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Numerical Investigation of Heat transfer in a cylinder of Hydrogen Fuel during refueling

A Research

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من قبل

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إشراف

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ ۖ وَسَتُرَدُّونَ إِلَىٰ عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ﴾

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ABSTRACT

The key to the hydrogen economy is to store hydrogen efficiently, effectively, and safely. In terms of infrastructure needs, high pressure gaseous hydrogen storage is the simplest approach and has become the most popular and advanced technology.

In this study, the theoretical work was represented using the COMSOL multi physics software suit in 3-D to predict the temperature distribution in a hydrogen fuel cylinder. The cylinder consists of aluminum metal covered with carbon fibers, a volume (74 L) and a length of (90 cm), and it was filled with a hydrogen gas used as fuel. It was represented by a horizontal and vertical position and using different pressures and different amounts of hydrogen. Several tests were conducted on it to determine the effect of temperature generated from hydrogen. What is the effect of these variables on the refueling process, the filling process, was adopted to obtain a safe temperature of (85 ^{o}C) to avoid the risks of overheating the cylinder which leads to the explosion that occurs as a result of the high temperatures generated during filling the cylinder. The simulation parameters for the study in this study were pressure (33, 25,20MPa) several different blocks (1500, 1000,500g) and mass flow rate (5,3.33,1.6g/s) For different scenarios were modeled. Firstly the cylinder was in a horizontal position. The results showed that the cylinder temperature increased with the mass of (1500g) and decreased when the mass was shrunk to (1000g), and it can be concluded that the temperature of the cylinder decreases with decreasing the mass of the block. Secondly, the Previous conservation scenario was studied when the cylinder was in a perpendicular position with the same amount of hydrogen gas, It was found that the relative decrease in the temperature of the cylinder was in the vertical position than that in the horizontal position .Thirdly, reducing the pressure to the lower value at (1000, 500g) different blocks The temperature of the cylinder still had a high

temperature this was due to the high value of the flow rate. Finally, change the pressure to(20MPa) with the mass of the (500g) block in the horizontal and vertical position, and it was found that the cylinder temperature decreases in the vertical position compared to the horizontal position for the effect of mass flow rate. The comparison of the result showed good agreement between our results and those reported in previous studies give confidence as to the accuracy of the finite element model.

الخلاصة

مفتاح اقتصاد الهيدروجين هو تخزين الهيدروجين بكفاءة وفعالية وأمان. فيما يتعلق باحتياجات البنية التحتية ، يعد تخزين الهيدروجين الغازي عالي الضغط هو أبسط نهج وقد أصبح أكثر التقنيات شيوعًا وتطورًا.

في هذه الدراسة، تم تمثيل العمل النظري باستخدام برنامج COMSOL للفيزياء المتعددة ثلاثي الابعاد للتنبؤ بتوزيع درجة الحرارة في أسطوانة وقود الهيدروجين. تتكون الاسطوانة من معدن الألمنيوم المغطى بألياف الكربون، حجم (74 لتر) وطول (90 سم)، وكانت مملوءة بغاز الهيدروجين المستخدم كوقود. تم تمثيله في وضع أفقي ورأسي وباستخدام ضغوط مختلفة وكميات مختلفة من الهيدروجين. أجريت عليه عدة اختبارات لتحديد تأثير درجة الحرارة الناتجة عن الهيدروجين. ما هو تأثير هذه المتغيرات على عملية التزود بالوقود ، فقد تم اعتماد عملية التعبئة للحصول على درجة حرارة آمنة (85 درجة مئوية) لتجنب مخاطر ارتفاع درجة حرارة الأسطوانة مما يؤدي إلى الانفجار الذي يحدث نتيجة ارتفاع درجات الحرارة تتولد أثناء ملء الاسطوانة. كانت معلمات المحاكاة للدراسة في هذه الدراسة هي الضغط (20،25،33 ميجا باسكال) عدة كتل مختلفة (500،1000،1500 جم) ومعدل التدفق الكتلي (1.6،3.33،5 جم / ثانية) لسيناريوهات مختلفة تمت نموذجيتها. أولاً، كانت الأسطوانة في وضع أفقي. أظهرت النتائج أن درجة حرارة الاسطوانة تزداد مع كتلة (1500 جم) وتنخفض عند تقلص الكتلة إلى (1000 جم)، ويمكن الاستنتاج أن درجة حرارة الأسطوانة تتناقص مع انخفاض الكتلة. ثانيًا، تمت دراسة سيناريو الحفظ السابق عندما كانت الأسطوانة في وضع عمودي بنفس كمية غاز الهيدروجين، ووجد أن الانخفاض النسبي في درجة حرارة الأسطوانة كان في الوضع الرأسي عن الوضع الأفقي. ، تقليل الضغط إلى القيمة الأقل عند (1000، 500 جم) كتل مختلفة. درجة حرارة الأسطوانة لا تزال تحتوي على درجة حرارة عالية، ويرجع ذلك إلى القيمة العالية لمعدل التدفق. أخيرًا ، قم بتغيير الضغط إلى (20ميجا باسكال) مع الكتلة (500جم) في الوضع الأفقي والرأسي ، ووجد أن درجة حرارة الأسطوانة تنخفض في الوضع الرأسي مقارنة بالموضع الأفقي لتأثير معدل التدفق الكتلي. . أظهرت مقارنة النتيجة توافقًا جيدًا بين نتائجنا وتلك الواردة في الدراسات السابقة مما أعطى الثقة فيما يتعلق بدقة نموذج العناصر المحدودة.

CHAPTER ONE

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Introduction

1.1. General

Hydrogen is most likely one of the most significant energy carriers. With the increased use of hydrogen, the need for hydrogen storage will skyrocket. At the moment, the primary technologies for hydrogen storage are gaseous hydrogen, liquid hydrogen, metal hydride, and carbon nanotubes. Although each of these methods has appealing characteristics, high pressure hydrogen storage is the most common and developed storage option due to its technological simplicity and inexpensive cost. According to data, more than 80–90% of hydrogen stored at filling stations and in fuel cell cars is held in high-pressure containers as presented by **Liu et al. [1]**

1.2. Hydrogen production methods

Kalamaras & Efstathiou. [2] explained the several technologies for hydrogen production, the most important of which are:

1-Hydrogen from Renewable Sources

a-Electrolysis.

Water electrolysis may be a potential future method for hydrogen production. This technology now produces only about 4% of the hydrogen used in the world. Water electrolysis, or the separation of water into hydrogen and oxygen, is a well-known technique that was first used commercially in the 1890s. Electrolysis is a process in which a direct current is sent through two electrodes in an aqueous solution that causes chemical bonds in a water molecule to decompose into hydrogen and oxygen.

b-Biomass Gasification.

Biomass is expected to be the potential renewable organic alternative to petroleum in the near future. Animal waste, municipal solid waste, crop residue, short-cycle woody crops, agricultural residues, sawdust, aquatic plants, short-cycle grass species (such as grass switch), paper waste, corn, and so on are all sources of biomass .

c-Pyrolysis and Copyrolysis

Another currently promising method of hydrogen production is pyrolysis or copyrolysis Raw organic material is heated and gasified at a pressure of [40-43] MPa in the tempreture range of 500–900 ^{o}C. The process (0.5–0.1) takes place in the absence of oxygen and air,

d-Photoelectrolysis

Photoelectrolysis is one of the sustainable approaches to producing hydrogen at a promising efficiency and price, but it is still in the experimental stage. It is currently the most cost-effective and efficient technology for producing hydrogen from renewable resources.

e-Thermochemical Water Splitting

Thermochemical cycles have been in place since the 1970s and 1980s, when they were asked to contribute to the search for new sources of alternative fuel generation during the petroleum crisis. Heat alone is used in thermochemical water splitting, also known as pyrolysis, to break down water into hydrogen and oxygen.

2-Hydrogen from Fossil Fuels

a-Steam Reforming

Steam reforming is now one of the most common and least expensive methods of hydrogen production. Its competitive advantage stems from its excellent operational efficiency, low operational expenses and productivity. Natural gas, lighter hydrocarbons, methanol and other oxygenated hydrocarbons are the most commonly used raw materials.

b-Partial Oxidation

Hydrocarbon Partial Oxidation (POX) and Catalytic Partial Oxidation (CPOX) have been proposed as methods for hydrogen production for vehicle fuel cells and for other commercial purposes. The gasified feedstock can be methane or biogas, but it is often the heavy oil fractions (such as food residue or heating oil) that are difficult to handle and use. POX is a non-catalytic process in which raw materials are converted to a gas in the presence of oxygen and possibly steam (ATR) at temperatures from 1300 to 1500°C and pressures from 3 to 8 MPa.

1.3. Properties of Hydrogen fuel

Hydrogen is the fuel of the future, an energy carrier capable of transforming our fossil fuel economy into a hydrogen economy. It is a zero-emissions transportation fuel when combusted with oxygen, it does not produce virtually any greenhouse gas emissions when used in internal combustion engines or fuel cells. Water vapor is the only significant emission. Hydrogen should be a technically feasible, economically viable alternative fuel that quickly converts into another energy form, safe to use, and potentially environmentally friendly. It is the most common element on earth as illustrated by **Ghergheleş & Ghergheleş.[3]**

1.4. Applications of hydrogen fuel

Momirlan & Veziroglu.[4] Showed that hydrogen is a colorless, odorless gas that makes up 75% of the mass of the universe. Only in combination with other elements such as oxygen, carbon and nitrogen can hydrogen be found on earth. Hydrogen must be separated from other elements before it can be used. Today, hydrogen is largely used in the production of ammonia, petroleum refining, and the manufacture of methanol. It is also used in NASA's space program as fuel for space shuttles and as fuel cells that provide astronauts with heat, electricity, and drinking water. Fuel cells are devices that convert hydrogen directly into electricity. Hydrogen can be used to fuel cars and planes of the future, as well as to power our homes and businesses.

1.5. Hydrogen storage and its work

Hydrogen is rapidly being recognized as a promising source of energy storage for reuse on or off the grid. Wind and wave energy are used to generate clean electricity.

Electrolysis can be utilized to create hydrogen in power projects of water-diverting it into its basic elements .The elements are hydrogen and oxygen. Hydrogen may be stored in a variety of ways, including:

1- Cryogenic has the highest gravimetric energy density.

2 -High-pressure cylinders; pressures as high as 690 bar are possible.

3- Metal hydride absorbs hydrogen, resulting in an extremely low pH. Pressure and incredibly safe mechanism, however it is hefty and cumbersome more costly than cylinders.

4- Chemical transporters, such as anhydrous ammonia, provide an option. providing comparable gravimetric and volumetric energy ethanol and methanol densities as presented by **Momirlan & Veziroglu.[4]**

1.6. Objective of the present study

1- Estimate the average temperature of hydrogen gas inside a compressed gas cylinder during filling process.

2- Determining the effect of initial filling rate and pressure on the temperature field.

3- Determining the relationship between temperature rise and the amount of gas during filling. In order using COMSOL program to predict the gas temperature distribution inside the cylinder

1.7. Outline of thesis

Chapter one: Introduces a general introduction about hydrogen include production ,application and storage method also the aim of the study

Chapter two: Deals with previous related literature, which presents the contributions and work of the experimental and theoretical investigation in a cylinder filled with a hydrogen fuel

Chapter three: Display theoretical study and explains the mathematical model to analyses the temperature distribution inside the hydrogen of cylinder

Chapter four: Presents Results and discussion of theoretical work at different positions ,mass flow rates and pressures.

Chapter five: Collects the conclusions arrived at the end and the recommendations for future studies

Literature review

2.1. Introduction

Through the rapid filling process of hydrogen thermal stress is produced due to the increase in the pressure and temperature of hydrogen cylinder .Thus it is needful to control and portend the temperature change in the cylinder of hydrogen.

Several theoretical and experimental investigations have been carried out regarding the heat of compression in cylinder filled with fuel of hydrogen.

2.2. Previous research of the theoretical side

Dicken and Merida. [5] presented numerically a CFD model for filling a compressed gas cylinder with hydrogen based on the local observation of the gas temperature. The model of this study was two-dimensional and axial symmetric, and it solved the governing equations for unstable and compressible turbulent flow. The model includes real-world gas effects, convective heat transfer from gas to cylinder walls, and conduction from cylinder walls to the surrounding environment. The results revealed a large geographical fluctuation in the temperature of the gas inside the cylinder during filling. The modeling results also helped the determination of the appropriate positioning of the onboard gas temperature sensor because the local data was better representation the average mass temperature.

Immel & Mack-Gardner. [6] studied numerically one-dimensional heat conduction in the radial direction to represent heat transfer through the cylinder wall. An intense 3D computational transient fluid dynamics (CFD) simulation gave the heat transfer coefficient from the stored gas to the inner cylinder wall. All solids layers have been resolved in this CFD simulation. In addition to the gas volume using a real gas model to assess the validity of the simulation results, a tank fitted with thermocouples inside bothof the gas and cylinder walls that were constructed and tested under a variety of operational conditions. The test series consisted of refueling and defueling at hydrogen gas flow rates from 0.5 to 30 g/sec and ambient temperatures from -40 to +40°C.

Liu et al.[7] provided numerically a two-dimensional computational fluid dynamics (CFD) model for the rapid filling of a 70 MPa hydrogen composite cylinder is provided in this study. The numerical simulations were based on a modified version of the traditional perturbative k model.. The thermodynamic equation simulated results in rapid filling reactions at different patterns of pressure rise and filling times.

Heitsch et al. [8] designed numerically simulations to describe the rapid filling process of hydrogen tanks. The main result of the simulation was the local temperature distribution in the tank as a function of the lining and external thermal insulation materials. Various combinations of materials (Types III and IV) were investigated. Some measurements were available from the literature and are used to validate the method that are used in CFX to mimic rapid tank filling. To increase the predictability of calculations for random geometries and groups of materials, validation must be continued in the future.

Li et al. [9] investigated numerical method for controlling the most effective techniques for controlling temperature rise using simulations based on Computational Fluid Dynamics (CFD). Cylinders with varying length-to-diameter ratios and intake sizes were modelled. They discovered that control of temperature distribution is improved by reducing length to diameter stakes. They also found that the temperature increase can be reduced by inducing cloud diameter. The simulation results were compared with increasing, decreasing and stabilizing the mass flow rate, where the refueling reached the lowest value while increasing the mass flow rate to the highest value.

Zheng et al. [10] discussed theoretically high pressure gaseous hydrogen storage vessels into three types: fixed, compound and bulk transport. First, recent developments in low-cost, large-capacity, lightweight, high-pressure gaseous hydrogen storage tanks .Three important safety features of high-pressure gaseous hydrogen were discussed, namely, hydrogen bombardment of metals at room temperature, rapid filling of high-temperature hydrogen after hydrogen leakage, and potential risks such as diffusion, combustion and explosion appeared. They observed were a brief description of the code and standard development for high-pressure hydrogen storage

Deymi-Dashtebayaz et al. [11] investigated numerically the full modeling of the filling process in a hydrogen fuel vehicle storage cylinder. Rapid filling caused an unexpected rise in temperature and a violation of safety regulations. Initially, a correlation based on numerical simulation was established to estimate the rate of heat transfer between the flow within the cylinder and the inner wall of the cylinder. During the filling process, a thermodynamic model was built to predict transient fluctuations in temperature and pressure within the cylinder, as well as wall temperature during the filling process. The form was used to fill a Type III storage cylinder on board the ship. The numerical results were compared with previously measured values and revealed a high level of agreement. The results also showed that the cylinder wall stored a significant amount of heat dissipation from the cylinder flow. It has been discovered that the ambient temperature during the refueling process has a significant effect on the overall filling behavior, especially on the final cylinder temperature and the filled block.

Brachmann et al. [12] studied numerically various types of new models have been created to predict the temperatures of gas and materials inside the vessel during filling and removal of the fuel. To validate these models, a pilot program involved 82 filling and unloading tests of type 4 and type 3 vessels. New methods have been developed and used to obtain the value of the gas-to-wall heat transfer coefficient from temperature readings. In a Type 4 vessel, the heat transferred from the gas to the liner and the heads was balanced. CFD models were implemented to examine temperature differences and existing thermal stratification was repeated for specific packing states. Standards for gas injection conditions were adopted in order to ensure gas temperature uniformity. A critical assumption was applied the refueling procedures. Temperature changes in the wall material were investigated in order to showed the less conservative definitions of the maximum permissible temperature in future hot-state conditions. The effect of changing the conduction temperature profiles without changing the average conduction temperature was also studied**.**

Sadi & Deymi-Dashtebayaz [13] studied numerically the refueling process of the buffer and the cascade storage bank. A thermodynamic analysis was implenented to explore the filling process of transferring fuel from the storage bank to the hydrogen cylinder. They were focused on the process of refueling from buffer and cascade storage banks. The volume and pressure of the storage bank affected temperature as an important property that influences the starting condition, final condition, and refueling process of both buffer and cascade storage banks. It was found that the comparison of buffer and successive storage banks revealed that the refueling time with the buffer was storage bank needed 200 seconds less time than the cascade storage bank. However, the required the lower of value of energy to store gas in a buffer storage system is greater. They observed that lower the final temperature of the filling process dependented on the ambient temperature, the starting pressure, and the fuel charge rate**.**

Li et al. [14] presented numerically an innovative technique to slow the heat transfer from gas to wall by a porous filler in gas tanks. They were used a pooled parameter model to simulate the filling process and to generate several time-independent temperature evolutions, using a 2D and 3D finite volume model, they assessed the geographical distribution of the temperature rise. For examples, each with a distinct filling characteristic, were simulated and compared. Filling caused a reduction in the tank wall temperature at the expense of higher gas temperature at the end of the rapid filling. The final distribution of temperature was mostly determined by the combined effect of the internal gas temperature and the effective thermal conductivity of the gas phase. Significant reduction of the convective heat transfer was predicted due to the presence of a filler, but a highly resistant porous filler.

Liu et al.[15] Studied numerically the correlation between the high-temperature hydrogen gas and solids in OBGHSC and the engineering standards for encapsulation and lining materials in OBGHSC, as well as generating several high-temperature correlations. A two-dimensional (2D) computational fluid dynamics model was used to simulate the rapid filling and retention processes of 70 MPa OBGHSC. The simulation results showed that the temperature distribution during filling differed for the type III storage cylinders, but the highest temperature was always in the intersection of the vertical dome of the type IV storage cylinders. The trends of temperature disribution for carbon fiber epoxy composite sheets (CFEC) were not the same for different type III storage cylinders, but the temperature in type IV storage cylinder decreases with increasing thickness of CFEC. Finally, the correlations of the maximum value of the average mass temperature rise for hydrogen gas and the correlations for the maximum CFEC temperature rise representing the effects of non-dimensional parameters were increased based on the obtained numerical data. Correlations illustrate the association between temperature rise and hydrogen storage cylinder construction were used to drive the OPHSS rapid filling procedure .

Sapre et al. [16] studied numerically the effect of hydrogen supply temperature and filling rate, as well as vehicle tank parameters such as filling time, on the tank's storage capacity.

To examine the effect of station settings on tank storage density, a refueling simulation was performed using Computational Dynamics Fluid Technology. Furthermore, a root cause analysis was performed to evaluate the role of station and vehicle tank specifications in increasing tank storage density. Finally, a regression model was generated based on the refueling characteristics to estimate the density reached under different fills. The results showed that the pressure, the filling time and ,the supply temperature had a significant effect on tank density, while temperature and rates had little effect. The results may be provide new interested data on the tank refilling behavior of Type IV fuel cell vehicles**.**

Wu et al. [17] Proposed computational fluid dynamics (CFD) simulation model ,to replicate the rapid filling process under different starting conditions. Several simulation calculations were performed. The effect of different mass flow rates was studied in order to manage the temperature increase during the rapid filling process. Different time delay filling solutions were implemented for different situations based on mass flow rate management to satisfy the requirements to reducing filling time as much as possible without exceeding the maximum temperature. They were discovered that after determining the duration of the delay, the assignment of the filling time did not affect the final rise in temperature. In a typical setup, the proposed technology may complete filling in 155 seconds, saving 62 percent of the time compared to filling at a constant mass flow rate. The results provided the theoretical basis and technology support for rapid filling mass flow management techniques at hydrogen filling stations, as well as guidance for the filling process ,of actual large capacity hydrogen tanks

2.3. Previous research of the experimental side

Dicken and Mérida. [18] showed experimentally the effects of starting mass and total fill time on temperature increase and temperature distribution within a compressed hydrogen cylinder during refueling. Internally, a type 3, 74 L hydrogen cylinder was outfitted with 63 thermocouples arranged throughout the mid vertical plane. The experimental fills were carried out at gas supply rates corresponding to notional fill durations of 1, 3, and 6 minutes from starting pressures of 50, 75, 100, 150, and 200 bar. The authors concluded that the temperature variations were greater in the experimental circumstances with higher final-to-initial mass ratios. The lowest ratios, on the other hand, resulted in the fastest rates of temperature rise. They also found that the Longer fill durations resulted in lower final average gas temperatures (as compared to shorter fill times) as well as a temperature field with considerable vertical stratification owing to buoyancy effects at lower gas inlet velocities.

Hirotani et al. [19] described experimentally the thermal behavior of a hydrogen storage tank during rapid filling a gas is pushed into the tank, they found that temperature of the hydrogen gas was increase, In the Type 3 and Type 4 tanks. Changing the frequency and pattern of filling and measuring the gas temperature in different areas was carried out.

Liu et al. [1] carried out an experimental study to evaluate the thermal behaviors such as the increase and distributions of the temperature at 35 MPa, 150 L hydrogen storage cylinders during refueling. The major parameters that effected temperature rise during the rapid fill process, such as mass filling rate and starting pressure in the cylinder were investigated. The experimental results show that the mass filling rate is constant when the pressure ratio in the tank to the cylinder was greater than 1.7, and it decreased when the ratio is less than 1.7; the temperature inside the cylinder increases nonlinearly during the filling process, with the maximum value of temperature occurred at the end of the process. The caudal area of the cylinder interface has a higher temperature with a lower starting pressure in the cylinder or a faster mass filling rate. the limit of mass filling rate was determined for various ambient temperatures.

Beden et al. [20] studied experimentally a lightweight of type 4 cylinder with a polyethylene terephthalate (PET) liner for use in UAVs., a parametric analysis of the internal phenomena of the cylinder were perform during the filling process. They selected a cylinder of type 4 with a capacity of 6.8 liters. During the filling test, fluctuations in pressure and temperature were observed inside the cylinder. The internal pressure and temperature reached 450 bar and58 ^{o}C at the end of the filling test,. The cylinder expanded closer to the middle of the cylinder body than the dome of the joint. The effect of the inlet gas temperature on the internal phenomena of the produced cylinder was studied. As the temperature of the incoming gas decreases, the temperature of the stored gas and the rate of expansion decrease. Finally, the suggested cylinder stocking density was compared with the density of different container types. The stocking density of the suggested cylinder was 4.8 percent, which was higher value than that of the previous types of cylinders.

De Miguel et al.[21] studied experimentally the thermal behavior of three commercial hydrogen tanks (type III and IV) (filled from 2 H 3 MPa to 78 H 84 MPa, kept under pressure and degassed again to 2 H 3 MPa). During several hydrogen cycles, the temperature of the gas was monitored at various locations within the tank, as well as the temperature at the heads and the outer surface of the tank. The evolution of gas temperatures during the entire cycle process was studied using experimental data. They found that the effect of filling rate on gas temperature during filling is increased. They also studied the thermal interaction between metallic lead and the outer surface of tanks. The influence of tank construction materials on its thermal behavior, the suitability of the initial thermal state of the tank in the refueling process, and the difficulties of filling a type IV tank without pre-cooling in an acceptable period of time were emphasized. The idea of monitoring the external temperatures of the tank to track the evolution of the internal gas temperature during the filling and emptying phases was also examined.

Ortiz Cebolla et al. [22] used experimentally two distinct types of tanks on board filling tests were performed with varying gas temperatures and mass flow rates (Type 3 and 4). The temperature of the inlet gas has a significant influence on the state of charge. This dependence was especially evident in Type 4 tanks. Since the lowest pre-cooling temperature (-40 ° C) is not always necessary for user needs, energy savings can be achieved if the starting conditions of the tank are accurately determined. The results of their studies were compared with the SAE J2601 search tables for non-contact fillings. In these tables, a large margin of safety is observed. If starting conditions and hydrogen storage system design are well established, refueling can be faster with less demanding pre-requisites.

De Miguel et al. [23] studied experimentally the effect of the starting tank temperature on the evolution of internal gas temperature during refueling in onboard hydrogen tanks. Two different types of tanks were evaluated, as well as four different fuel supply temperatures (ranging from ambient refueling temperature to pre-cooled hydrogen at 40°C), various fill speeds, and starting pressure. The final gas temperature was linearly increased as the starting tank temperature increased, while the temperature (DT) and final state of charge (SOC) was decreased linearly as the initial temperature increased. They were observed that this dependence was greater on the tanks of the third type than of the fourth, and it increased as the starting pressure increased. CFD simulations were also implemented gain to better understaning the influence of key phenomena on gas temperature records, such as gas pressure, gas mixing and heat transfer. The effect of initial gas temperature on the process was separated from the effect of the initial wall temperature by comparing the results of the simulations between the thermal gas and thermal tank walls.

2.4. Previous research of the theoretical and experimental side

Kim et al. [24] presented numerical and experimental study quantify the temperature change of the cylinder during hydrogen filling to 35 MPa. The CFD analysis predicts reasonable agreement with the experiments, and the difference between the CFD results and the experimental data was decreased with larger starting values. In the vertical direction, there was a temperature difference between the upper and bottom sections of the vessel. Because of the buoyancy effect in the vessel, the gas temperature in the upper section was greater than that in the lower. For the scenario when the vessel was pressured from 0 MPa to 35 MPa, the maximum gas temperature was greater than the maximum gas temperature was permitted by the ISO safety code (85 ^{o}C).

Xiao et al. [25] investigated the analytical and experimental study of the temperature of hydrogen during the rapid filling process.

The final hydrogen temperature can be calculated from the analysis such as the weighted average of the starting temperature, flow temperature, and ambient temperature using the rule of mixtures. Other refueling characteristics, such as starting mass, initial pressure, refueling duration, refueling mass rate, average pressure ramp rate (APRR), final mass, final pressure, etc., are related to the weighted factors. The functional formula was derived from the analytical solution of the thermodynamic model that was more physically convenient and mathematically efficient in fitting the observed temperatures.They found that estimating the final hydrogen temperature from refueling data using the law of mixtures was a simple and effective way to manage the maximum temperature and ensure the safety of hydrogen during the rapid filling process.

Li et al. [26] investigated experimentally and numerically the hydrogen charging process in a hydrogen charging station storage tank. A computational fluid dynamics (CFD) model for the actual non-stationary filling of a 50 MPa hydrogen cylinder was presented. A shear stress transfer model (k-!) and a real gas model were used to calculate the thermodynamics during filling of a hydrogen storage tank (50 MPa, 343 L).the authors concluded that when compared with the simulation results using matched experimental data, the temperatures calculated from the non-adiabatic state results were lower (by 5.3 percent) than those derived from the theoretical adiabatic state calculation. The theoretical calculation was based on the experimentally obtained pressure value. They also found that the calculated simulation mass was 8.23% more than that of theoretical value

2.5. Summary

Many researchers were investigated theoretically and experimentally the heat of compression in cylinder filled with a hydrogen fuel .Therefore, according to the above review pf previous studied , the heat of compression in cylinder filled with a hydrogen fuel has not yet been studied at least in Iraqi universities or in the literature. The present analysis will cover the numerically the heat of compression in cylinder filled with a hydrogen fuel.at different fuel flow rate and pressure of hydrogen . two cases which use vertical and horizontal erientation for the cylinder are considered by the three-dimensional finite element model approach of the COMCOL multi physics solver

Table (2-1) Summery for the previous studies

Authors	Studying	The aim
Dicken, C. J. B., & Merida, W. (2007)	theoretical work Keywords: Hydrogen refueling, compressed	presents a CFD model of the filling of a hydrogen compressed gas cylinder. The model developed in this study is 2D and

	gas cylinder, temperature distribution, compressible viscous flow	axi-symmetric, and solves the governing equations for compressible, unsteady, viscous turbulent flow. The model incorporates real gas effects, convective heat transfer from the gas to the cylinder walls and conduction through the cylinder walls to ambient.
Hirotani, R., Terada, T., Tamura, Y., Mitsuishi, H., & Watanabe, S. (2007).	theoretical work KEYWORDS : Alternative Fuel, Hydrogen, Storage Tank, Filling, Fuel Cell Vehicle	they changed the filling speed and pattern and measured the gas Temperature of different parts in type 3 and type 4 tanks.
Dicken, C. J. B., & Mérida, W. (2007).	Experimental work Keywords: Compressed gas cylinder; Hydrogen refuelling; Temperature distribution	in order to assess the effect of the initial mass of gas on the temperature rise during filling. The greatest rate of temperature increase occurred at the onset of filling where the ratio of the current mass of gas to the initial mass of gas was the lowest
Yan-Lei Liu, Yong-Zhi Zhao, Lei Zhao, Xiang Lia, Hong-gang Chena, Li-Fang Zhang, Hui Zhao, Run-Hua Sheng, Tian	Experimental work Keywords: Hydrogen Fast filling Experiment Hydrogen storage cylinder Temperature rise	The mass filling rate is constant when the ratio The pressure in the tank on the cylinder is higher than 1.7 The mass filling rate decreases when the ratio is less than 1.7. Also, it reaches a larger value with a lower initial pressure in cylinder and shorter filling time.

