Visualisation of Process Engineering Application

Faculty of Process and Systems Engineering
&
Faculty of Computer Science

Pyrolysis of Plastics

Poorna Chandrasekar Pedhiredla - 245855 (CEE)
Shubham Chandrakant Borkar - 249251 (CEE)
Arjun Babu Chandra Mouleshwari Surendra Babu - 241191 (DE)

02.05.2025

Contents

1 Introduction

Plastics have dramatically improved the quality of life through their versatility and ability to be used in almost every industry. Plastic possesses desirable properties such as low cost and weight, electrical insulation, and resistance to heat, chemicals, and water. However, these come with escalating environmental costs, including global warming, increasing non-biodegradable waste in landfills, and ocean pollution with hazardous effects on marine species.

There are many methods to recycle plastic, which include mechanical recycling, pyrolysis, and hydrothermal processes. Each of these processes has positive and negative benefits to both the environment and society. However, this study will focus specifically on the process of converting plastic waste to fuel via pyrolysis. Pyrolysis utilises high temperatures and often chemical catalysts in an oxygen-free environment to convert mixed plastic wastes back into the base monomers or larger hydrocarbons [3]. The monomers can then be used as a chemical feedstock to create new recycled plastics, creating a circular economy, or the hydrocarbons can be used as a fuel mixture to gain energy. Therefore, there is high potential for this process to reduce the environmental impacts of plastic waste while still allowing plastics to improve daily life.

2 Objective and Approach

The main objective was to design an app that would be useful for chemical engineering students to visualise the process of pyrolysis of plastic waste.

For the process, we considered the recycled plastic to be fed to the reactor where an oxygen-free environment was created by purging nitrogen. The reactor was set at a temperature of 500 °C, which converted the plastic to various hydrocarbons. Then these hydrocarbons were passed through a catalyst tower for further conversion. Finally, a distillation column was attached to separate hydrocarbons.

We planned to visualise this entire process inside the app using Blender and Unity to create an interactive and immersive learning experience. The 3D models and animations were designed to demonstrate stages of pyrolysis. Additionally, we included explanatory text to guide users through the chemical reactions and equipment functions. The app was intended to enhance students' understanding by allowing them to explore the process.

3 Process description

3.1 Pyrolysis Fundamentals

Pyrolysis is a thermochemical decomposition process that occurs in the absence of oxygen at elevated temperatures. For plastic waste processing, this endothermic process involves breaking the long polymer chains by applying heat energy in an inert atmosphere. The chemical bonds in the polymer structure are cleaved, leading to the formation of smaller, more volatile compounds.

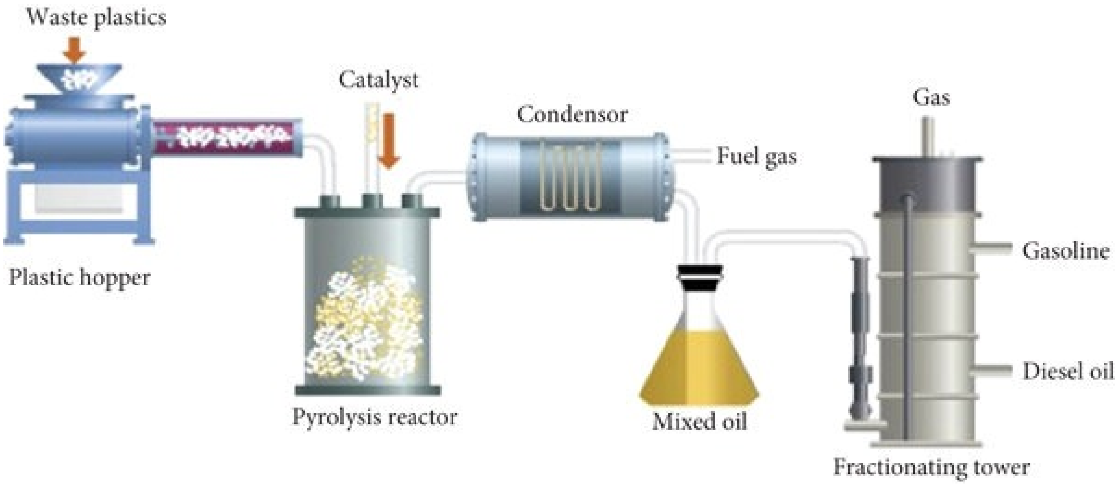

Figure 3.1: Plastic pyrolysis process description[4].

The complete pyrolysis process involves several interconnected stages:

a. Primary decomposition: The initial break of polymer chains into smaller fragments (oligomers).

b. Secondary reactions: These fragments are further decomposed into even smaller molecules through various pathways:

o *Cracking*: Breaking of C-C bonds to form smaller hydrocarbons.
o *Dehydrogenation*: Removal of hydrogen to form unsaturated compounds.
o *Cyclisation*: Formation of cyclic compounds from linear fragments.
o *Aromatisation*: Formation of aromatic rings through cyclisation and dehydrogenation.

c. Tertiary reactions: Interactions between fragments leading to recombination, condensation, or further decomposition.

