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Development of Multistage Reactor Mobile Plant for Pyrolysis Oil Production from HDPE Plastic

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Abstract: Pyrolysis has been rapidly studied in the past decade as its potential of converting such organic waste into biofuels. The overall energy consumption, as well as the quality of the product yield, are affected by the heating rate and the operating temperature. For that purpose, the project is basically divided into three main phases. The first phase is the establishment of the Basic Flow Diagram (BFD) and Process Flow Diagram (PFD). The second stage is the development of schematic drawing, fabrication and commissioning. Finally, the third stage is an analysis of the pyrolysis of oil production from HDPE plastic. The portable multistage pyrolysis reactor of black oil will be able to fabricate and function properly based on the design and analysis involves. Besides, the relationship between temperature and product yield ranges from 150 °C to 300 °C. The temperature is used as a result of the multistage reactor process. Using two different types of reactors: pyrolysis reactors and nickel reactors. Furthermore, the use of nitrogen N_2 pressure to purge the pressure in the reactor is one of the reasons for the low temperature in this process. According to the analysis of the obtained results, the multistage reactor time required to produce an oil product is 1 hour 30 minutes in parallel with the temperature circulation ranging from 150°C to 300°C. This is due to open area on the surface of the reactor when the temperature exceeds 350°C and will cause leakage on the reactor will affect the temperature and pressure drop. The outcome of this work has the potential to successfully developed a portable test rig bench that complies with the actual plant operating condition.

Keywords: Pyrolysis Reactor, Black Oil, Portable Test Rig Bench

1. Introduction

Pyrolysis has been rapidly studied in the past decade as its potential of converting such organic waste into biofuels. According to [1], pyrolysis has been applied in waste treatment since the 1970s, however, their commercial application does not achieve widespread so far. In general, most plant

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stationary units are typically large units that can process more than 100 tons/day. However, case study results based on the current large-scale commercial plants reveal that the modern incineration could fulfill an environmentally sound technology, which performs better than the selected pyrolysis plants. To be commercially successful, the pyrolysis WtE must develop the whole process chain which are pre-treatment, thermal conversion, product utilization, and residue management [2]. Plastics are generally non-biodegradable [3], and plastic waste management methods such as open burning emit large amounts of harmful gases that have negative environmental effects. Among the various conversion technologies, pyrolysis of plastic waste offers a practical way to produce fuel grade bio-oil while also managing plastic waste in an environmentally friendly manner [4].

This research is conducted in order to further clarify and understand the processes of pyrolysis for maximizing range product, and by designing a pyrolysis apparatus at a small scale which is a portable test rig bench. [5] This portable test bench will behaving as same as the actual plant operating conditions and covering the whole process chain involved.

2. Materials and Methods

The project is basically divided into three main phases. The first phase includes the design, manufacture, development and commissioning of a portable test bench system for multi-stage pyrolysis reactors. The second stage is the analysis and filtering stage at the exit of the process. Finally, the condensation process moves from the first stage to the second stage, allowing you to obtain black oil products.

2.1 Conceptual Design of Portable Multistage Reactor Pyrolysis Test Rig

This project is the development of a pyrolysis test rig bench. This phase is focused on the design, development and commissioning of the pyrolysis test rig bench. It included the conceptual design stage, in which the main target is to design and assembly the process pyrolysis operation. This covers several unit steps of the process as below:

- Development of Process Flow Diagram (PFD) and Basic Flow Diagram (BFD).
- Design of part unit operation using solidwork software.
- Assembly of all units in item.

The phase 1 is the pretreatment stage consists of stove gas produce burning into burner tank and pyrolysis reactor as shown in Figure 1. A pyrolysis reactor and burner tank had been commissioned and used for the conversion of HDPE plastic into liquid oil and char. The reactor has 5 L ability and is made from carbon metallic which lets in the most temperature of 150 °C to 300 °C.

The phase 2 is the upstream stage, which was the analysis and filtering unit for steam supply has been installed above the reactor. The reading of temperature at indicator will occur from thermocouple type K. The pressure gauge will show a reading of the pressure in a bar from the flow of steam supply until gaining the optimum temperature. The nickel catalyst is to change harmful substances in gasses, such as carbon monoxide, nitric oxide, nitrogen dioxide and hydrocarbons, into less harmful substances like carbon dioxide and water vapor by means of chemical reactions.

The phase 3 is the downstream stage consists of unit operations such as condenser and product tank to produce liquid and gas. The condenser unit functions to cool down the organic vapor from the pyrolysis reactor systems in order to condense the excess water content after the reaction.

