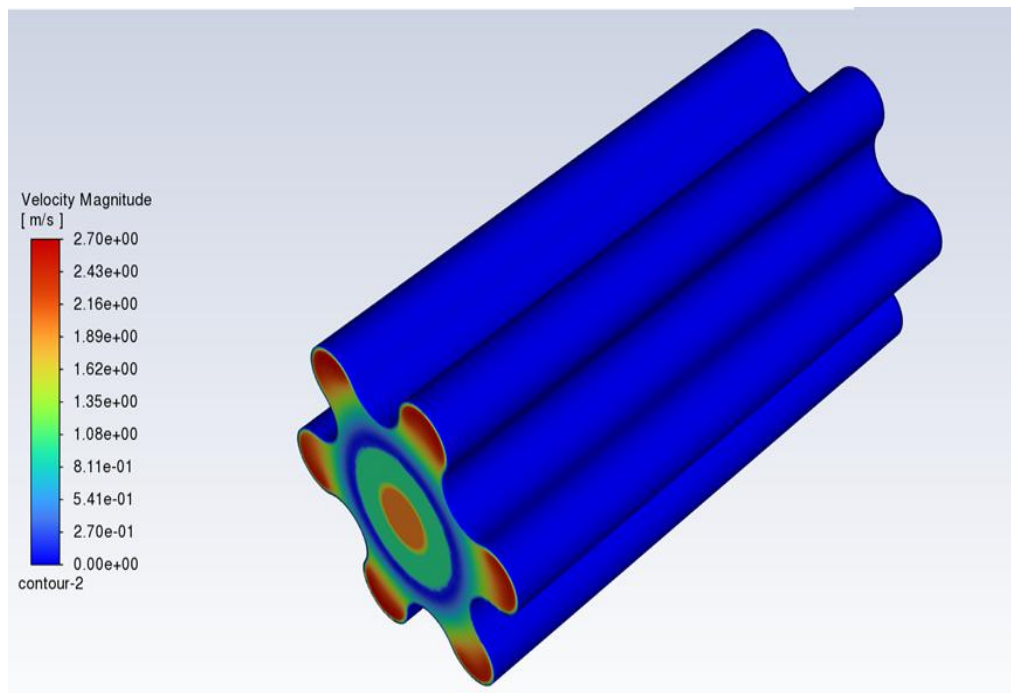


Fig.III.18. Combustion chamber velocity

The flow velocity is highest at the combustion chamber inlet, then it becomes distinctly monotonous and low over the chamber surface as can be seen in Figure III.18.

### III.5.2.3. Pressure

Figure III.19 clearly illustrates the pressure exerted on the surface of the new combustion chamber design. It is observed that this pressure is higher downstream than upstream of the flame. This difference can be explained by the proposed undulation, which deforms the flame and facilitates the release of the burnt combustion gases.