Xie, Dong-Hao Hub, Jin-Yang Zheng (2010).		
Sung Chan Kim, Seung Hoon Lee, Kee Bong Yoon . (2010). ,	Experimental work Keywords: Hydrogen Type IV CFD Fueling High pressure	The upper and lower parts of the bowl showed a temperature difference in the vertical direction. The upper gas temperature was higher than the lower gas temperature Part due to the buoyancy effect of the ship..
Rainer Immel and André Mack-Gardner (2011)	theoretical work Hydrogen defueling operation a compressed gas storage	The CFD simulations managed to predict the average gas temperature of the fluid to an accuracy of 2°C when averaged over the refueling period. A reduced transient simulation model was developed to simulate the thermal response of a compressed gas storage cylinder under refueling and defueling operation.
Liu, G., Zhao, Y., Liu, Y., Zheng, J., & He, Y. (2011)	theoretical work hydrogen cylinder fast filling	For the linear pressure-rise pattern, the mass flow rate rises rapidly to a certain upper limit in the first seconds. Then the rate is falling down with nonlinearity during the residual time. And the gradient of the falling rate increases with the decreasing of the filling time
M. Heitsch,D. Baraldi, P.	theoretical work Keywords:	The high final fill pressure requires the application of a real gas description rather

Moretto. (2011)	Hydrogen safety Tank Fast filling High pressure Temperature distribution	than the ideal gas law. A 3D geometrical model as opposed to a 2D approach was used in the calculations in order to properly simulate buoyancy effects when longer fill times are of interest.
Qianfeng Li , Jianqiu Zhou, Qing Chang , Wei Xing (2012)	theoretical work Keywords: Hydrogen Numerical simulation Temperature rise Fast filling Pressurized gas cylinder	From simulation result, temperature rise within the cylinder with larger ratio of length to diameter is higher than the smaller one. The maximum temperature appears during the refueling process with larger length to diameter rate while with smaller one appears at the end of the refueling. The temperature rise within the larger inlet diameter cylinder is lower than within the smaller one.
Beden, M., Abdullah, S., & Arif, K. (2012).	Experimental work Keywords: Hydrogen cylinder Temperature rise	examined the effect of the inlet gas temperature on the internal phenomena of the cylinder. As the inlet gas temperature decreased, the maximum gas temperature inside the cylinder decreased. For a 15 °C decrease in the inlet gas temperature, the temperature of the cylinder wall decreased by 5 °C.
Jinyang Zheng , Xianxin Liu, Ping Xu,Pengfei Liu, Yongzhi Zhao	theoretical work Keywords High pressure hydrogen storage	Durability of components in contact with high pressure hydrogen It is necessary to establish a property database for fatigue and hydrogen embrittlement of materials

,Jian Yang . (2012)	Hydrogen storage vessels Hydrogen safety	used in high pressure hydrogen service and to develop related evaluation method for components in contact with high pressure hydrogen.
N. de Miguel, R. Ortiz Cebolla, B. Acosta, P. Moretto, F. Harskamp, C. Bonato (2015).	Experimental work Keywords: Compressed hydrogen storage High pressure Refuelling Hydrogen cycling Thermal behaviour Manufacturing materials	the temperature distribution of the gas inside the tank was almost uniform in all tanks investigated. The temperature increase in Type IV tanks was higher than in Type III and this difference grew with the mass flow rate used for the filling. In the Type III tank, more than twice faster fillings have been possible without reaching the allowable maximum temperature limit of 85 C.
R. Ortiz Cebolla, B. Acosta,N. de Miguel, P. Moretto . (2015).	Experimental work Keywords: On-board compressed hydrogen storage Fast filling Refueling protocols Hydrogen precooling State of charge	Precooling was needed, for safety reasons (not to surpass 85 C to reach an acceptable SoC (>90%). In the case of type 3 tanks, this cooling demand was lower than the one for type 4 tanks. Decreasing the inlet gas temperature, the increase of tank energy content was higher than the energy spent in the additional precooling of the gas
Deymi-Dashtebayaz, M., Farzaneh-Gord, M., Nooralipoor, N., & Niazmand,	theoretical work Keywords: Hydrogen fuelling station; Fast-filling process; Heat transfer rate;	numerical simulation for predicting the heat transfer rate between in-cylinder flow and the cylinder inside wall. Then, a thermodynamic model was developed for predicting transient variations of

H. (2016).(	Complete thermodynamic modelling.	temperature and pressure inside the cylinder and wall temperature during the filling.
-De Miguel, N., Acosta, B., Baraldi, D., Melideo, R., Ortiz Cebolla, R., & Moretto, P. (2016)	Experimental work Keywords: Compressed hydrogen storage Hydrogen refuelling Initial tank temperature Hydrogen safety Computational fluid dynamics	With experimental data it was showed that the maximum gas temperature reached at the end of the filling increases linearly with the increase of the initial temperature while the temperature increase and the state of charge decreases linearly with increasing initial temperature.
-Brachmann, T., Barth, F., Bourgeois, T., Ammouri, F., Acosta-Iborra, B., Ravinel, B., Londer, H., Herr, M., Wurster, R., Dey, R., & Saury, D. (2016.(	theoretical work Keywords: Hydrogen vehicle refuelling Fuelling protocol Fast filling Heat transfer coefficient	Application of the temperature limits to the tank material rather than to the gas inside the tank, Specification of the average delivery temperature rather than of the delivery temperature profile.
Jinsheng Xiao , Pierre Benard Richard Chahine . (2017)	theoretical work Keywords: Hydrogen storage Refueling	The simple uniform formula, inspired by the concept of the rule of mixtures with its weighted factors obtained from the analytical solution of thermodynamic

	Fast filling Thermodynamics Temperature Rule of mixtures	model, is applied to fit experimental or simulated results. These results show the effect of initial and final mass, effect of inlet and initial temperatures, effect of initial pressure and average pressure ramp rate (APRR), effect of initial pressure, ambient temperature and mass flow rat
Meisam Sadi ,Mahdi Deymi-Dashtebayaz (2019) .	theoretical work Keywords: Hydrogen station HV cylinder Buffer storage bank Cascade storage bank Refueling process	Filling the hydrogen cylinder to the required final condition is influenced by the volume and pressure of storage bank. For both buffer and cascade storage banks, ambient temperature is also an important parameter that affects the initial condition, the final condition and the refueling process.
Ji-Qiang Li, No-Seuk Myoung, Jeong-Tae Kwon, Seon-Jun Jang and Taeckhong Lee (2020).	Experimental work Keywords: compressed hydrogen storage; fast filling; thermal theory; simulation validation; hydrogen safety	Compared to the simulation results with the experimental data carried out under the same conditions, the temperatures calculated from the simulated non-adiabatic condition results were lower by (5.3%) than those from the theoretical adiabatic condition calculation. The theoretical calculation was based on the experimentally measured pressure value. The calculated simulation mass was 8.23% higher than the theoretical result.

Hangyue Li, Zewei Lyu, Yaodong Liu, Minfang Han, He Li . (2021).	theoretical work Keywords: Hydrogen storage safety Fast fill Infill Thermal simulation Numerical	introducing porous infill in gas tanks to slow down gas-to-wall heat transfer. The porosity of the infill is no less than 97% to maintain the volume capacity of gas tanks and modelled the filling process with a lumped-parameter model and obtained various time-independent temperature evolution curves.
Jun Liu, Huaqing Ma, Shuiying Zheng, Zhixin Zhang, Jinyang Zheng, Yongzhi Zhao . (2021).	theoretical work Temperature-rise Fast filling Holding Hydrogen storage cylinder Solid material	The maximum temperature-rise occurs in different region for the type III storage cylinder with different TL and TC due to the difference on the heat transfer between the jet flow of hydrogen gas and the inner wall of OBGHSC and the difference on the heat stored in aluminum liner. For the type IV storage cylinder, the maximum temperature-rise occurs in the region of head dome junction of cylinder, which is attributed to low thermal conductivity of HDPE
Shitanshu Sapre, Mayank Vyas, Kapil Pareek . (2021).	theoretical work Keywords: Hydrogen storage Type IV tank Refueling parameters Root cause analysis	The prediction analysis confirms that the storage density obtained by considering the refueling parameters has more than the density obtained in refueling simulation at all filling conditions. The results provide better understanding of potential role of station and vehicle tank refueling parameters to optimize the

		refueling process for higher storage density.
Xian Wu, Jitian Liu, Jianwang Shao, Guoming Deng . (2021)	theoretical work Keywords: Hydrogen fast filling Filling strategy Time-delayed High pressure	the two-stage time-delayed filling strategy is studied. By setting different delay points, the whole filling process is divided into three sections, and different delay durations are set between each filling section. By comparing the temperature rise of different cases, it is found that the delay duration has a great influence on the temperature rise,

Numerical study

3.1. Introduction

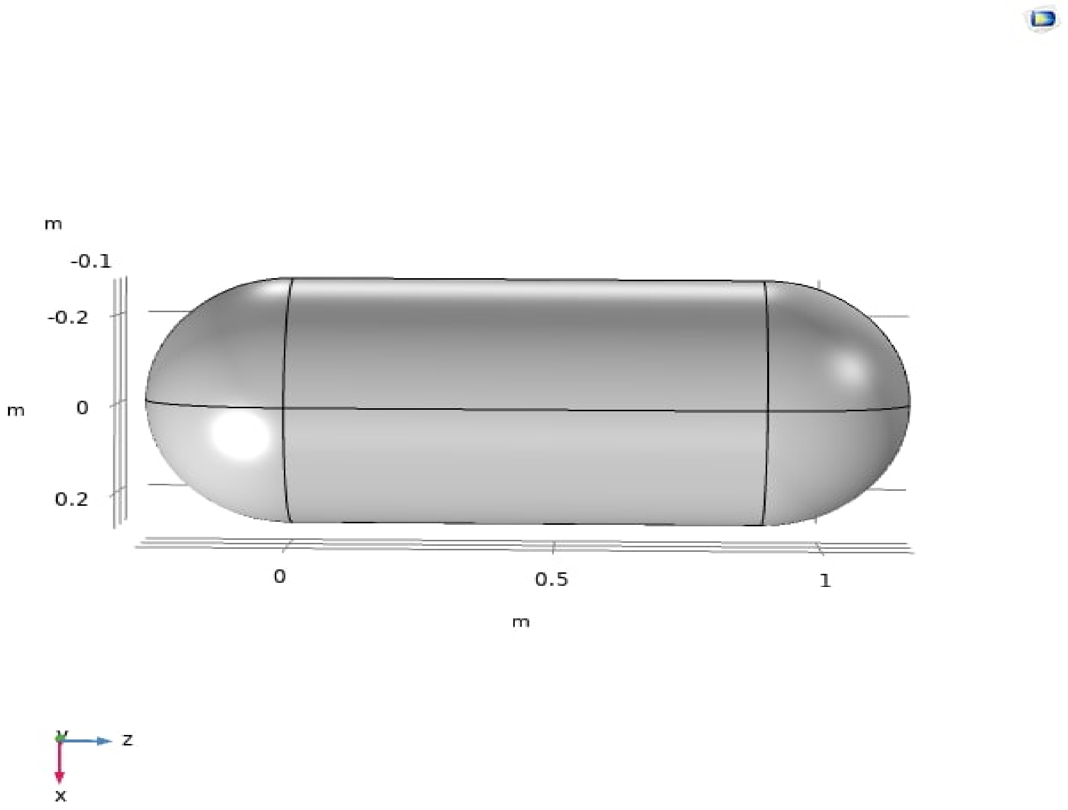
Inherent to the fill process is a significant increase in gas temperature. The temperature rise during filling is the result of the combination of two phenomena. Hydrogen has a negative Joule-Thomson coefficient at the temperatures and pressures of filling. Hence, an isenthalpic expansion of the gas from the high-pressure tank through the dispenser throttling device into the low-pressure cylinder results in an increase in hydrogen temperature. It is important to emphasize that the isenthalpic expansion occurs within the dispenser and the result is a higher gas temperature entering the cylinder. The second phenomenon that causes a temperature rise during filling is the compression of the gas inside the cylinder. At the start of filling the gas is compressed by the introduction of the higher-pressure gas from the fueling station. This is repeated throughout the fill as the addition of gas into the cylinder compresses the gas already in the cylinder. When gas is compressed, its temperature will rise and this temperature change is called the heat of compression.For fills to 35MPa, a comparison of the magnitudes of these two phenomenon shows that the Joule-Thomson effect has a much smaller effect on the overall temperature rise when consideration is given to the thermodynamics of the entire process. As presented by **Dicken and Mrida [27]** .The temperature rise is mitigated through heat transfer from the gas to the cylinder walls. In the present study, the temperature distribution on the surface of the cylinder is analyzed using COMSOL multi-physics software suit to formulate a 3D digital model that can be used to analysis the heat and flow behavior of hydrogen gas inside the cylinder .Different pressure values ,mass flow rate of hydrogen and directions of the cylinder are studied.

3.2. Pre-analysis and geometry modeling

In the COMSOL model setting, the geometry of the cylindrical shell is set to be made in 3 dimensions. In this study, the geometry is created to depict the case study model which is a metal cylinder coated with carbon fiber. Cylinder dimensions as show in Table (3-1) and the volume of this cylinder is (74 L). The metal of cylinder wall is aluminum .The semi-symmetrical geometry is used parallel to the direction of gravity due to the effect of gravity force of to make the solution easier. The surface is created from drawings using the Geometry icon. Once the geometry of 3-D cylinder is complete the object will be imported into the grid. Figure (3-1) shows the geometric modeling of the domain.

Table (3-1) shown dimension of cylinder illustrated by **Dicken and Mrida [27]**

Dimension	Description	Value	Unit
L	Length of the cylinder	0.893	M
r_i	Inner radius of the cylinder	0.179	M
r_o	Outer radius of the cylinder	0.198	M
λ_{liner}	Liner thickness (assumed to be uniform throughout)	0.004	M
λ_{lam}	Laminate thickness (assumed to be uniform throughout)	0.015	M
d_{inlet}	Inside diameter of the gas inlet tube	0.005	M
λ_{tube}	Wall thickness of the gas inlet tube	0.002	M
L_{tube}	Length of the tube protruding into the cylinder	0.082	M



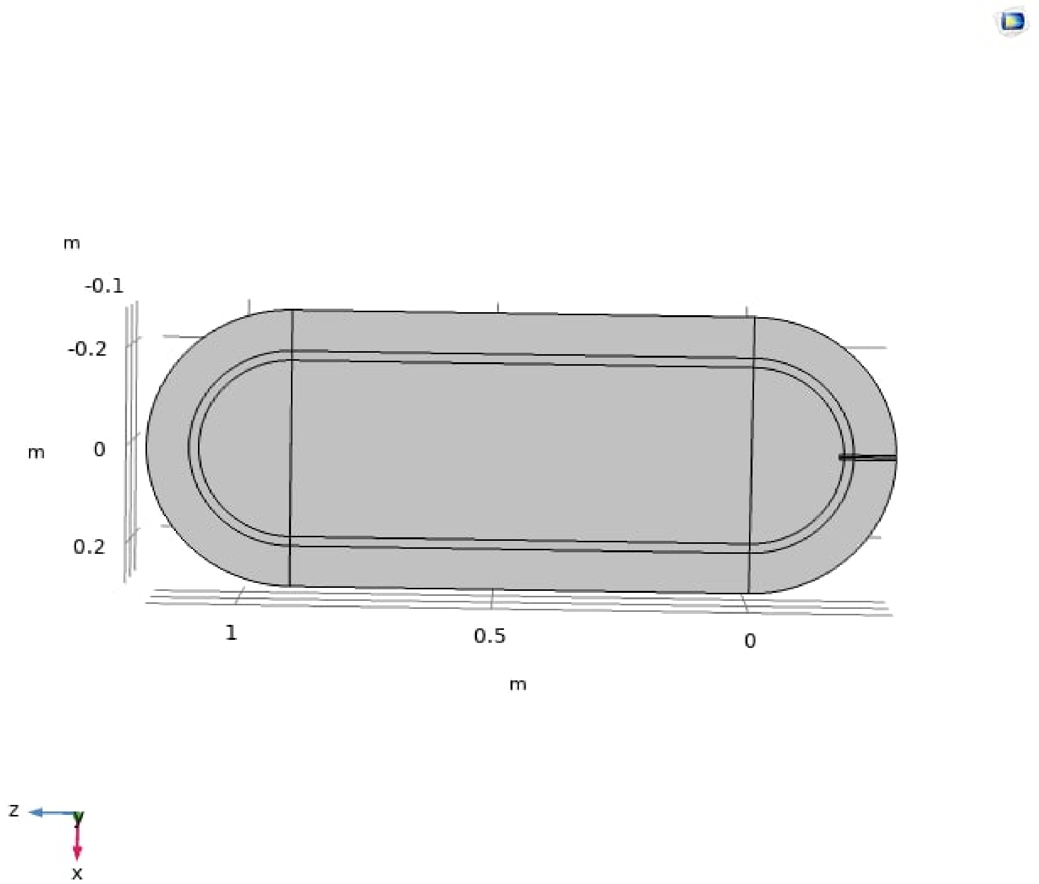


Figure (3-1) geometrical modeling of the cylinder

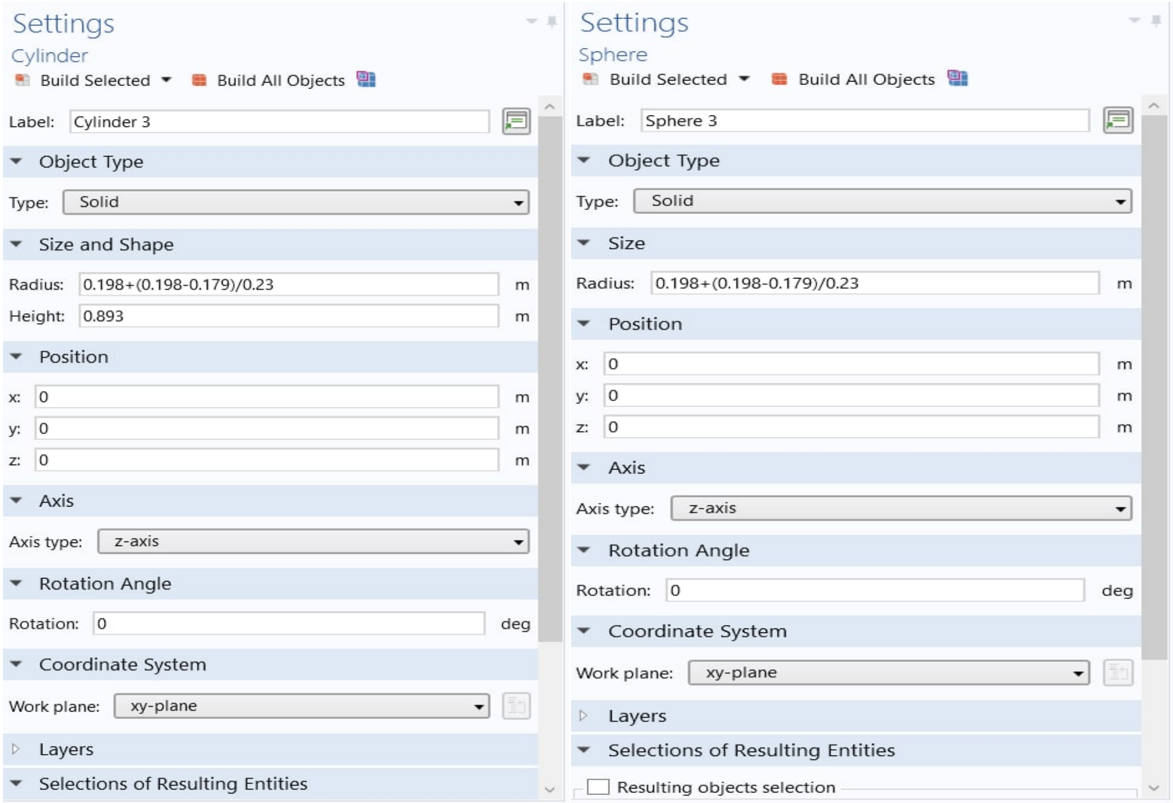


Figure (3-2) part of spacemen

3.3. Physical properties of material

3.3.1. Physical properties of the hydrogen

Table (3-2) shown physical properties of hydrogen**[28]**

Thermal conductivity	0.1825	W/mK
Density	0.08375	kg/m^3
Specific heat	14310	J/kgK
Viscosity	8.813	g/cm-sec

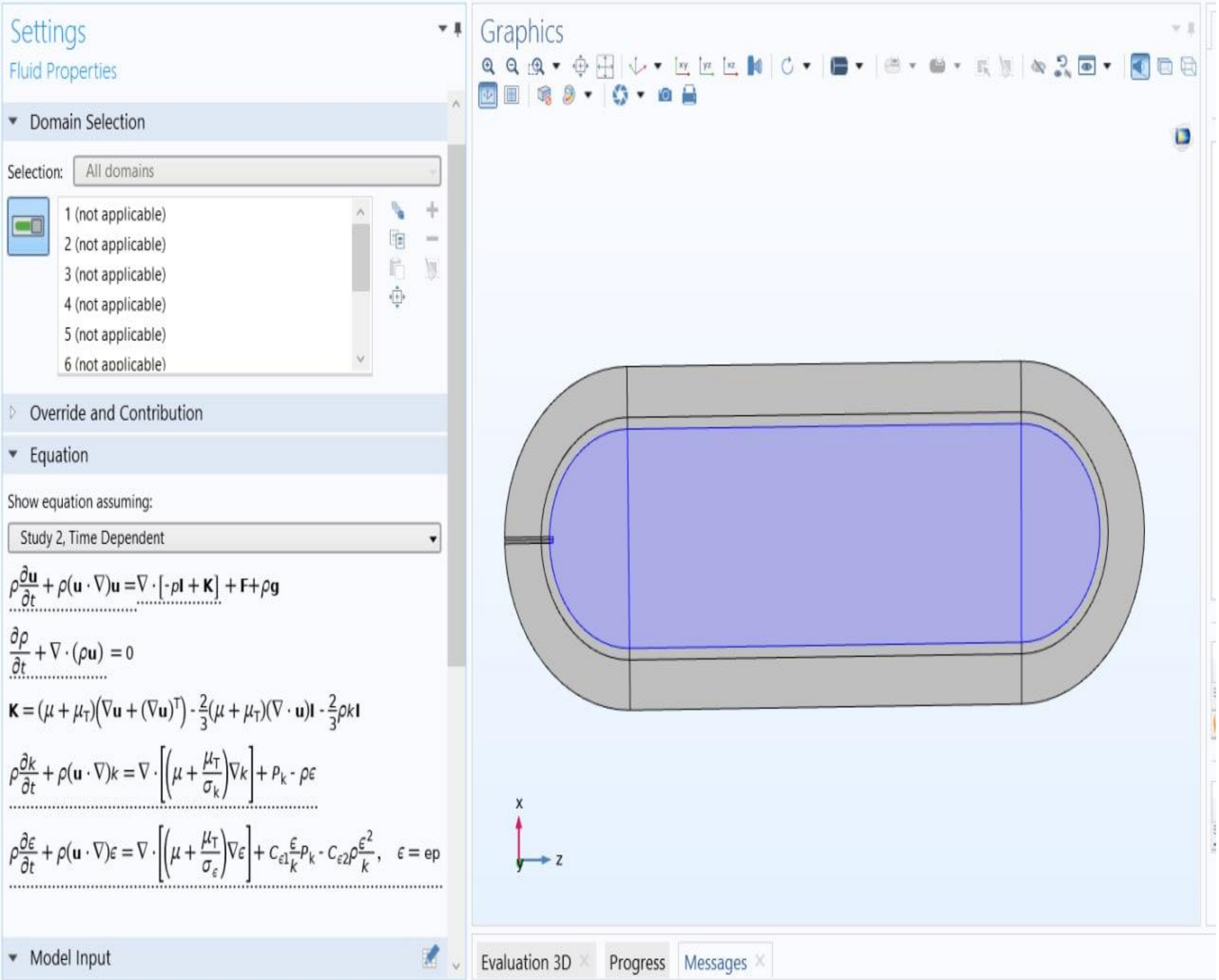


Figure (3-3) properties of hydrogen

3.3.2.Properties of Aluminum

The physical properties of aluminum

Table (3-3) shows the physical properties of aluminum as illustrated by **Dicken and Mrida [27]**

Thermal conductivity	167	W/mK
Density	900	kg/m^3
Specific heat	2730	J/kgK

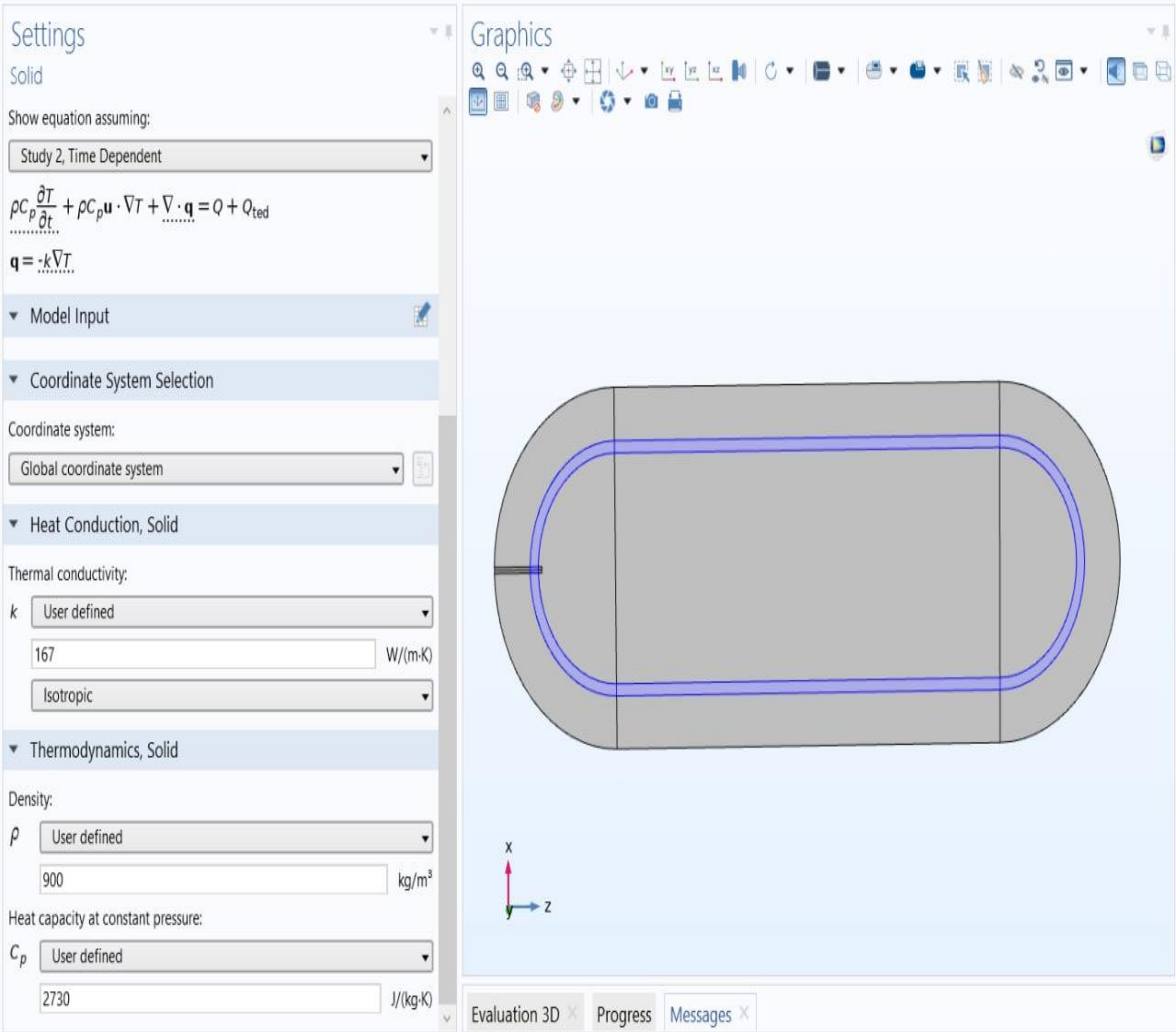


Figure (3-4) properties of aluminum

3.3.3. Properties of Carbon fiber

The physical properties of Carbon fiber

Table (3-4) shown the physical properties of Carbon fiber as illustrated by **Dicken and Mrida [27]**