2.2 Fabrication and Development of Test Bench

Once the development of PFD was established, the next step is designing and fabrication of major unit operations such as a pyrolysis reactor, condenser and nickel catalyst. Figure 2.1 was showing the basic flow diagram of a portable multistage reactor from HDPE plastic as a reactant, through the conversion process.

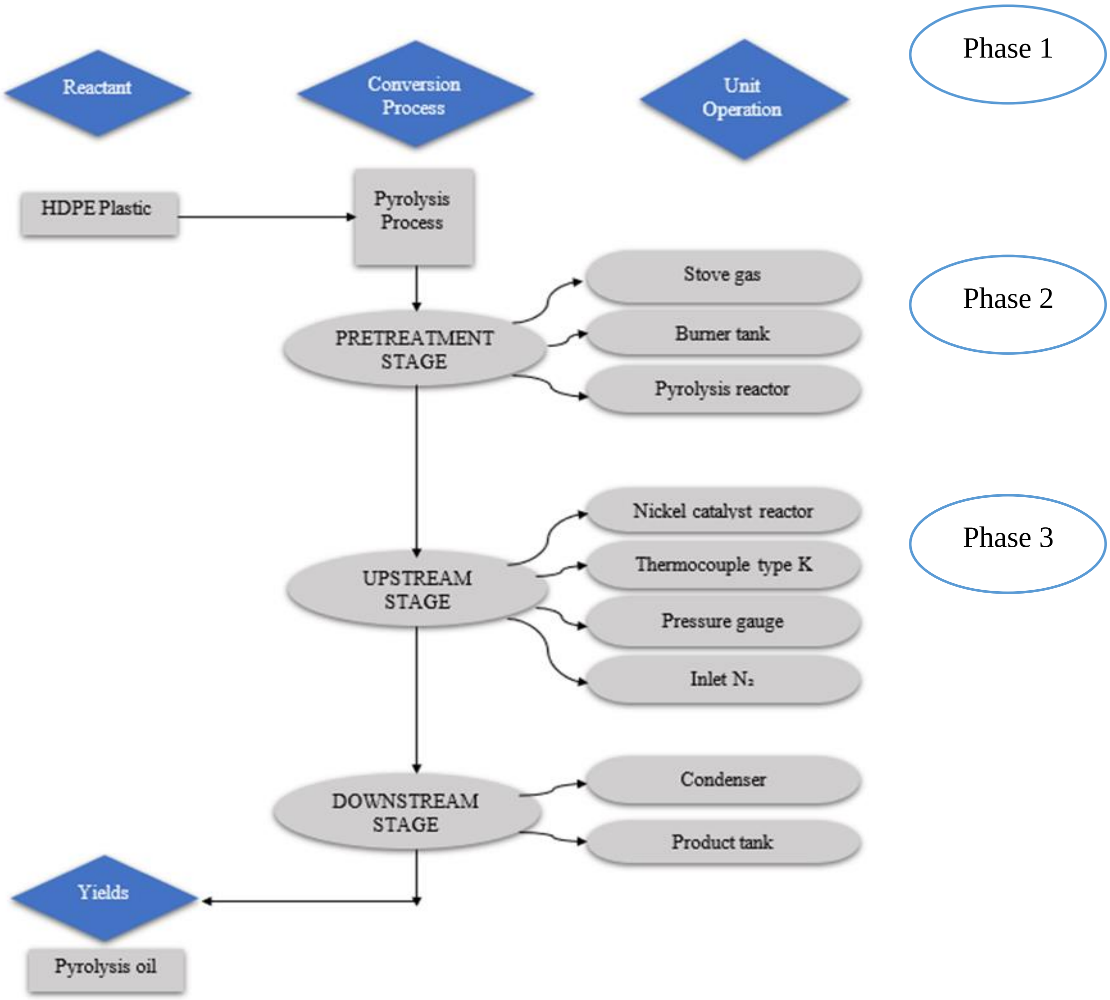

Figure 1: Basic Flow Diagram (BFD) and Unit Operation Involves in Multistage Reactor Pyrolysis Process

2.3 Pyrolysis reactor startup

The reactor has a 5 L capacity and is made of carbon steel and covered with a brick, which allows a maximum temperature of 150 to 300 °C. HDPE plastic was converted through a nickel catalyst, which was condensed into liquid oil after passing through the condenser and collected in the product tank at the bottom. Table 1 below shows the pyrolysis reactor components and their features. [6]

Table 1: Pyrolysis reactor components and features

Reactor components	Features
Height of heating tank	500 mm
Diameter of heating tank	400 mm
Reactor capacity for feedstock	5 L
Length of condenser	250 mm
Diameter of condenser	200 mm
Maximum temperature	300 to 500 °C

2.4 Condenser

The lab scale condenser has been designed, fabricated, and developed. All required items, such as the tank and condenser coil, are defined based on heat transfer rate. The physical properties of the condenser system, as well as the technical drawing, are shown in Table 2.