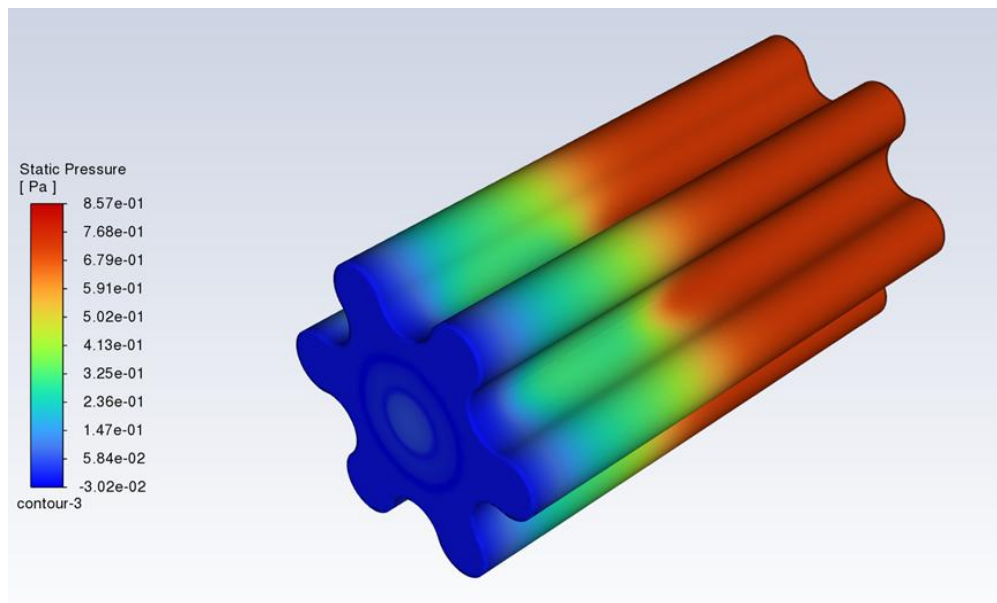


Fig.III.19.Combustion chamber pressure

### III.5.2.4. Rake temperature, rake pressure and rake velocity

In the combustion chamber of a boiler, the terms "rake pressure," "rake velocity," and "rake temperature" refer to measurements of pressure, velocity, and temperature made along the centerline of the combustion chamber. The "rake pressure" corresponds to the measurement of the pressure along this line, obtained using a series of virtual probes (rake) placed at different positions in the simulation. Similarly, rake velocity measures the speed of the fluid along the center line, and rake temperature captures temperature variations along the same line.

Figures III.20, III.21, and III.22 respectively depict the evolution of rake temperature, rake pressure, and rake velocity. They show that temperature and pressure decrease towards the center as one progresses towards the rear of the combustion chamber, while velocity increases

monotonically.

