International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
June 2024 | Issue 59 | Volume 16 | Number 2 | Pages 24-31

MODELING AND NUMERICAL STUDY OF THERMOMECHANICAL BEHAVIOR OF A PYROLYSIS REACTOR FOR CONVERSION OF PLASTIC WASTE INTO FUEL

J. Oufkir S. Zerraf S. Belaaouad

Laboratory of Physical Chemistry of Materials LCPM, Faculty of Sciences Ben M'sik, Hassan II University, Casablanca, Morocco, oufkir_jamal@yahoo.fr, soufiane.zeraf@gmail.com, sbelaouad@yahoo.fr

Abstract- Plastic is a widely used material in our daily life, but it poses a major environmental problem due to its non-biodegradable nature. To solve this problem, plastic pyrolysis has emerged as a promising technique in order to transform plastic waste into fuel. The study at hand focuses on the thermomechanical analysis of a plastic pyrolysis reactor. The virtual design of the reactor is created via 3D-CAD using SolidWorks software and evaluated using the FEM method with a numerical simulation on ANSYS software. The plastic waste used in the pyrolysis process was Low Density Polyethylene (LDPE) bags. ANSYS software measured, through thermo-structural analysis, thermal strain, thermal stress and total deformation of the reactor throughout the pyrolysis process at different temperatures. The results indicate that the maximum values of thermal strain, thermal stress and total deformation are 0.0011730, 160.67 MPa and 1.525 mm respectively. The obtained results clearly show that the reactor is capable of stable operation at a maximum temperature of 600 °C.

Keywords: Plastic Waste, Reactor, Pyrolysis, Fuel, Thermomechanical Analysis, Hydrocarbon.

1. INTRODUCTION

Plastic waste has become a serious issue for the environment due to its increasing accumulation in landfills, oceans and terrestrial ecosystems. Plastics are not biodegradable and can take hundreds of years to degrade. Based on a current study that was published in the Science Advances journal, around 8.3 billion tons of plastic have been manufactured globally since large-scale plastic production first started in the 1950s. Of this amount, only 9% was recycled and 6.3 billion tons of plastic that were produced became waste. The rest has been incinerated or ended up in landfills, oceans and natural ecosystems [1]. Alarming amounts of plastic garbage have been found in the world's oceans. According to a study by the Ellen MacArthur Foundation, there will be more plastics than fish in the oceans by 2050 if no action is taken to reduce plastic production and improve its management [2]. Pyrolysis, which is regarded as an energy recovery process, is a way to treat this waste in order to address the environmental disaster. Pyrolysis is a method of thermal treatment of plastic waste that uses heat to break down the polymers into simpler hydrocarbons. This method can be used to produce liquid hydrocarbons, gases and charcoal, which can be used as fuels or feedstocks for the production of new chemicals. The thermal cracking of plastic waste has been the subject of several investigations. Singh, et al. [3] investigated the impact of fast and slow pyrolysis on the composition and quality of pyrolyzed products, while Miandad, et al. [4] examined the use of catalytic pyrolysis to become a key technology in biorefineries. Other studies, such as the work of Syamsiro, et al. [5], have focused on optimizing pyrolysis to maximize the production of high-quality liquid hydrocarbons. A steel pyrolysis reactor is a piece of equipment used to convert waste plastics thermochemically into energetically valuable chemicals. The design of such a reactor must take into account several parameters, including corrosion resistance, high temperature resistance and structural stability. In this context, the goal of this study is to perform a thermomechanical analysis of a mild steel pyrolysis reactor, using the Finite Element Method (FEM) with the help of a numerical simulation on ANSYS software. The analysis will aim to evaluate the thermal stresses and strains in the reactor at various temperatures, so as to determine the efficiency and stability of the reactor under actual operational circumstances. The obtained results will be applied to enhance the pyrolysis reactor's design and functionality.

2. RELATED WORKS

Numerical modeling is a widely used simulation method for the analysis and prediction of pyrolysis processes of plastic and biomass waste. In this context, several studies have been conducted to understand the complex phenomena that occur during the pyrolysis process, such as heat and mass transfer, as well as fluid dynamics. Jackson, et al. [6] have developed a simulation tool whose purpose is to analyze and simulate reactors such as batch, continuous stirred and plug flow reactors.

Registered: 230704 Article Info: 1765 Accepted: 240527
Reserved: 231123 Available: 240630

It has java-based graphical user interfaces and simulates reaction kinetics in the liquid phase. Ajay, et al. [7] used 3D CAD software for the design and modeling of a prototype pyrolysis of plastic materials and SolidWorks. At a base temperature of about 600 °C, Low-Density Polyethylene was pyrolyzed in a batch system reactor, and the steam produced was directed into a horizontal condenser with tubes and shells oriented in the opposite direction. Kehinde, et al. [8] performed the design, simulation, as well as implementation of an electrically driven pyrolysis furnace. The design was thoroughly analyzed and then validated by numerical simulation via Finite Element Analysis (FEA). Cassava peels were used to test the newly created oven. The system showed an efficiency of 54%, while the ratio between the energy produced and the energy consumed in the process was 0.952.

