

## Design of a Pyrolysis Reactor for Polystyrene Plastic Waste and Numerical Analysis of Temperature and Thermal Stress Distribution Using Ansys

Ali Syamsuddin, Moh Mufti

Department of Mechanical Engineering, Faculty of Engineering, Universitas 17 Agustus 1945 Surabaya

### ABSTRACT

The difficult to degrade polystyrene (PS) waste requires efficient pyrolysis technology to be converted into styrene fuel through a 450°C thermal process. This study designed a batch reactor with a conical cylinder (with a diameter of 300 mm, a height of 300 mm, a diameter of 50,8 mm at the base of the cone, and a height of 150 mm, with a capacity of 3 kg of polystyrene) using Ansys for steady-state thermal-structural analysis to determine the best material based on the highest safety factor. The best material was SS 316, with a heating power of 1394 W, which produced the highest temperature distribution of 533,86 °C at the surface near the burner. Meanwhile, the internal surface of the reactor had reached 530,08 °C, which could degrade the polystyrene pyrolysis temperature at an operating temperature of 450 °C, with an average temperature of 141,47 °C. The total heat flux on this material is 0.093654 W/mm<sup>2</sup> in the area of the connection. The safety factor for the reactor with SS 316 material is 1.4844 at the maximum Von Misses stress due to the actual thermal gradient of 195,37 MPa.

**Keywords:** *Pyrolysis Reactor, Polystyrene, Numerical Analysis, Ansys, Steady-State Thermal, Thermal-Structural, Stainless Steel.*

#### **Corresponding author**

**Name:** Moh Mufti

**Email:** [mufti@untag-sby.ac.id](mailto:mufti@untag-sby.ac.id)

### INTRODUCTION

Waste is an environmental issue that has become a global problem, particularly in Indonesia. Due to the growing population and changing lifestyles of Indonesians, the amount of waste generated continues to increase every day. Waste is divided into two types: organic and non-organic. Organic waste comes from the remains of living organisms (humans, animals, and plants) and decomposes easily. In contrast, non-organic waste, such as plastic and metal, is difficult to decompose and has the potential to pollute the environment.

The annual increase in waste volume has become a serious environmental issue. According to data from the National Waste Management Information System (SIPSN) for 2024, the total waste generated by 312 regencies and cities in Indonesia reached approximately 33.34 million tons per year. Of this total, the largest portion of waste comes from food scraps at 41.6%, and plastic waste at 18.71% or 257,858.21 tons, while the

remaining 39.69% consists of metal and other waste. From this data, approximately 59.89% is managed properly, while 40.11% of the waste is not yet managed optimally. Plastic waste is a major concern, as the use of plastic in daily life, particularly in households, is quite high. The chemical properties of plastic, which make it difficult to decompose naturally, lead to the accumulation of plastic waste, which ultimately causes environmental pollution.

Plastic waste has many uses, which is why it is widely used by people in Indonesia; however, despite its many uses, plastic waste has a negative impact on the environment. Various types of plastic waste are commonly found and even pollute both terrestrial and marine ecosystems in Indonesia.

There are several types of plastic materials, one of which is frequently used by Indonesians: polystyrene (PS). Polystyrene (PS) is a type of plastic commonly used as synthetic foam (styrofoam). PS foam (polystyrene) offers excellent thermal insulation and is water-resistant, making it suitable for use as building insulation. Synthetic foam (styrofoam) made from PS is also frequently used in disposable food packaging, as the material is lightweight and can keep food cold; however, it is not recommended for high-temperature foods, as this can cause chemical leaching from the container into the food. However, PS plastic is also difficult to decompose in any environment, whether on land or in water. This inevitably leads to a large accumulation of unused plastic waste, which pollutes the environment.

As plastic waste continues to accumulate day by day, efforts are being made to ensure the proper and optimal utilization or processing of plastic waste. In an effort to reduce the amount of plastic waste that increases daily, the disposal of plastic waste through incineration is ineffective and risky because the burning process releases pollutants from exhaust emissions (CO<sub>2</sub>, CO, NO<sub>x</sub>, and SO<sub>x</sub>) and other particulate pollutants; therefore, alternative methods are needed to process plastic waste (Wicaksono & Arijanto, 2017).

One method of plastic waste treatment is pyrolysis, which is the subject of the author's research. Plastic waste pyrolysis is a process of decomposing the organic compounds found in plastic through heating with little or no oxygen, in which the raw material undergoes the breakdown of polymer chains into a gaseous phase, oil, and residues in the form of wax and charcoal (Abdullah et al., 2020). In this pyrolysis method, plastic waste is heated inside a reactor; the smoke produced by heating the plastic then flows through a connecting pipe from the reactor into a condenser, where it condenses into a liquid that can be used as fuel oil. It is hoped that this method will reduce the amount of plastic waste in Indonesia, and that the products of this process can be utilized by the community.

In the pyrolysis method, the main component is the reactor, which is used to heat the plastic so that the organic compound chains in the plastic can be broken down. The reactor must be able to distribute heat evenly to heat the plastic uniformly, so that the organic compounds in the plastic waste can be completely decomposed.

The reactor's role is not only to efficiently transfer heat but also to serve as a vessel where decomposed hydrocarbon gas or vapor is contained before proceeding to the

condensation stage. If the reactor used can withstand the thermal stress—meaning it can expand freely—it will not experience cracking or structural failure due to thermal loads. This is possible because the pyrolysis process generally operates at high temperatures. Hydrocarbon compounds inside the reactor can explode if a flame enters the reactor.

Given this phenomenon, reactors must be carefully engineered, starting with structural design and the selective or appropriate choice of materials, before construction or the manufacturing process begins. If the reactor cannot expand freely or is constrained, thermal stress will increase, thereby increasing the likelihood of cracking or structural failure. If the reactor is designed for a pyrolysis process using a burner, and the crack is located in the flame contact area, the reactor could explode because the flame can enter through the crack into the reactor, which contains hydrocarbon compounds during the pyrolysis process..

When designing a reactor, software such as Ansys can be used, as it includes several modules for predicting heat transfer and the stress response of a component due to temperature changes through numerical simulation. It is expected that the reactor design will meet the desired requirements.