Thermal conductivity	1.0	W/mK
Density	938	kg/m^3
Specific heat	1,494	J/kgK

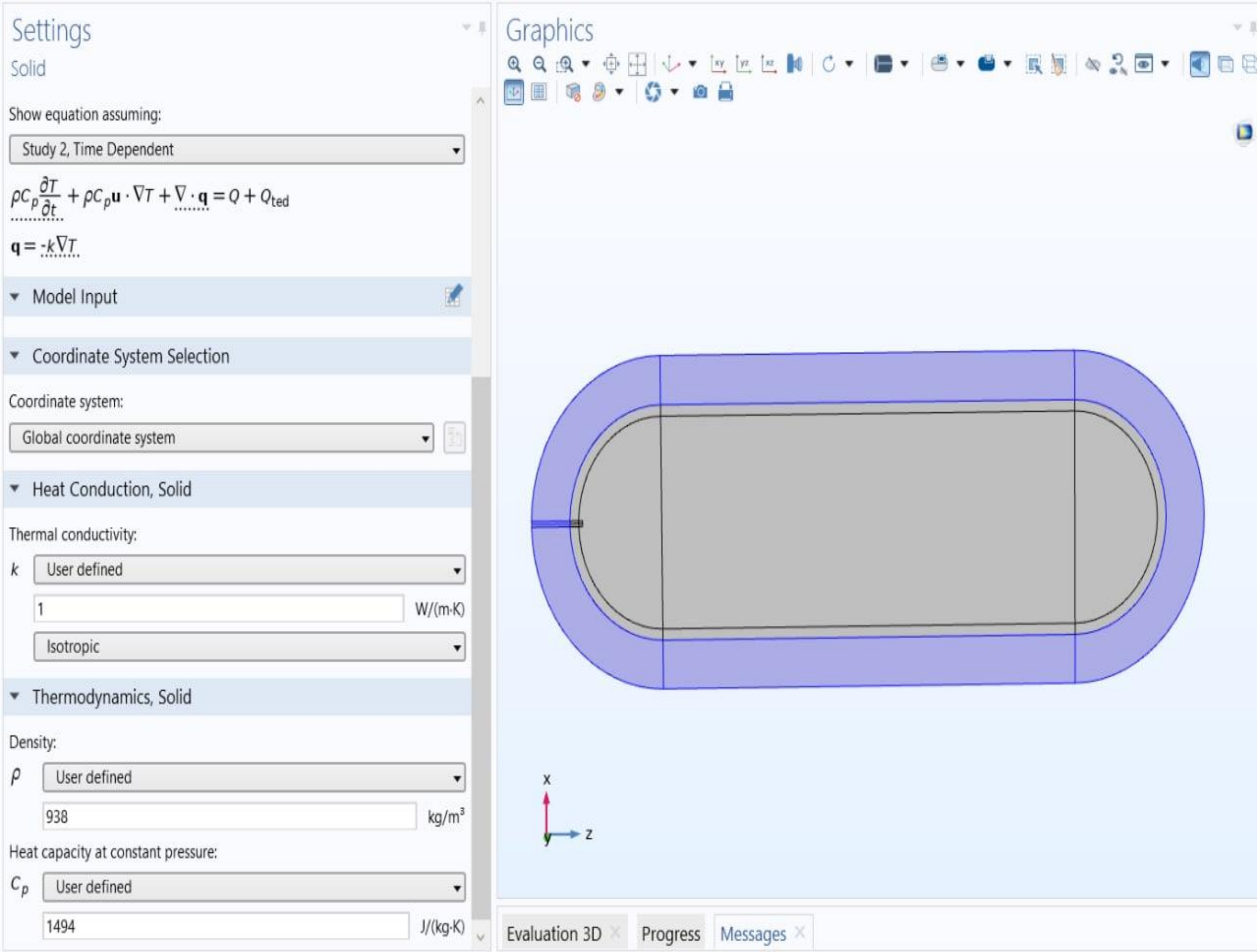


Figure (3-5) properties of Carbon fiber

3.4. Governing Equation

The momentum and heat transport equations are used. The partial differential equations (PDEs) of the present system are complex; the finite element method converts these equations into an algebraic matrix depending upon boundary conditions and mesh distribution. The algebraic equations of momentum transport are solved first at the initial temperature. Then, the resultant velocity profile is introduced to the heat transfer equation in the convection term. The resultant temperature distribution is used to estimate the physical properties of momentum and heat transport. The momentum transport equation is solved again in new temperature distribution and so on. The assumption and boundary condition

1- The flow is considered as unsteady state, three dimensional, compressible, and turbulent.
2- Ambient temperature (20 ^oC)
3- Convective heat transfer coefficient between the cylinder outer surface and the ambient air is ($10W/m^2 k$)
4- Constant properties of hydrogen
5- The hydrogen in this study used in a compression state

Equations in the present study are exhibited in the following expressions as illustrated in **Li at el.[9]**

$$dU=dH_{in}-dH_{out} + \delta Q - \delta W$$

$$dU=dH_{in}+ \delta Q$$

$$U_2=U_1+dU$$

$$U_2=U_1+dH_{in}+ \delta Q$$

$$u=aT-b$$

$$U_1=m_1(aT_1-b)$$

$$U_2=m_2(aT_2-b)$$

$$m2=m1+\int \dot{m}\, dt$$

$$dH_{in}=h_{in}\int \dot{m}\, dt$$

$$\delta Q=\int q\, dt$$

$$T2=\frac{m1(aT1-b)+hin\int \dot{m}\, dt+\int q\, dt}{a(m1+\int \dot{m}\, dt)}-\frac{b}{a}$$

Also, work and heat transfer for polytropic compression of hydrogen is showed by Chhabra [29]

$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{int\\rev}} = -\frac{nRT_1}{n-1}\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n} - 1\right] \quad \text{(ideal gas, } n \neq 1) \quad ..(3.5)$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{(n-1)/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.6)$$

3.5.Boundary and initial condition

Table(3 -5)boundary and initial condition

Ambient temperature	293	K
Convective heat transfer coefficient between the cylinder outer surface and the ambient air	10	W/m^2K
Gas inlet pressure ramp rate	45	MPa
Inlet mass flow rate	0.025[a]	Kg/s
Gas inlet temperature	293	K
Inlet gas pressure	2	MPa
Final gas pressure	35	MPa

3.6. Meshing and the grid-independent test

Mesh refers to the free areas in a network or net. After completing the geometry and stabilizing the boundary conditions, the right meshing condition must be determined in order to achieve a more accurate display of the result, because meshing informs the program to do a computation. The choice of network type is effected several factors such as system design and flow type. There are several mesh types, including extremely coarse, extra coarse, coarse, coarser, standard, and fine mesh as illustrated in **Mohammed [30]**. The mesh is built up as shown in Figure (3-5).

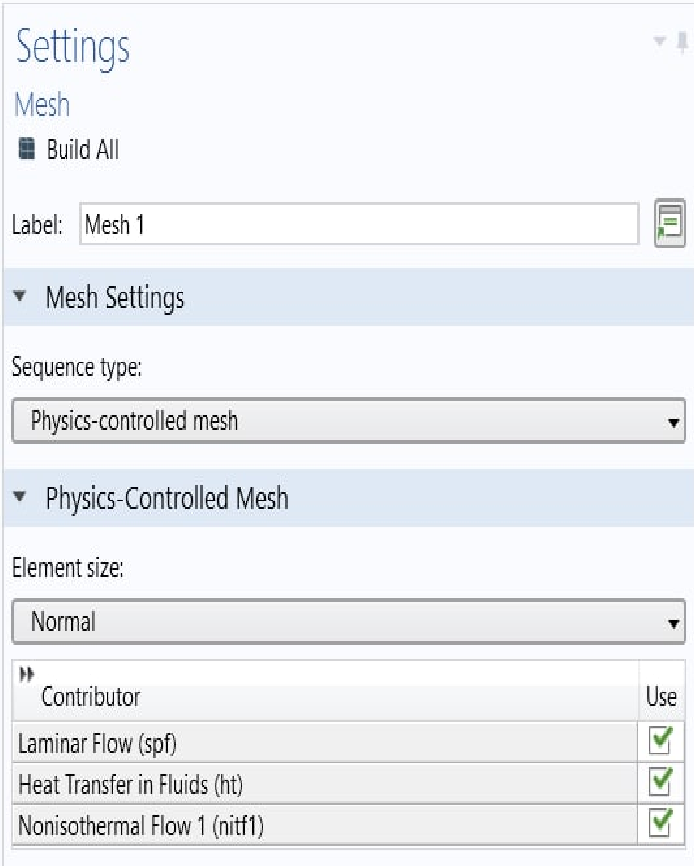


Figure (3-6) mesh setting

In this study, the selected number of element are (77243), the number of edge elements are (701), and the boundary element are (10833). Given that the discretization grid is triangular, unstructured, and non-uniform as shown in Figure (3.6). Ultimately, a grid size of (77243) was used in this study as this represented the best compromise in terms of both accuracy and computational time and figure (3-6) show mesh shape of cylinder.

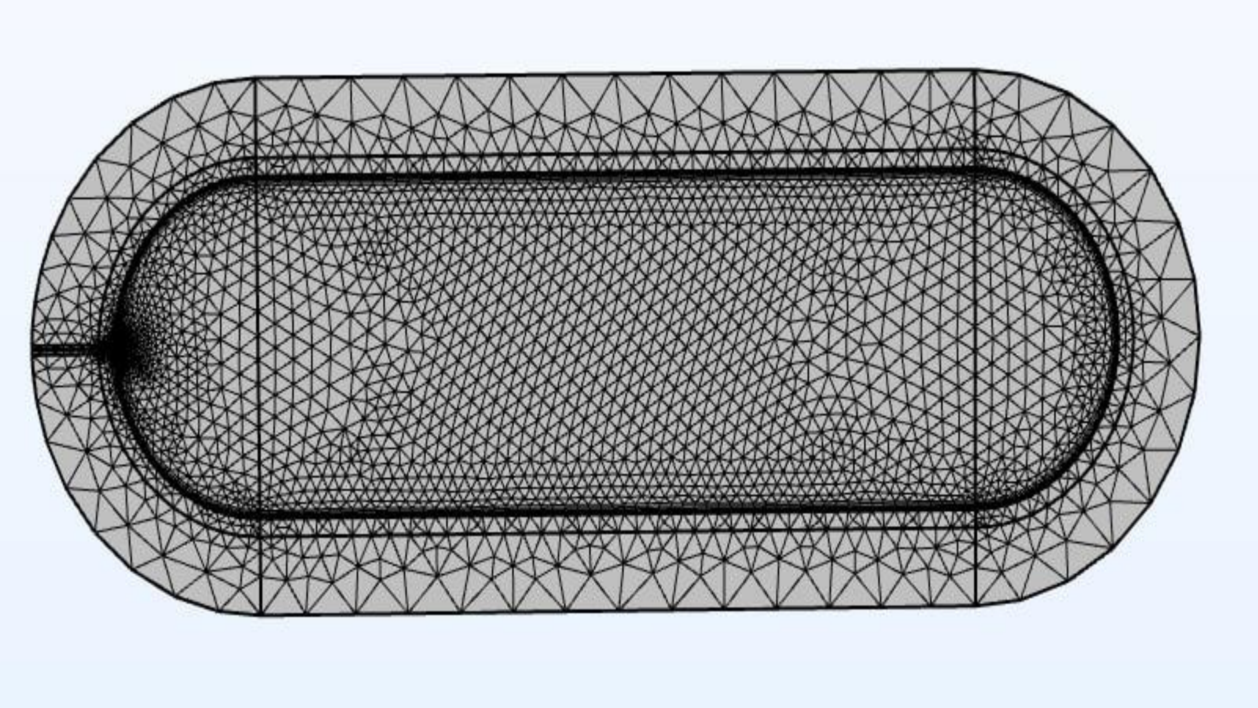
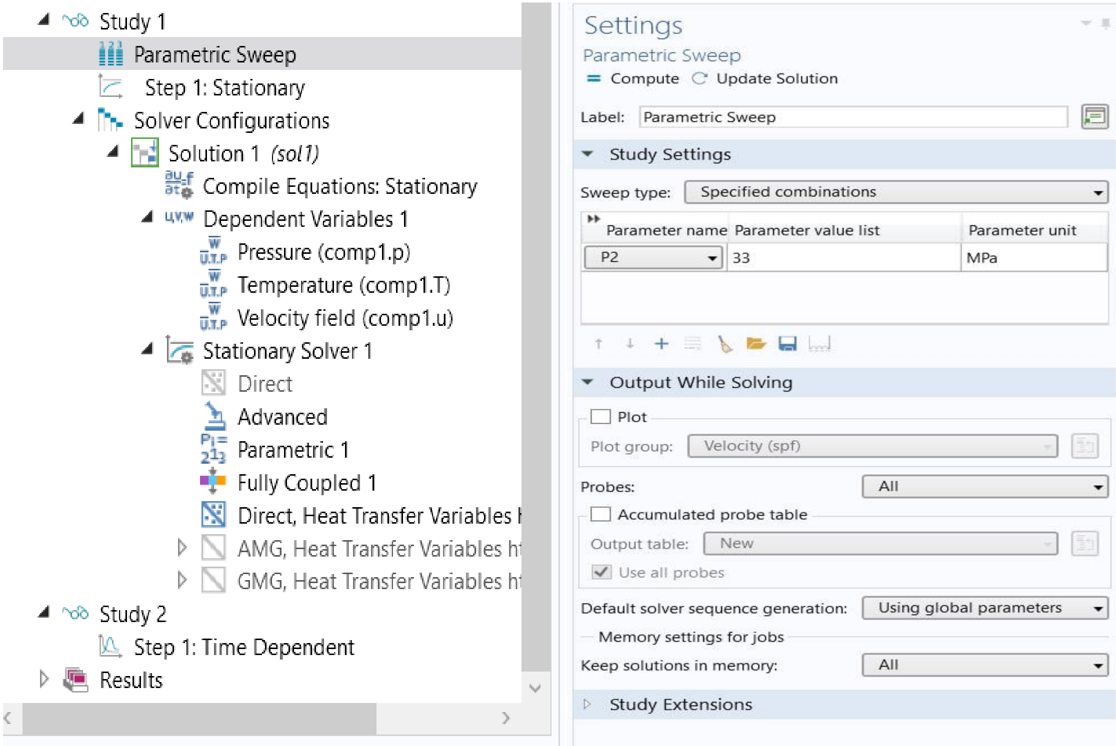


Figure (3-7) show mesh shape of cylinder

3.7. Study setting

References value is set in this step, the number of iteration is an important factor in this stage. The setting of the study is illustrated in figure (3-7).



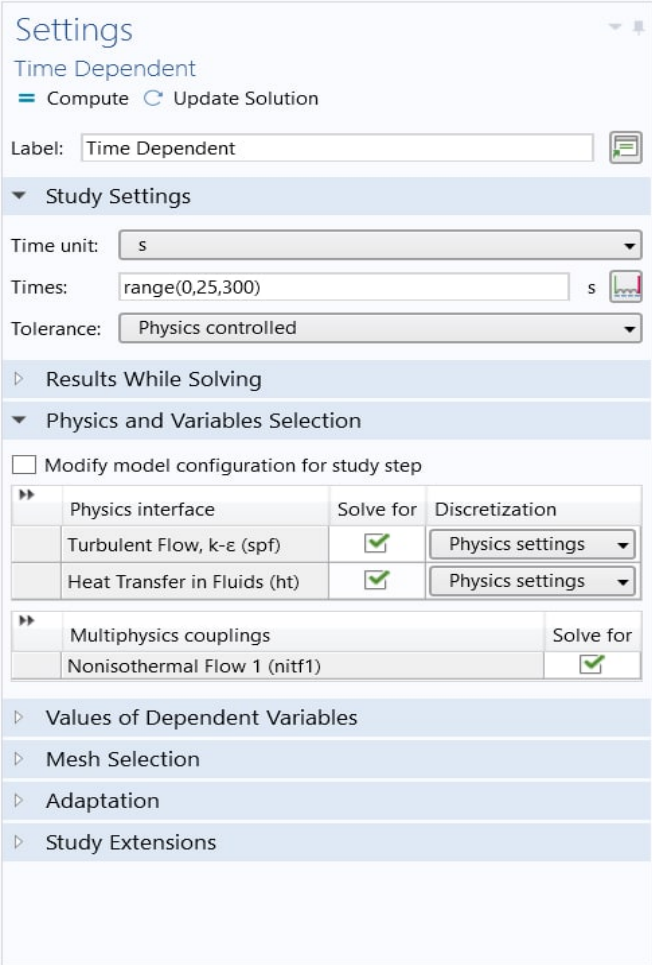


Figure (3-8) time dependent setting

3.8. Results setting

A CFD post-processor was launched to verify the calculated results in the form of graphical results such as temperature profile and graphs, for a cylinder filled with the compressed hydrogen. Results and data can also be analyzed, computed and imported into further analysis and verification. At - 300 seconds after the fill, the temperature distribution was monitored throughout the cylinder. According to the model results, the greatest temperature will be found near the filling end.as shown in figure (3-8) .

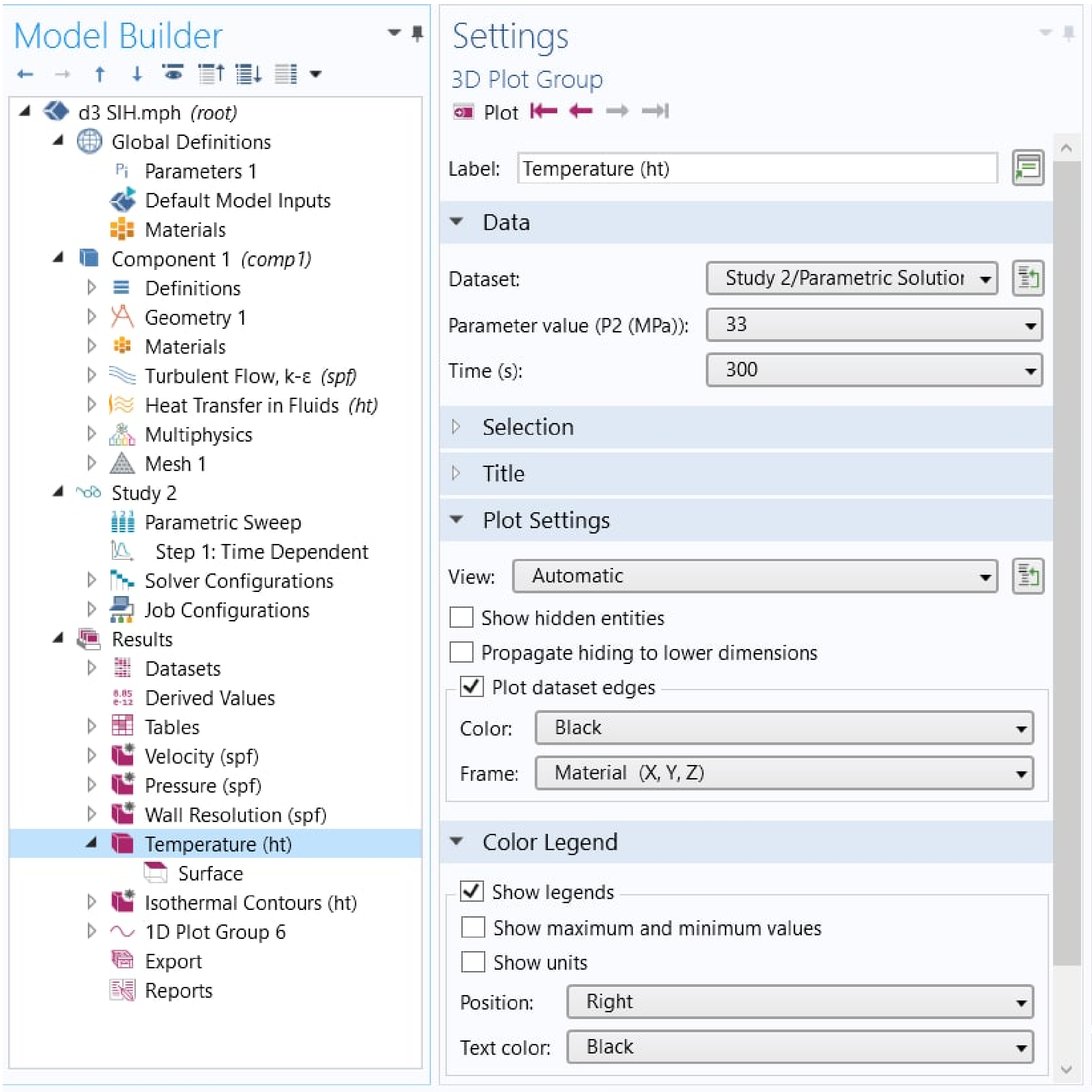


Figure (3-9) results Setting

3.9. Simulation steps

To model the dynamic model of a cylinder filled with compressed hydrogen gas, the following steps were performed

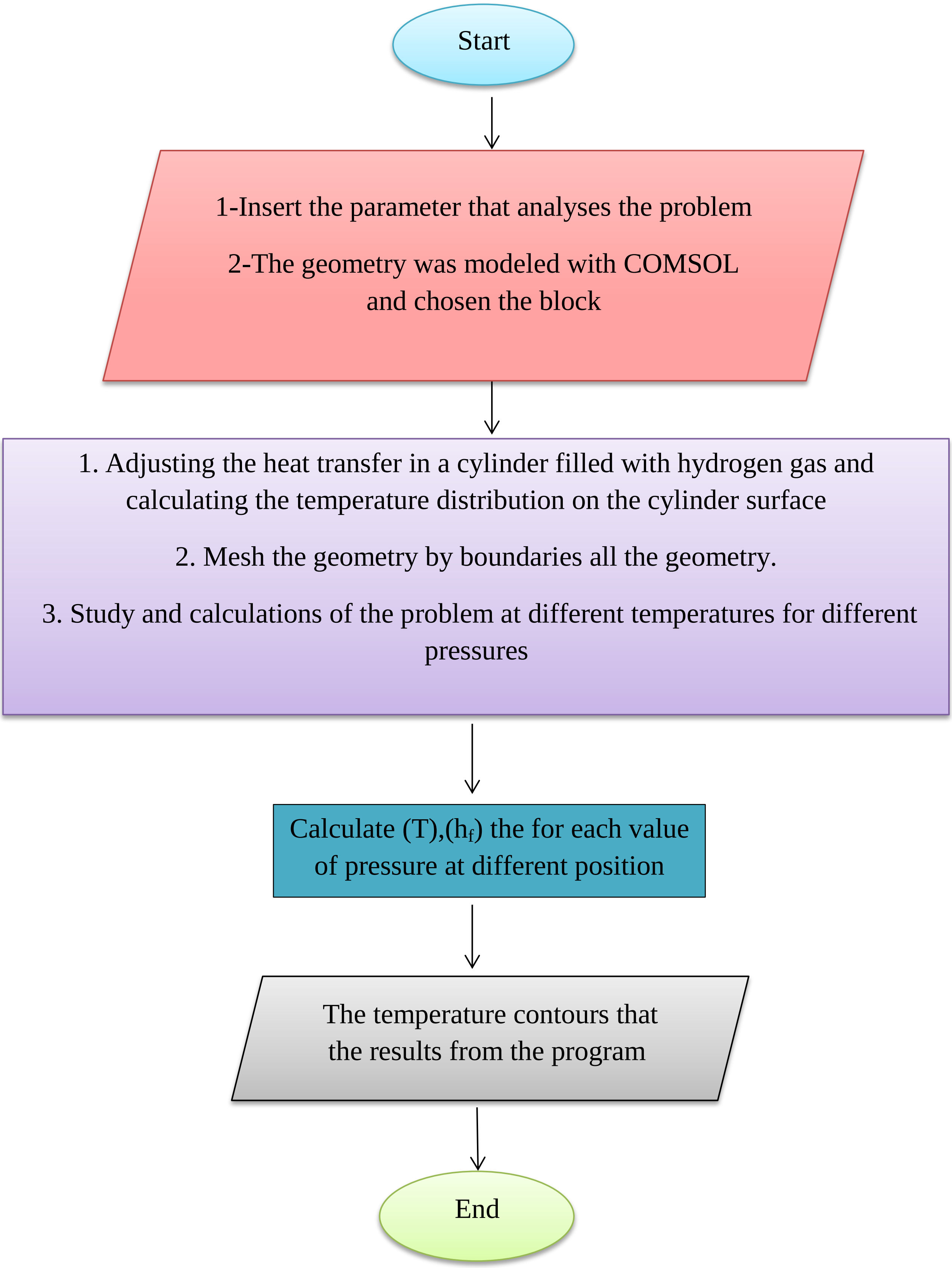


Figure (3-10) results estimation flow chart

Results and discussion

4.1. Theoretical result

Theoretical calculations were performed to solve the governing equations through a finite element approach using the Multiphysics COMSOL software suite and find the temperature distribution as well as the heat transfer coefficient for the physical domain as illustrated in figure (4-1).