Table 3.1: Key operational parameters influencing pyrolysis reaction rate and selectivity

Parameter	**Description**
Temperature	Typically 300–900°C (optimized at 500°C for this project)
Residence time	60–120 minutes in this project
Heating rate	Affects product distribution during pyrolysis
Plastic type/composition	Different polymers yield different product profiles
Catalysts	Presence and type influence reaction pathways
Reactor design/mixing efficiency	Affects heat transfer and reaction uniformity

3.2 Feedstock Preparation and Characteristics[6]

The quality and preparation of plastic feedstock significantly influence the pyrolysis process efficiency and product distribution. The visualisation system represents the following feedstock characteristics:

Plastic Types Processed:

- *Low-Density Polyethene (LDPE)*: Common in packaging films and bags.
- *High-Density Polyethene (HDPE)*: Used in bottles, containers, and pipes.
- *Polypropylene (PP)*: Found in packaging, automotive parts, and textiles.
- *Polystyrene (PS)*: Used in disposable cutlery, packaging, and insulation.

Feedstock Preparation Steps:

1. Collection and sorting of plastic waste.
2. Removal of contaminants (dirt, metals, other non-plastic materials).
3. Washing and drying to remove surface impurities.
4. Size reduction through shredding/grinding to $\leq 20\,\text{mm}$ particle diameter.
5. Storage in the feed hopper system.

The visualisation allows users to select different plastic types and observe how their chemical structures and properties affect the pyrolysis process and product distribution.

Table 3.2: Key Feedstock Properties for Plastic Processing

Property	Specification	Notes
Particle size	≤20 mm diameter	Optimized for heat transfer and residence time
Moisture content	≤0.053%	Higher moisture reduces process efficiency
Bulk density	200-500 kg/m^3	Depends on plastic type
Composition variability	Mixed or single polymer streams	Affects product consistency
Contaminant level	As low as possible	Lower contamination yields higher-quality products

3.3 Reactor Design and Components

The visualisation project focuses on a comprehensive reactor system with the following key components:

Horizontal Screw Kiln Reactor:

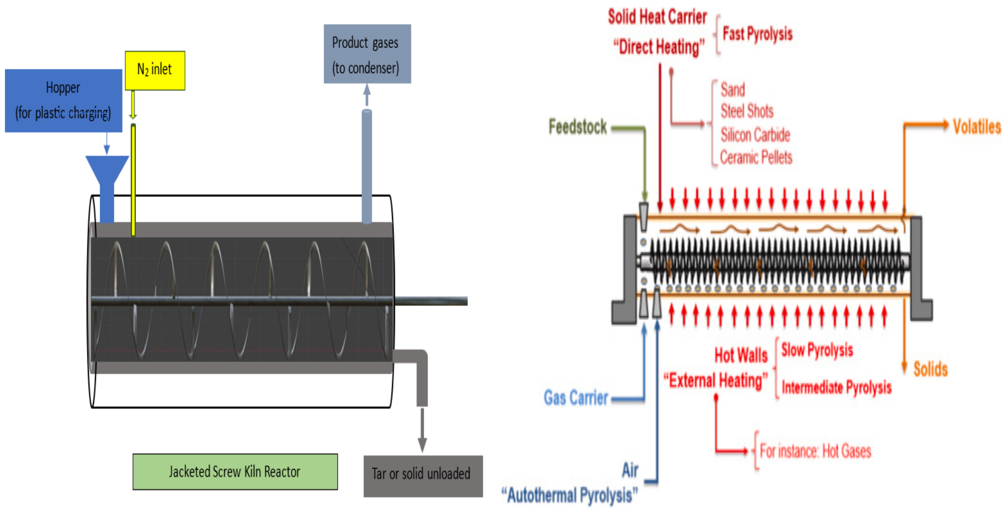

Figure 3.2: Horizontal screw kiln reactor [2].

The horizontal screw kiln reactor is where the plastic feedstock undergoes thermal decomposition [1], [2]. The detailed specifications of the reactor are listed in Table 3.3.

Table 3.3: Specifications of the Horizontal Screw Kiln Reactor System

Component	Specification	Value/Dimension
Core Dimensions	Diameter	0.4 m
	Length	1.2 m
	Working volume	0.151 m^3
	Wall thickness	0.008 m
Screw Conveyor	Screw diameter	0.384 m
	Core diameter	0.032 m
	Pitch	0.2 m
	Flight thickness	0.005 m
	Number of flights	6 turns
	Clearance	8 mm
	Rotation speed	5-15 RPM
Feed System	Hopper dimensions	5 cm (Inner Diameter) $\times$ 6 cm (Outer Diameter) $\times$ 5 cm (Height)
	Feed pipe diameter	0.06 m
	Feed rate control	Adjustable
	Anti-bridging mechanism	Included
Gas Outlet	Outlet pipe diameter	0.04 m
	Pressure relief valve	Included
Materials	Reactor body	High-temp stainless steel
	Screw	Heat-resistant alloy steel
	Insulation	Ceramic fibre/mineral wool
	External cladding	Stainless steel/aluminium
Design Features	Orientation	Horizontal
	Temperature monitoring	Multiple points
	Atmosphere control	Sealed inert system
	Motor dimensions	30 cm $\times$ 20 cm $\times$ 15 cm

3.4 Heating System and Temperature Control

Temperature control is critical for optimising pyrolysis reactions and product distribution. The visualisation system includes a comprehensive heating system.

3.4.1 Jacket Design

The jacket design ensures efficient heat transfer while maintaining structural integrity and thermal insulation. The detailed specifications of the jacket are listed in Table 3.4.