Recently, Ramin, et al. [9] simulated the fluidization hydrodynamics of the biomass gasification process using both a multiphase Euler approach and Computational Fluid Dynamics (CFD) based model. It was determined that the K-turbulent RNG model provided the most accurate representation of the process. It was revealed that the Syamlal-O'Brien drag model could effectively estimate the decrease in bed pressure. Also, the distributions of the gas composition for biomass gasification in a fluidized bed with chemical loop technology were predicted using CFD. This was possible because CFD can simulate the mixing and segregation characteristics between two solid phases. Xiong, et al. [10] conducted a comprehensive review of research on computer modeling of rapid biomass pyrolysis. Their results highlighted that to achieve high tar yield, it is recommended to keep the inlet temperature and wall temperature around 800 K, with a nitrogen flow rate of approximately 0.6 $m.s^{-1}$.

To simulate the fast thermal cracking of red oak and examine the impact of gas phase duration of stay on tar production, the researchers employed the CFD Multi-Fluid Modeling (MFM) technique. A study conducted by Mukesh et al. involved simulating fast biomass pyrolysis in a rectangular bubbling fluidized bed using a multiphase particle-in-cell (MP-PIC) framework, which included a comprehensive three-dimensional reactive gas-solid computational fluid dynamics (CFD) model with two-stage semiglobal kinetics to match experimental data and analyze the impact of operating conditions and reactor configurations on product yields, providing essential insights for potential reactor enhancement and optimization. Furthermore, the results of this research demonstrate that the model effectively captures the evolution of product performance (non-condensable gases, tar and coal) at varying reaction temperatures. To model the hydraulics of a pilot-scale dual-light fluidized system for biomass gasification, Luo, et al. [12] created a 3D CFD model. In this model, they performed a comparison between an EMMS hybrid train model and a Gidaspow train model. The hybrid EMMS trajectories' predictions of the solid circulation rate, solid inventory distribution, and solid pressure distribution were more in line with the experimental data.

3. MATERIALS AND METHODS

3.1. Key Laboratory Scale Pyrolysis Reactor and Procedure

In this work the pyrolysis tests were performed in a pilot scale batch reactor. The reactor volume was specifically sized to accommodate a maximum of 6 kilograms of plastic waste. The reactor was made of mild steel with a sealed end and an exhaust tube at the other end that was connected to a three-section condenser. The reactor is shaped like a cylinder, measuring 512 mm in height, 200 mm in outer diameter, and 6 mm in thickness. Figure 1 shows a visual representation of the developed pyrolysis reactor. Table 1 shows the parameters of the reactor used.

Figure 1. Geometry of the pyrolysis reactor

Table 1. Parameters of the pyrolysis reactor

Reactor components	Dimension
Feedstock reactor capacity	12.5 L
Reactor height	512 mm
Outside diameter	200 mm
Thickness	6 mm
Length of condenser section	400 mm
Diameter of the condenser section	40 mm

To provide the necessary heat for the transformation of the plastic waste, electrical heating elements were used in this process. The entire system is purged with nitrogen gas for 10 to 15 minutes to ensure an oxygen-free environment, as oxygen interferes with the pyrolysis and causes unfavorable side reactions. The temperature of the reactor is measured and controlled by a K-type thermocouple which transmits the temperature to a Proportional-Integral Derivative (PID) controller connected to the heating resistors. The temperature of the various phases can be precisely controlled and regulated by this system. The hydrocarbon vapor cracked from the plastic waste passes through a condenser, with two sections, installed at the outlet of the reactor. A storage tank is used to condense the gases and to collect the liquid fraction, and the second outlet which ensures the flow of the incondensable gases. In Figure 2, the experimental setup is displayed.

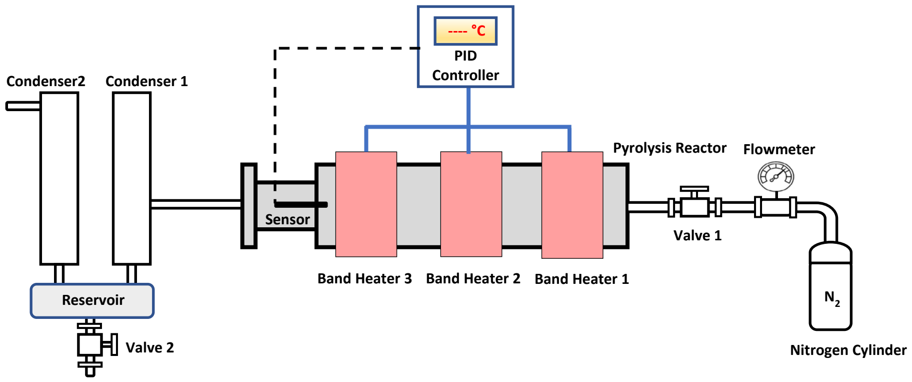

Figure 2. Schematic representation of the experimental setup

3.2. Preparation of the Sample

The raw materials used for the pyrolysis process were Low Density Polyethylene (LDPE) bags obtained from the final disposal site in the city of TIT MELLIL in Morocco. The washing, drying and grinding of the materials were performed manually. The quantity of plastic waste used in this process was about 4Kg. The LDPE are thermoplastic polymers characterized by a low density around 0.90 g/cm^3 and a melting temperature close to 105 °C. The LDPE plastic waste is used in the pyrolysis process as a raw material to be transformed into liquid fuel with energy value.