The presented study is validated by comparing its predictions with the results by **Kim et al.[24]** the validation test is that of a cylinder filled with hydrogen gas. The comparisons are shown in the figure (4-2). The results can be seen to be in good agreements with the published reference data for the same boundary conditions when the temperature reached 90 ºC

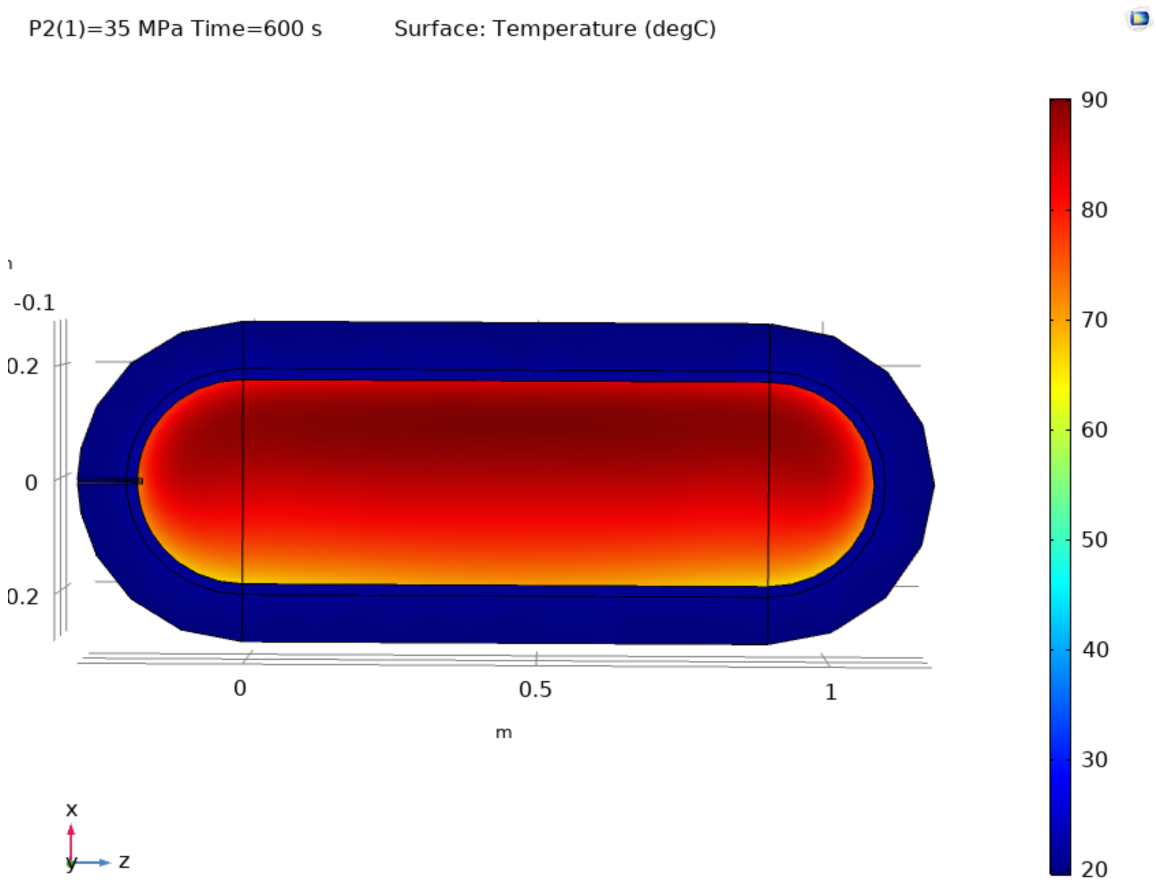


Figure (4-1) Variation temperature between the inner and outer of the cylinder for the validation spacemen in the horizontal direction (1423g)

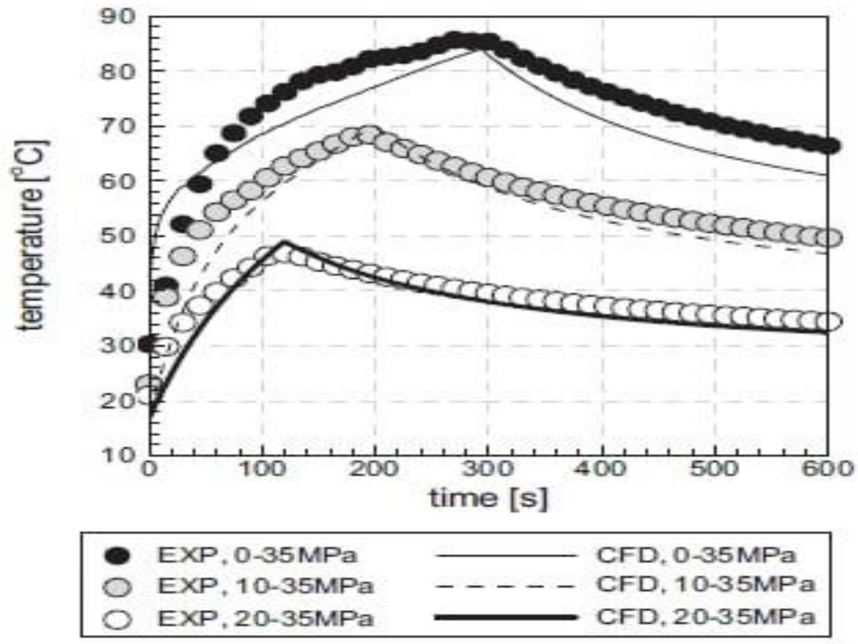


Figure (4-2) shows the results obtained by the researcher **Kim et al. [24]**

4.2. Temperature distribution

4.2.1. The cylinder with pressure of hydrogen gas (33MPa) in a horizontal position

For the first case study, a quantity of hydrogen gas (1500 g) was pumped at a pressure of (33 MPa) and mass flow rate (5g/s), and the results showed an increase in the temperature to (90 °C), and this increase in temperature is a result of the effect of continuous pumping of hydrogen gas at high pressure and high mass flow rate this was in agreement with the researcher **Li et al.[9]** indicate that reason of temperature rise is the compression of hydrogen and rates are nearly the same when the mass flow rate is larger, where it was the highest temperature is the temperature of hydrogen and also the temperatures were calculated on the surface of the cylinder, but it was noted that there is a difference in the amount of temperatures between the inside of the cylinder and the cylinder wall, where the cylinder wall is always colder than inside the cylinder and the reason is due to the presence of heat exchange between the surface of the cylinder and outside, the figure (4-3) show the temperature difference between inside and outside the cylinder

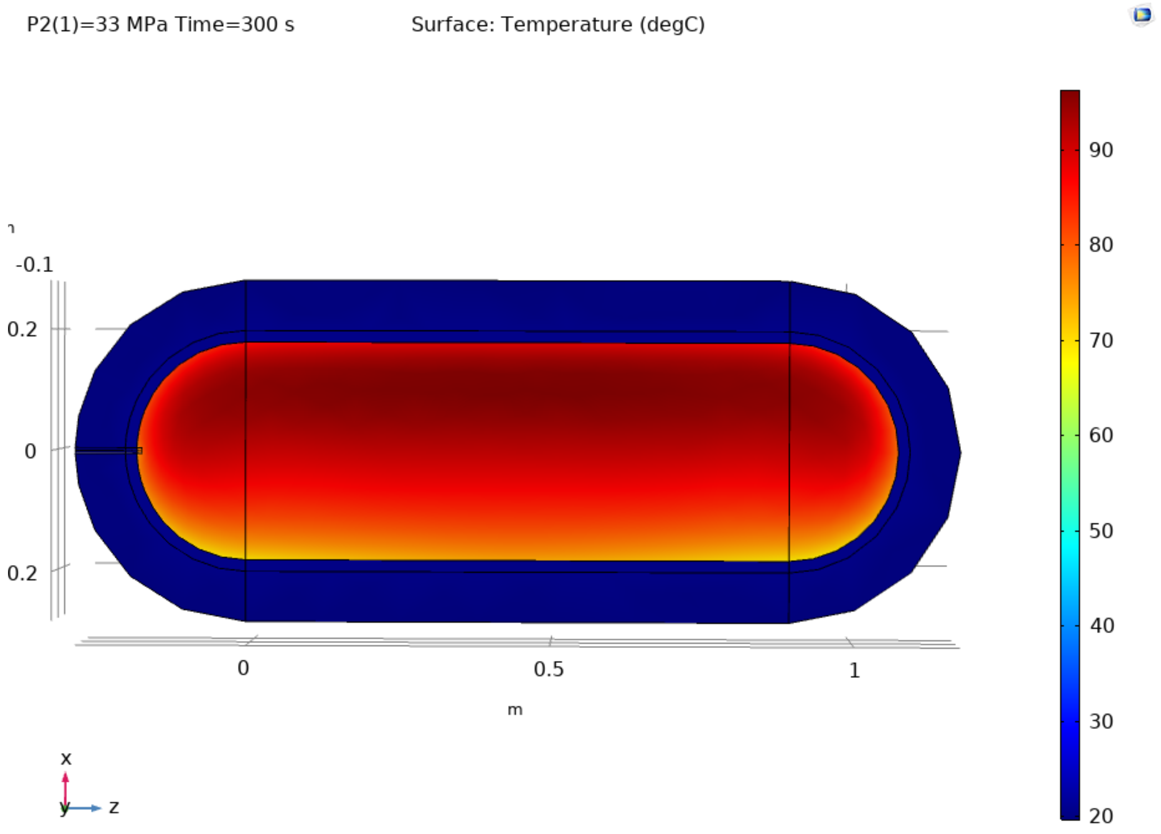


Figure (4-3) the temperature variation between inner and outer of the cylinder for spacemen one in the Horizontal direction (1500g)

In this case, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated through the pressure and the amount of hydrogen applied to the points taken on the cylinder wall, where a difference was observed in the distribution of temperatures according to the different places they were taken on a wall the cylinder, where the results showed that the higher temperature was at the location of the node on the throttle device, which is represented by the following node (10,20,27), and the lowest temperature was in the node on the outer surface that is close to the temperature surrounding the cylinder

Which was represented by the following nodes (30, 31), and this was in agreement with the researcher **Dicken and Mrida. [27]** as shown in Figure (4-4) and Figure (4-5) below.

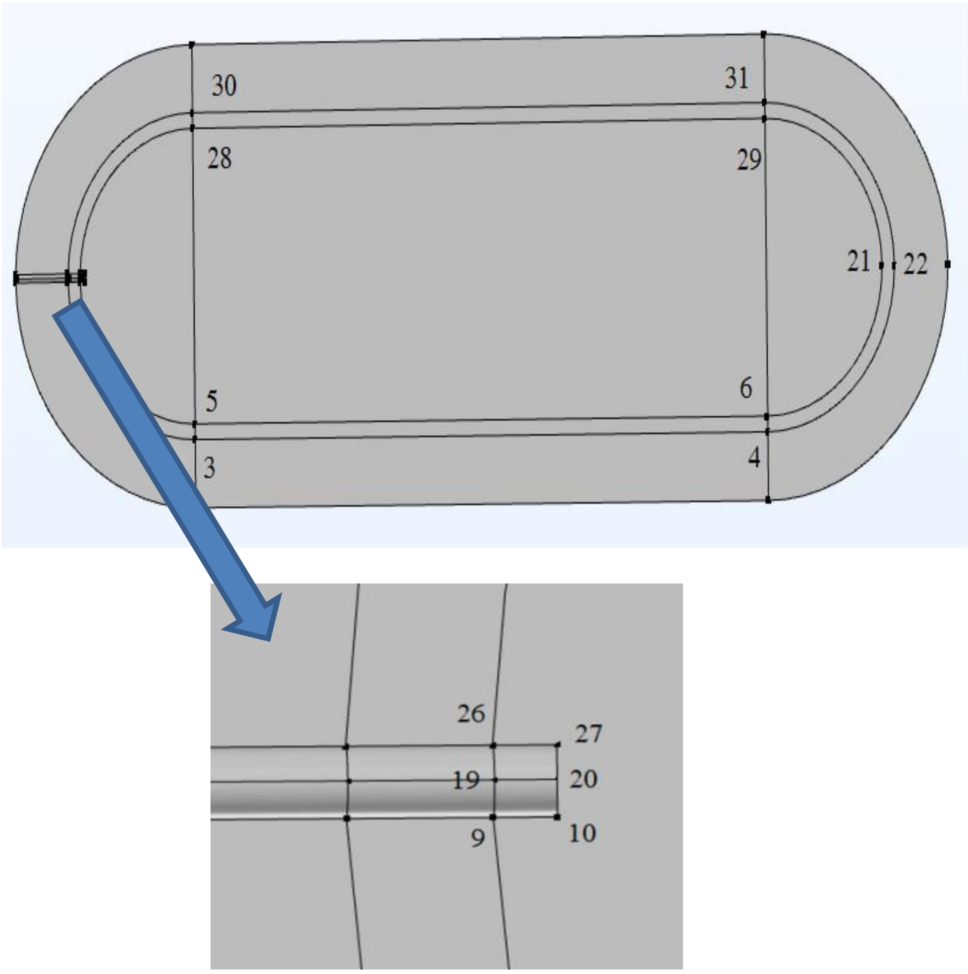


Figure (4-4) Calculate the temperature change of the surface of the cylinder with the points represented

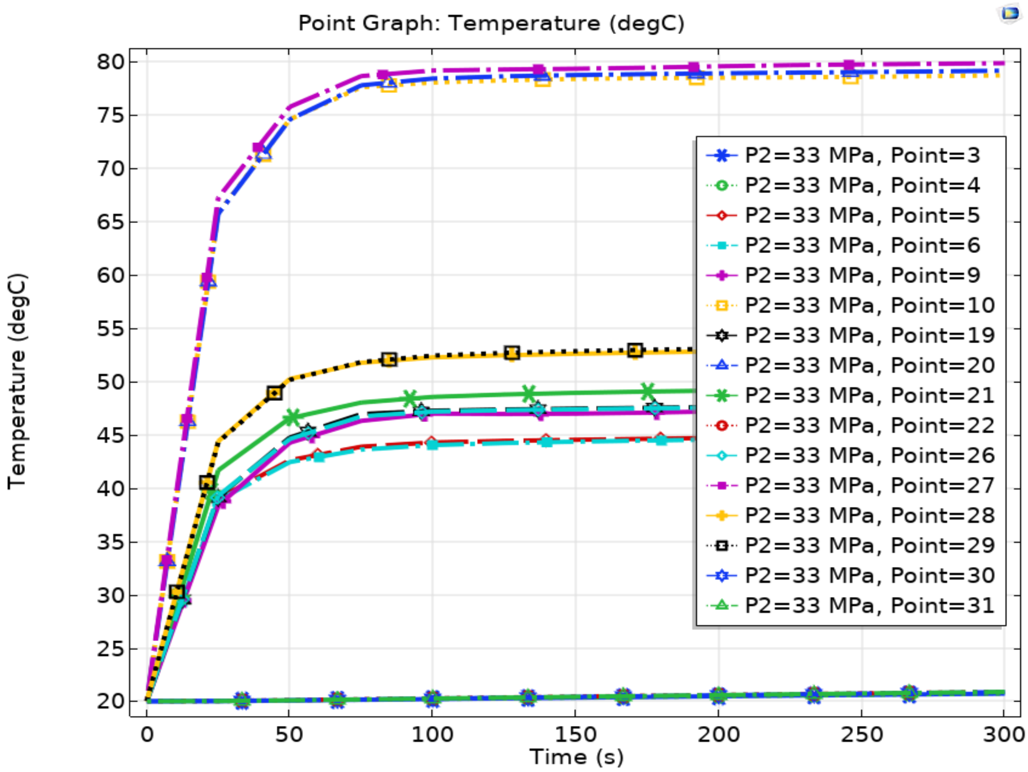


Figure (4-5) the relationship between temperatures distribute and time required for specimen one in horizontal direction with mass of hydrogen gas (1500g)

For the second case study, where the hydrogen gas pressure (33 MPa) was applied to the same cylinder but in a lower amount (1000 g), and the mass flow rate was lower (3.33 g/s), the temperature was lower than in the first embodiment and where the drop rate was (22.22%) compared to the first model. A decrease in the temperature inside the cylinder was noted, and the reason is due to the low mass of the hydrogen pump so that the temperature that reached (70 °C) is considered a safe temperature compared to the rest of the previous research, the following figure (4-6) Variation of temperatures between inside and outside the cylinder

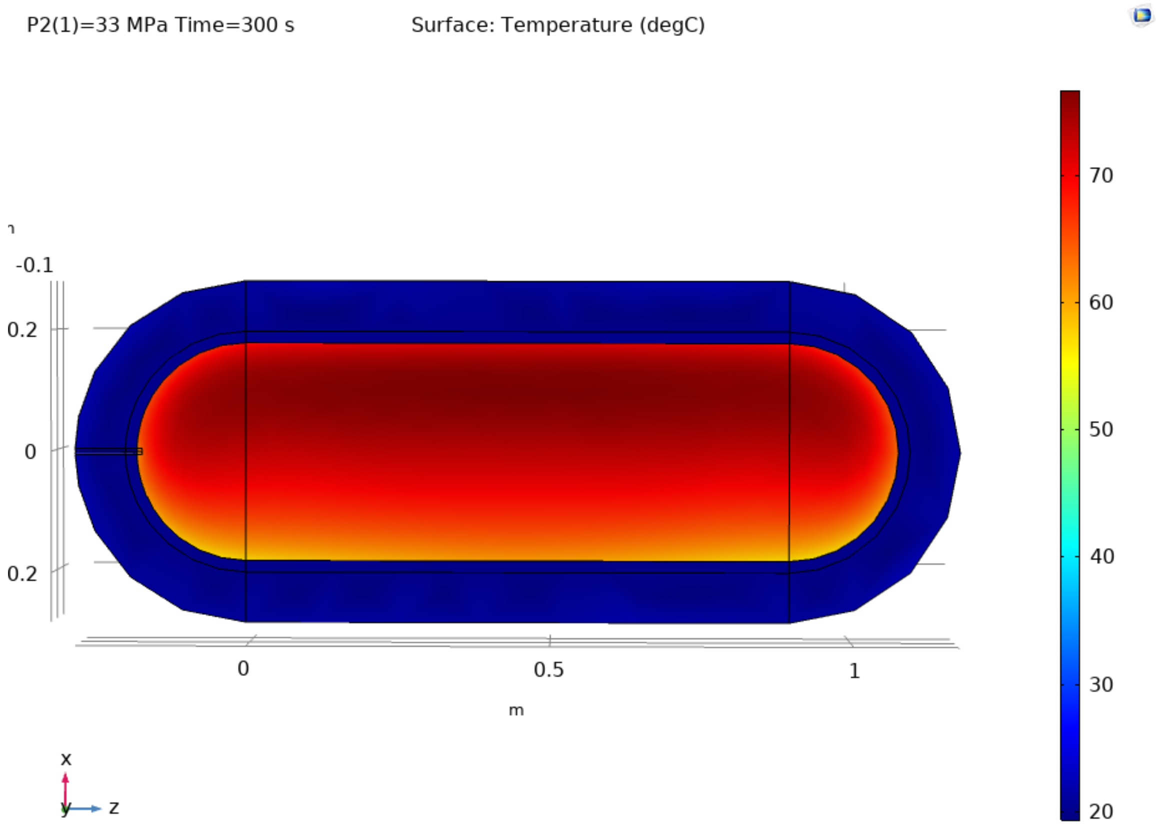


Figure (4-6) variation temperature between inner and outer of the cylinder for spacemen two in the Horizontal direction with mass of hydrogen gas (1000g)

In this case, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated through the applied pressure and the amount of hydrogen applied to the points taken on the cylinder wall, where a difference is observed in the distribution of temperatures according to the different places that selected in the cylinder walls, as shown in Figure (4-7).

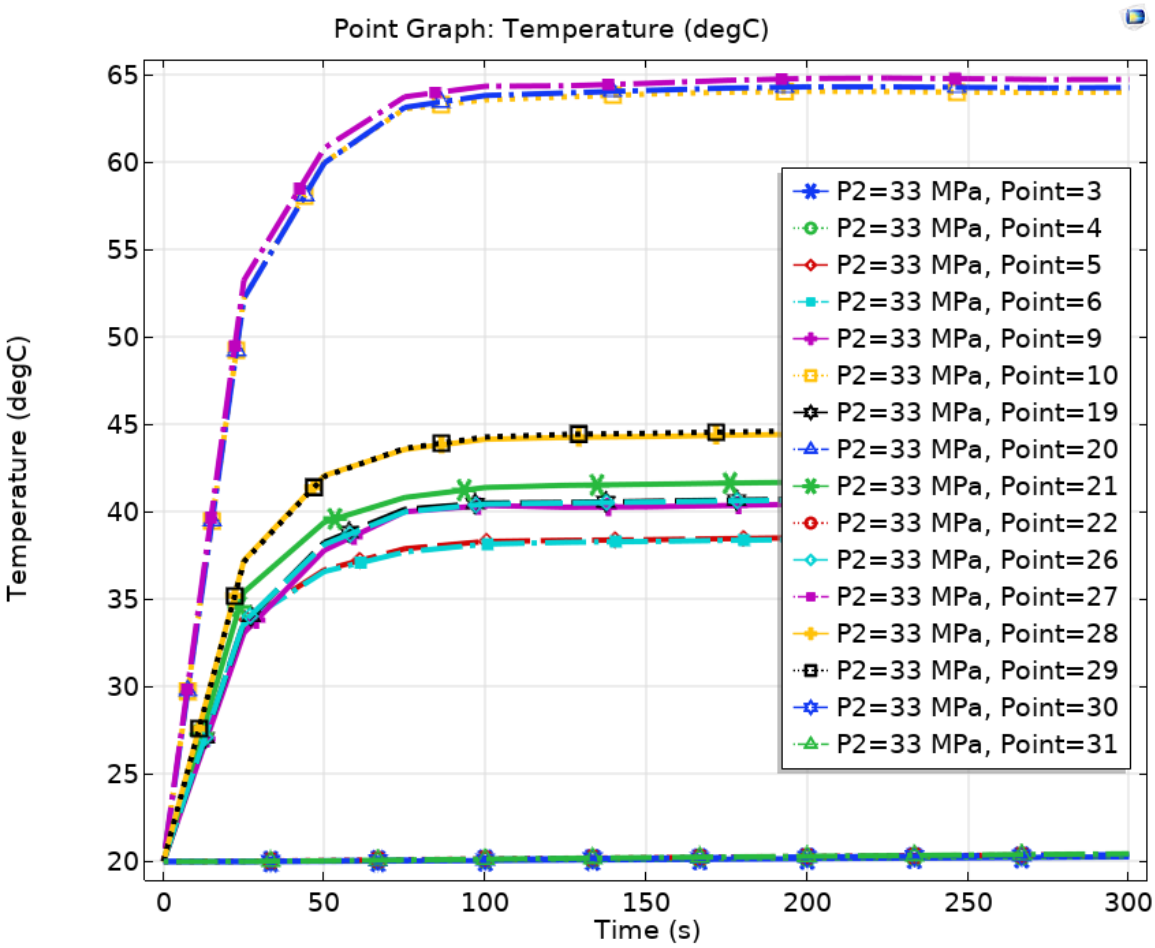


Figure (4-7) the relationship between temperatures distribute and time required for spacemen two in horizontal direction with mass of hydrogen gas (1000g)

For the third model, where the hydrogen gas pressure (33 MPa) was applied to the same cylinder but in a smaller amount (500 g), and the mass flow rate was lower (1.67 g/s), the temperature was lower in terms of the drop rate by (44.44%) compared to the first model and the decrease in temperature, and the percentage of decrease compared to the second model was (28.57%) A decrease in the temperature is observed inside the cylinder, and the reason is due to the decrease in the mass of hydrogen that you are pumping until the temperature reaches (50 ^{o}C).this value of temperature id also considered safer heat compared to other previous research the following figure (4-8) shows the temperature difference between inner and outer the cylinder.

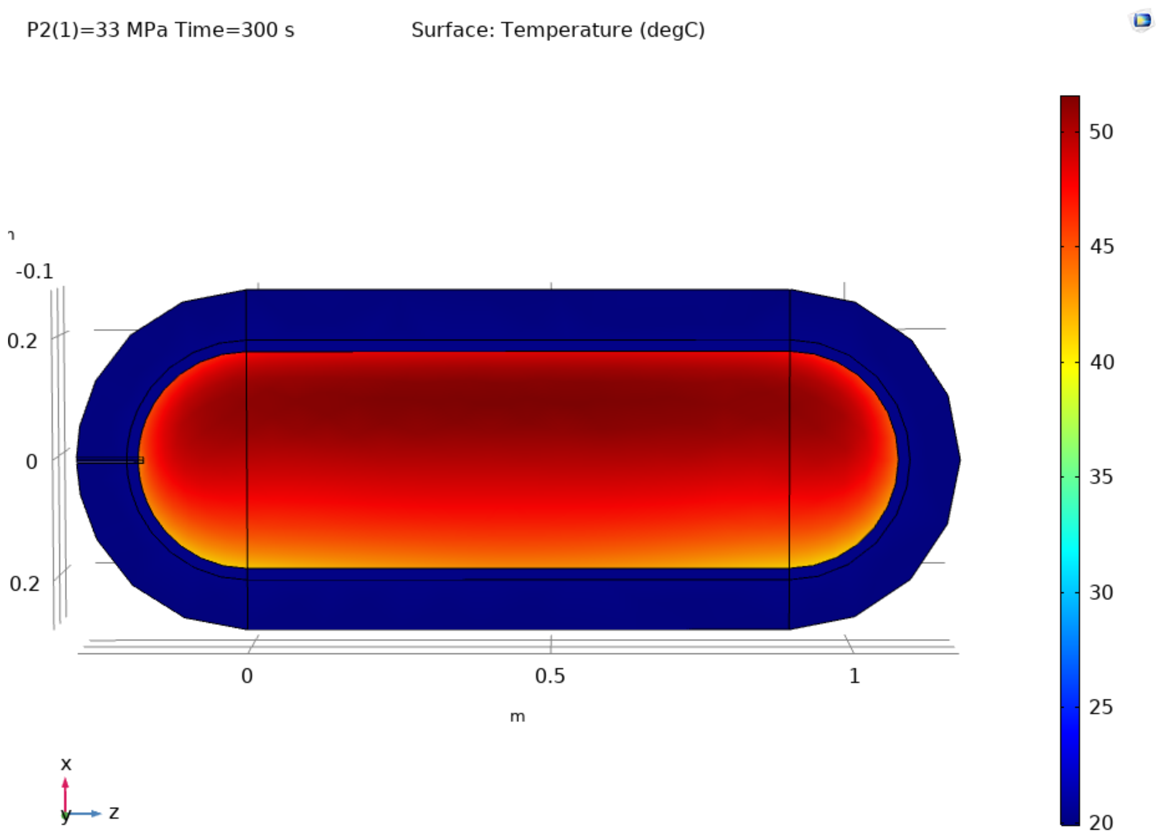


Figure (4-8) variation temperature between inner and outer of the cylinder for spacemen three in the Horizontal direction with mass of hydrogen gas (500g)

In this case, the time taken to fill the cylinder is (300 seconds), and the relationship between temperature and time was calculated through the pressure and the amount of hydrogen applied to the points taken on the cylinder wall, where a difference was observed in the distribution of temperatures according to the different places they selected in the cylinder walls, as shown in Figure (4-9).

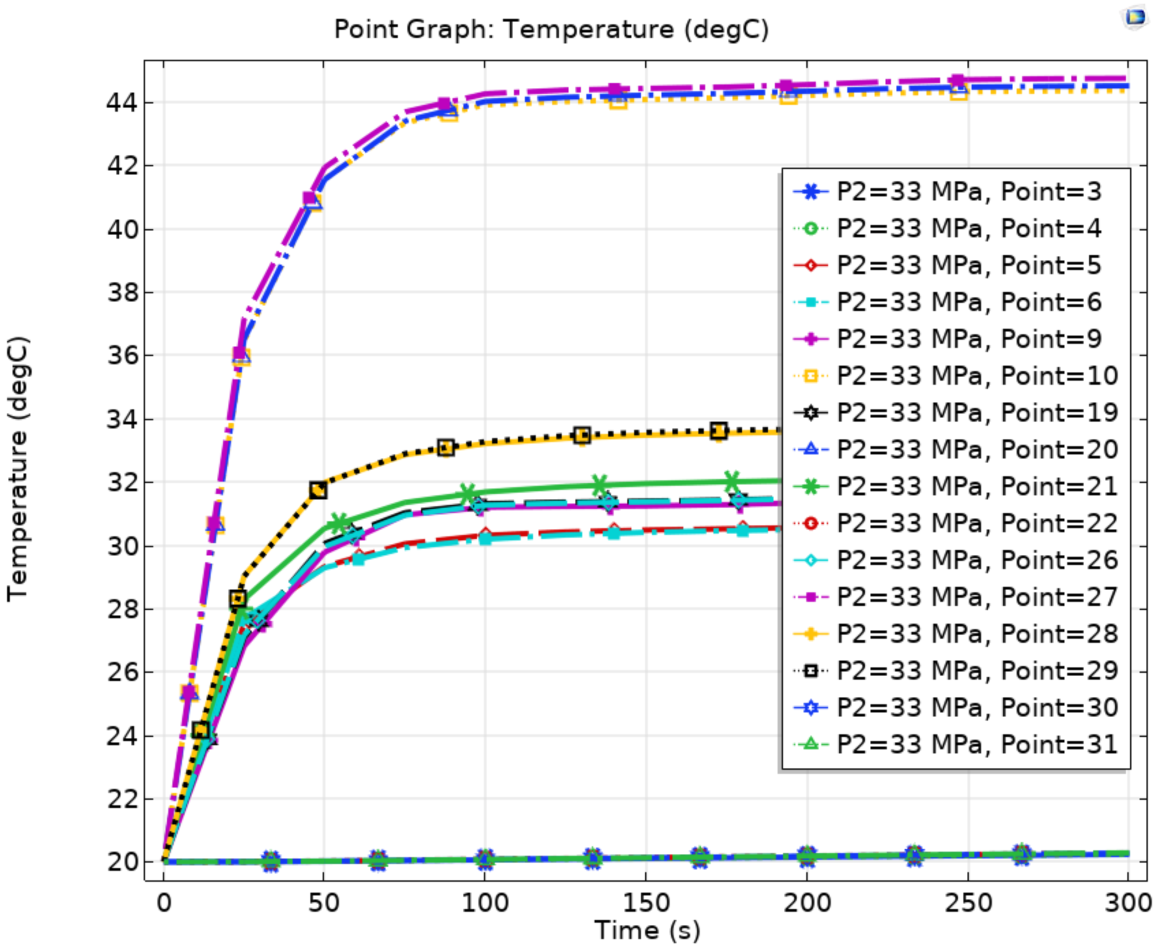


Figure (4-9) Relationship between temperatures distribute and time required for spacemen three in horizontal direction with mass of hydrogen gas (500g)

4.2.2. The cylinder with pressure of hydrogen (33MPa) and vertical position

For the second position, the cylinder was in the vertical position. The first sample was studied. A quantity of hydrogen gas (1500 g) was pumped at different pressures (33 MPa), and the mass flow rate was (5 g/s) and the results showed an increase in temperature to (80°C) the temperature was distributed where the highest temperature was the temperature of hydrogen gas when compared to the surface of the cylinder was colder, and the reason is due to the heat exchange between the surface and the outside, and this increase in temperature is caused by the continuous pumping of hydrogen gas at high pressure and high mass flow rate as well, but when comparing this model in the vertical position with the first model in the horizontal position at the same pressure and the same mass of hydrogen found that there is a decrease in temperature by (11.11%), we conclude from this that the vertical position is safer than the horizontal position for a safe filling process and the following figure (4-10) shows the temperature difference between the inside And outside the cylinder**.**

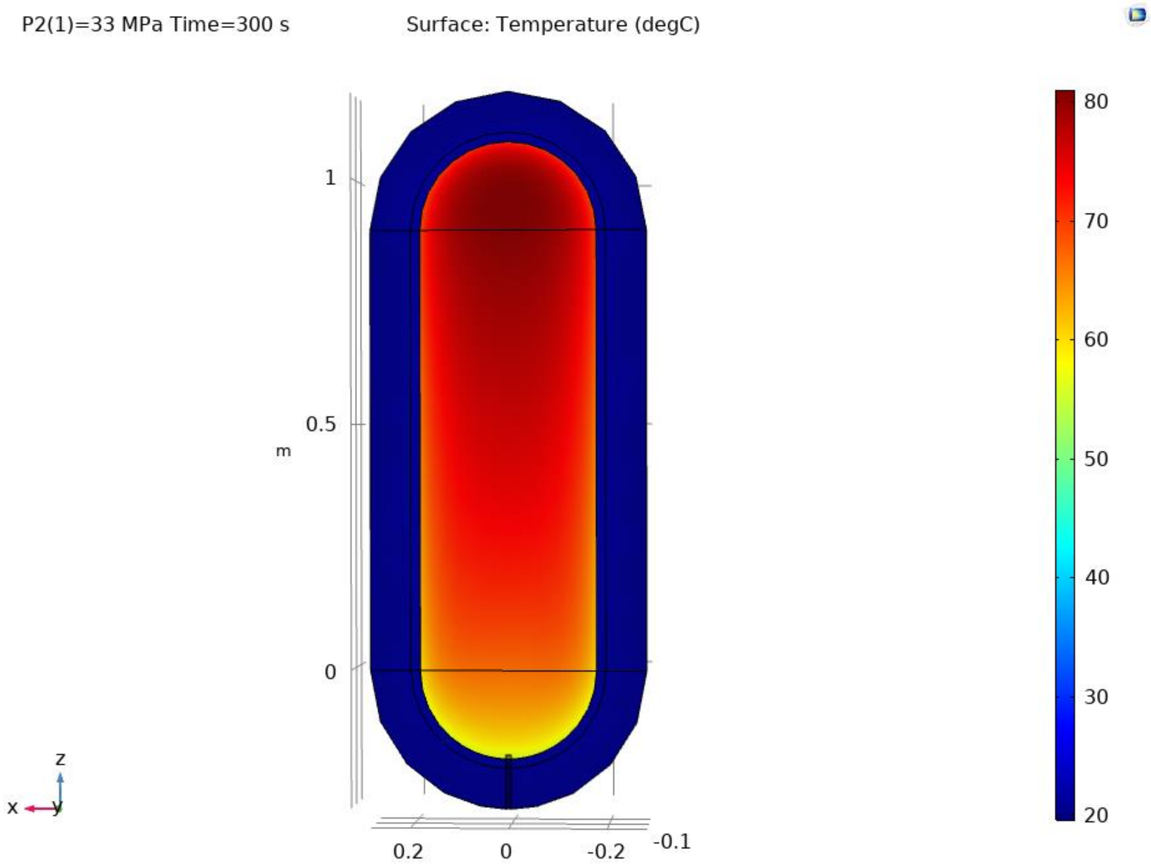


Figure (4-10) variation temperature between inner and outer the cylinder for spacemen one in the vertical direction with mass of hydrogen gas (1500g)

In the vertical position, the time required to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated by the applied pressure applied from points taken on the cylinder wall, where there is a difference in the temperature distribution was observed according to the different places captured on the wall of the cylinder. The cylinder and the pressure applied to the same amount of hydrogen gas that is pumped into the cylinder, as well as a difference in the relationship between temperature and time in the horizontal position than in the vertical position as shown in the following figure (4-11).