Therefore, research on the design and analysis of thermal and thermostructural distributions in PS pyrolysis reactors is crucial as a first step toward designing reactors that are safe, efficient, and tailored to operational needs.

## **Research Methodology**

To ensure the research is well-focused, the following are the stages of this study

### **1. Start**

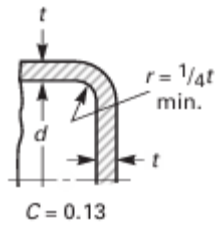
The researcher began by observing a current phenomenon of interest, then developed a research proposal that was submitted to the academic advisor during a consultation. Based on the feedback and guidance received from the academic advisor, the researcher designed and analyzed the temperature and thermostructural distributions using the finite element method in Ansys, while varying the reactor wall material to identify the optimal material for the reactor design.

### **2. Literature Review**

A literature review was conducted to gather the necessary data. The literature reviewed included (polystyrene plastic pyrolysis, reactors, stainless steel materials, steady-state heat transfer, energy balance, thermo-structural analysis, numeric thermo-structural simulation, Ansys Steady State Thermal and Static Structural).

### **3. Volume, Wall Thickness, Surface Radius, Heat Requirements for the Pyrolysis of Polystyrene Plastic, and Heating Power**

1. In this process, calculate the reactor's capacity by designing a reactor capable of holding 3 kg of polystyrene plastic,
2. Determine the minimum safe wall thickness based on the planned maximum steam or pyrolysis gas pressure in the reactor of 0.20265 MPa or 2 atm, to ensure the reactor remains safe during operation. As well as a weld joint efficiency of 0.85.
3. Determine the fillet radius of the surface in accordance with the design used.



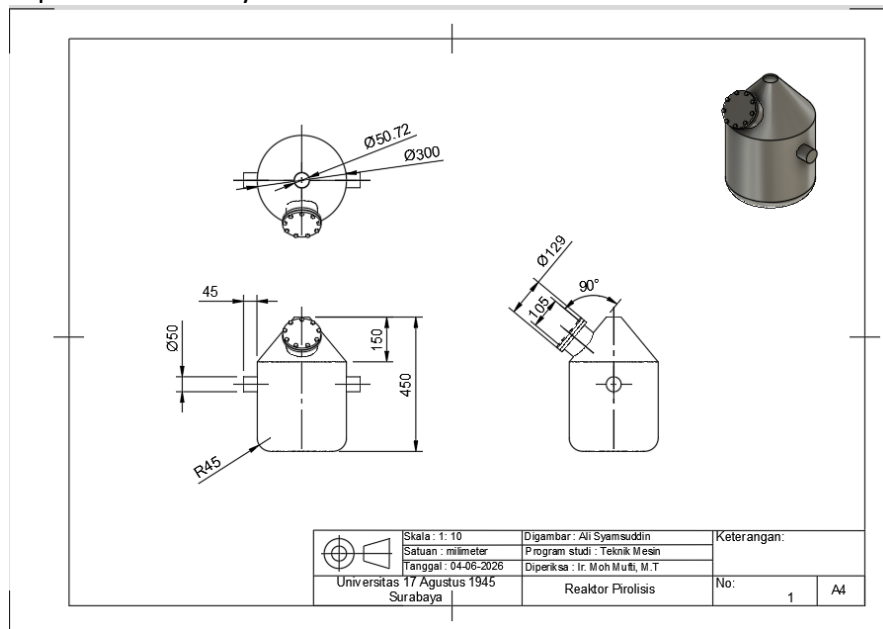
(d)

**Figure 1.** Radius fillet  
Source: (ASME, 2023)

4. Calculate the heat required during the pyrolysis of polystyrene plastic, with a pyrolysis time of 2 hours or 7,200 seconds.
5. Determining the reference heating power for performing an external iteration with a 30-watt reduction in input energy, in order to achieve a power level that is not too wasteful in the structural circuit, to heat the reactor to a pyrolysis temperature of 450°C, with an LPG gas LHV value of 47,081 kJ/kg.
6. Creating Design Concepts Using Autodesk Fusion

The design concept is a vertical batch-type reactor with a single-walled cylindrical-conical reactor vessel, featuring fixed supports on the left and right sides of the reactor; the reactor utilizes burner heating fueled by LPG.

The design concept was created using an Autodesk Fusion Student License in accordance with the specified wall thickness, with the addition of ear supports to brace the reactor, as described by (Akinsade et al., 2024). The design was then saved as an IGES file and imported into Ansys software.



**Figure 2.** Design of reactor pyrolysis

#### 4. Input Material Engineering Data

Material data is entered into the engineering data for use in simulations by opening the Ansys Workbench software, selecting “Engineering Data,” then selecting “Edit Material,” and entering the material data. The material used in this study is SS 316.

**Table 1. Material properties SS316 in engineering data**

Material SS 316		Score	Unit
Temperature Melting		1400	°C
Thermal Expansion	0°C - 100°C	1.6e-005	(1/°C)
	101°C - 315°C	1.62e-005	
	316 °C - 540°C	1.75e-005	
Density		8	g/cm <sup>3</sup>
Specific Heat		0,5	J/g°C
Tensile Yield Strength		290	Mpa
Poisson ratio		0,3	-
Tensile Ultimate Strength		550	Mpa
Young’s Modulus		193	Gpa
Emisivity		0,3056	-

Source: (Matweb, 2026; Maiyena et al., 2024)

The steady-state simulation stage also uses temperature-dependent thermal conductivity data for SS 316.

**Table 2. Thermal conductivity of SS 316 depends on the material**

Material SS 316		Score	Unit
Thermal Conductivity	26,85°C	14,9	W/m.K
	100°C	16,2	
	326,82°C	19,8	
	526,85°C	22,6	
	726,85°C	25,4	

Source: (Bergman & Lavine, 2017)

#### 5. Ansys Testing Method

During testing, researchers follow several steps to obtain accurate results. The following are the steps involved in Ansys testing.