Table 3.4: Specifications for Reactor Jacket Design

Parameter	**Specification**
Inner diameter	0.5 m (reactor diameter + 2 × 0.05 m clearance)
Outer diameter	0.7 m (includes 0.1 m insulation thickness)
Length	1.2 m (matches reactor length)
Flow path	Baffles or spiral guides for uniform heating
Material	High-temperature resistant steel with ceramic insulation

3.4.2 Heating Options

The reactor can be heated in two ways: with a natural gas burner or electric coils. The tables below show the details of each heating option.

a. Natural Gas Burner System:

Table 3.5: Specifications of Natural Gas Burner System for Reactor

Parameter	**Specification**
Heat output (1-hour reaction)	992 kW
Burner efficiency	80%
Gas pipe diameter	50 mm
Natural gas flow rate (1-hour reaction)	71.43 kg/h
Natural gas flow rate (2-hour reaction)	35.715 kg/h
Volumetric flow rate	89.29 m^3/h (0.025 m^3/s)
Burner placement	Positioned at one end of the jacket

b. Electric Heating Alternative:

Table 3.6: Specifications of Electric Heating System for Reactor

Parameter	**Specification**
Heating Element Material	Nickel-chromium alloy
Insulation Material	Glass wool
Power Rating	1 kW
Maximum Temperature	1000°C
Heat Distribution	Uniform along reactor length

3.4.3 Temperature Control System

• Multiple thermocouples are installed at strategic locations along the reactor to monitor temperature variations.

• A PID control system maintains the target temperature within the desired range.

• The temperature gradient is visualized along the reactor length, from the inlet to the outlet.
• Temperature-time profile following the equation:

$$T(t) = T_f - (T_f - T_i) \times e^{-k \times t} \tag{1}$$

Where:

T_f: Final temperature (500 °C).
T_i: Initial temperature (25 °C).
k: Heat transfer rate constant.
t: Time in minutes.

3.4.4 Insulation System

The insulation system is designed to minimize heat loss and ensure thermal efficiency. Key features include:
• Material: High-temperature-resistant ceramic fiber or mineral wool.
• Thickness: 0.1 m (optimized for thermal efficiency).
• External cladding: Stainless steel or aluminum for enhanced mechanical protection.
• Thermal conductivity: <0.1 W/m·K at operating temperature (ensuring effective insulation).

3.5 Reaction Chemistry and Kinetics

The chemical reactions represented in the visualisation are based on established pyrolysis mechanisms:

3.5.1 Polymer Breakdown Mechanisms:

a. **Polyethene (PE) Decomposition:**

- Random scission of C-C bonds:

$$(C_2H_4)_n \longrightarrow \text{various } C_xH_y \text{ fragments}$$

- Primary products: Propane (C_3H_8), Hexane (C_6H_{14}), other alkanes/alkenes.
- Reaction kinetics: First-order with $k = 0.005\,\mathrm{s}^{-1}$.

b. **Polypropylene (PP) Decomposition:**

- Preferential breaking at tertiary carbon sites:

$$(C_3H_6)_n \longrightarrow C_3H_6 \text{ (Propene)} + \text{other hydrocarbons}$$

- Higher olefin content compared to PE pyrolysis.

c. **Polystyrene (PS) Decomposition:**

- Depolymerization to styrene monomers:

$$(C_8H_8)_n \longrightarrow C_8H_8 \text{ (Styrene)} + \text{aromatics}$$

- Significant yield of original monomer ($> 60\%$ potential).

3.5.2 Product Distribution Models:

For a typical PE feedstock at 500°C:

- Conversion rate: 80% of the initial material
- Product distribution:
  - 75% Propane (C_3H_8)
  - 20% Hexane (C_6H_{14})
  - 5% Tar (average molecular weight: 400 g/mol)

3.5.3 Reaction Parameters:

- Activation energy: 200–300 kJ/mol (polymer dependent)
- Heat of reaction: 420 kJ/kg
- Reaction rate constant (k): $0.005\,\mathrm{s}^{-1}$
- Temperature dependence: Follows Arrhenius equation $k = Ae^{-E_a/RT}$

3.5.4 Catalytic Effects:

- Enhanced C-C bond scission at specific catalyst acid sites
- Reduced activation energy for cracking reactions
- Promotion of isomerisation and cyclisation
- Selective formation of aromatics through shape-selective catalysis

The visualisation enables users to observe these reaction pathways and product formations through dynamic molecular representations with animated color changes.

4 Engineering Design and Calculations for Pyrolysis Process

4.1 Mass Balance Analysis[9]

The mass balance analysis for the pyrolysis process establishes the relationship between inputs and outputs, providing the foundation for reactor sizing, product yield estimation, and system efficiency evaluation. This analysis was performed using established chemical engineering principles and experimental data from the literature.