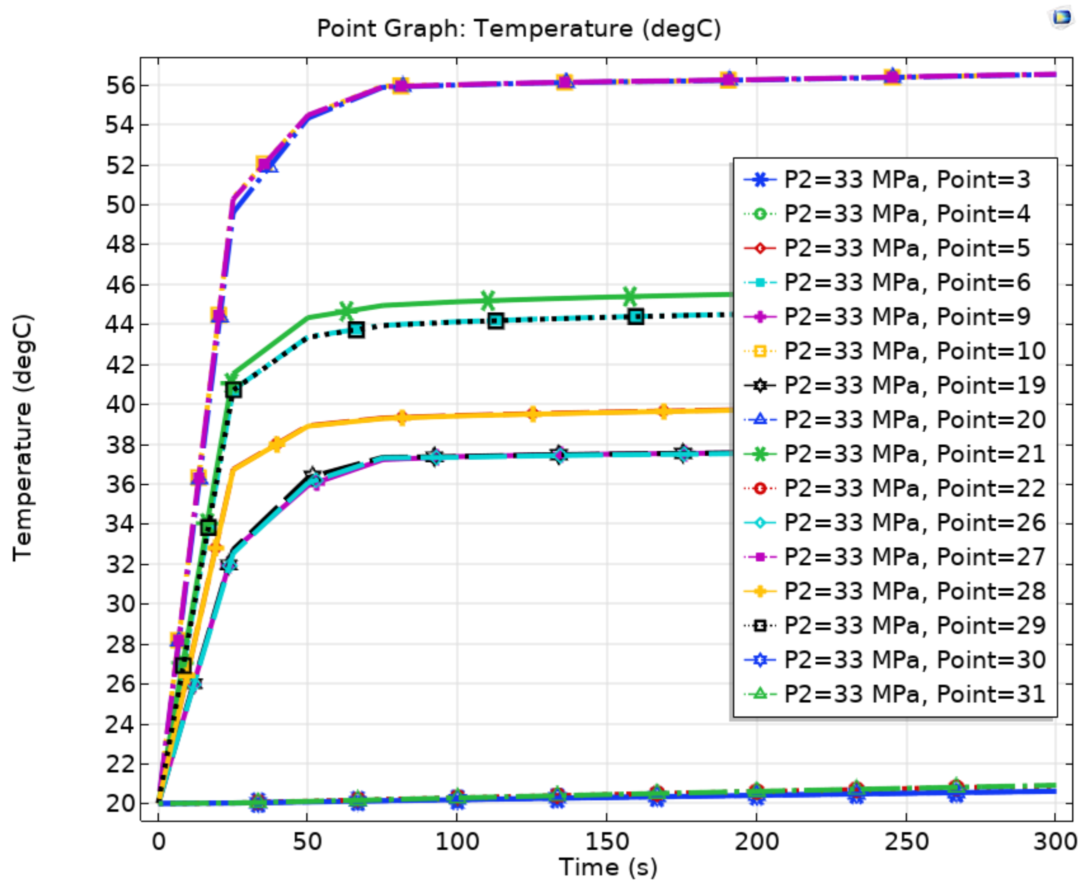


Figure (4-11) the relationship between temperatures distribute and time required for spacemen one in vertical direction with mass of hydrogen gas (1500g)

In the second model in the vertical position, hydrogen gas pressure was applied to the same cylinder with the same amount (33 MPa), but with a lower mass (1000 g), a lower flow mass ratio amount (3.33 g/s) and a lower temperature than in The first and second models. Where the percentage of reduction is (25%) compared to the first model, so that the temperature inside the cylinder (60 °C) and the reason for this is due to the low mass of hydrogen pumped into the cylinder and the reduction in the percentage of low flow mass applied inside the cylinder, the temperature is taken the resultant, taking into account the safe temperature compared to the rest of the previous research, also observed a decrease in the temperature in the vertical position compared to the horizontal position of the same cylinder and the same amount of hydrogen that is pumped into the cylinder using the same applied pressure where the amount of decrease (14.28%) compared to the model in the horizontal position and figure (4-12) shows the variation in temperature between inside and outside the cylinder.

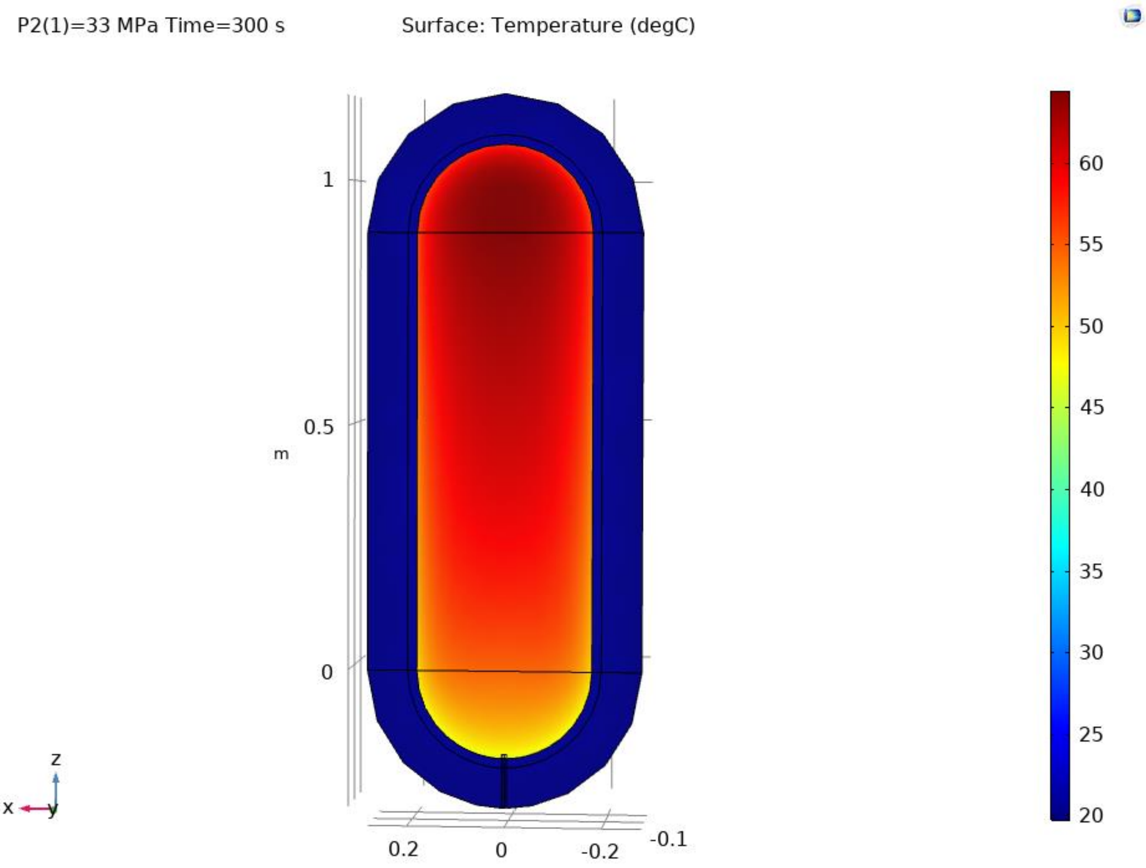


Figure (4-12) the temperature variation between inner and outer the cylinder for spacemen two in the vertical direction with mass of hydrogen gas (1000g)

In the vertical position, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution was observed according to the different places taken on the cylinder wall and pressure applied to the same amount of hydrogen gas being pumped into the cylinder, as well as a difference in the relationship between temperature and time in the horizontal position than in the vertical position as shown in the following figure (4-13).

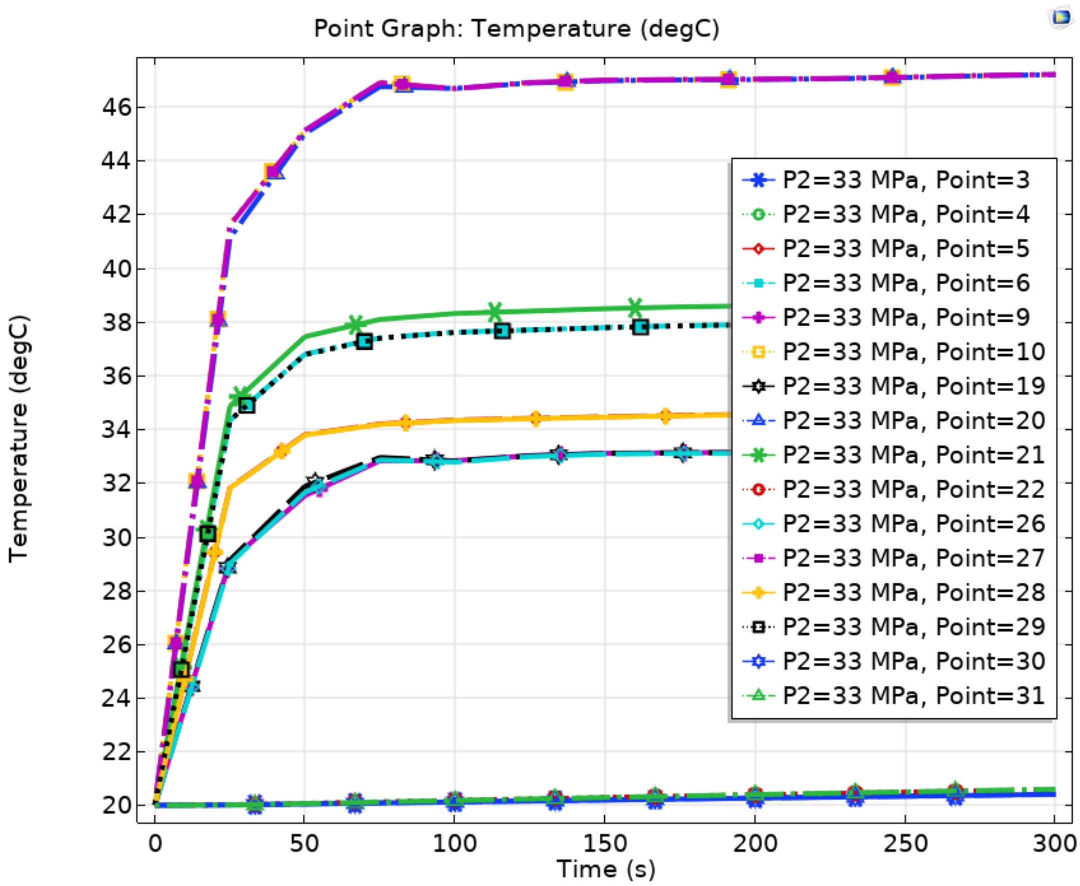


Figure (4-13) the relationship between temperature disrepute and time required for spacemen two in vertical direction with mass of hydrogen gas (1000g)

For the third case study in the vertical position, hydrogen gas pressure was applied to the same cylinder with the same amount (33 MPa), but with a lower mass (500 g) and a lower flow mass ratio amount (1.67 g/s) and the temperature was lower than in previous models. Where the percentage of decrease (43.7%) compared to the first model, compared to the second model, and the percentage of decrease in temperature (25%) compared to the second model. So that the temperature inside the cylinder is reduced (45 °C) and the reason for this is due to the lower mass of hydrogen pumped into the cylinder and the reduction in the proportion of flow mass applied inside the cylinder, the resulting temperature is taken into account as a safe temperature compared to the rest of the previous research, it was also noted a decrease in temperature in the vertical position compared to the horizontal position of the same cylinder and the same amount of hydrogen pumped into the cylinder in the same way applied. Pressure where the amount of decrease (10%) compared to the model in the horizontal position and Figure (4-14) shows the difference in temperature between inside and outside the cylinder.

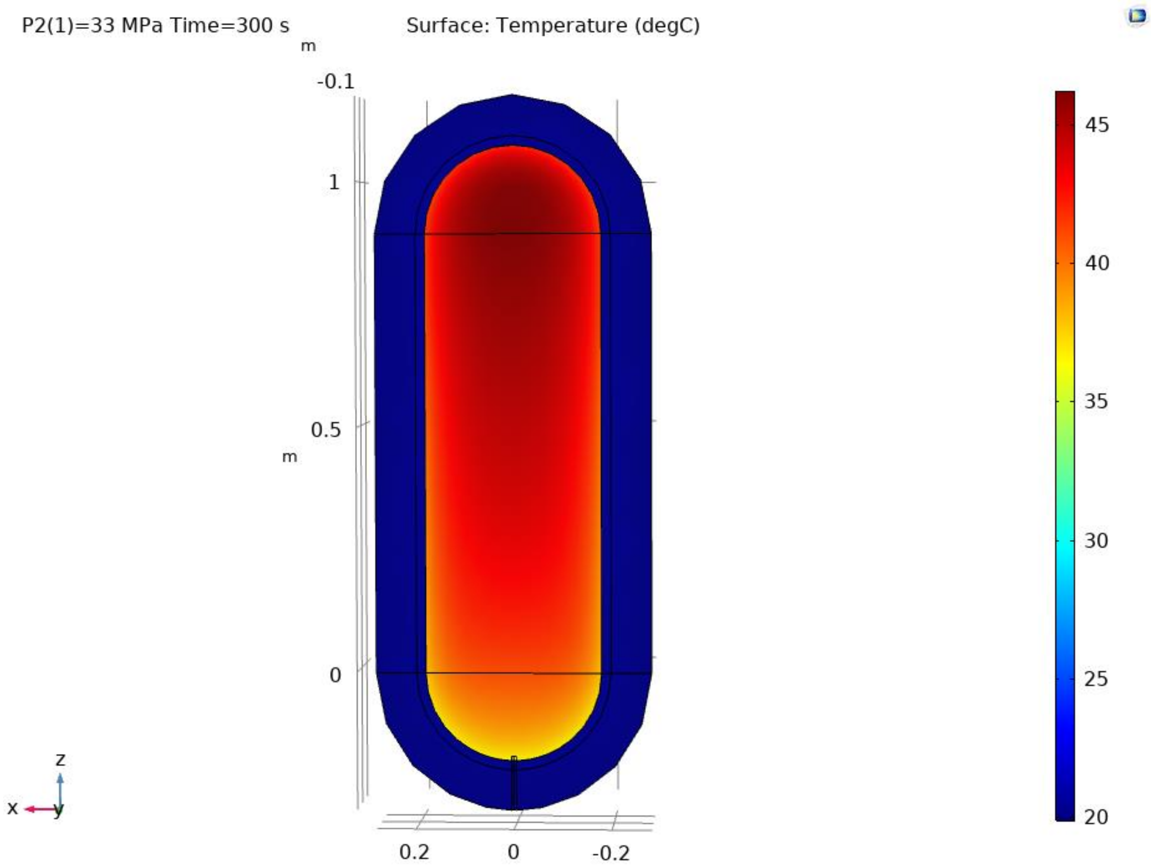


Figure (4-14) variation temperature between inner and outer of the cylinder for spacemen three in the vertical direction with mass of hydrogen gas (500g)

In the vertical position, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution was observed according to the different places taken on the cylinder wall and pressure applied to the same amount of hydrogen gas being pumped into the cylinder, as well as a difference in the relationship between temperature and time in the horizontal position than in the vertical position as shown in the following figure (4-15).

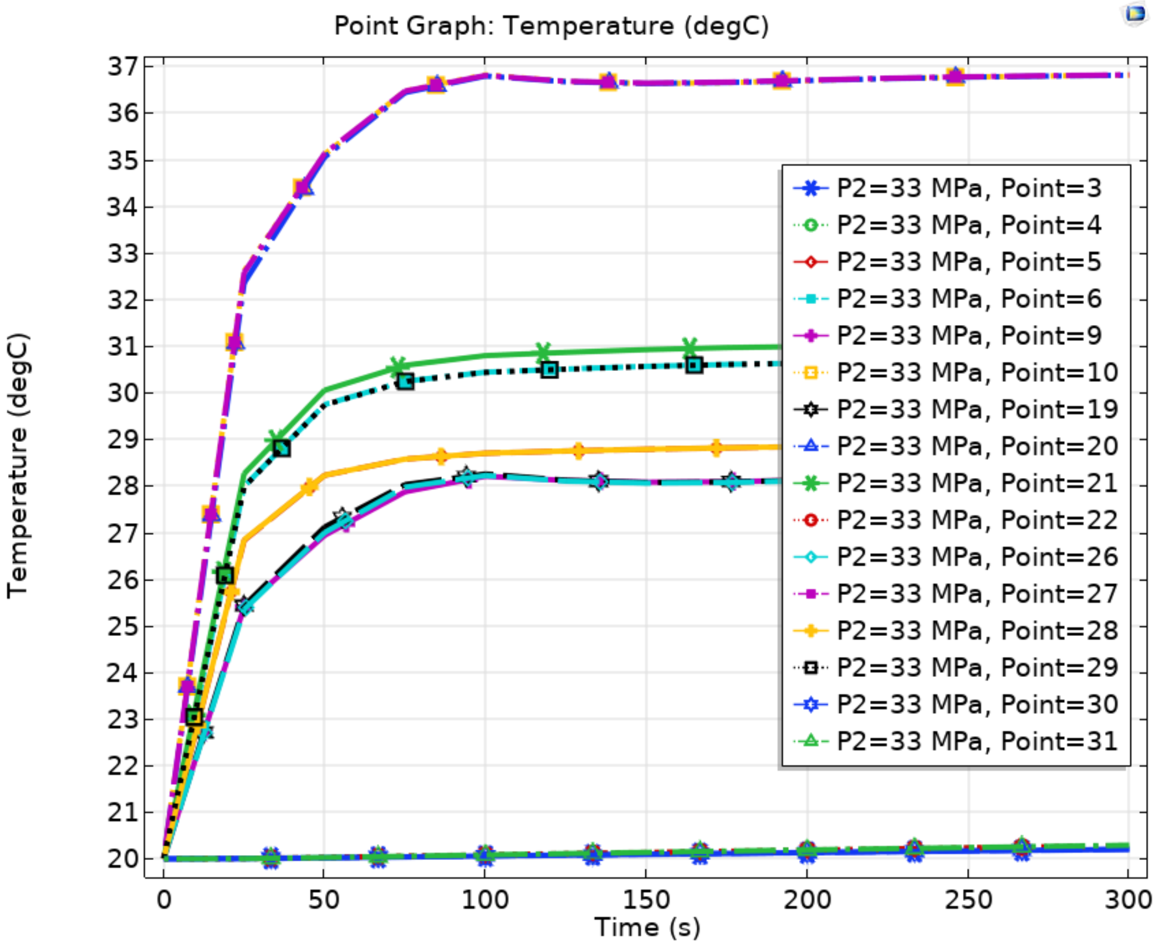


Figure (4-15) relationship between temperature distribution and time required for spacemen three in vertical direction with mass of hydrogen gas (500g)

4.2.3. The cylinder with pressure of hydrogen (25MPa) and horizontal position

For the second case study, the first sample was studied, where a quantity of hydrogen gas (1000 g) was pumped at a pressure of (25 Mpa), and the results showed that the temperature rose to (80 °C) to throw the highest pressure (25MPa) Flow mass ratio (3.33 g/s) although the pressure applied to the cylinder was lower than in the previous case to (25 MPa), an increase in temperature was found due to the mass flow rate effect where is higher with lower pressures and this was in agreement with the researcher **Liu et al.[1]** which indicated that the filling from a lower pressure in cylinder yields a higher temperature rise as a greater amount of hydrogen filled into the cylinder, and he found that the increase in temperature was (12.5%) compared to pressure (33MPa) with the same mass that was pumped into the cylinder. The cylinder temperature was distributed, where the highest temperature was the hydrogen temperature, compared to the other parts of the cylinder, where the cylinder surface was the coldest as a result of heat exchange between the cylinder surface and its surroundings. Figure (4-16) shows the temperature difference between the inside and outside of the cylinder

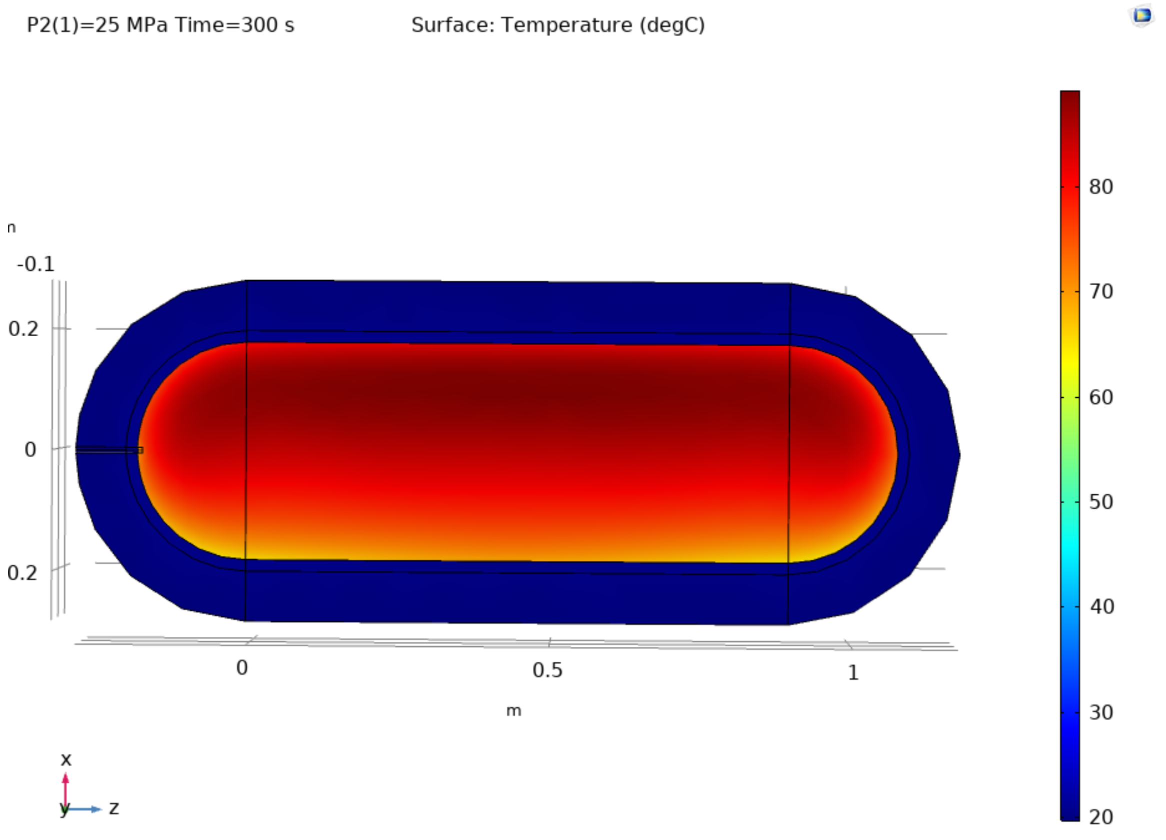


Figure (4-16) variation temperature between inner and outer the cylinder for spacemen one in the horizontal direction with mass of hydrogen gas (1000g)

In the horizontal position, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution that was observed according to the different places taken on the cylinder wall and the pressure applied the same amount of hydrogen gas is pumped into the cylinder, as shown in the following figure (4-17).