3.3. Numerical Modeling Procedure by Finite Elements

In this study, the virtual design of the reactor is produced using SolidWorks software via three-Dimensional Computer-Aided Design (3D-CAD), and it is then assessed using the FEM method. This is a numerical method used for solving systems of complex differential equations that describe the behavior of physical structures. This method is widely used in engineering, materials science and physics to simulate the behavior of complex structures [13]. The structure is decomposed into elements of simple geometric form with common sides and whose vertices (nodes) are the points of articulation of several elements between them. These nodes will be the points of application of internal or external forces. The decomposition operation is "the mesh". The finer the mesh, the more accurate the results, but this can also increase the computation time required.

The choice of mesh type and density depends on the physical properties of the system, as well as the accuracy and computational speed required for the simulation [14]. In this work, FEA is used to simulate the mechanical and thermal behavior of the pyrolysis reactor under boundary conditions. This method allows to evaluate the thermal stresses, thermal braids, and total deformations that occur in the reactor at different temperatures and under various process conditions. Using this method, it is possible to simulate the actual operating conditions of the pyrolysis reactor and identify the areas where thermal stresses are the highest. The simulation results can be used to optimize the system design and to ensure its safety and durability under operating conditions.

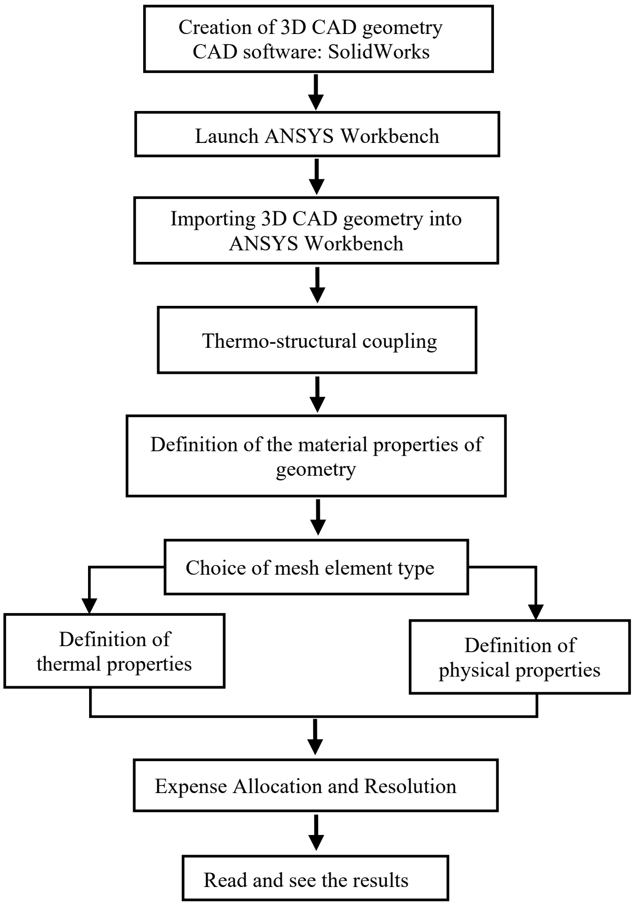

Figure 3. Thermomechanical analysis procedures

The approach consists in performing a thermo-structural coupling based on the ANSYS calculation software by involving the integration of thermal and structural modeling to simulate the behavior of the reactor subjected to high temperature conditions. It also consists in modeling the mechanical structure in a first step and then to couple the thermal effect in a second step (Figure 3). Thus, by creating the geometry in the first physical environment, it can be used in all subsequent steps. The geometry is kept constant. Although the geometry must remain constant, the types of elements can change. For example, thermal elements are needed for a thermal analysis while structural elements are needed to determine the stresses in the geometry.

4. RESULTS AND INTERPRETATIONS

The manufacturing process that converts waste plastics into liquid fuels is based on the thermolysis of plastic polymers and the resulting condensation of volatile fractions. A temperature range of approximately 350 °C to 570 °C caused decomposition reactions of the waste plastic molecules inside the reactor to provide hydrocarbons of different chain lengths. FEM was used in this study to model and simulate the reactor behavior and structure. This structure was created using a 3D model. Based on ANSYS computational software, thermal analysis is used to simulate the thermal stress distribution and thermal strains through the wall of the pyrolysis reactor.