##### 1. Ansys Steady-State Thermal

In this step, select the steady-state thermal analysis. In the steady-state thermal analysis, polystyrene plastic is not modeled inside the reactor, meaning there are no chemical reactions occurring within the reactor, but instead, a negative (-) Eout or heat flow value is applied to the bottom surface inside the reactor, representing the energy absorbed in the form of heat during the polystyrene pyrolysis process at

the optimal pyrolysis temperature of 450°C, thereby yielding a temperature distribution within the reactor that closely resembles real-world conditions. Next, define the boundary conditions:

- a. Air convection at 15 W/m·K, at an ambient air temperature of approximately 28°C
- b. Radiation at an ambient temperature of approximately 28°C, with the surface emissivity of the material assumed at a temperature of 600°C.
- c. Eout or heat flow with a negative (-) value on the lower surface inside the reactor
- d. Heating power (Ein) or heat flow with a positive (+) value on the outer surface of the reactor. Selection of a solution to determine temperature, total heat flux, and convective and radiative losses.

In this simulation, external iterations were performed in addition to the internal iterations carried out by Ansys, with a reduction of 30 watts in input energy or heating power at each iteration, using the pyrolysis heat energy divided by an efficiency of 0.75 as the maximum iteration limit.

## 2. Static Structural ANSYS

After obtaining the temperature from the steady-state simulation, the researcher added a static structural analysis to the steady-state thermal module to determine the thermal stress values resulting from steady-state heating under the boundary conditions

- a. Add the temperature load from the Steady-State Thermal analysis as a thermal load on the reactor, then
- b. Add a fixed support to the reactor stand,
- c. Add an internal pressure of 0.20265 MPa inside the reactor
- d. Add a force of 30 N to represent the mass of 3 kg of raw material.

In the Solution menu, the researcher selected the equivalent stress (Von Mises) as the accumulated stress resulting from mechanical and thermal loads, total deformation, and the maximum equivalent safety factor (Von Mises). In the static structural testing, the geometry underwent external iteration with an internal pressure increment of 0.1 MPa per iteration to determine the maximum allowable internal pressure for the design geometry, using the design internal pressure reference of 0.20265 MPa as the initial iteration value.

## 6. Results and Analysis

In this stage, all results from the Ansys numerical tests will be analyzed comparatively to determine the optimal design.

## 7. Conclusion

This section presents the conclusions drawn from the initial design and analysis of the simulation tests through to the conclusion of the study, which serves as the final part of this testing process.

## 8. Done

Now that all testing and analysis have been completed and the calculation data and conclusions have been obtained, the author has finished carrying out the steps involved in this test.

## Results and Discussion

### Reactor Design

Determining the capacity by calculating the volume of 3 kg of polystyrene plastic. The material used in this study was 316 stainless steel, as it offers good corrosion resistance and the ability to withstand stress at high temperatures

$$V_{\text{plastic}} = \frac{m}{\rho} = \frac{3\text{kg}}{1050\text{kg/m}^3} = 0,00285 \text{ m}^3 \quad (2.1)$$

Reactor chamber volume,

Cylinder section:

$$V_{r,\text{cylinder}} = \pi \cdot d_i \cdot h = 3,14 \cdot 0,146 \cdot 0,294 = 0,01967 \text{ m}^3 \quad (2.2)$$

Cone section:

$$V_{r,\text{cone}} = \frac{1}{3} \pi (r_{i,1}^2 - r_{i,2}^2) (h_c - t_d) \quad (2.3)$$

$$V_{r,\text{cone}} = \frac{1}{3} 3,14 (0,146^2 - 0,0508^2) (0,15 - 0,004) = 0,00315 \text{ m}^3$$

Total reactor volume:

$V_{\text{total}} = V_{\text{cylinder}} + V_{\text{cone}} = 0,01967 + 0,00315 = 0,02282 \text{ m}^3$ , The reactor can hold 3 kg of plastic because the volume of the reactor chamber is greater than the volume of the plastic

### a. Minimum Plate Thickness

A design can be considered safe if the plate thickness is not less than the minimum thickness allowed by the formula below:

$$t = \frac{PR}{SE - 0,6P} \quad (2.4)$$

Where:

P = maximum design internal pressure (MPa)

R = inner radius of the cylinder (m)

S = maximum allowable stress (MPa)

E = weld joint efficiency It is assumed that under critical conditions, where the surface plate near the burner has reached a temperature of 600°C, (American Society of Mechanical Engineers, (American Society of Mechanical Engineering (ASME), 2021) Table 5A lists the

maximum allowable stress for SS 316 material (UNS S31600) as 80.3 MPa. With a planned maximum internal pressure of 0.20265 MPa and a weld joint efficiency of 0.85, then:

$$t = \frac{0,26265 \cdot 0,146}{80,3 \cdot 0,85 - 0,6 \cdot 0,20265} = 4,34 \times 10^{-4} \text{ m} = 0,4 \text{ mm}$$

The minimum allowable plate thickness is 0.4 mm; plate thicknesses of 4 mm and 6 mm are planned for the surface.

### b. Surface Radius

This is done to reduce the stress concentration factor; a fillet is formed at the edge of the surface because a flat, deep surface is used (ASME, 2023). The BPVC An International Code, Division 1, Section VIII, specifies the radius of the head to reduce the stress concentration factor, thereby making the structural design safer.

$$r = \frac{1}{4} t_{\text{permukaan}} = \frac{1}{4} 6 = 1,5 \text{ mm} \tag{2.5}$$

The safe fillet radius is 1.5 mm; the planned radius is 45 mm.

### Calorie Requirements

In the plastic pyrolysis process, heat is required to decompose the plastic into vapor. According to data from (Bangs Laboratories, 2015), Polystyrene has a density of 1.04 g/cc to 1.65 g/cc and melts at a temperature of 240°C with a latent heat of 8.37 kJ/mol. In the study (Mo et al., 2013), Polystyrene products such as expanded polystyrene (EPS) require an activation energy of 230 kJ/mol during pyrolysis, with an enthalpy of 224 kJ/mol. In this case, the operating temperature for polystyrene pyrolysis is set at the optimum temperature of 450°C; however, research (Rachmawati & Awal, 2025) shows that polystyrene can decompose at a temperature of 420°C