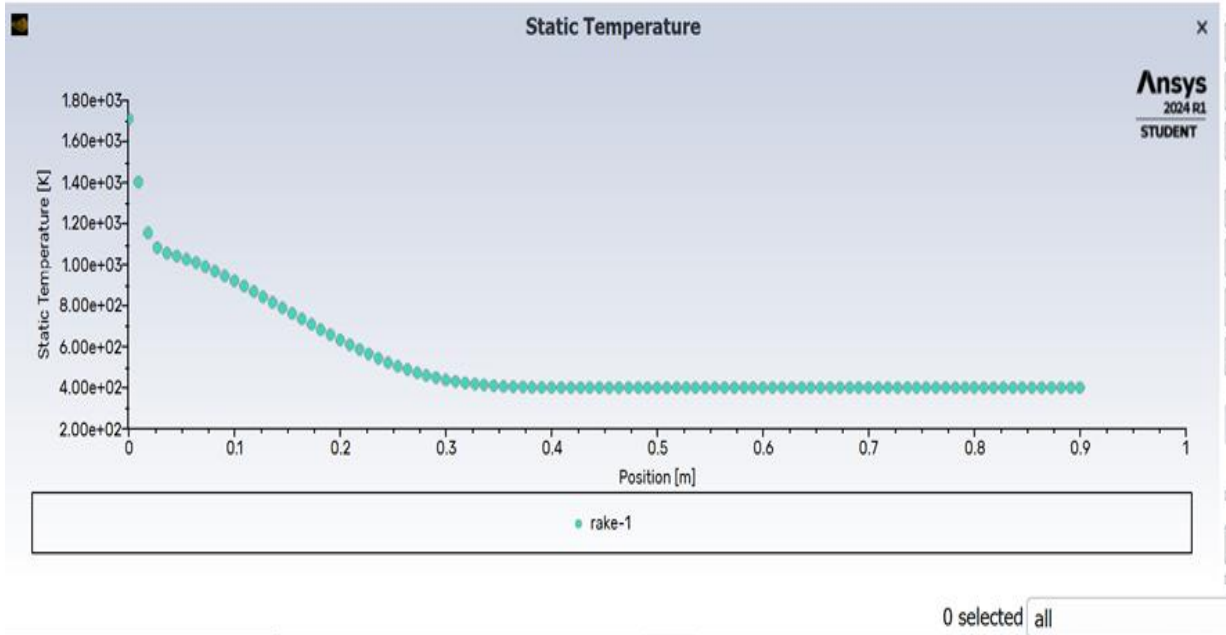


Fig.III.20.Rake Temperature

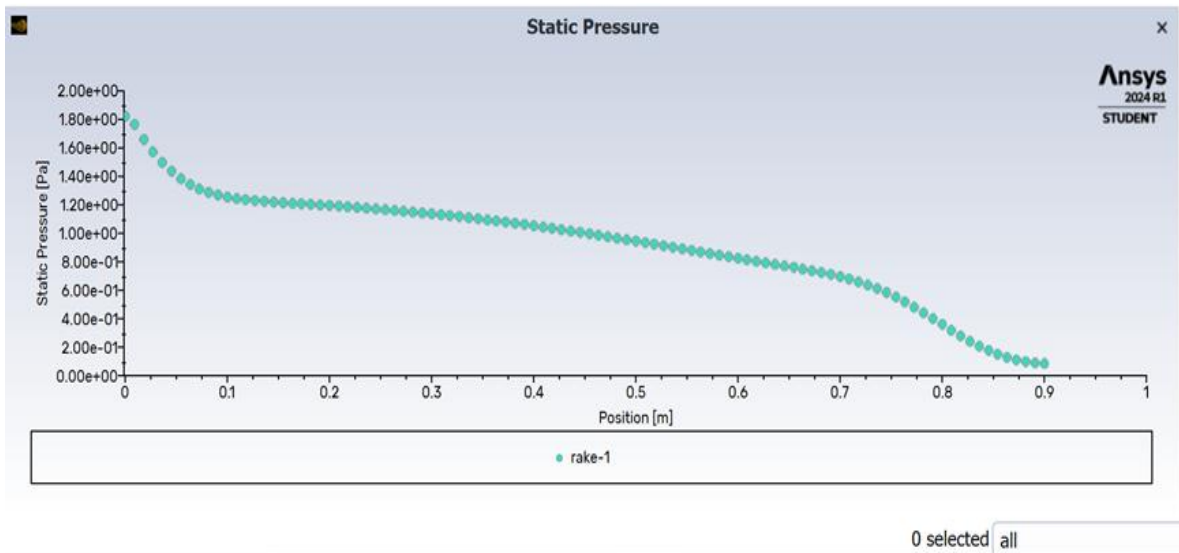


Fig.II.21. Rake Pressure

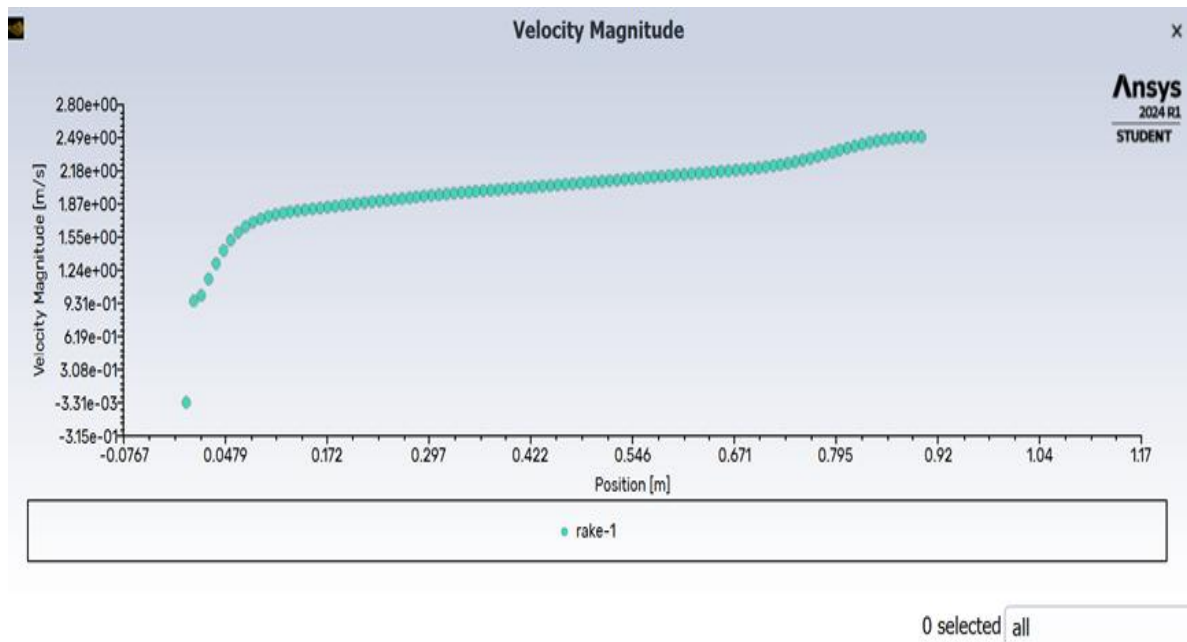


Fig. III.22. Rake Velocity Magnitude

# General conclusion

Thermal boilers are essential in many industrial and domestic sectors, serving to produce hot water or steam. In this graduation project, we explored various technical and conceptual aspects of thermal boilers, highlighting possible innovations and improvements to optimize their performance and energy efficiency, particularly through a new design of the combustion chamber.

Using Ansys software, we proposed a new design for the combustion chamber, characterized by a wavy cylindrical surface. This waviness is parallel to the combustion flame and perpendicular to the section of the combustion chamber.

The adoption of this new wavy surface in combustion chambers has demonstrated:

- Significant potential to increase heat exchange by increasing the contact surface between the heat transfer fluid and the combustion chamber.
- A reduction in flow disturbances, thus contributing to better overall performance of the thermal system.

In conclusion, the prospects for the evolution of thermal boilers are promising, with many opportunities for innovation and optimization. A holistic approach, integrating advanced design, numerical simulation, and rigorous environmental management, will be key to meeting future challenges and improving the sustainability and efficiency of thermal heating systems.

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