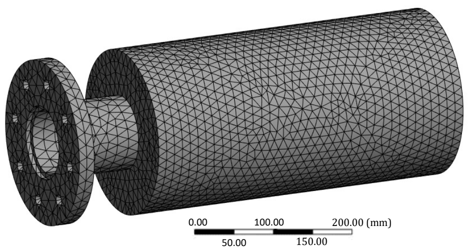

Figure 4. FE model of the geometry

In this method, the stress-strain field is calculated using the sequential coupling method, where the temperature field is first calculated to determine the temperature cycle history of each node in the finite element model, and is then used as the thermal load to determine the displacement of each node and the stress-strain value of each element. In order to avoid prohibitive computational time and without losing accuracy and efficiency, the mesh of the finite element model is relatively intense around the heat-affected area, specifically the contact surface with the electrical resistors, and sparse in other locations. The model includes a total number of 23.831 nodes and 12.023 elements. Figure 4 shows the finite element mesh representation of the three-dimensional model.

One end of the reactor would be held fixed, while the other end would be free to expand due to thermal expansion (Figure 5). This possibility of expansion on both sides resembles that of a solid bar, and the fixation was applied so as to facilitate the resolution of the model. During the thermal cracking process and with temperature variation, there is a possibility of contraction or expansion through the reactor shell layer which will cause deformation of the reactor shell. Therefore, a thermal analysis was performed using ANSYS software to test the strength of the reactor material during the temperature increase. The thermal strains, thermal stresses and total deformation were calculated to find the excellent design of the reactor. Variations in thermal conditions are caused by the electrical resistances used and the temperature produced. The thermal conditions were defined with limits of 350, 400, 450, 500, 550 and 600 °C. The ambient temperature was set at 22 °C. Table 2 shows the values of thermal strain, thermal stress and total deformation of the reactor at different temperatures.

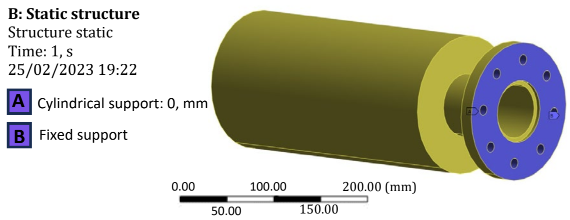

Figure 5. Fixed side in the expansion under thermal

Table 2. Values of thermal strain, thermal stress and total deformation of the reactor at different temperatures

Thermal Strain	Total Deformation (mm)	Thermal Stress (MPa)	Temperature (°C)
0.0005598	0.865	116.35	350
0.0006398	0.997	127.43	400
0.0007731	1.129	138.51	450
0.0009064	1.261	149.59	500
0.0010397	1.393	155.13	550
0.0011730	1.525	160.67	600

Figure 6 shows the distribution of thermal stress created during pyrolysis in the reactor shell. The thermal stress values vary from 116.35 MPa to 160.67 MPa as the maximum value. The maximum value recorded in this simulation does not exceed the elastic limit of the material. The distribution of thermal strain in the reactor at various temperatures is shown in Figure 7. The maximum value of the stress equal to 0.0011730 is reached at 600 °C. The excessive thermal stresses are generated at the reactor shell within acceptable limits, which allows an efficient transformation of the plastic waste. The thermal study performed by ANSYS software also predicted the corresponding total deformation. Figure 8 shows the plot of the deformation on the outer surface of the reactor at different temperatures. The values of the total deformation vary from 0.865 mm to 1.525 mm. On the reactor model we have a color degradation from green, yellow and brown to red where the critical value of the largest deformation which is located in the unfixed side of the reactor (Figure 9). However, these total deformation values are also relatively small compared to the dimensions of the reactor, indicating that the deformations of the reactor are not excessive.

Figure 6 shows the distribution of thermal stress created during pyrolysis in the reactor shell. The thermal stress values vary from 116.35 MPa to 160.67 MPa as the maximum value. The maximum value recorded in this simulation does not exceed the elastic limit of the material. The distribution of thermal strain in the reactor at various temperatures is shown in Figure 7. The maximum value of the stress equal to 0.0011730 is reached at 600 °C. The excessive thermal stresses are generated at the reactor shell within acceptable limits, which allows an efficient transformation of the plastic waste. The thermal study performed by ANSYS software also predicted the corresponding total deformation. Figure 8 shows the plot of the deformation on the outer surface of the reactor at different temperatures. The values of the total deformation vary from 0.865 mm to 1.525 mm.