4.1.1 Process Inputs

- Initial mass of polyethene (PE): 2000 kg
- Nitrogen purge gas: Minimal mass contribution, primarily for maintaining an inert atmosphere
- Catalyst: 0.023 mass fraction of raw material (46 kg for 2000 kg feedstock)

4.1.2 Process Assumptions

- Conversion efficiency of PE: 80% (based on optimal temperature of 500 °C and residence time)
- Product distribution based on experimental data for PE pyrolysis at 500 °C
- Steady-state operation with continuous feeding
- Negligible mass losses through leakage or sampling
- Complete recovery of products (ideal case for visualisation)
- Molecular weight assumptions:
  - Propane (C3H8): $44.1\,\mathrm{g\,mol^{-1}}$
  - Hexane (C6H14): $86.18\,\mathrm{g\,mol^{-1}}$
  - Average tar components: $400\,\mathrm{g\,mol^{-1}}$

4.1.3 Mass Balance Equations

Overall Mass Balance:

$$m_{\text{input}} = m_{\text{output}} \tag{2a}$$

$$m_{\text{PE input}} = m_{\text{unconverted PE}} + m_{\text{propane}} + m_{\text{hexane}} + m_{\text{tar}} \tag{2b}$$

4.1.4 Detailed Mass Distribution Calculations

$$\begin{aligned}
\text{Unconverted PE} &= (1 - \text{conversion efficiency}) \times \text{initial PE mass} \\
&= (1 - 0.8) \times 2000\,\text{kg} = 400\,\text{kg} \\
\text{Converted PE} &= \text{conversion efficiency} \times \text{initial PE mass} \\
&= 0.8 \times 2000\,\text{kg} = 1600\,\text{kg} \\
\text{Mass of Propane} &= \text{propane fraction} \times \text{converted PE} \\
&= 0.75 \times 1600\,\text{kg} = 1200\,\text{kg} \\
\text{Mass of Hexane} &= \text{hexane fraction} \times \text{converted PE} \\
&= 0.2 \times 1600\,\text{kg} = 320\,\text{kg} \\
\text{Mass of Tar} &= \text{tar fraction} \times \text{converted PE} \\
&= 0.05 \times 1600\,\text{kg} = 80\,\text{kg}
\end{aligned}$$

4.1.5 Verification of Mass Conservation

$$\text{Total output mass} = 400\,\text{kg} + 1200\,\text{kg} + 320\,\text{kg} + 80\,\text{kg} = 2000\,\text{kg}$$

This confirms that the total mass is conserved within the system.

4.1.6 Molar Balances

The mass balance can be extended to a molar basis for deeper chemical analysis:

Table 4.1: Molar Conversion Calculations

Component	**Moles**
Propane	$\frac{1200\,\text{kg}}{44.1\,\text{g}\,\text{mol}^{-1}} = 27\,211\,\text{mol}$
Hexane	$\frac{320\,\text{kg}}{86.18\,\text{g}\,\text{mol}^{-1}} = 3713\,\text{mol}$
Tar	$\frac{80\,\text{kg}}{400\,\text{g}\,\text{mol}^{-1}} = 200\,\text{mol}$

4.1.7 Carbon Balance

Carbon in PE (assuming C2H4 repeating unit) :

$$\text{Carbon fraction} = \frac{24\,\mathrm{g\,mol^{-1}}}{28\,\mathrm{g\,mol^{-1}}} = 0.857$$

$$\text{Total carbon in input} = 0.857 \times 2000\,\mathrm{kg} = 1714\,\mathrm{kgC}$$

Table 4.2: Carbon Distribution in Products

Product	**Carbon Mass**
Propane (C3H8)	$3 \times \frac{12\,\mathrm{g\,mol^{-1}}}{44.1\,\mathrm{g\,mol^{-1}}} \times 1200\,\mathrm{kg} = 979.6\,\mathrm{kg}$
Hexane (C6H14)	$6 \times \frac{12\,\mathrm{g\,mol^{-1}}}{86.18\,\mathrm{g\,mol^{-1}}} \times 320\,\mathrm{kg} = 267.1\,\mathrm{kg}$
Tar (estimated)	$0.85 \times 80\,\mathrm{kg} = 68\,\mathrm{kg}$
Unconverted PE	$0.857 \times 400\,\mathrm{kg} = 342.8\,\mathrm{kg}$
Total carbon in output	$1657.5\,\mathrm{kg}$

The small difference in input and output carbon (approximately 3%) falls within acceptable error margins for complex reaction systems.

4.2 Energy Balance Analysis[8],[9]

The energy balance analysis is crucial to determine heating requirements, evaluate process efficiency, and design appropriate heat transfer systems for the pyrolysis reactor.

4.2.1 Energy Balance Framework

The overall energy balance for the pyrolysis system can be expressed as:

$$E_{\text{in}} = E_{\text{out}} + E_{\text{accumulated}} + E_{\text{losses}} \tag{3}$$

Where:

E_{in}: Energy input to the system (heating)
E_{out}: Energy output (in products, including sensible and chemical energy)
$E_{\text{accumulated}}$: Energy accumulated within the system (typically zero at steady state)
E_{losses}: Energy losses to the environment (minimized through insulation).

4.2.2 Process Assumptions

- Reaction temperature: 500 °C (773 K)
- Initial temperature: 25 °C (298 K)
- Heat of reaction (endothermic): $\Delta H_r = 434\,\mathrm{kJ\,kg^{-1}}$ of converted plastic
- Specific heat capacity of PE: $C_p = 2.3\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$
- Natural gas heating value: $50\,000\,\mathrm{kJ\,kg^{-1}}$
- Heat transfer efficiency from burner to reactor: 80%

4.2.3 Detailed Energy Calculations

Sensible Heat Requirement :

$$\begin{aligned} E_{\text{heating}} &= m \times C_p \times (T_{\text{final}} - T_{\text{initial}}) \\ &= 2000\,\mathrm{kg} \times 2.3\,\mathrm{kJ\,kg^{-1}\,K^{-1}} \times (773\,\mathrm{K} - 298\,\mathrm{K}) \\ &= 2\,185\,000\,\mathrm{kJ} \end{aligned} \tag{4a}$$