**Table 3.** Properties of polystyrene plastic

<b>Density</b>	<b>1,05 g/cm<sup>3</sup></b>
<b>Plastic Mass</b>	3 kg
<b>Steam Mass</b>	3 kg x 0,7474 = 2,24kg
<b>Heat Capacity Cp<sub>solid</sub></b>	1,228 kJ/kg <sup>o</sup> K
<b>T<sub>amb</sub></b>	28 °C = 301,15
<b>Cp<sub>liquid,avg</sub></b>	2,4498 kJ/kg <sup>o</sup> K
<b>T<sub>melt,avg</sub></b>	330,15 °C = 603,15°K
<b>Molar Mass</b>	104,15 g/mol
<b>Degradation Temperature</b>	420°C = 693,15°K
<b>Cp<sub>steam,optimum</sub></b>	2,26 kJ/kg
<b>Operation Temperature</b>	450°C = 723,15°K

Source: (Gaur & Wunderlich, 1982; Green & Perry, 2008)

**a. Sensible Heat (in the solid state)**

$$Q_1 = m_{plastic} \cdot C_{psolid} \cdot (T_{melt} - T_{amb}) \quad (2.6)$$

$$Q_1 = 3 \text{ kg} \cdot 1,228 \text{ kJ/kg}^\circ\text{K} (240 - 28)$$

$$Q_1 = 781,008 \text{ kJ}$$

**b. Latent heat (the heat required to melt the plastic)**

$$Q_2 = m_{plastic} \cdot L_m \quad (2.7)$$

$$Q_2 = 3\text{kg} \cdot 80,36 \text{ kJ/kg}$$

$$Q_2 = 241,094 \text{ kJ}$$

**c. Latent Heat of Vaporization (in the liquid state)**

$$Q_3 = m_{liquid} \cdot C_{p_{liquid,avg}} \cdot (T_{deg} - T_m)$$

$$Q_3 = 3\text{kg} \cdot 2,4498 \text{ kJ/kg} (420 - 240)$$

$$Q_3 = 1322,892 \text{ kJ}$$

**d. Heat of Reaction/Reaction Enthalpy (the change from liquid to vapor or gas)**

$$Q_4 = m_{steam} \cdot \Delta H_{pyr} \quad (2.8)$$

$$Q_4 = 2,24 \text{ kg} \cdot 2342,77 \text{ kJ/kg}$$

$$Q_4 = 5247,81 \text{ kJ}$$

**e. Final Sensible Heat (in the vapor or pyrolysis gas state)**

$$Q_5 = m_{steam} \cdot C_{p_{steam,avg}} \cdot (T_{optimum} - T_{deg})$$

$$Q_5 = 2,24 \text{ kg} \cdot 2,26 \text{ kJ/kg} \cdot (450 - 420)$$

$$Q_5 = 151,872 \text{ kJ}$$

**f. Total heat of plastic pyrolysis**

The heat required to turn plastic into steam

$$Q_{pyr} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

$$Q_{pyr} = 781,008 + 241,094 + 1322,892 + 5247,81 + 151,872$$

$$Q_{pyr} = 7.744,676 \text{ kJ}$$

Energy required in joules per second

$$E_{out} = \frac{Q_{pyr}}{\text{waktu pirolisis}} \quad (2.9)$$

$$E_{out} = \frac{7744676 \text{ J}}{7200 \text{ detik}} = 1075,649 \text{ J/s} = 1076 \text{ J/s} = 1076 \text{ W}$$

**g. Maximum input energy or heating power during the iteration**

In this case, this refers to the maximum power limit for the iteration, or the input energy or heating power during the process ( $E_{in}$ ):

$$E_{in} = \frac{E_{out}}{\eta} = \frac{1076}{0,75} = 1434 \text{ J/s} = 1434 \text{ W} \tag{2.10}$$

**Simulasi Steady State Thermal**

A steady-state thermal simulation was performed to determine the reactor wall temperature at an efficient power level; the data used were the same as those described previously in the numerical research method. This simulation utilized Autodesk Fusion Student License software to create the design geometry, which was then imported as an IGES file into Ansys Workbench Student License 2025 using the Steady-State Thermal module.

Table of Design Points							
	A	B	C	D	E	F	G
1	Name	P12 - Heat Flow Magnitude	P14 - Temperature Maximum	P15 - Temperature Average	P16 - Temperature Minimum	<input type="checkbox"/> Retain	Retained Data
2	Units	W	C	C	C		
3	DP 0	1434	584,18	152,99	28,375	<input checked="" type="checkbox"/>	✓
4	DP 1	1404	546,65	144,4	28,348	<input checked="" type="checkbox"/>	✓
5	DP 2	1374	507,83	135,52	28,32	<input checked="" type="checkbox"/>	✓
6	DP 3	1334	453,81	123,23	28,282	<input checked="" type="checkbox"/>	✓
7	DP 4	1344	467,58	126,35	28,292	<input checked="" type="checkbox"/>	✓
8	DP 5	1314	425,75	116,87	28,262	<input checked="" type="checkbox"/>	✓
9	DP 6	1390	528,7	140,29	28,335	<input checked="" type="checkbox"/>	✓
10	DP 7	1380	515,7	137,32	28,326	<input checked="" type="checkbox"/>	✓
11	DP 8 (Current)	1394	533,86	141,47	28,339	<input checked="" type="checkbox"/>	✓
*						<input type="checkbox"/>	

**Figure 3.** Results of the input energy iteration (heat flow)

In the external iterations, the input energy that satisfies the temperature distribution on the surface is the second iteration, with an input energy of 1394 W or 1394 J/s. With an energy efficiency of:

$$E_{in} = \frac{E_{out}}{\eta}$$

$$\eta = \frac{E_{out}}{E_{in}} \times 100 \% = 77,18 \%$$

Therefore, the total heat energy required

$$Q_{in,total} = E_{in} \times \text{pyrolysis time} = 1394 \text{ J/s} \times 7200 \text{ s} = 10036800 \text{ J} = 10036,8 \text{ kJ}$$

Based on the amount of LPG fuel required

$$m = \frac{E_{in}}{L_{h\nu}} = \frac{10036,8 \text{ kJ}}{47081 \text{ kJ/kg}} = 0,213 \text{ kg} \tag{2.11}$$