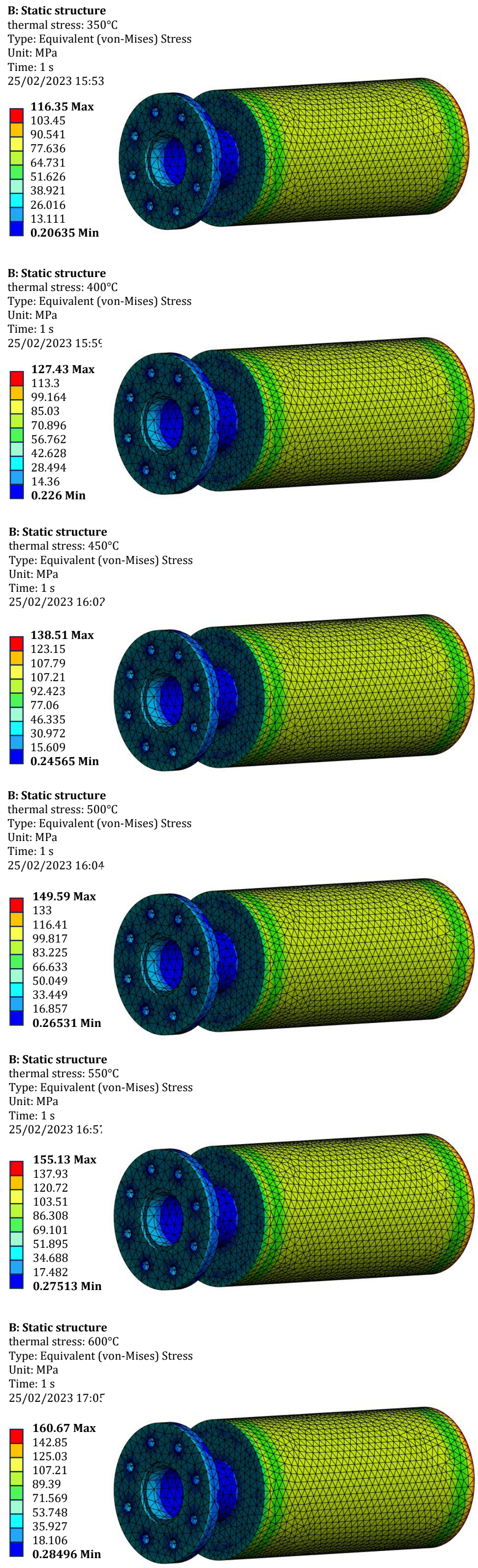

Figure 6. Thermal stress distribution in the model at different operating temperatures

On the reactor model we have a color degradation from green, yellow and brown to red where the critical value of the largest deformation which is located in the unfixed side of the reactor (Figure 9). However, these total deformation values are also relatively small compared to the dimensions of the reactor, indicating that the deformations of the reactor are not excessive.

Figure 10 shows the thermal stresses and strains developed as a function of temperature change in the reactor. During fuel production, thermal stresses were applied, causing minor deformations in the reactor wall. Temperature fluctuations can exert a significant influence on the strength and durability of the reactor. It is observed that thermal displacements and thermal stresses caused by temperature changes during the thermal cracking process, increase as the reactor temperature rises, and there is no thermal expansion that could lead to reactor failure. The results indicate that the safety and reliability of the reactor is assured for producing fuel from plastic materials. However, higher temperatures can also be used for shorter reaction times to increase the conversion rate or to produce specific products. The analysis of the stability of the pyrolysis reactor at high temperatures is crucial to ensure the safety of the plant. Our results showed that the reactor is capable of withstanding temperatures up to 600 °C with acceptable thermal stresses and total deformations. However, to evaluate the capacity of the reactor at even higher temperatures, simulations were also run at 700, 800, 900, and 1000 °C.

Figure 11 provides a visual illustration of the results obtained from the analysis performed. The results of the study indicated that the thermal stresses increase rapidly with temperature, reaching a maximum value of 466.89 MPa at 1000 °C. These values greatly exceed the elastic limit of the pyrolysis reactor at temperatures above 600 °C, which can lead to structural failure or even reactor rupture. Therefore, it is recommended not to use the reactor above 600 °C to ensure its long-term stability and safety.

5. CONCLUSION

The process of converting plastic waste into liquid fuels is a promising technology for plastic waste management. Thermolysis of plastic polymers in a pyrolysis reactor can generate hydrocarbons of different chain lengths with energy values, but requires careful analysis to ensure the strength and durability of the reactor at high temperatures. In this study, a temperature range of approximately 350 °C to 570 °C resulted in decomposition reactions of waste plastic molecules within the reactor to provide a liquid fuel. The use of finite element modeling and simulation was used to analyze the thermal behavior and structure of the pyrolysis reactor. The study's findings demonstrated that the maximum thermal stress levels in the reactor shell ranged from 116.35 MPa to 160.67 MPa. The highest value that did not exceed the elastic limit of the reactor material was recorded at a temperature of 600 °C.