Reaction Energy Requirement :

$$\begin{aligned} E_{\text{reaction}} &= m_{\text{converted}} \times \Delta H_r \\ &= 1600\,\mathrm{kg} \times 420\,\mathrm{kJ\,kg^{-1}} \\ &= 672\,000\,\mathrm{kJ} \end{aligned} \tag{4b}$$

Total Theoretical Energy Requirement :

$$\begin{aligned} E_{\text{total}} &= E_{\text{heating}} + E_{\text{reaction}} \\ &= 2\,185\,000\,\mathrm{kJ} + 672\,000\,\mathrm{kJ} \\ &= 2\,857\,000\,\mathrm{kJ} \end{aligned} \tag{4c}$$

Practical Energy Input Requirement :

$$\begin{aligned} E_{\text{actual}} &= \frac{E_{\text{total}}}{\eta_{\text{transfer}}} \\ &= \frac{2\,857\,000\,\mathrm{kJ}}{0.8} \\ &= 3\,571\,250\,\mathrm{kJ} \end{aligned} \tag{4d}$$

Natural Gas Consumption :

$$
\begin{aligned}
m_{\text{gas}} &= \frac{E_{\text{actual}}}{\text{HV}_{\text{gas}}} \\
&= \frac{3\,571\,250\,\text{kJ}}{50\,000\,\text{kJ}\,\text{kg}^{-1}} \\
&= 71.43\,\text{kg}
\end{aligned}
\tag{4e}
$$

4.2.4 Energy Return on Investment (ERoI)

Energy in products :

$$
\begin{aligned}
\text{Propane} &= 1200\,\text{kg} \times 46\,350\,\text{kJ}\,\text{kg}^{-1} = 55\,620\,000\,\text{kJ} \\
\text{Hexane} &= 320\,\text{kg} \times 44\,700\,\text{kJ}\,\text{kg}^{-1} = 14\,304\,000\,\text{kJ} \\
\text{Total energy} &= 69\,924\,000\,\text{kJ}
\end{aligned}
$$

Energy Return on Investment :

$$
\text{ERoI} = \frac{\text{Energy in products}}{\text{Energy input}} = \frac{69\,924\,000\,\text{kJ}}{3\,571\,250\,\text{kJ}} \approx 19.6
$$

This indicates that the process produces nearly 20 times more energy in fuel products than it consumes, demonstrating high energy efficiency.

5 Application Development

This section outlines the software development process of the application, highlighting the tools and frameworks used, the key features implemented, and how the app functions. The application simulates the pyrolysis process of plastic waste using 3D modeling, animation, and interactive elements for educational purposes.

5.1 Functionality Implementation

5.1.1 3D Modeling

The 3D components of the application were created using Blender, a powerful open-source 3D modeling software. Key reactor components were modeled according to technical specifications, including the reactor body and rotating screw. These models were later imported into the game engine for integration and animation.

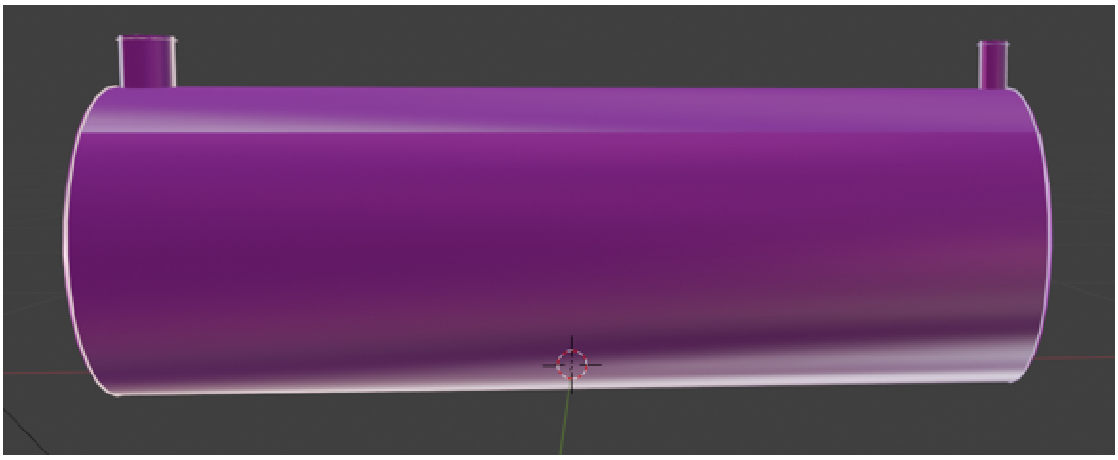

Figure 5.1: Horizontal screw kiln reactor designed using Blender (outer view).