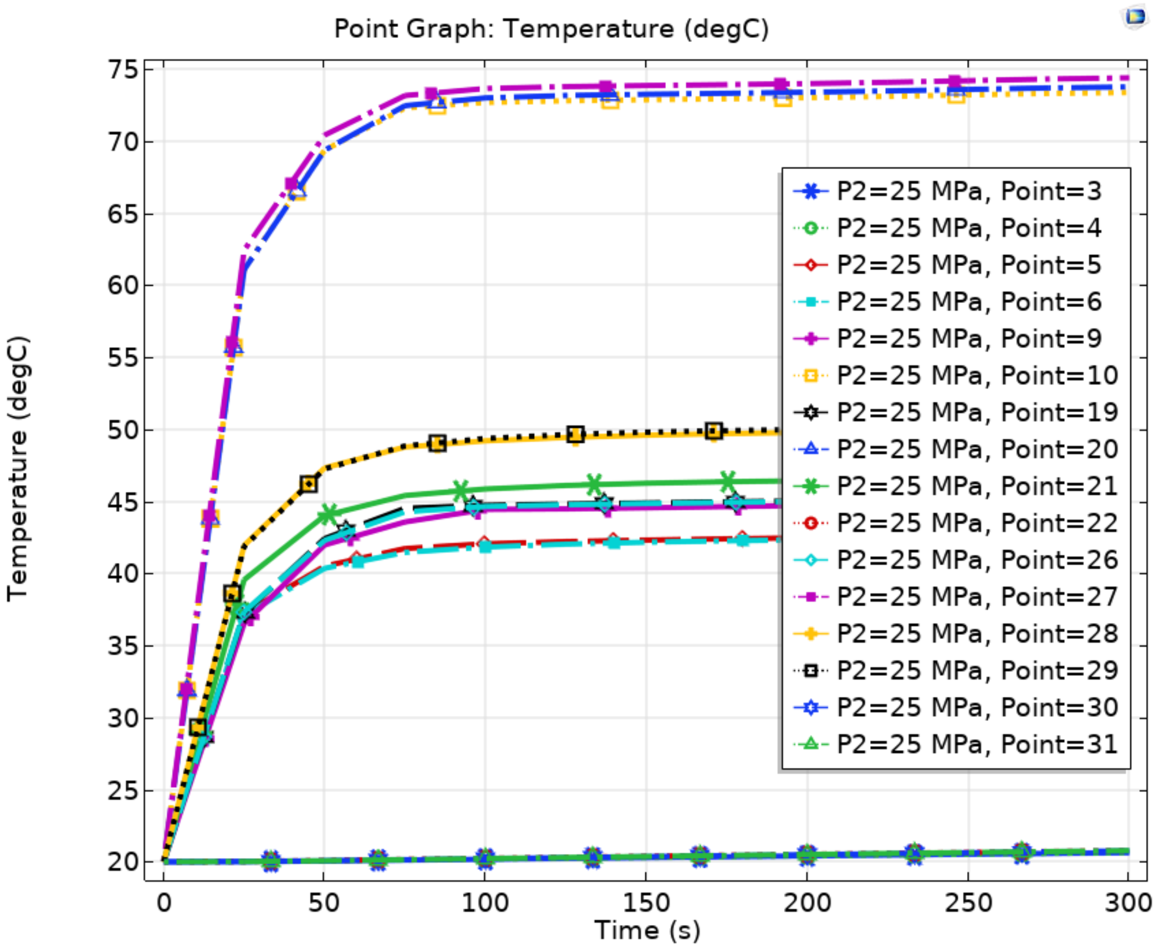


Figure (4-17) the relationship between temperature distribution and time required for spacemen one in horizontal direction with mass of hydrogen gas (1000g)

For the second case, the three-dimensional sample was studied, where a quantity of hydrogen gas (500 g) was pumped at a pressure of (25 MPa), and the results showed that the temperature reached (55 °C) at a pressure of (25 MPa).) and the mass flow rate was (1.67 g/s) although the pressure applied to the cylinder was lower than in the previous case to (25 MPa), there is an increase in temperature due to the effect of mass flow and it was found that the increase in The temperature was (9.09%) compared to the pressure (33 MPa) with the same mass pumped into the cylinder, and this increase is attributed to the effect of mass flow rate which has a greater effect when used with lower pressures. The cylinder temperature was distributed, with the highest temperature being the temperature of hydrogen, compared to the rest of the cylinder parts, and the cylinder surface has a lost temperature as a result of heat exchange between the cylinder surface and its surroundings. Similarly, when compared to the first model at the same pressure, but with a lower mass flow rate, the temperature reduced to (31.25%). Figure (4-18) shows the temperature difference between the inside and the surface of the cylinder

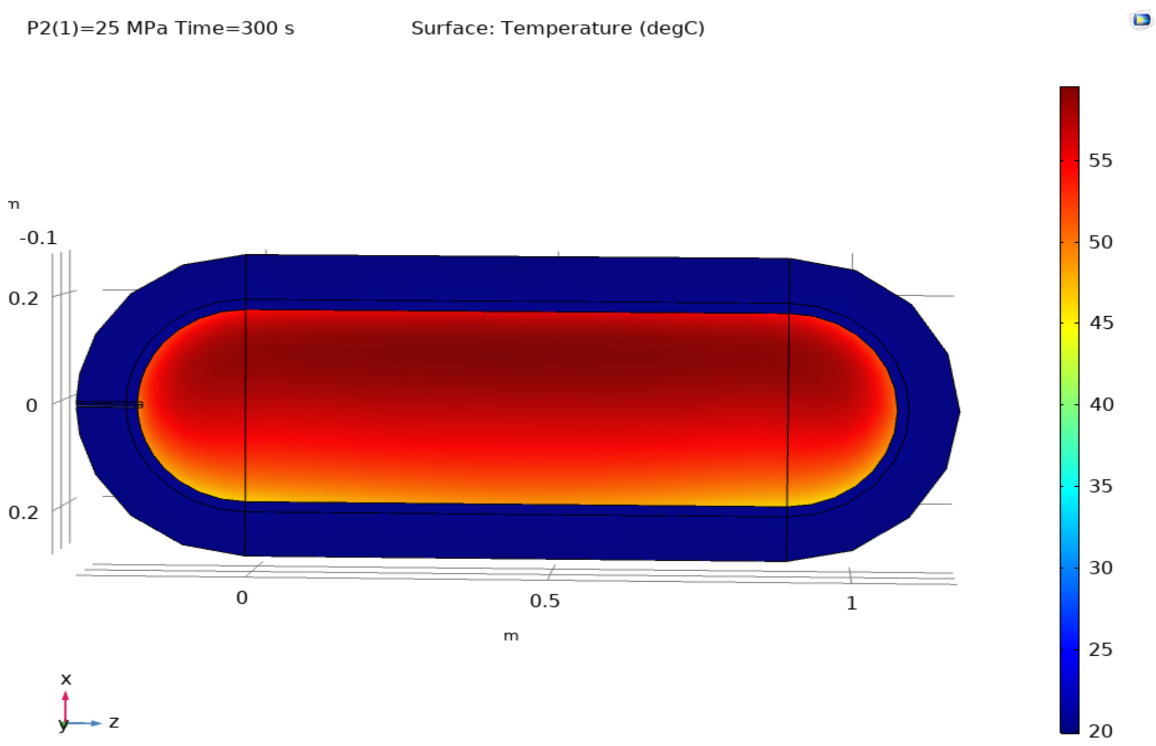


Figure (4-18) variation temperature between inner and outer the cylinder for spacemen two in the horizontal direction with mass of hydrogen gas (500g)

In the horizontal position, the time required taken to fill the cylinder was (300 sec) and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution that was observed according to the different places taken on the cylinder wall and the pressure applied The same amount of hydrogen gas is pumped into the cylinder, as shown in the following figure (4-19).

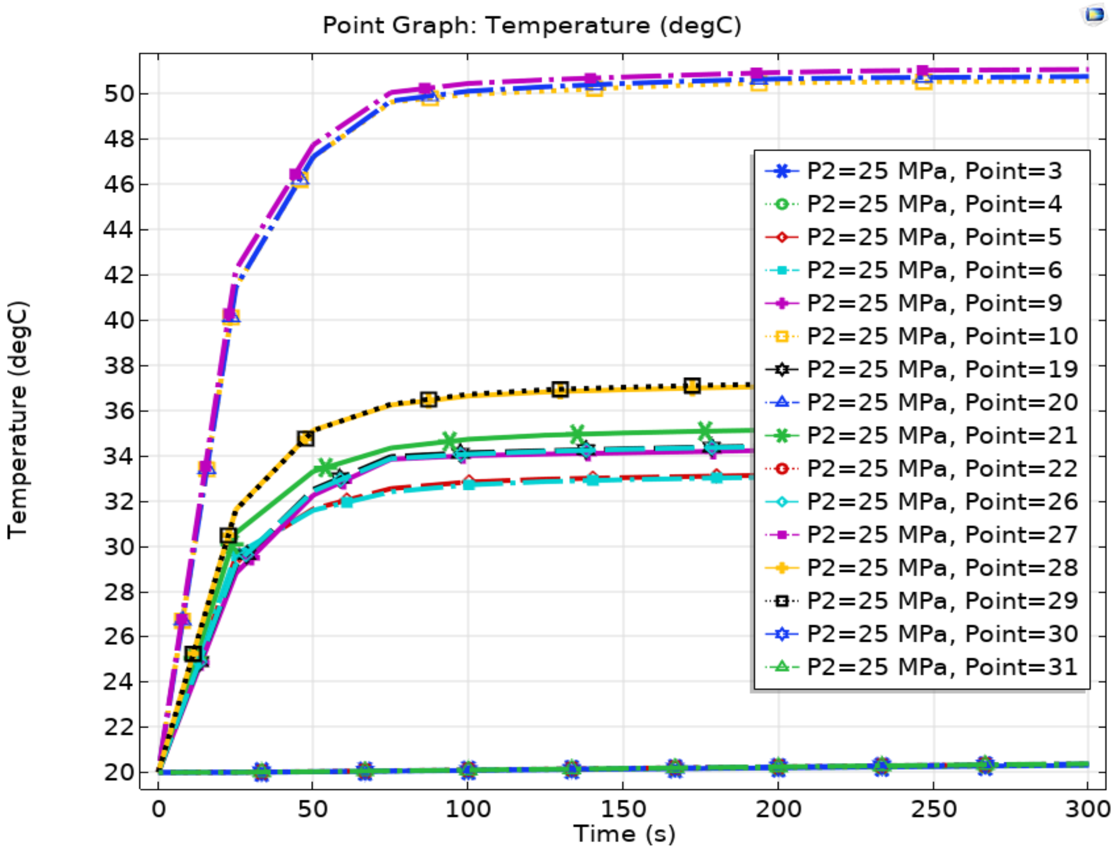


Figure (4-19) the relationship between temperature distribution and time required for spacemen three in the horizontal direction with mass of hydrogen gas (500g)

4.2.4. The cylinder with pressure of hydrogen (25 MPa) and vertical position

For the second case, the first sample was studied in the vertical position, where a quantity of hydrogen gas (1000 g) was pumped at a pressure of (25 MPa), and the results showed an increase in the temperature to (70 °C). For pouring the highest pressure (25 MPa) and mass flow ratio is (3.33 g/s) Although the pressure applied to the cylinder was lower than in the previous case to (25MPa), there was an increase in temperature due to the effect of mass flow and it was found that the increase in temperature was (14.28%) compared to With a pressure (33 MPa) of the same mass in the vertical position that was pumped into the cylinder this is due to the effect of mass flow rate when used with lower pressures. When compared to the horizontal position at the same pressure (25MPa) and the same mass, a temperature decrease of (12.5%) was observed the temperature of the cylinder was distributed where the highest temperature was hydrogen temperature compared to the rest of the cylinder where the surface of the cylinder was lowest of temperature. The result of heat exchange between the surface of the cylinder and its surroundings. The following figure (4-20) shows the temperature difference between the inside and outside of the cylinder from the hydrogen in the cylinder.

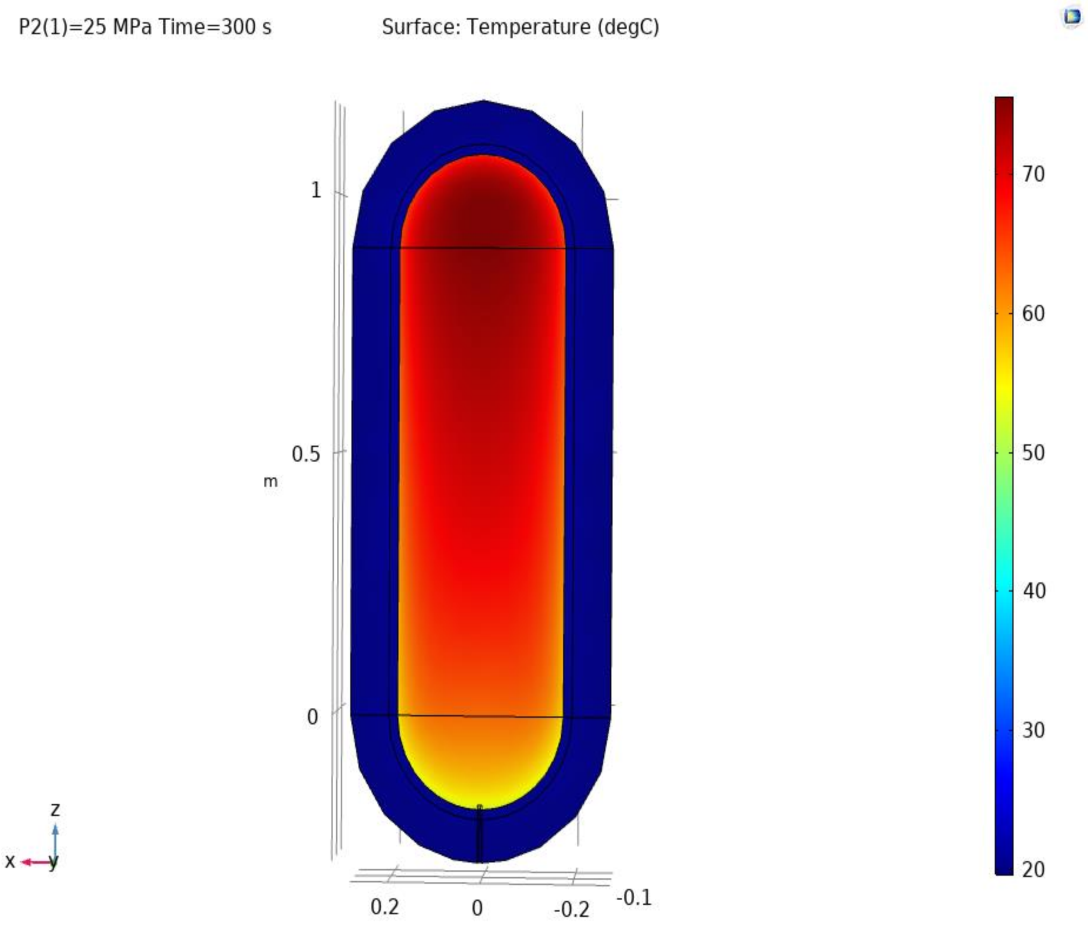


Figure (4-20) variation temperature between inner and outer the cylinder for spacemen one in the vertical direction with mass of hydrogen gas (1000gm)

In the vertical position, the time taken to fill the cylinder was (300 sec), and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution was observed according to the different places taken on the cylinder wall and pressure applied to the same amount of hydrogen gas being pumped into the cylinder, as well as a difference in the relationship between temperature and time in the horizontal position than in the vertical position as shown in the following figure (4-21).

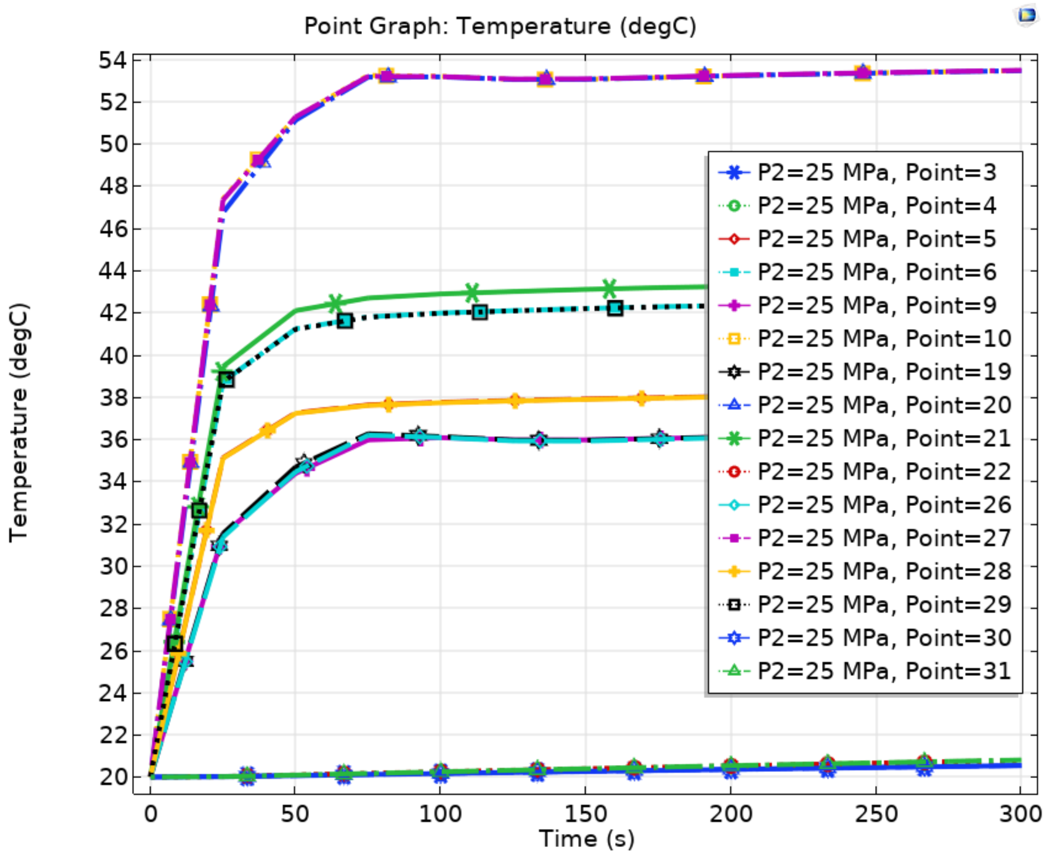


Figure (4-21) the relationship between temperature distribution and time required for spacemen one in the vertical direction with mass of hydrogen gas (1000g)

For the second case, the second sample was studied in the vertical position, where a quantity of hydrogen gas (500 g) was pumped at a pressure of (25MPa), and the results showed that the temperature reached (50 °C). For a higher cast pressure degree (25 MPa) and flow mass ratio (1.67 g/s) although the pressure applied to the cylinder was lower than in the previous case to (25 MPa), there was an increase in temperature due to the effect of Mass flow and it was found that the increase in temperature was (10%) compared to pressure (33 MPa) with the same mass being pumped into the cylinder, and this increase is due to the effect of mass flow rate which has a greater effect. When used with less pressure. The cylinder temperature was distributed, with the highest temperature being the temperature of hydrogen, compared to the rest of the cylinder parts, and the cylinder surface being the coldest as a result of heat exchange between the cylinder surface and its surroundings. Similarly, when comparing with the first model at the same pressure in the vertical position, but with a lower flow rate, we find that the temperature drops to (28.57%). Similarly, also when comparing with the same pressure and same mass but in the horizontal position it was found that there is a decrease in temperature in the vertical position recorded in the horizontal position a decrease of (16.67%). The following figure (4-22) shows the temperature difference between the inside and outside of the cylinder

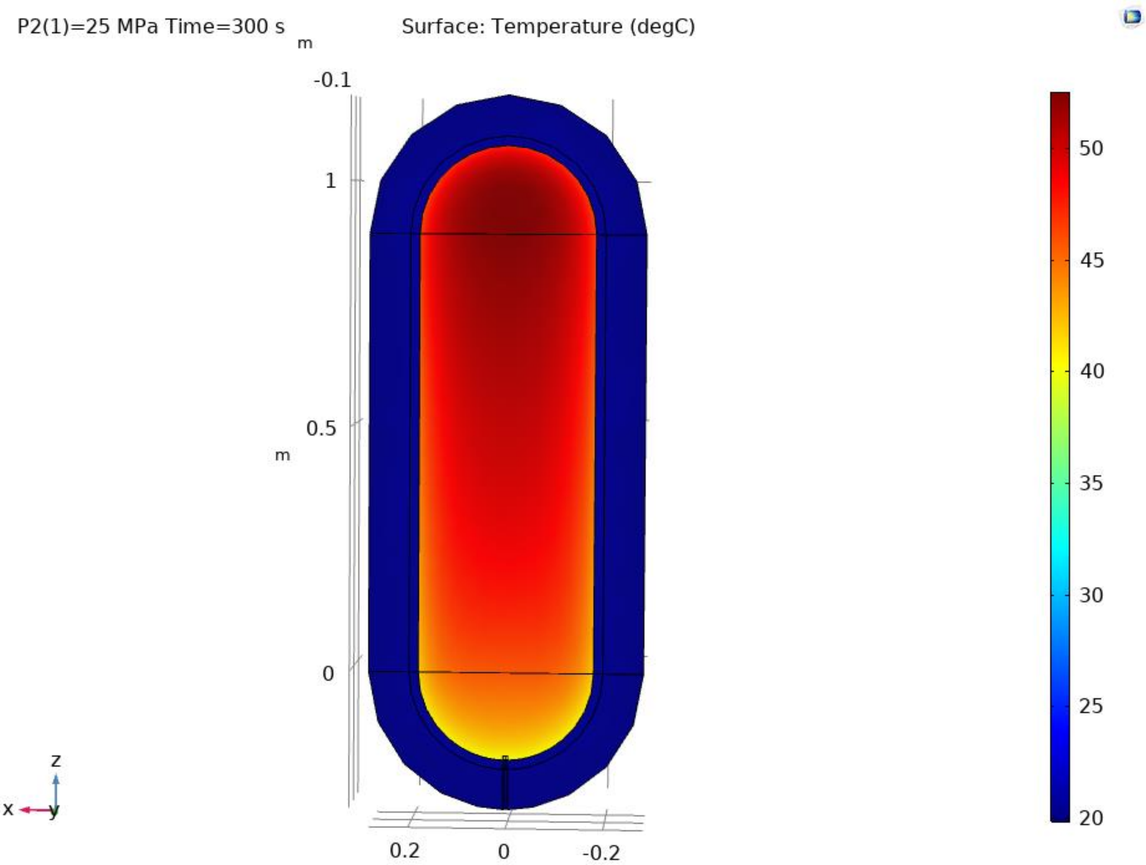


Figure (4-22) variation temperature between inner and outer the cylinder for spacemen two in the vertical direction with mass of hydrogen gas (500g)

In the vertical position, the time taken to fill the cylinder was (300 seconds), and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution was observed according to the different places taken on the cylinder wall and pressure applied to the same amount of hydrogen gas being pumped into the cylinder, as well as a difference in the relationship between temperature and time in the horizontal position than in the vertical position as shown in the following figure (4-23).

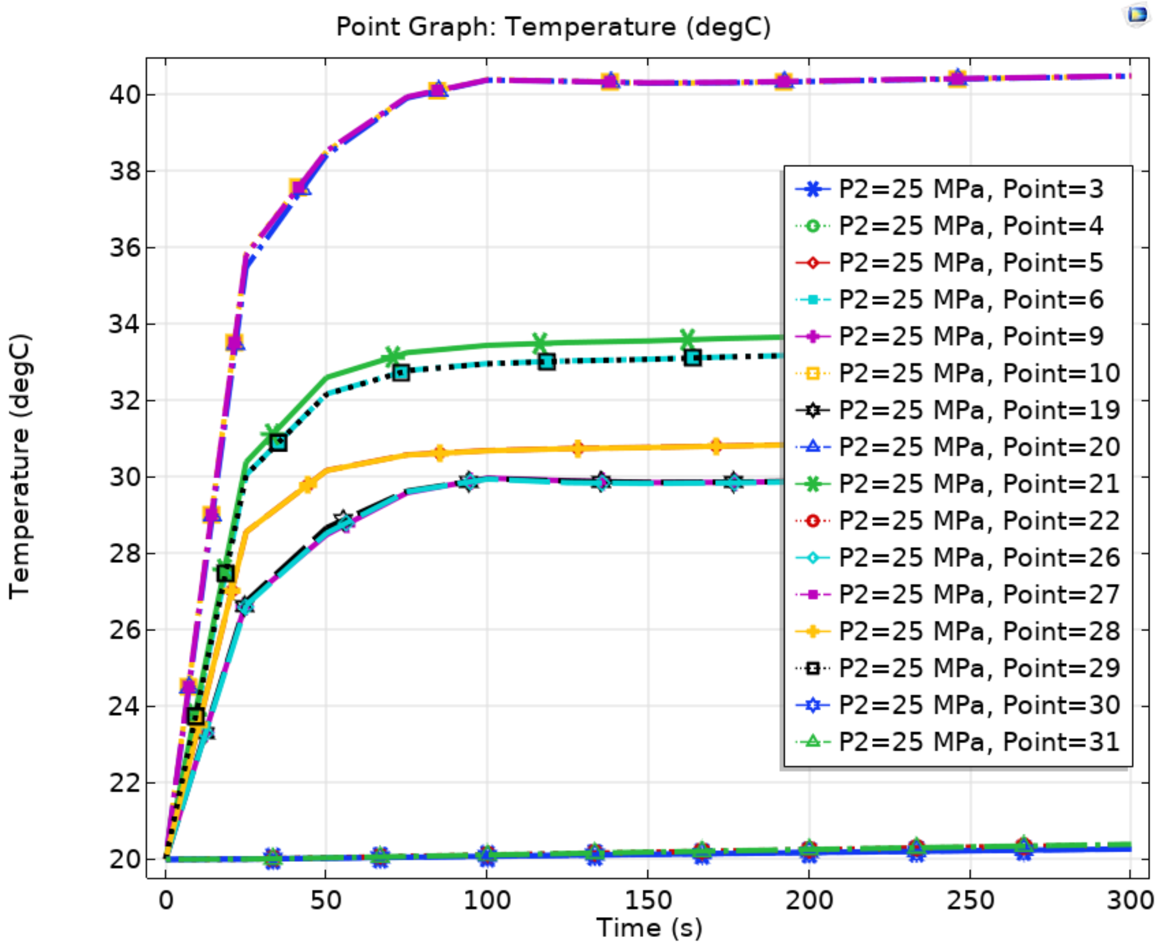


Figure (4-23) the relationship between temperature distribution and time required for spacemen two in vertical direction with mass of hydrogen gas (500g)

4.2.5. The cylinder with pressure of hydrogen (20MPa) and horizontal position

For the third case, the sample was studied where a quantity of hydrogen gas (500 g) was pumped at a pressure of (20 MPa), and the results showed an increase in the temperature to (65 °C) at a pressure of (20 MPa) and the mass flow rate (1.67 g/s) Although the pressure applied to the cylinder was lower than in the previous case to (20 MPa), an increase in temperature was found due to the mass flow effect and that was found to be the increase in temperature was (23.07%) compared to pressure (33 MPa) with the same mass that was pumped into the cylinder. It was found that the increase in temperature was (15.38%) compared to pressure (25 MPa) with the same mass that was pumped into the cylinder. It was found that there is a difference in temperature inside the cylinder and between the cooler surface of the cylinder as a result of heat exchange between the surface of the cylinder and its surroundings. The following figure (4-24) shows the temperature difference between the inside and outside of the cylinder.

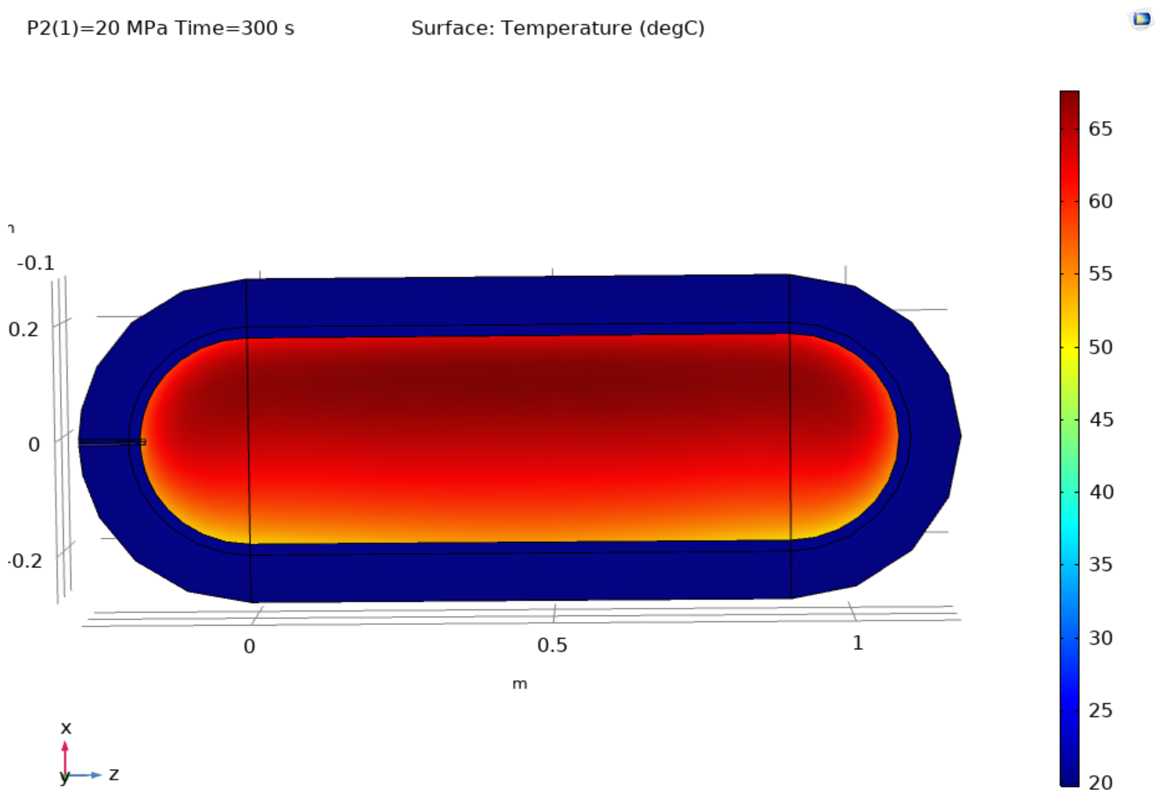


Figure (4-24) variation temperature between inner and outer of the cylinder for spacemen one in the Horizontal direction with mass of hydrogen gas (500g)

In the horizontal position, the time taken to fill the cylinder was (300 sec) and the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution that was observed according to the different places taken on the cylinder wall and the pressure applied The same amount of hydrogen gas is pumped into the cylinder, as shown in the following figure (4-25).