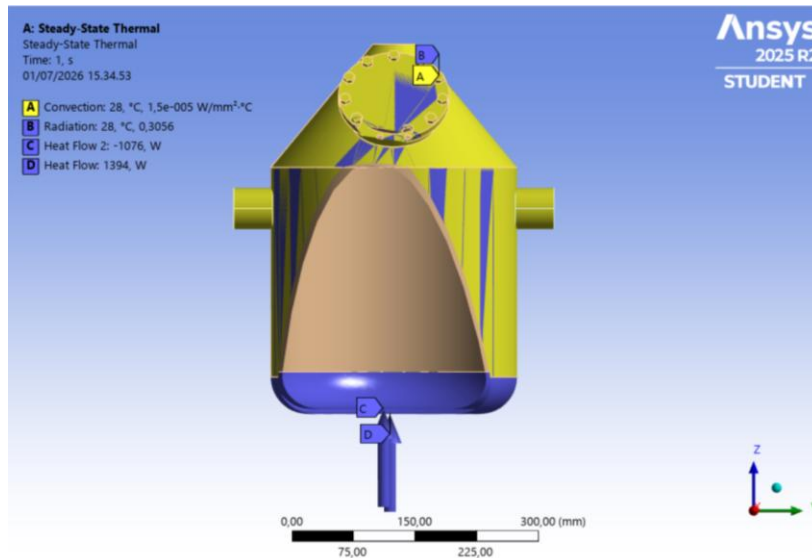


Figure 4. Steady-state thermal simulation boundary conditions

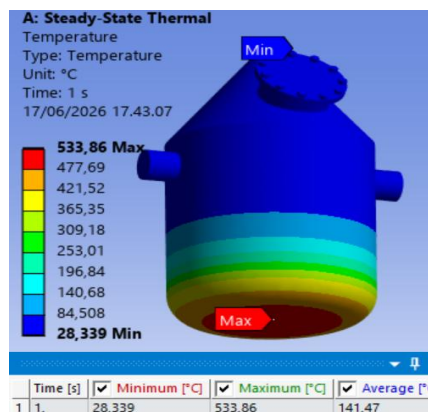
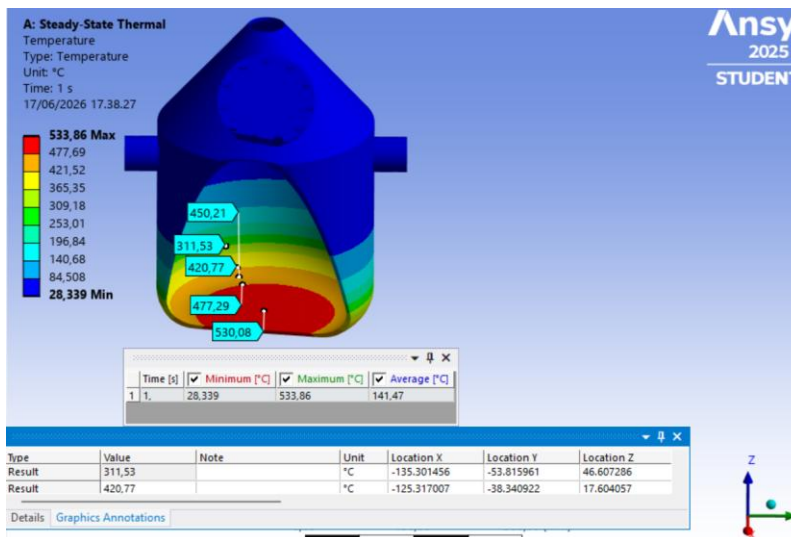
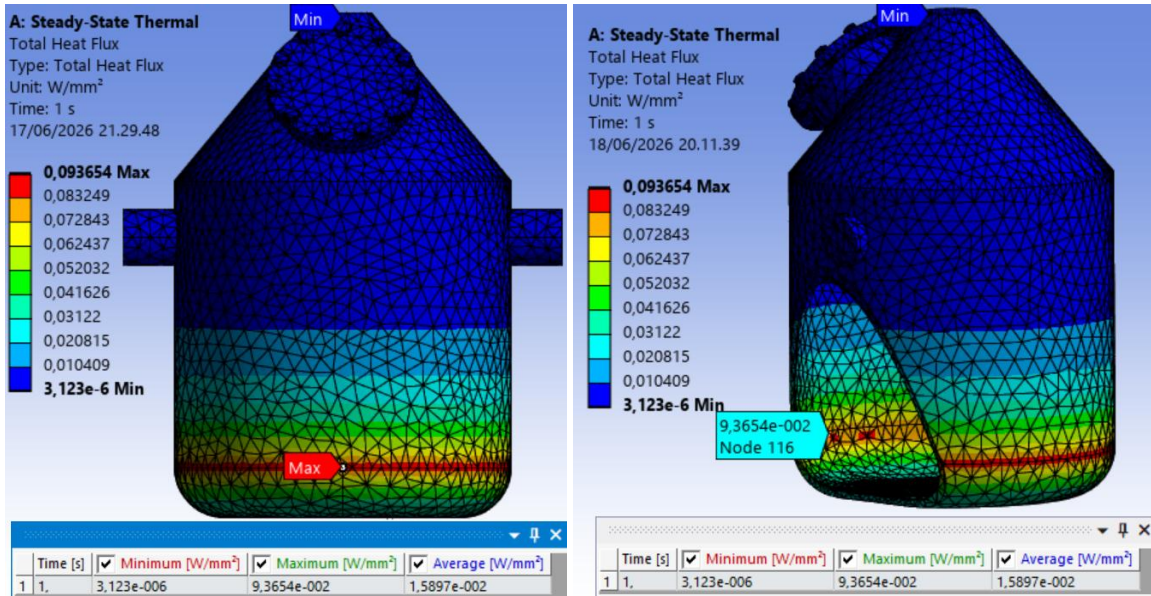