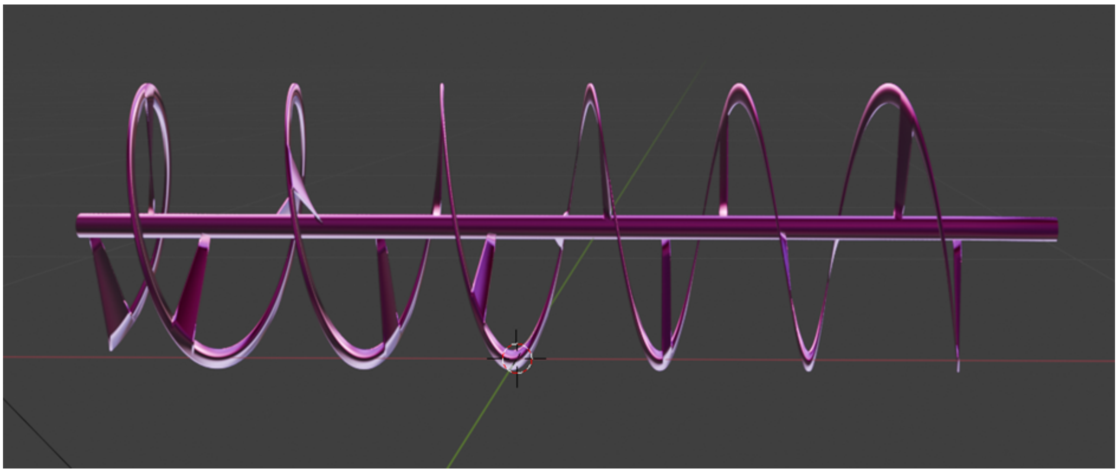

Figure 5.2: Rotating screw designed using Blender.

5.1.2 Game Engine and Core Features

The application was developed in Unity, targeting Windows platforms. Unity's robust feature set allowed the integration of multiple technical elements, including:

- Particle systems to simulate gas flow and plastic decomposition
- Gravity and physics for realistic movement
- Colliders (box and mesh types) to contain and control particle movement
- Canvas system for GUI elements such as images, text, and buttons

These elements were essential in creating a realistic simulation of the pyrolysis process.

5.1.3 Custom Scene Scripting

C# was used as the primary scripting language within Visual Studio. Several custom scripts were implemented, including:

- Automatic rotation of the screw at the start of the process, stopping when the process ends
- Button interactions for scene transitions (e.g., load, go back, restart, and exit)
- Timed text animations that display relevant process information in synchronization with the particle system behavior

These scripts ensured both automation and interactivity, improving the user experience.

5.1.4 Image and Avatar Processing

Visual assets were enhanced using AI-based tools. Background images were generated with ChatGPT's image capabilities[5], while ToonMe[7] and ChatGPT[5] were used to create avatar illustrations for the credits scene, ensuring a visually appealing and customized interface.

5.2 Application Structure and Use

This section describes the structure of the application and how users interact with it through different scenes.

5.2.1 Home Scene

The Home Scene serves as the entry point (Figure 5.3). At the top, it displays the project title: "Pyrolysis of Plastics". In the center are three buttons: Start, Credits, and Exit.

- **Start** loads the Process Animation scene
- **Credits** displays acknowledgments
- **Exit** closes the application

5.2.2 Credits Scene

Clicking Credits button loads the Credits Scene (Figure 5.4), designed with a classroom theme featuring a green board. This scene introduces the team and contributors involved in the development of the application.

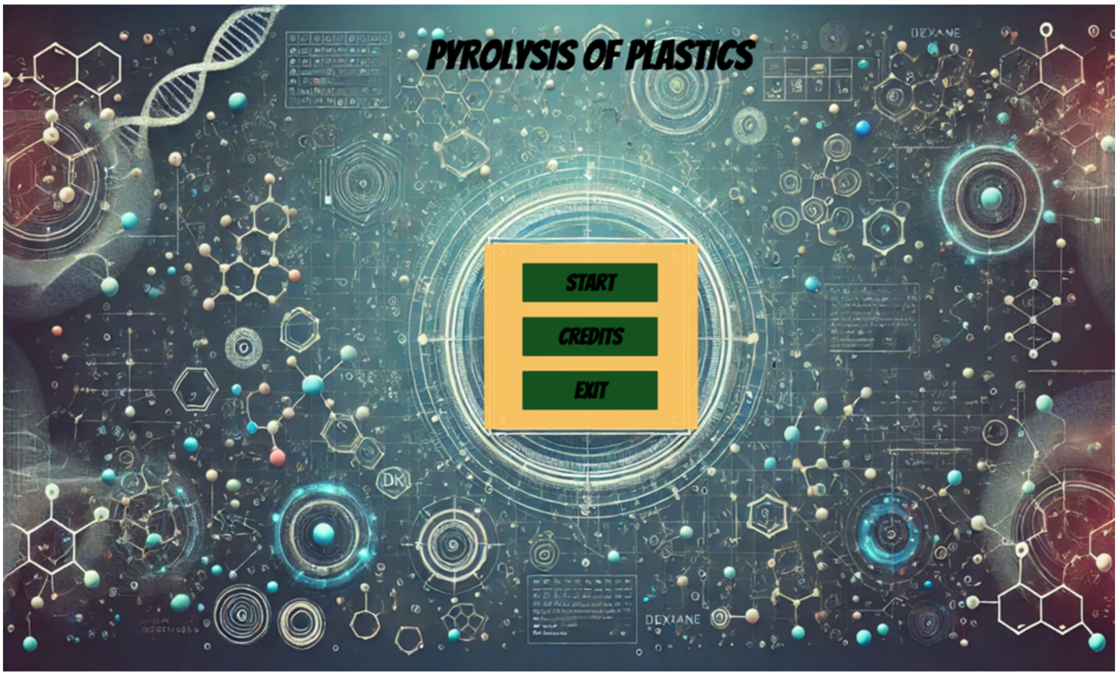

Figure 5.3: Home scene of the application.