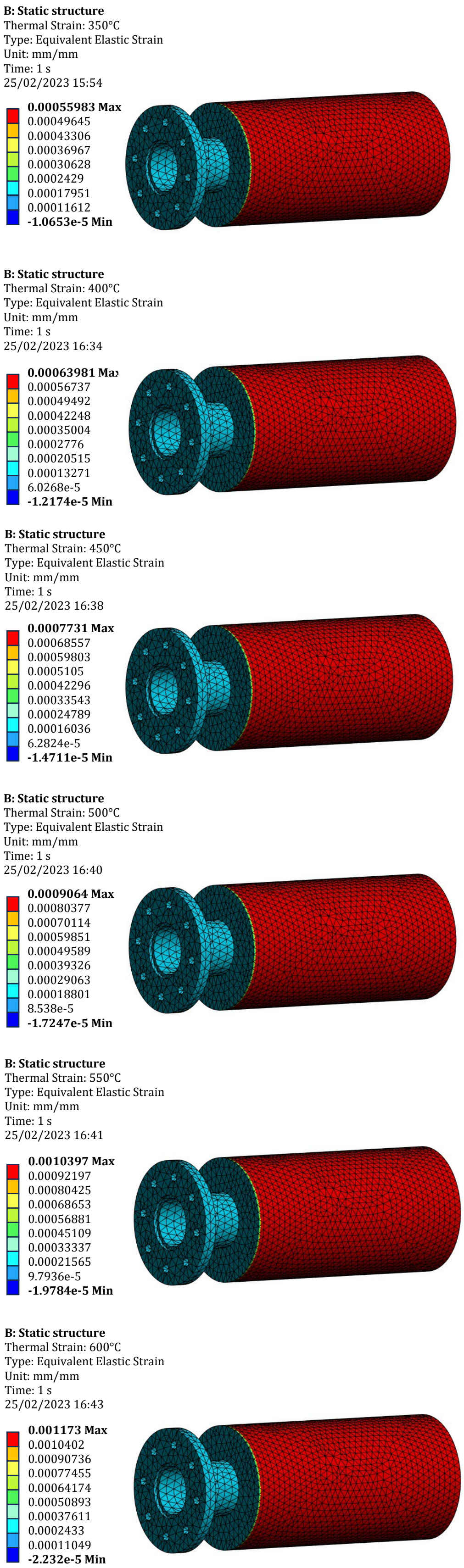

Figure 7. Thermal Strain distribution in the model at different operating temperatures

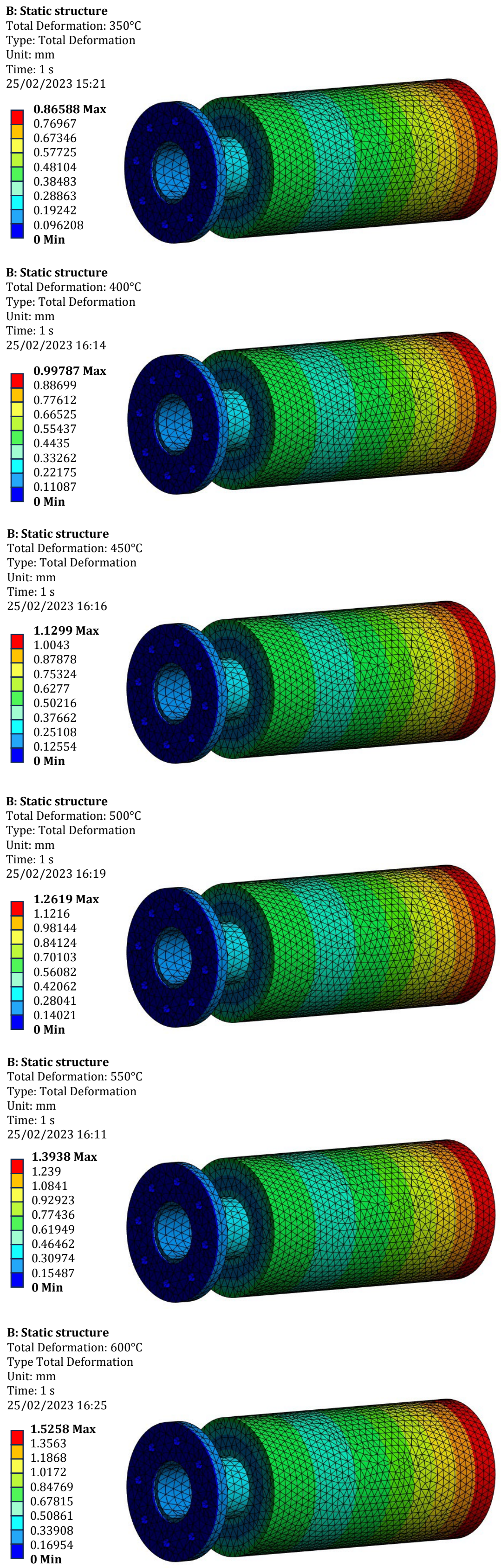

Figure 8. Total deformation of the model in thermomechanical coupling at different operating temperatures