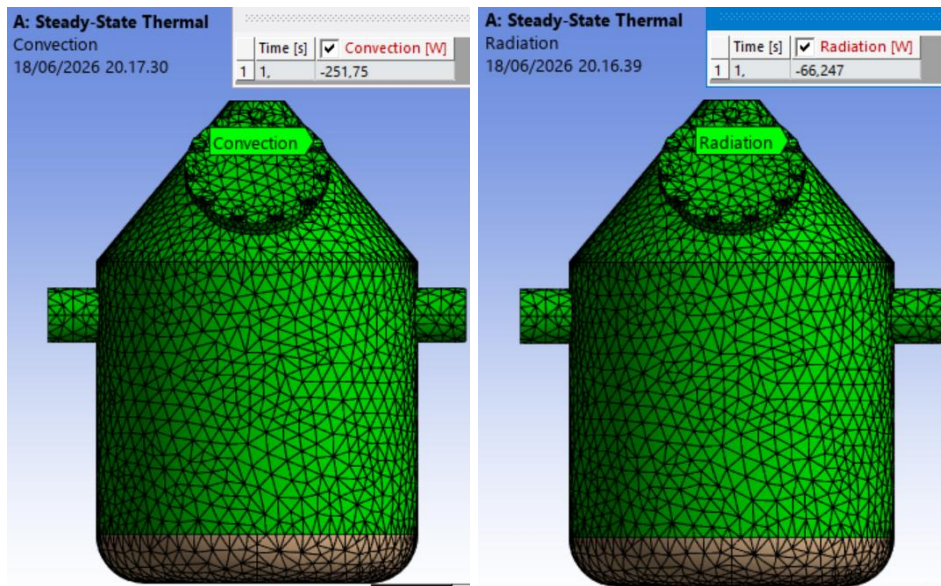
Figure 5. Temperature distribution results

From the simulation, the temperature distribution gradients on the outer and inner walls of the reactor were obtained, with a maximum temperature of 533,86 °C indicated in the red-colored region on the surface area directly adjacent to the heat flow point, representing the burner flame, while the inner surface temperature reached 530,08°C. The yellow-colored area indicates that the temperature has reached the thermal degradation temperature of polystyrene pyrolysis at 420°C. The average temperature is 141,47 °C. The minimum temperature is shown in the blue-colored area on the lid at 28,339°C.



**Figure 6.** Total heat flux

The simulation results show a maximum total heat flux of 0,093654 W/mm<sup>2</sup> in the red-shaded area—specifically, the junction between the reactor body and the outer base surface—while the heat flux at the inner junction is 0,09634 W/mm<sup>2</sup>. The minimum total heat flux of 4,2796 x 10<sup>-6</sup> W/mm<sup>2</sup> is located in the upper region of the conical shape marked in dark blue. The average total heat flux value is 0,015897 W/mm<sup>2</sup>.



**Figure 7.** Convection and radiation heat losses

Simulation results obtained by applying boundary conditions to the outer wall surface for convection and radiation show heat loss of 251,75 W due to convection and 66,247 W due to radiation to the environment; the minus sign (-) indicates that energy is leaving the system.

Therefore, the total energy leaving the system,

$$E_{in} = E_{out} + Q_{konveksi} + Q_{radiasi}$$

$$1434 \text{ W} = 1076 \text{ W} + 251,75 \text{ W} + 66,247 \text{ W}$$

$$E_{in} = E_{out} = 1394 \text{ W}$$

### Simulasi Static Structural

In this case, the static structural simulation is used to test the robustness of the reactor design by determining the boundary conditions described in the research methodology.