Figure 5.4: Credits scene of the application.

5.2.3 Process Animation Scene

Clicking the Start button on the home screen navigates the user to the Process Animation Scene (Figure 5.5). This scene is the most detailed and functionally rich part of the application. The majority of features are implemented here.

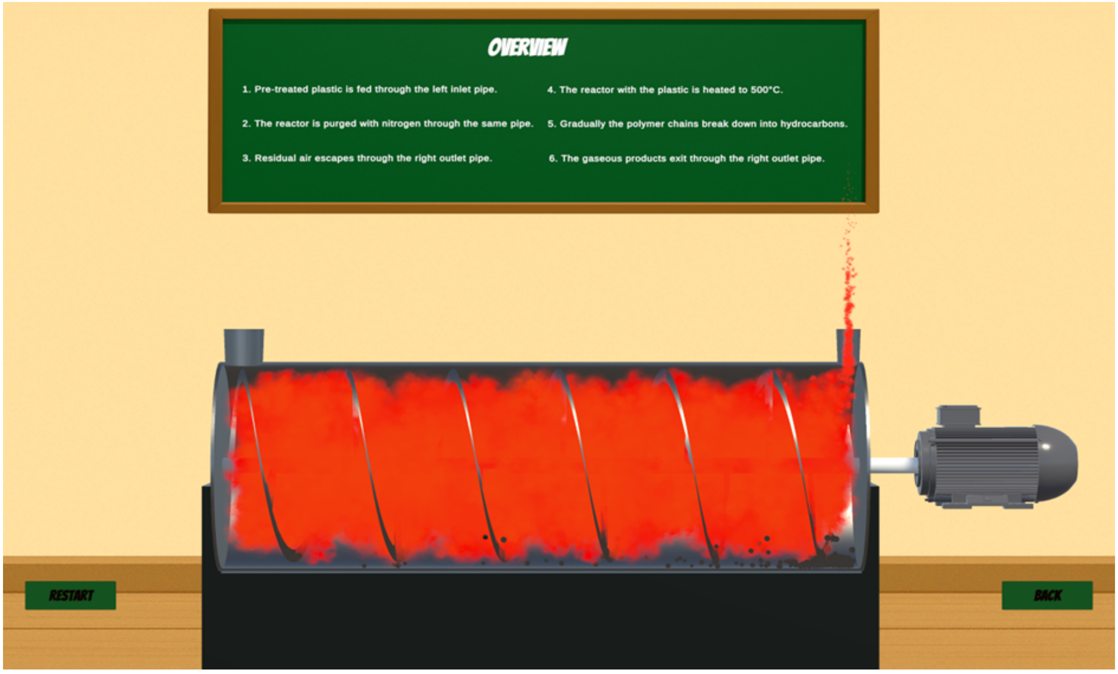

Figure 5.5: Process animation scene of the application.

The consistent classroom theme continues in this scene, with a greenboard displayed at the top centre, showing an overview of the ongoing process. At the bottom left, a Restart button allows users to replay the simulation from the beginning at any time. A Back button in the bottom right corner returns the user to the home screen.

The reactor assembly is placed in the bottom centre of the scene, with the inlet pipe on the left and the outlet pipe on the right. The greenboard dynamically updates to explain the current stage of the process in synchrony with the animation, enhancing user comprehension.

The simulation begins with the rotation of the screw, initiating the feed of pre-treated plastic through the inlet pipe. This plastic moves through the reactor with the assistance of the screw mechanism. Simultaneously, nitrogen gas is purged into the system through the same inlet, represented visually by a yellow gas. As the nitrogen enters, it displaces the existing air in the reactor, which exits through the outlet pipe. The outlet remains open throughout the process to prevent pressure build-up within the vessel.

The reactor then gradually heats to 500°C. This increase in temperature is visually depicted by a gradual transition of the gas colour from yellow to red. As the plastic is exposed to heat, the long polymer chains begin to break down into smaller hydrocarbon molecules. These gaseous products exit through the outlet pipe and would, in a real-world application, undergo further purification to remove any residual impurities.
Once the plastic has been fully converted and the gaseous products have exited, the screw automatically stops, marking the end of the process.

6 Discussion – Project Challenges, Highlights, and Achievements

The design of the Process Animation Scene posed several significant challenges and also led to notable achievements in both visual realism and interactivity.
To enhance the user's understanding of the reactor process, the reactor was made semi-transparent, allowing visibility into the interior. This required careful material selection and advanced modelling work. Achieving the correct perspective projection also involved precise camera positioning to preserve a natural 3D view.
Simulating the movement and interaction of particles within the reactor was particularly complex. A particle system with gravity was employed to create a realistic motion of the plastic inside the reactor. Particles were designed to interact with both the rotating screw and the reactor walls. A major issue encountered was the unintended escape or loss of particles. This was addressed by developing and strategically placing multiple hidden colliders, carefully modelled in Blender to retain particles within the reactor.
A key success of the project was the realistic visualisation of gas movement. Multiple particle systems were used to depict the nitrogen purging and the transformation of gas with rising temperature. The colour of the gas was programmed to change gradually, indicating increasing heat, and randomised motion was added for natural turbulence. A high emission rate at the inlet pipe further enhanced the realism.
The outlet pipe is kept open throughout the process to prevent pressure build-up within the reactor vessel. An additional particle system was implemented to simulate the initial expulsion of air from the reactor. Another particle system was used to continuously depict the release of impure gases, reflecting real-world operating conditions.
Initially, gas particles flickered or disappeared unexpectedly. After extensive troubleshooting, this issue was resolved by integrating the Universal Render Pipeline (URP), which provided better rendering control and stability.