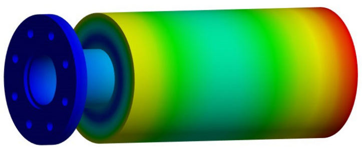

Figure 9. Maximum total deformation of the pyrolysis reactor

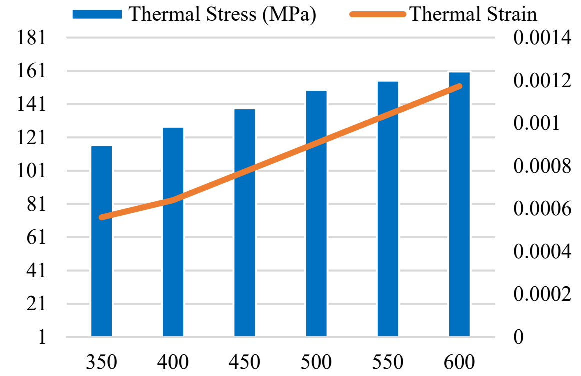

Figure 10. Correlation between the temperatures and the thermal Stress and Strain undergone by a reactor

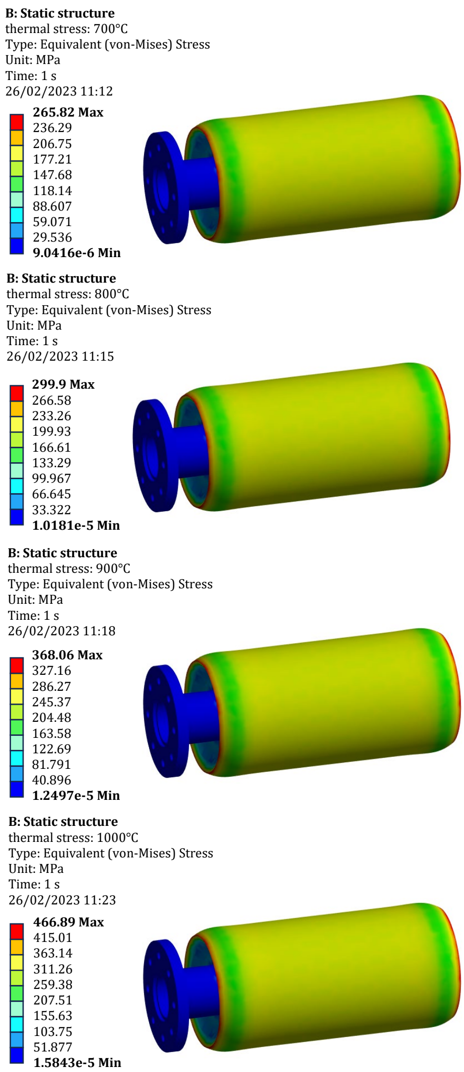

Figure 11. Thermal stress of the reactor body at different operating temperatures of 700, 800, 900 and 1000 °C

This indicates that the material can withstand the thermal stresses generated during pyrolysis of the plastic waste at this temperature. Excessive thermal stresses were produced at acceptable levels in the reactor shell, allowing for efficient processing of the plastic waste. The maximum thermal strain values were recorded at 600 °C, reaching 0.0011730. The results also showed that the total deformation levels in the reactor varied between 0.865 mm and 1.525 mm. The maximum value of total deformation was also recorded at 600 °C, but these deformation levels are relatively small compared to the dimensions of the reactor. This suggests that the deformations of the reactor are not excessive. The critical deformation was located in the non-fixed side of the reactor, with a maximum value of 1.525 mm. In conclusion, these results indicate that the reactor is capable of withstanding the thermal stresses and strains generated during the thermal cracking process. It is essential to note that although the results of the study indicate that the reactor is capable of withstanding the thermal stresses and strains generated throughout the pyrolysis process of the plastic waste, this is only true up to a maximum temperature of 600 °C. Above this temperature, the reactor material could be subjected to levels of thermal stress and strain that exceed acceptable limits, which could result in damage and loss of efficiency in the pyrolysis process.

REFERENCES

[1] R. Geyer, J.R. Jambeck, K.L. Law, "Production, Use, and Fate of all Plastics Ever Made", Science Advances, Issue 7, Vol. 3, No. 1, p. 33, 2017.
[2] EMF, "The New Plastics Economy: Rethinking the Future of Plastics and Catalyzing Action", Ellen MacArthur Found, 2017.
[3] R.K. Singh, B. Ruj, A.K. Sadhukhan, P. Gupta, "Impact of Fast and Slow Pyrolysis on the Degradation of Mixed Plastic Waste: Product Yield Analysis and their Characterization", Journal of the Energy Institute, Issue 6, Vol. 92, pp. 1647-1657, 2019.
[4] R. Miandad, et al., "Catalytic Pyrolysis of Plastic Waste: Moving Toward Pyrolysis Based Biorefineries", Frontiers in Energy Research, Vol. 7, No. 27, March 2019.
[5] M. Syamsiro, et al., "Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors", Energy Procedia, Vol. 47, pp. 180-188, 2014.
[6] J. Gunorubon, S. Chukwudera, "Development of a Simulation and Analysis Tool for Chemical Reactors", International Journal of Engineering, Issue 12, Vol. 7, No. 6, pp. 27-34, December 2017.
[7] A. Jayswal, A. Kumarsah, P. Pradhananga, R. Sah, A. Kumar Sah, H. Bahadur Darlami, "Design, Fabrication and Testing of Waste Plastic Pyrolysis Plant", The IOE Graduate Conference, Vol. 5, pp. 275-282, Lalitpur, Nepal, December 2017.
[8] K.M. Adeleke, O.E. Itabiyi, O.O. Ilori, "Design, Simulation Analysis and Performance Evaluation of a Fluidized Bed Reactor for the Pyrolysis of Biomass",