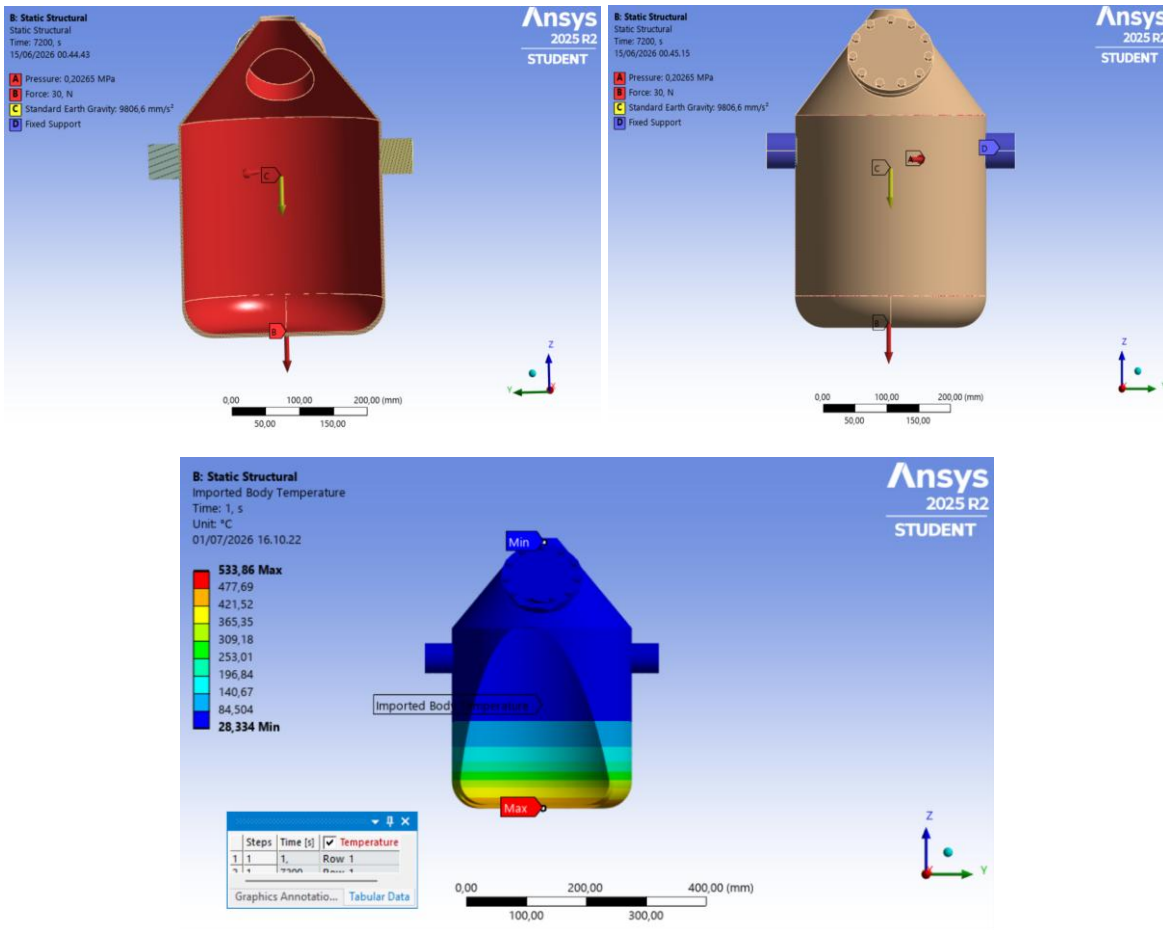


Figure 8. Boundary conditions for static structural simulation

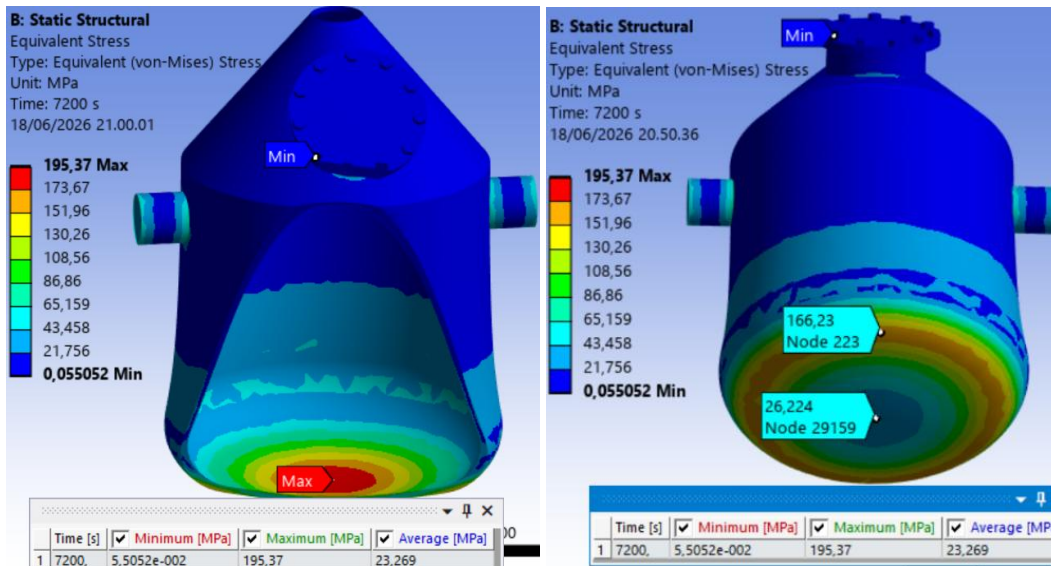
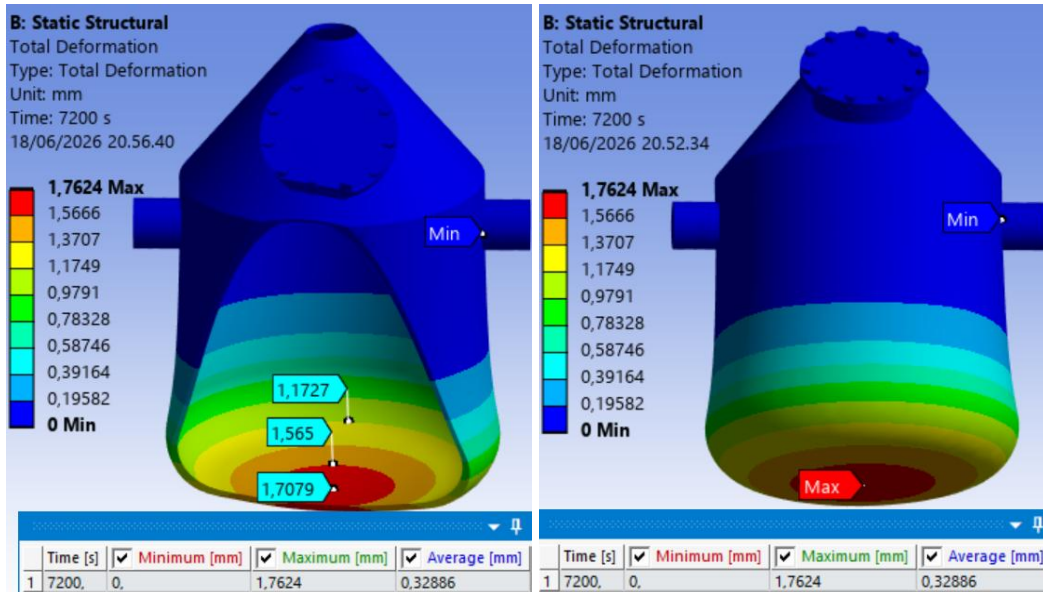


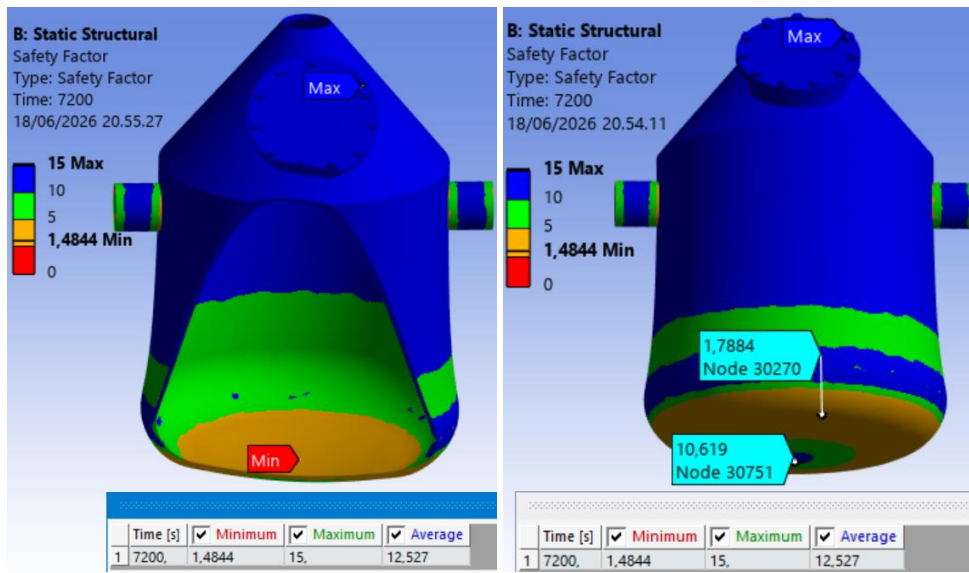
Figure 9. Thermal von Mises results

The simulation results show a maximum thermal Von Mises stress of 195,37 MPa, indicated by the dark red area on the inner surface of the reactor, while the stress on the outer surface near the burner is 26,224 MPa. The minimum thermal Von Mises stress is 0,055052 MPa at the locking bolts in the dark blue area of the cover. The average thermal Von Mises stress is 23,269 MPa.