The plastic particles were programmed to gradually shrink and vanish as the reaction progressed, visually representing their conversion into gaseous products.
In tandem, a custom animation system was developed for the greenboard text. Information appeared in sync with the simulation timeline to explain each stage as it began. Special care was taken to ensure the text fit within the board and did not overwhelm the reactor animation. The layout of the greenboard and reactor underwent several iterations to maintain a clean, intuitive interface.
A custom script was written to start and stop the screw rotation automatically based on the simulation's progress. This ensured synchronisation between the mechanical and visual elements of the scene.
Finally, the app was tested on multiple devices and screen sizes. Every component was made responsive, ensuring a consistent user experience across platforms.

7 Conclusion

The developed application successfully simulates the core stages of the pyrolysis process, providing an accurate and visually intuitive model for the conversion of plastic waste into fuel products. A key achievement of the project was the realistic particle visualisation, which effectively represented both gas-phase and solid-phase movements within the kiln reactor. This dynamic visual approach allowed users to clearly observe how materials behaved as they progressed through the reactor, enhancing understanding of the process.
A particularly notable feature was the accurate depiction of gas dilution towards the end of the reactor, demonstrated by a visible decrease in gas density. The use of different colours to represent various process streams further improved clarity, making it easy to distinguish between phases and sequential steps.
By integrating precise reactor specifications, the application gained both educational and scientific credibility. Students were able to directly observe and comprehend internal changes within the reactor. An aspect often abstract and difficult to grasp through conventional teaching methods or textbooks.
Overall, the project highlights the value of cross-disciplinary collaboration and illustrates how advanced visualisation tools can make complex scientific processes more accessible, engaging, and effective for educational purposes.

8 Future Work

Several additional features were planned but could not be implemented due to time and a reduction in available resources. These include:

- A 3D visualization of the catalytic converter and fuel purification system
- Real-time graphs showing temperature vs. time and fuel production trends
- A dynamic heating system model, illustrating how heat is transferred to the reactor

These improvements remain open for future development by subsequent student teams.

[Note: The text for Sections 5-8 was written independently by the author and fed to ChatGPT[5]. ChatGPT was used only to improve clarity and readability of only the text. In particular, ChatGPT was used to rephrase and refine very long sentences and correct the grammar.]

9 Acknowledgements

We would like to thank Dr.-Ing. Nicole Vorhauer-Huget, Dr.-Ing. David Broneske for their valuable suggestions and criticism.

Bibliography

[1] Beston Group. *Waste Plastics Pyrolysis Plant*. 2024. URL: https://www.bestongroup.net/waste-plastics-pyrolysis-plant/ (visited on 05/03/2024).

[2] Felipe Campuzano, Robert C. Brown, and Juan Daniel Martínez. "Auger reactors for pyrolysis of biomass and wastes". In: *Renewable and Sustainable Energy Reviews* 102 (2019), pp. 372–409. ISSN: 1364-0321. DOI: https://doi.org/10.1016/j.rser.2018.12.014. URL: https://www.sciencedirect.com/science/article/pii/S1364032118308098.

[3] Harish Jeswani et al. "Life Cycle Environmental Impacts of Chemical Recycling via Pyrolysis of Mixed Plastic Waste in Comparison with Mechanical Recycling and Energy Recovery". In: *Science of The Total Environment* 769 (May 2021), p. 144483. DOI: 10.1016/j.scitotenv.2020.144483. URL: https://doi.org/10.1016/j.scitotenv.2020.144483.

[4] Dr Kabeyi and Oludolapo Olanrewaju. "Review and Design Overview of Plastic Waste-to-Pyrolysis Oil Conversion with Implications on the Energy Transition". In: *Journal of Energy* 2023 (May 2023), pp. 1–25. DOI: 10.1155/2023/1821129.

[5] OpenAI. *ChatGPT (Mar 14 version) [Large language model]*. Accessed: 2024-05-03. 2023. URL: https://chat.openai.com.

[6] Sivasankaran Panneerselvam and Student. "Reusing of Waste Plastics to Fuel by Pyrolysis Process". In: (Nov. 2020). DOI: 10.5281/zenodo.3783939.

[7] ToonMe. *ToonMe App (Version 2.3.1) [Mobile application software]*. Accessed: 2024-05-03. 2020. URL: https://toonme.com.

[8] Manon Van de Velden et al. "Fundamentals, kinetics and endothermicity of the biomass pyrolysis reaction". In: *Renewable Energy* 35.1 (2010), pp. 232–242. ISSN: 0960-1481. DOI: https://doi.org/10.1016/j.renene.2009.04.019. URL: https://www.sciencedirect.com/science/article/pii/S0960148109001803.

[9] Alexander Verclyte. "Mass and Heat Transfer Modelling in Screw Reactors". Promotors: Prof. dr. ir. Pieters & Prof. dr. ir. Ronsse; Tutor: Prof. dr. ir. Ronsse. Master's thesis. Ghent University, 2013. URL: https://libstore.ugent.be/fulltxt/RUG01/002/063/502/RUG01-002063502_2013_0001_AC.pdf.