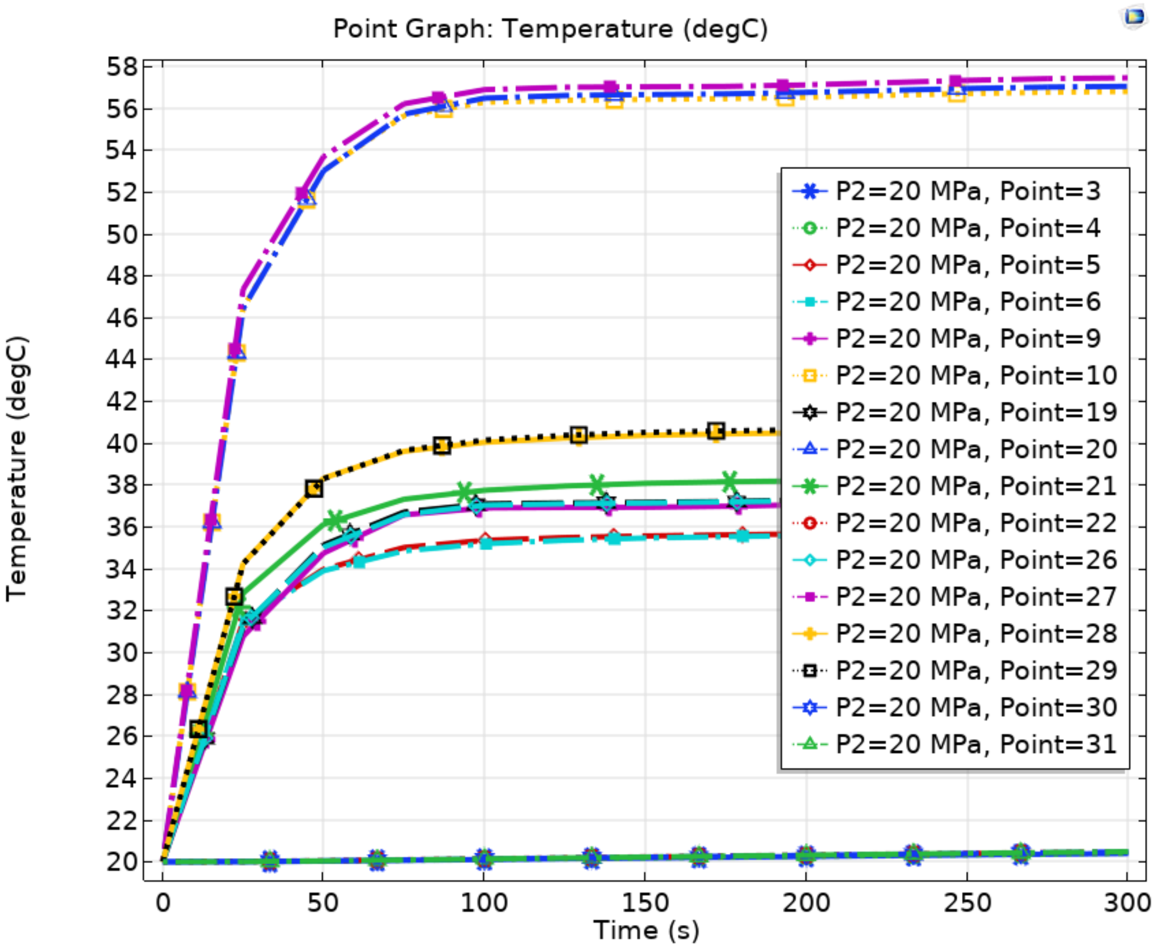


Figure (4-25) the relationship between temperatures distribution and time required for spacemen one in horizontal direction with mass of hydrogen gas (500g)

4.2.6. The cylinder with pressure of hydrogen (20MPa) and vertical position

For the third case, the sample was studied in the vertical position, where a quantity of hydrogen gas (500 g) was pumped at a pressure of (20 MPa), and mass flow rate (1.67 g/s) and the results showed an increase in temperature to (55 °C). Although the pressure applied to the cylinder was lower than the previous case to (20 MPa), there was an increase in temperature due to the mass flow effect and it was found that the increase in the temperature was (18.18%) compared to the pressure (33 MPa) with the same mass that was pumped into the cylinder, as well as when compared to the pressure (25 MPa), and with the same mass there was also a temperature increase by (9.09%), and this is attributed the increase to the effect of mass flow rate has greater effect when used at lower pressure. But when compared to the horizontal position at the same pressure and the same mass, it was found that there is a decrease in the temperature of the vertical position compared to the horizontal position by (15.38%), where the highest temperature was the temperature of hydrogen compared to the rest of the cylinder parts and the surface of the cylinder was the coldest as a result of heat exchange between the surface of the cylinder and its surroundings. The following figure (4-26) shows the temperature difference between the inside and outside of the cylinder

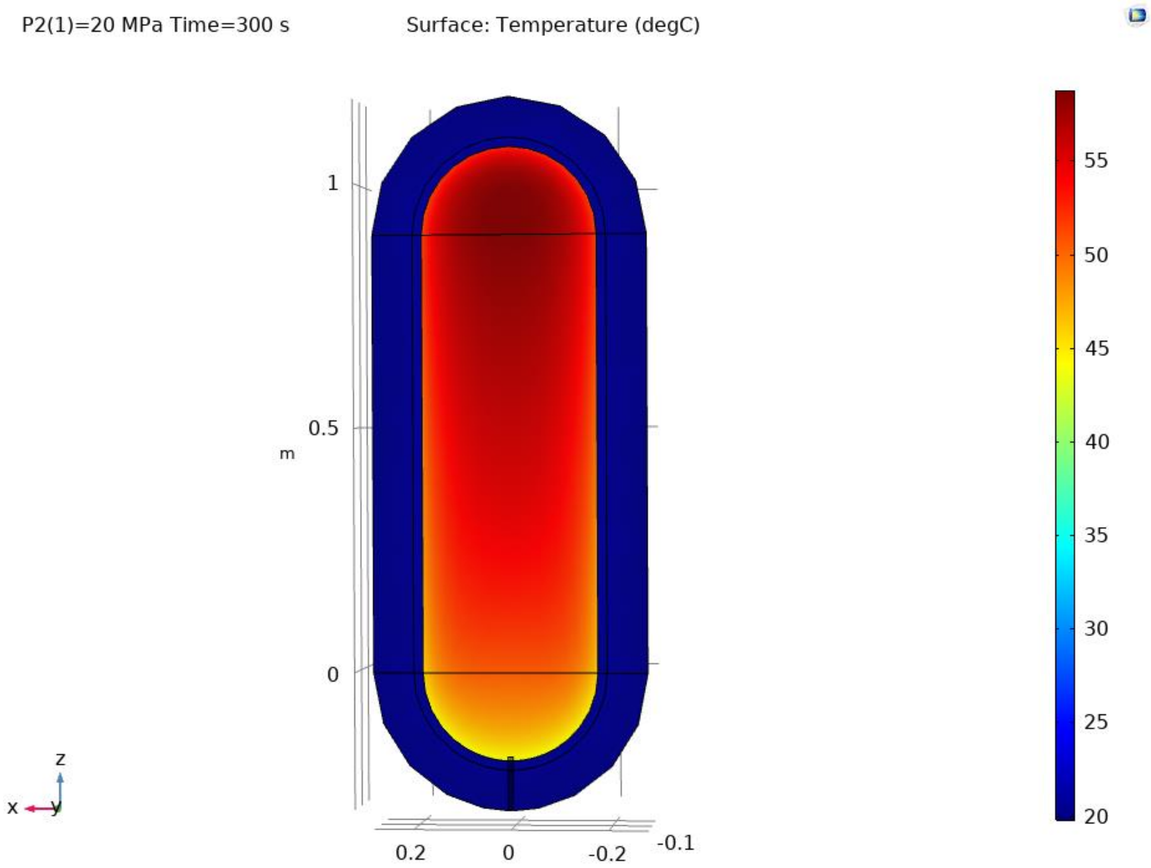


Figure (4-26) variation temperature between inner and outer of the cylinder for spacemen one in the vertical direction with mass of hydrogen gas (500g)

In the vertical position, the time taken to fill the cylinder was (300 sec), the relationship between temperature and time was calculated by the pressure applied from the point taken on the cylinder wall, where there is a difference in the temperature distribution that was observed according to the different places taken on the cylinder wall and the pressure applied on the same amount of hydrogen gas that is pumped into the cylinder, in addition to a difference in the relationship between temperature and time in the horizontal position from the vertical position as shown in the following figure (4-27).

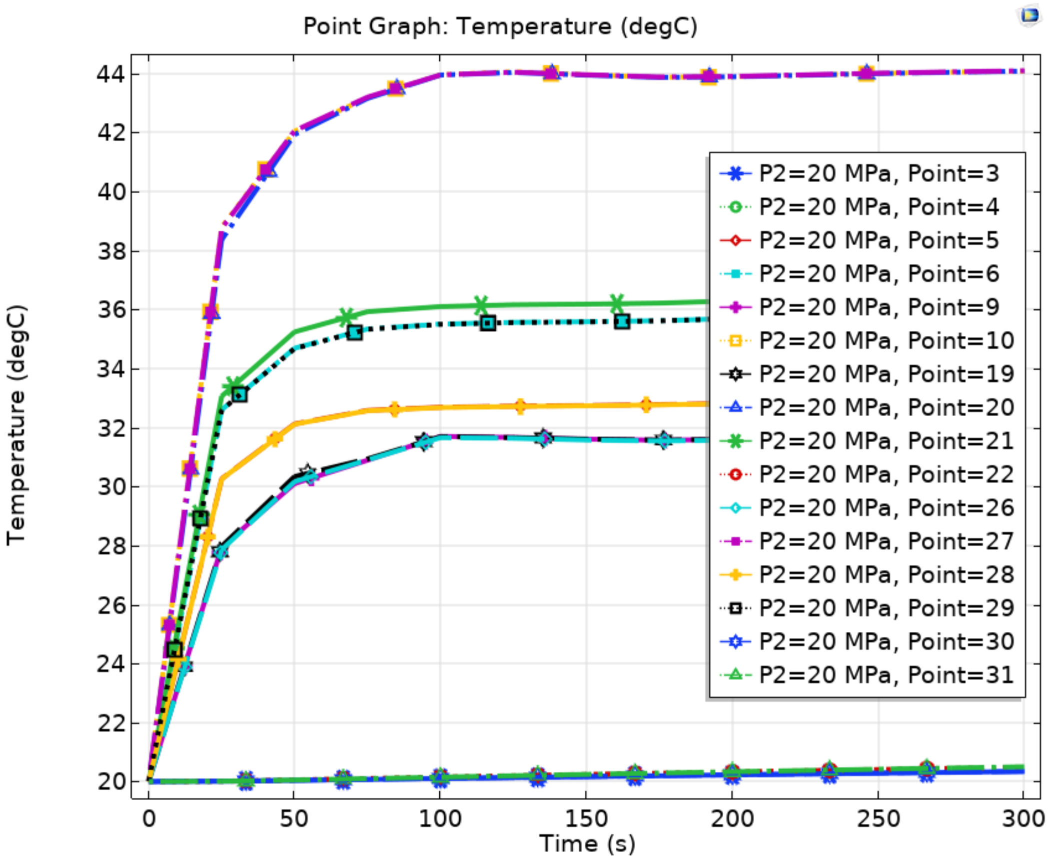


Figure (4-27) the relationship between temperature distribution and time required for spacemen one in the vertical direction with mass of hydrogen gas (500g)

4.3. Heat transfer coefficient

4.3.1 Heat transfer coefficient at pressure (33 MPa) with horizontal position

Heat transfer between gas and cylinder liner remains the most important for simplified uniform temperature models. The heat transfer coefficient of the case was calculated at a pressure of (33 MPa) and a mass of (1500 g) as a result of the high pressure and the high flow rate, which reached its peak of (2962.7 W/m^2 ^{o}C) at the time of (300sec), noting that the rise in the heat transfer coefficient is because of the high mass flow rate, as there is a close relationship between the mass flow rate and the heat transfer coefficient, where the higher the mass flow rate, the higher the heat transfer coefficient, and that was in agreement with the researcher **Dicken and Mrida, [27]** which indicate the high mass flow rate, caused to the increase in the heat transfer coefficient as shown in Figure (4-28).

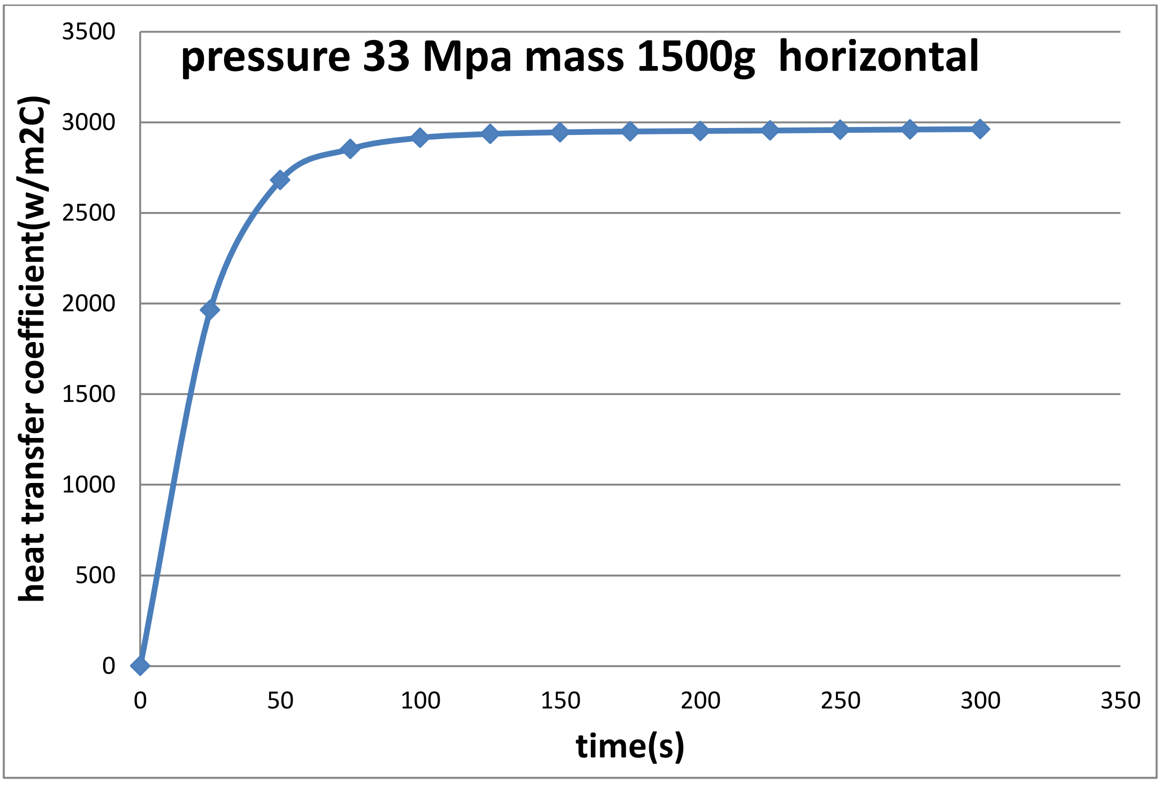


Figure (4-28) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (1500g) when the cylinder in the horizontal position

Also in this case, as a result of reducing the mass to (1000g) and the mass flow rate to (3.33g/s) with time at the same pressure (33MPa), it was found that the heat transfer coefficient also decreased, reaching its peak of (2058.7 W/m^2 ^oC) at the time (300sec) When comparing it with the first case it was found that the rate of decline reached (30.51%), as shown in Figure (4-29)

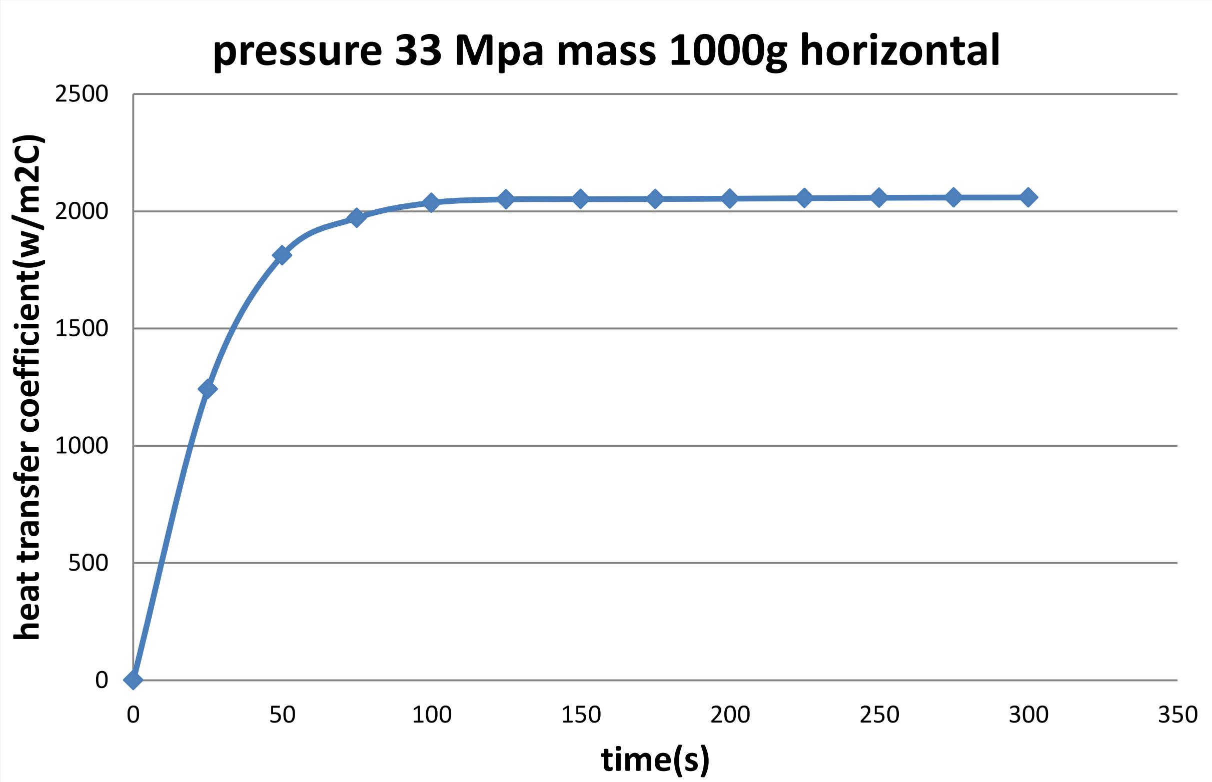


Figure (4-29) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (1000g) when the cylinder in the horizontal position

Also in this case, as a result of decreasing mass to (500 g) and mass flow rate to (1.67 g/s) with time at the same pressure (33 MPa), it was found that the heat transfer coefficient also decreased and reached its peak of (950.19 W/ m^2 ^oC) at that time (300 sec). We conclude from this that the lower the mass flow rate with time, the lower the temperature, and also the lower the heat transfer coefficient between the gas and the inner surface of the cylinder, when comparing it with the first and second cases, we found that the percentage of decrease has reached (67.92%), and with the second it has reached (53.84%) as shown in Figure (4-30)

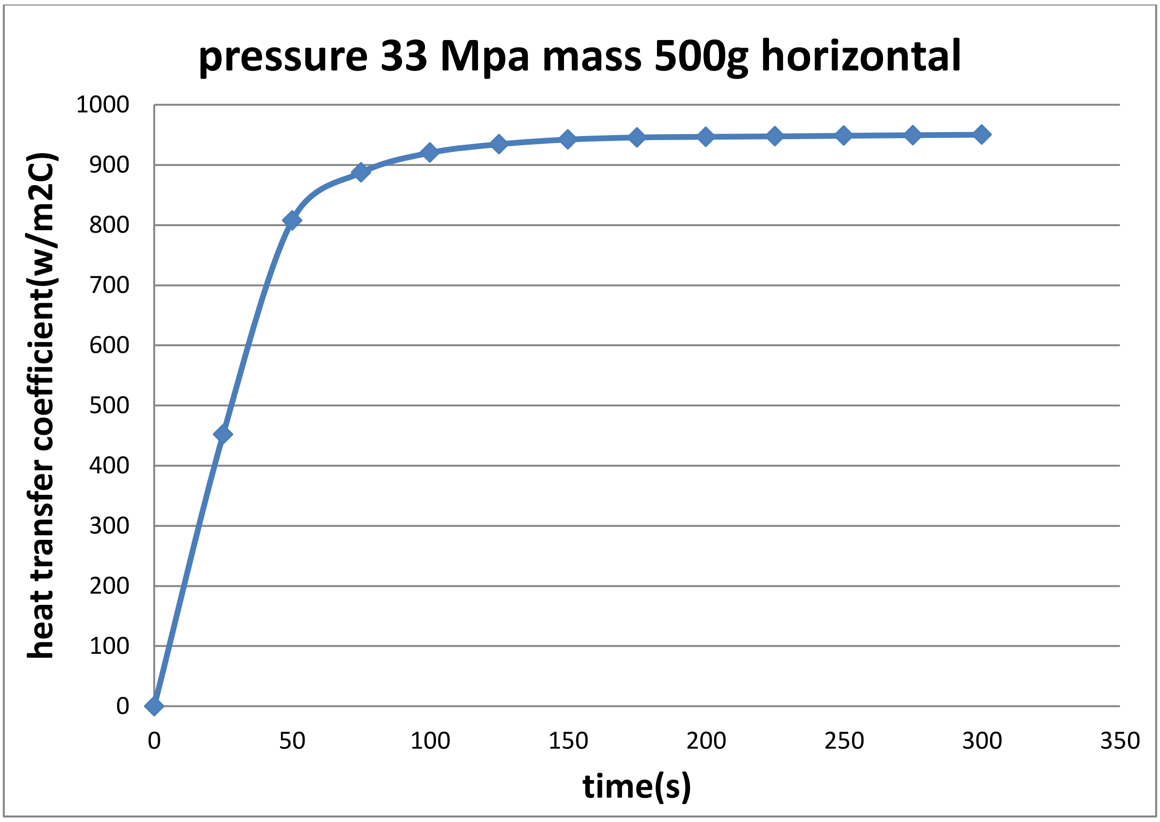


Figure (4-30) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (500g) when the cylinder in the horizontal position

4.3.2. heat transfer coefficient at pressure (33 MPa) with vertical position

But in this case in the vertical position when taking pressure (33 MPa), mass (1500 g) and mass flow rate (5 g/s) with time at the same pressure (33 MPa), it was found that the heat transfer coefficient reached a peak(3112.4 W/m^2 ^{o}C) as It is shown in Figure (4-31).

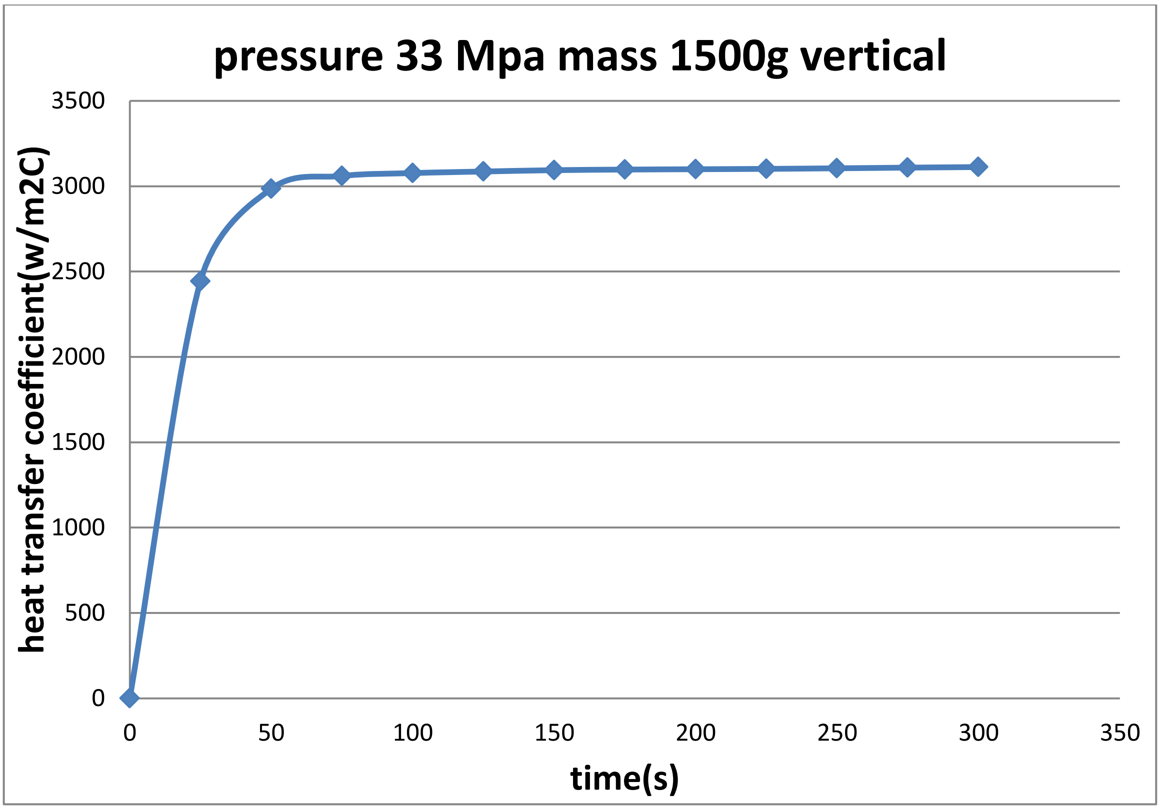


Figure (4-31) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (1500g) when the cylinder in the vertical position

But in this case in the vertical position when taking pressure of (33MPa) and mass of (1000g) and mass flow rate to (3.33 g/s) with time ,it was found that the heat transfer coefficient decreased and the reason for this is due to the reduction of mass that was pumped as well as the mass flow rate, which reached its peak at (2016.3W/m^2 ^oC), at that time (300 sec), When comparing it with the first case of the vertical position the percentage of decrease (35.21%)was found to be, as shown in Figure (4-32)

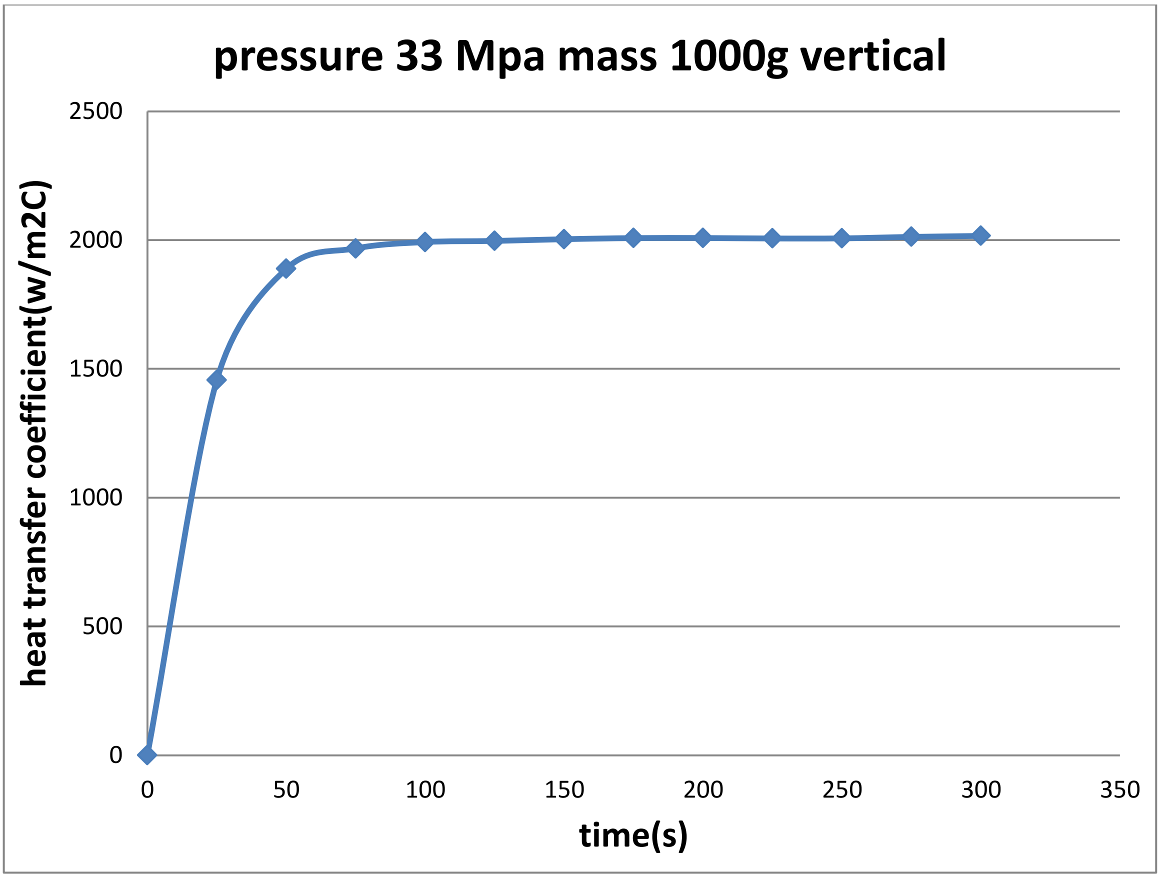


Figure (4-32) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (1000g) when the cylinder in the vertical position

also in this case in the vertical position when taking pressure of (33MPa) and mass of (500g) and mass flow rate to (1.67 g/s) with time ,it was found that the heat transfer coefficient decreased and the reason for this is due to the reduction of mass that was pumped as well as the mass flow rate, which reached its peak at (932.49W/m^2 ^{o}C), at that time (300 sec) when comparing it with the first and second cases, it was found that the percentage of decrease was reached(70.03%), and with the second it reached(53.75%) as shown in Figure (4-33).