**Figure 10.** Total deformation

The simulation results show that the total deformation is located on the outer surface of the reactor near the burner, with a maximum total deformation of 1,7624 mm, while the total deformation on the inner surface is 1,7079 mm. The minimum total deformation of 0 mm is located in the dark blue region at the support area, with an average total deformation of 0,32886 mm.



**Figure 11.** Safety factor result

The simulation results show that the minimum safety factor of 1,4844 is located in the brownish-orange area on the inner surface of the reactor, while the safety factor near the flame point on the outer surface is 10,619. The maximum safety factor of 15 is located in the dark blue area of the lid.

Table of Design Points							
	A	B	C	D	E	F	G
1	Name	U... O...	P1 - Pressure Magnitude	P2 - Safety Factor Minimum	P3 - Equivalent Stress Maximum	<input type="checkbox"/> Retain	Retained Data
2	Units		MPa		MPa		
3	DP 8 (Current)	1	0,20265	1,4844	195,37	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
4	DP 9	2	0,30262	1,3589	213,4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
5	DP 10	3	0,40262	1,253	231,44	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
6	DP 11	4	0,5062	1,1594	250,12	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
7	DP 12	5	0,6062	1,0814	268,16	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
8	DP 13	6	0,7062	1,0133	286,2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
9	DP 14	7	0,8062	0,9532	304,24	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
10	DP 18	8	0,71	1,0109	286,89	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
11	DP 19	9	0,72	1,0045	288,69	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
12	DP 20	10	0,73	0,9983	290,49	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
13	DP 21	11	0,727	1,0002	289,95	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
14	DP 22	12	0,7272	1	289,99	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
15	DP 23	13	0,72725	1	290	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
16	DP 24	14	0,7273	0,99998	290,01	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

**Figure 12.** Results of repeated external iterations

From the results of repeated iterations in increments of 0.1 MPa at a design internal pressure of 0.20265 MPa, with the increments subsequently reduced until the pressure limit was reached, a total of 14 iterations were performed. In the 14th iteration, with an internal pressure of 0.7273 MPa, the structure experienced a maximum thermal von Mises stress of 290,01 MPa, indicating that the structural design failed because this stress was equal to the yield strength, as indicated by a minimum safety factor of 0.99999.

Meanwhile, in the 13th iteration under an internal pressure load of 0.72725 MPa, the structure experienced a maximum thermal von Mises stress of 290 MPa, indicating that the structural design failed because this stress was at the yield threshold, as indicated by a minimum safety factor of 1.

## **DISCUSSION**

The temperature distribution results show that the highest temperature is found just below the outer surface of the reactor at 533,86 °C because this surface is close to the burner, while the temperature at the inner surface of the reactor remains at 530,08 °C because that surface is in direct contact with the material, and in the yellow area, the temperature has reached 420 °C, at which point the plastic has begun to decompose. The inner surface of the reactor also experiences a negative (-) heat flux, representing the energy released during the pyrolysis process; therefore, the temperature in that area is lower than in the outer area. The temperature distribution is also influenced by the material's temperature-dependent thermal conductivity; the simulation results show that the red-colored area with the highest temperature has a wider range than the light blue and green areas.

The simulation results for total heat flux show that the highest total heat flux occurs at the joint area, with a value of 0,093654 W/mm<sup>2</sup>, and that heat flux generally flows from areas with the highest temperature to areas with the lowest temperature (Alya et al., 2024), Therefore, the highest heat flux occurs at the joint area, as this is where the bottom surface plate connects to the reactor vessel wall. This is also evidenced by the convection and radiation losses leaving the system, with a total outgoing energy loss of 1394 W, ensuring that the reactor temperature remains in thermal equilibrium. (steady state thermal).

The highest maximum von Mises stress, at 195,37 MPa, is located on the lower surface of the reactor due to non-uniform temperature distribution, which triggers thermal stress caused by temperature differences. However, the maximum total deformation of 1,7624 mm is located on the lower surface near the burner because that surface receives a large amount of heat energy; that section has the maximum temperature due to direct contact with the burner. Consequently, that area experiences greater expansion due to thermal expansion compared to the cooler inner sections, and there are internal loads in that area, so the inner sections will experience greater stress. therefore, the smallest safety factor value is found on the lower surface area inside the reactor, at 1,4844. A safety factor of 1,4844 in the reactor design using 316 stainless steel can be considered safe because the loading on the pyrolysis reactor is static loading (Tasyah et al., 2025).

## **CONCLUSION**

The reactor design using SS 316 material has an energy transfer efficiency of 77.18%, with an energy input of 1394 W. Meanwhile, the heat lost to the environment by convection is 251,75 W and by radiation is 66,247 W. The entire inner surface has exceeded the thermal degradation temperature of polystyrene plastic, which is 420°C, during

optimum pirolisis operation at 450°C. The largest heat flux is 0,093654 W/mm<sup>2</sup>, directed towards the connection area, which is the area with the highest temperature. This indicates that the heat flow is vertical. This is due to the large surface area causing uneven heat distribution, as the thermal conductivity of SS 316 is only 22.6 at a temperature of 526.85°C.

In this case, the reactor design can be considered safe at an internal pressure of 0.20265 MPa because it experiences a thermal von Mises stress of 195,37 MPa, which is lower than the yield strength of SS 316 material, namely 290 MPa. The total deformation of 1,7624 mm can also be considered safe because it does not exceed the material's elastic deformation limit. This is because pyrolysis reactors generally operate under static load conditions. The internal temperature and pressure must be controlled so as not to exceed the maximum internal pressure at iteration 6.

To increase the safety factor, the thickness of the bottom surface plate can be increased, but the effects of thermal expansion must be carefully considered.

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