American Journal of Engineering Research, Issue 8, Vol. 7, pp. 128-145, August 2018.
[9] R. Khezri, W. Azlina, W. Ab, K. Ghani, S.M. Soltani, "Computational Fluid Dynamics Simulation of Gas - Solid Hydrodynamics in a Bubbling Fluidized-Bed Reactor: Effects of Air Distributor, Viscous and Drag Models", Processes, Issue 8, Vol. 7, pp. 1-16, 2019.
[10] Q. Xiong, F. Xu, E. Ramirez, S. Pannala, C.S. Daw, "Modeling the Impact of Bubbling Bed Hydrodynamics on Tar Yield and its Fluctuations During Biomass Fast Pyrolysis", Fuel, Vol. 164, pp. 11-17, January 2016.
[11] M. Upadhyay, H.C. Park, H.S. Choi, "Multiphase Fluid Dynamics Coupled Fast Pyrolysis of Biomass in a Rectangular Bubbling Fluidized Bed Reactor: Process Intensification", Chemical Engineering and Processing - Process Intensification, Vol. 128, pp. 180-187, June 2018.
[12] Z. Li, H. Xu, W. Yang, A. Zhou, M. Xu, "CFD Simulation of a Fluidized Bed Reactor for Biomass Chemical Loop Gasification with Continuous Feedstock", Energy Convers. Manag, Vol. 201, p. 112143, July 2019.
[13] H.A. Ariani, I. Iskender, M. Karakaya, "Performance Analysis of a Distribution Transformer", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 45, Vol. 12, No. 4, pp. 57-62, December 2020.
[14] A.A. Battawi, B.H. Abed, "Finite Element Simulation of Buckling Behavior of Epoxy Composite Plate Reinforced with Nano-Al Particles", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 52, Vol. 14, No. 3, pp. 144-149, September 2022.

BIOGRAPHIES

Name: **Jamal**
Surname: **Oufkir**
Birthday: 18.07.1986
Birthplace: Casablanca, Morocco
Bachelor: Bachelor of Science in Chemistry, Major in Natural Substances, Faculty of Sciences Ben M'sik - FSBM, Hassan II University, Casablanca, Morocco, 2008
Master: Quality Control in the Pharmaceutical, Food, and Cosmetic Industries, Faculty of Sciences Ben M'sik - FSBM, Hassan II University, Casablanca, Morocco, 2010
Research Interests: Pyrolysis of Biomass and Plastic Waste, Conversion into Biofuels and Valuable Chemicals
The Last Scientific Position: Lecturer, Physics and Chemistry, Ibn Khaldoun High School, Ministry of National Education, Casablanca, Morocco, Since 2011
Scientific Publications: 2 Papers, 2 Patents

Name: **Soufiane**
Surname: **Zerraf**
Birthday: 17.07.1989
Birthplace: Casablanca, Morocco
Bachelor: Physico-Chemistry of Materials and Spectroscopy, Faculty of Sciences Ben M'sik - FSBM, Hassan II University, Casablanca, Morrocco, 2012
Master: Research Master in Instrumentation and Physico-Chemical Analysis Methods (IMAPC), Faculty of Sciences Ben M'sick, Hassan II University, Casablanca, Morocco, 2014
Doctorate: Physico-Chemistry of Materials and Spectroscop, Faculty of Sciences Ben M'sik - FSBM, Hassan II University, Casablanca, Morocco, 2019
Research Interests: Chimie-Physics, Materials Science, Spectroscopy, Science Education
The Last Scientific Position: Assoc. Prof., FSBM, Hassan II University, Casablanca, Morocco, Since 2021
Scientific Publications: 22 Papers, 1 Book, 1 Thesis

Name: **Said**
Surname: **Belaaouad**
Birthday: 05.05.1964
Birthplace: Casablanca, Morocco
Bachelor: Physical Chemistry, Ben M'Sick Faculty of Sciences, Hassan II University, Casablanca, Morocco, 1988
Master: Physical Chemistry, Ben M'Sick Faculty of Sciences, Hassan II University, Casablanca, Morocco, 1990
Doctorate: Physical Chemistry, Ben M'Sick Faculty of Sciences, Hassan II University, Casablanca, Morocco, 2002
The Last Scientific Position: Prof., Higher Education, Ben M'Sick Faculty of Sciences, Hassan II University, Casablanca, Morocco, Since 2002
Research Interests: Physico-Chemical Properties, Crystal Structures and Valorizations of New Phosphates Condensed, Engineering of Training and Didactics of Sciences and Techniques
Scientific Publications: 179 Papers, 8 Projects, 1 Thesis