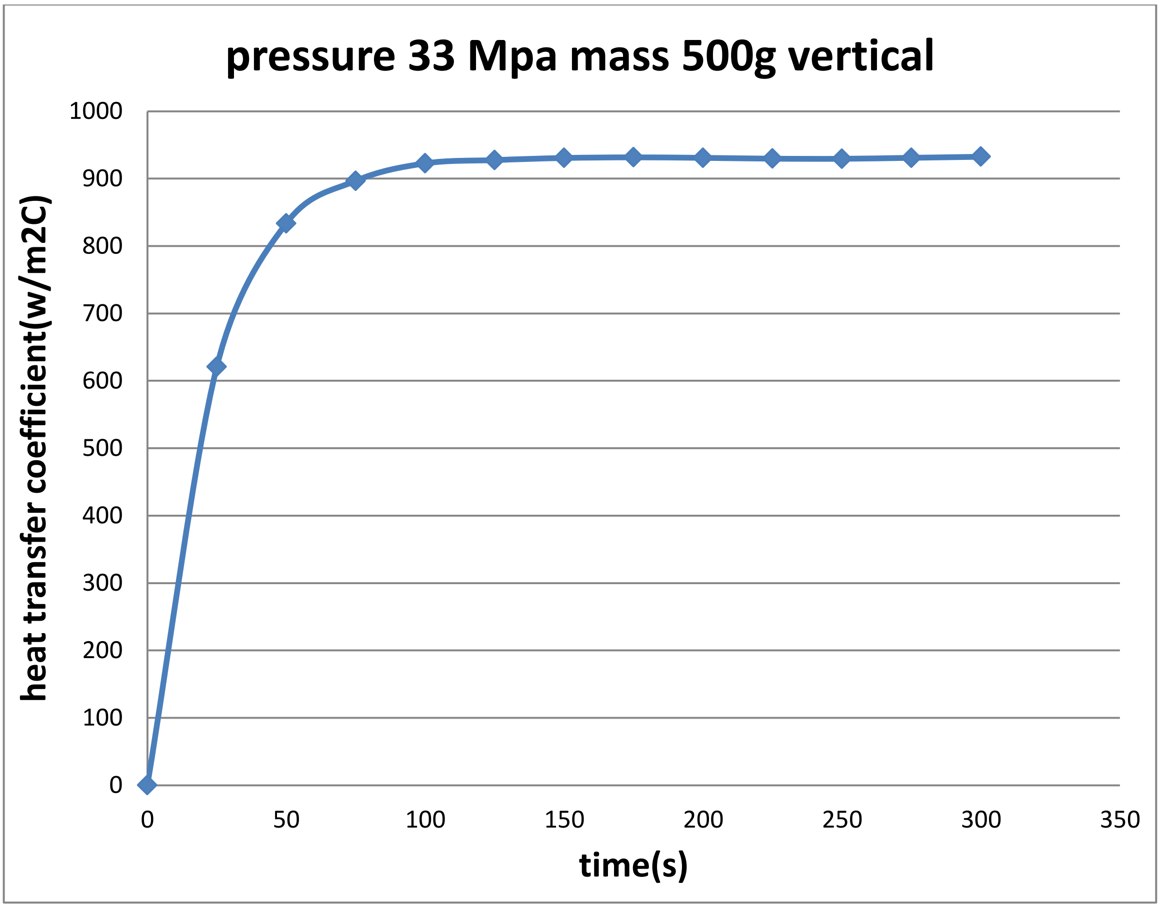


Figure (4-33) variation of the heat transfer coefficient versus the time at pressure (33Mpa) and mass (500g) when the cylinder in the vertical position

4.3.3. heat transfer coefficient at pressure (25 MPa) with horizontal position

In this case, we reduced the pressure to (25 MPa) with a mass (1000 g) and mass flow rate (3.33 g/s). It was found that the heat transfer coefficient increased to reach its peak (2629.5Wlm^2 ^{o}C). The reason for this is that the mass flow rate has a greater effect on the lower pressure and when we compare it with pressure of (33MPa) and with the same mass in the horizontal position; we find that the amount of increase was (21.7%). As shown in Figure (4-34).

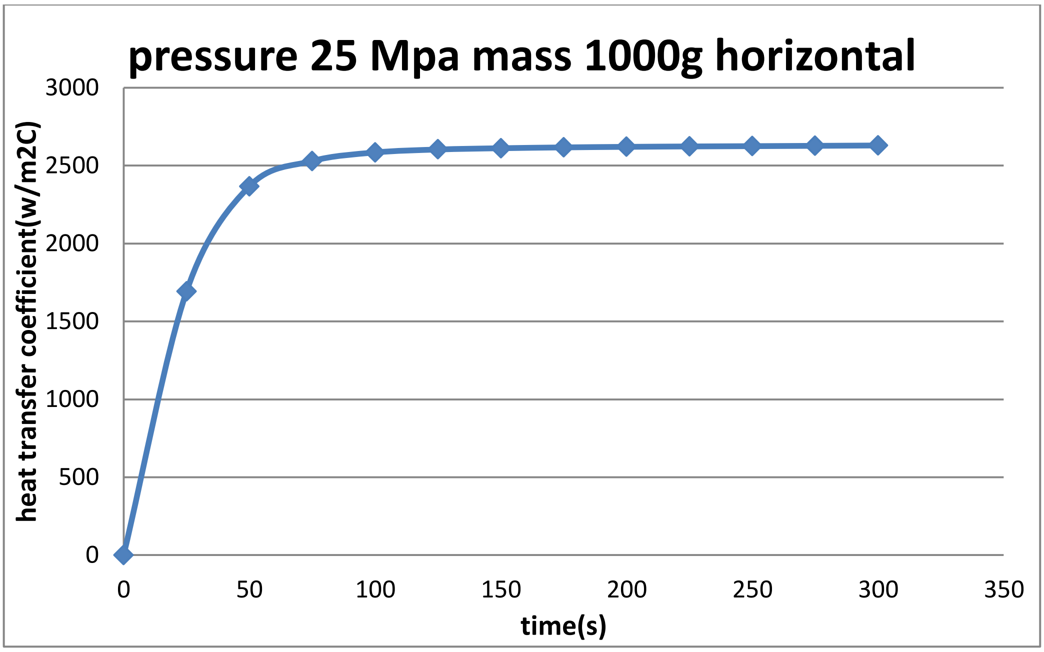


Figure (4-34) variation of the heat transfer coefficient versus the time at pressure (25Mpa) and mass (1000g) when the cylinder in the horizontal position

In this case, we reduced the pressure to (25 MPa) with a mass (500 g) and mass flow rate (1.67 g/s). It was found that the heat transfer coefficient decreased as a result of the decrease in mass, reaching its peak (1287 W/m^2 ^oC) When comparing it with mass (1000g) we find that the heat transfer coefficient decreases, and the percentage decreases(51.05%) to as shown in Figure (4-35).

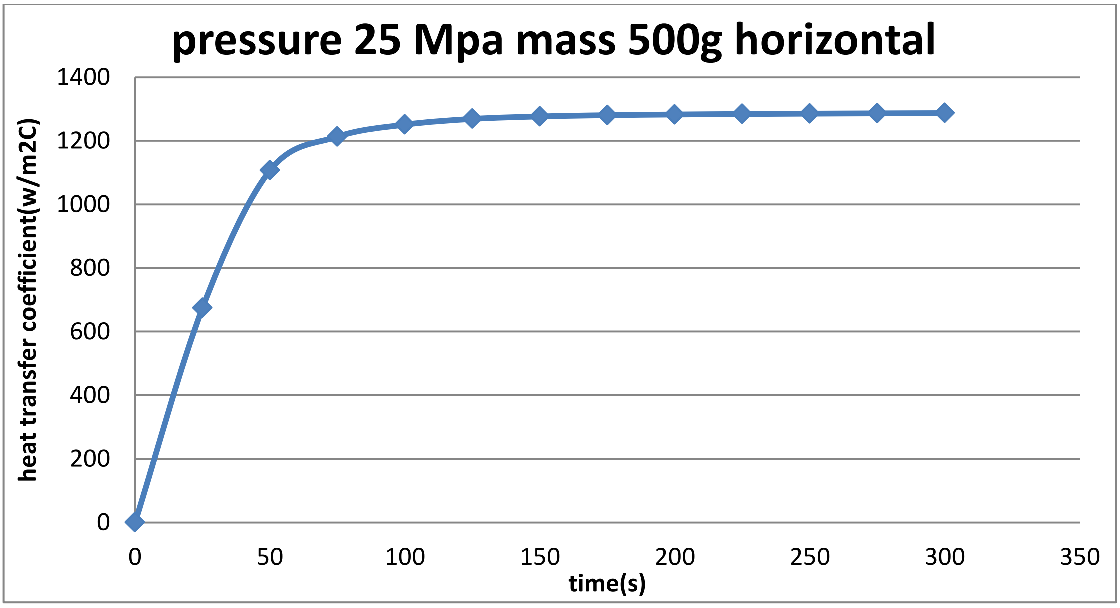


Figure (4-35 variation of the heat transfer coefficient versus the time at pressure (25Mpa) and mass (500g) when the cylinder in the horizontal position

4.3.4 heat transfer coefficient at pressure (25 MPa) with vertical position

In this case in the vertical position, we reduced the pressure to (25 MPa) with a mass (1000 g) and mass flow rate (3.33 g/s). It was found that the heat transfer coefficient increased, reaching its peak (2743.9W/m^2 ^{o}C). The reason for this is that the mass flow rate has a greater effect on the lower pressure and when we compare it with pressure of (33MPa) at the same mass and in the vertical position; we find that the amount of increase was (26.51%). As shown in Figure (4-36).

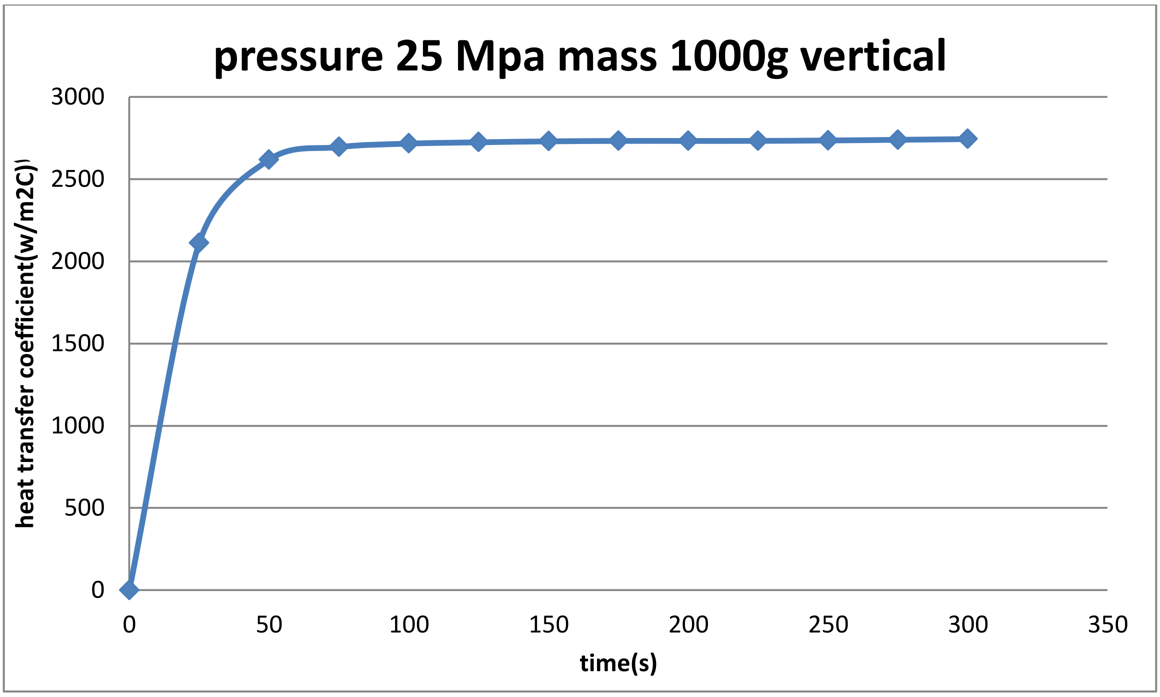


Figure (4-36) variation of the heat transfer coefficient versus the time at pressure (25Mpa) and mass (1000g) when the cylinder in the vertical position

In this case at vertical position, we reduced the pressure to (25MPa) with a mass of (500g) and a mass flow rate (1.67g/s). It was found that the heat transfer coefficient decreased as a result of the decrease in mass, as it reached a peak of (1286.7W/m^2 ^{o}C), but when we compare it with a pressure of(33MPa) at the same mass and the same mass flow rate, we find that the heat transfer coefficient increased and the reason is due In this, the mass flow rate has a greater effect with the lowest pressure(25MPa) The increase rate was (27.52%) as shown in Figure (4-37).

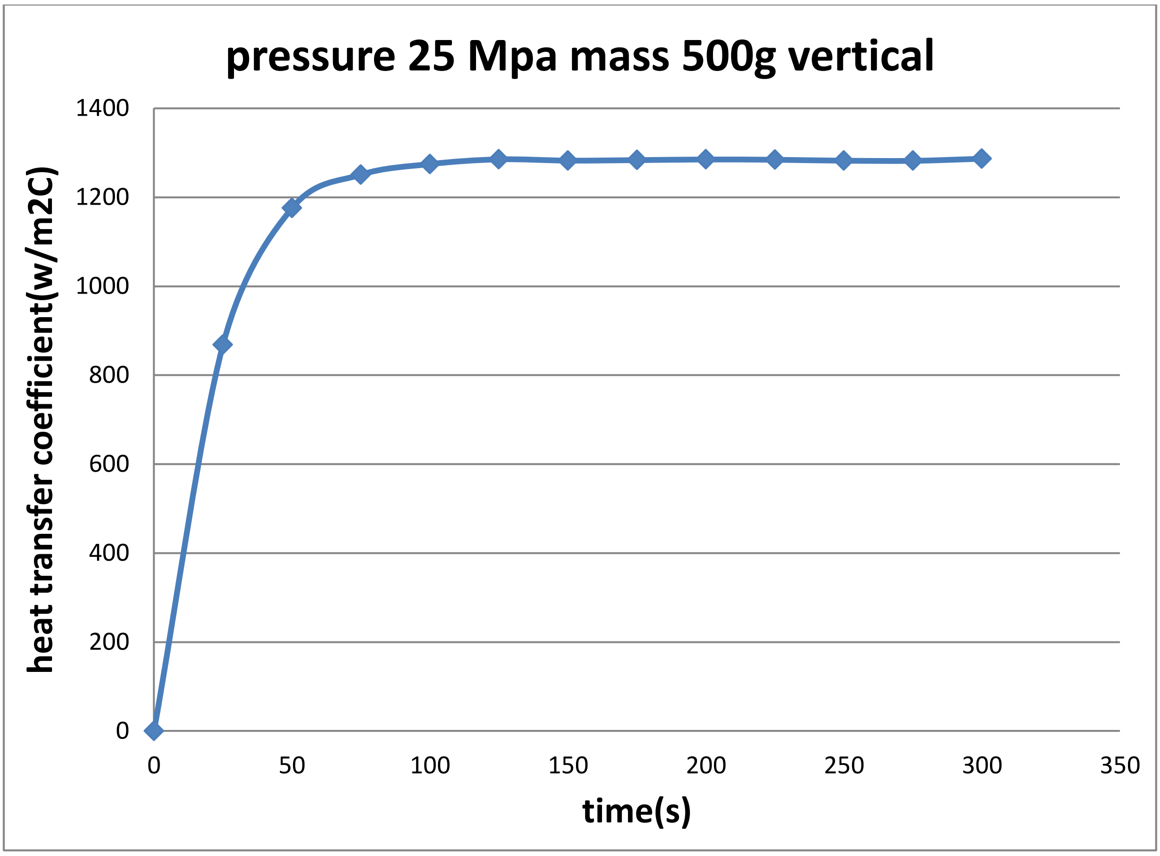


Figure (4-37) variation of the heat transfer coefficient versus the time at pressure (25Mpa) and mass (500g) when the cylinder in the vertical position

4.3.5. heat transfer coefficient at pressure (20 MPa) with horizontal position

In this case, we reduced the pressure to (20 MPa) with a mass (500 g) and mass flow rate (1.67 g/s). It was found that the heat transfer coefficient decreases as a result of the decrease in mass, reaching its peak (1641.8 W/m^2 ^oC), but when compared to a pressure (33 MPa) at the same mass and the same mass. Mass flow rate we find that the heat transfer coefficient has increased and the reason is that the mass flow rate has a greater effect with the lowest pressure (20 MPa) and the rate of increase was (42.12%) as shown in Figure (4-38).

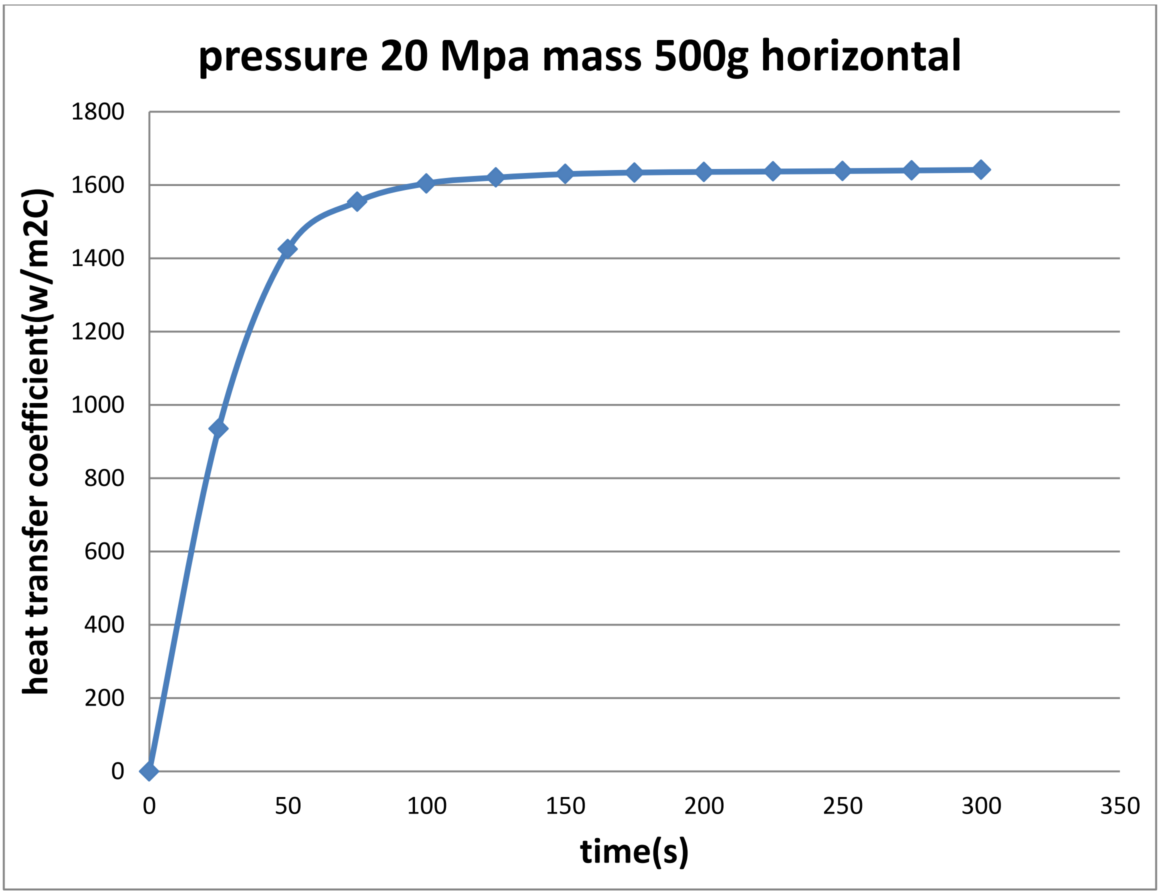


Figure (4-38) variation of the heat transfer coefficient versus the time at pressure (20Mpa) and mass (500g) when the cylinder in the horizontal position

4.3.6. heat transfer coefficient at pressure (20 MPa) with vertical position

In this case at vertical position, we reduced the pressure to (20MPa) with a mass of (500g) and a mass flow rate (1.67g/s). It was found that the heat transfer coefficient decreased as a result of the decrease in mass, as it reached a peak of (1661.2W/m^2 ^{o}C), but when we compare it with a pressure of(33MPa) at the same mass and the same mass flow rate, we find that the heat transfer coefficient increased and the reason is due In this, the mass flow rate has a greater effect with the lowest pressure(20MPa) The increase rate was (43.38%) as shown in Figure (4-39).`

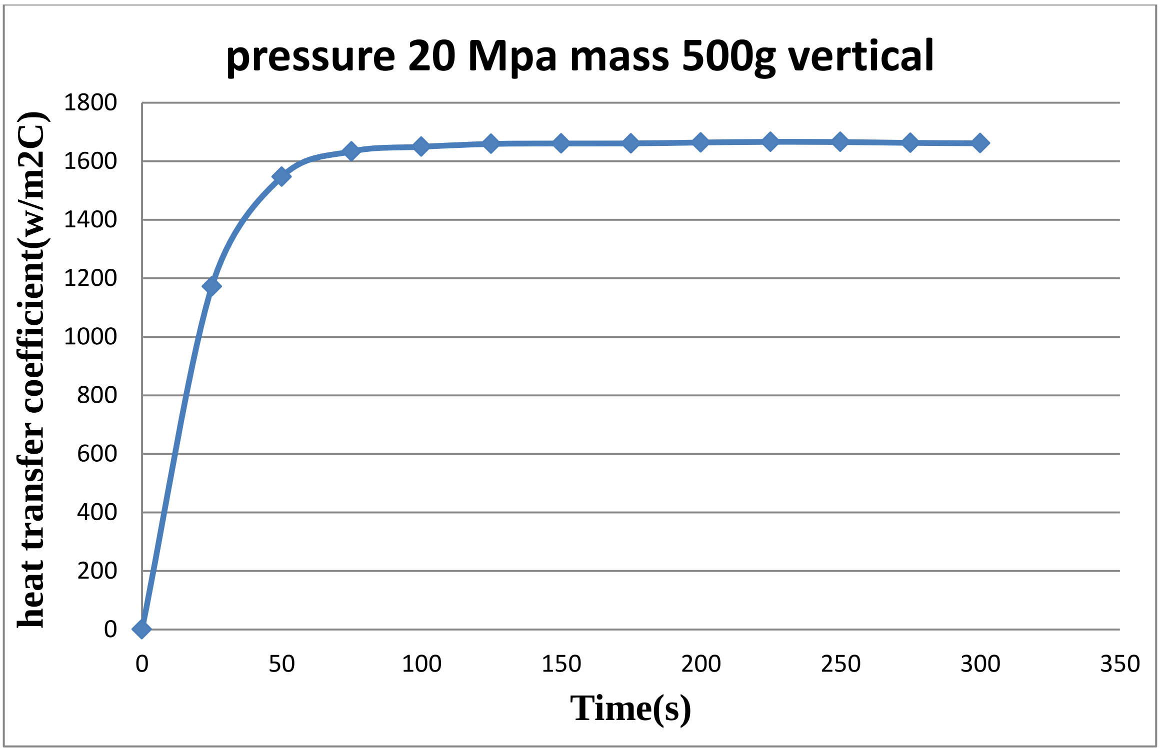


Figure (4-39) variation of the heat transfer coefficient versus the time at pressure (20Mpa) and mass (500g) when the cylinder in the vertical position

4.4. Summary

In this study we used an aluminum cylinder covered with carbon fibers filled with hydrogen gas used as fuel, and several tests were performed on it to determine the effect of temperature caused by hydrogen pressure during the filling process. These variables affect the refueling process, and what is the safest condition for the filling process, and its purpose is to obtain a safe temperature of (85 °C) to avoid the risk of overheating in the cylinder which leads to an explosion that occurs as a result of the high temperatures generated during filling cylinder. Several samples were used, including taking pressure (33 MPa) at different masses when the cylinder is horizontal, and we found that the temperature increased with a mass (1500 g) and this height is large. Since we reduce the mass to (1000g) the degree decreases, and we get a lower temperature, which is what is needed. We changed the experiment and used the same amount of hydrogen at the same pressures, but the position of the cylinder was perpendicular. We found that there was a drop in temperature. We concluded from this work that when the cylinder is in a vertical position, the temperature decreases and it is safer than in a horizontal position. We changed experiences. We used lower pressure (25 MPa) at different masses as well, and found that temperature was still higher due to the effect of higher mass flow rate when used at lower pressure. We repeated the experiment by changing the pressure to (20 MPa) also with a different flow rate, and there was also an increase in temperatures due to the effect of the mass flow rate.

CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

the finite element simulation using COMSOL multi physics software suit for the numerical investigation the heat of compression in a cylinder filled with a hydrogen fuel ,has been studied the following main conclusions and suggestion for future investigations and outline.

5.2. Conclusions

Based on the obtained results from numerical investigations, the following conclusions can be obtained:

1- It was concluded from this study that the increase in the temperature of the cylinder stemmed from of the increase in the pressure of the hydrogen gas, the higher the gas pressure led to the high temperature. For example, when gas was at a high pressure of (33MPa), there was an increase in temperature, but when the pressure was reduced to (25MPa) and (20MPa), the temperature decreased.

2- The temperature of the cylinder increases as a result of the increase in the mass of hydrogen gas that was pumped into the cylinder. As the mass increased, the temperature increases. For example, when gas of hydrogen at a high flow rate of (1500g), the temperature increased. Reduced the mass to (1000g) and (500g) at the same pressure, the temperature decreasing

3 - The temperature also increases when using a higher mass flow rate with lower pressures,

4- The heat transfer coefficient increased with the increasing in the mass of the flow rate, where there was a close relationship between the heat transfer coefficient and the mass flow rate

5- The temperature increased when the cylinder was in a horizontal position at the same pressure and mass of hydrogen gas

6- The temperature decreased when the cylinder was in a vertical position at the same applied pressure and the amount of hydrogen

7- Ambient temperature has a little effect on the filling process

8- Carbon fibers strengthened the cylinder from the pressure on it. As for the metal of the cylinder, it is aluminum, which helps prevent corrosion of the cylinder from rust and extends the life of the cylinder in addition to being light in weight.

9-The throttle device in the cylinder increased the temperature of the cylinder and caused a sudden augmentation in temperature

5.3. Recommended Future Work

Some points have been suggested to involve the recommended future work of cylinders as follows:

1- Changing the applied pressure to the cylinder.

2- Changing the masses of hydrogen gas that is pumped into the cylinder.

3- Changing the dimensions of the cylinder, which consists in changing the diameter, height, length and thickness of the cylinder.

4- Using another type of cylinder metal for the purpose of the study.

5- The position of the cylinder can be changed in an oblique angle

6- Changing the length of the throttle device in the cylinder to accurately know the effect of the throttle device on the sudden rise in temperature and calculate concentration of temperatures

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Nomenclature

Symbol	**Description**	**Units**
A	cross-sectional area	m^2
c_p	specific heat capacity	J/kgK
D	Diameter	m
$h_{conv,avg}$	heat transfer coefficient	$W/m^2\ ^oC$
K	thermal conductivity	$W/m\ ^oC$
L	length of the cylinder	m
L_{tube}	length of tube protruding from inlet	m
M	Mass	Kg
$\dot{m}$	mass flow rate	kg/s
P	Pressure	MPa
Q	heat transfer	J
R	universal gas constant	J/mol K
r_i	inner radius of test cylinder	m
r_o	outer radius of test cylinder	m
T	Temperature	^oC
T	time,	Sec
λ_{liner}	liner thickness	m
λ_{tube}	tube thickness	m
λ_w	total wall thickness	m
ρ	Density	kg/m^3
U	internal energy	J
U	Velocity	m/s
$\dot{Q}$	total heat transfer rate	W
Re	Reynolds number	