Table 2: Physical properties of condenser system

No.	Part	Dimension	Material
1.	Tank	200mm (Outer Diameter) x 400mm (Height)	Carbon Steel
2.	Condenser coil	90mm (Outer Diameter) x 13 coils x 1/4” copper tube	Copper
3.	Cooling medium	Mass flow rate (g/s)	Tap water

3. Results and Discussion

The results and discussion section describes the result and discussion for this research project. The portable multistage pyrolysis reactor of black oil is able to be fabricate and commission properly based on the design and analysis involves. The hot commissioning is carried out in the condition of a multistage reactor, with reaction temperatures ranging from 150 °C to 300 °C. Compared to (Oladejo et. al., 2019), pyrolysis is the heat treatment of biomass in the absence of oxygen at a temperature higher than 400 °C. This study proves that the reactors on a small scale can only withstand the following temperatures and must not exceed the set rate as it will affect the rate of temperature and pressure drop. Hence, the portable multistage pyrolysis reactor of black oil was able to fabricate and function properly based on the design and analysis involves, and the objective have been achieved.

3.1 Process Flow Diagram

The process flow diagram (PFD) has been designed as in Figure 2. The PFD is divided into three main sections which are pretreatment, upstream and downstream stages. The pretreatment stage consists of a burner tank, a stove, and a pyrolysis reactor.

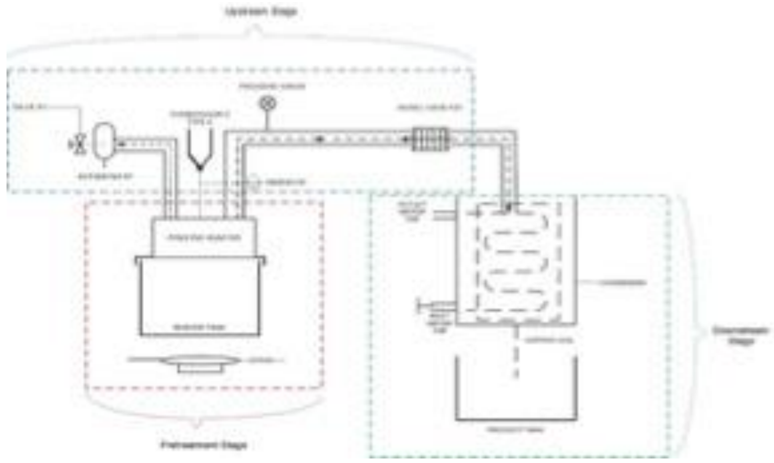

Figure 3: Process flow diagram and unit operation involve

3.2 Nickel Catalyst

Catalyst is defined as the preparation of an active site on top of a deposit catalyst by removing the oxidation agent, such as oxygen. This stage is carried out within the Portable Multistage Reactor's nickel reactor system. The activation parameter is shown in Table 3. this is used as the baseline for the type of nickel catalyst used.

Table 3: Nickel Catalysts Activation Parameter

No.	Operating Condition	Indicator
1.	Target Temperature	150°C to 300°C
2.	Pressure	1 bar
3.	Reduction agent	Purified Nitrogen
4.	Retention time	90 minutes

3.3 Hydrostatic pressure test

The pressure drops for loading catalyst and unloading catalyst conditions is directly proportional to the input pressure, as shown in Tables 4(a) and 4(b). This result indicates that the loading pressure drop is slightly greater than the without load condition. During the interception part of the graph, there is a possibility of disturbance happen during pressure measurement.

Table 4 (a): Hydrostatic pressure with catalyst test

No.	Input Pressure (bar)	Holding time (s)	Pressure drops (bar) - load	Pressure drops (bar) – without load
1.	1	60	0.0605	0.2175
2.	0.9	60	0.1379	0.2294

3.	1	60	0.4333	0.4612
4.	0.8	60	0.6121	0.5605
5.	0.9	60	0.7365	0.5971

A hydrostatic pressure test is a method in which a multistage reactor with and without catalyst is tested for strength, leaks, and pressure drop. To determine whether the pressure drop at the multistage reactor is proportional to applied pressure, a hydrostatic test is required.

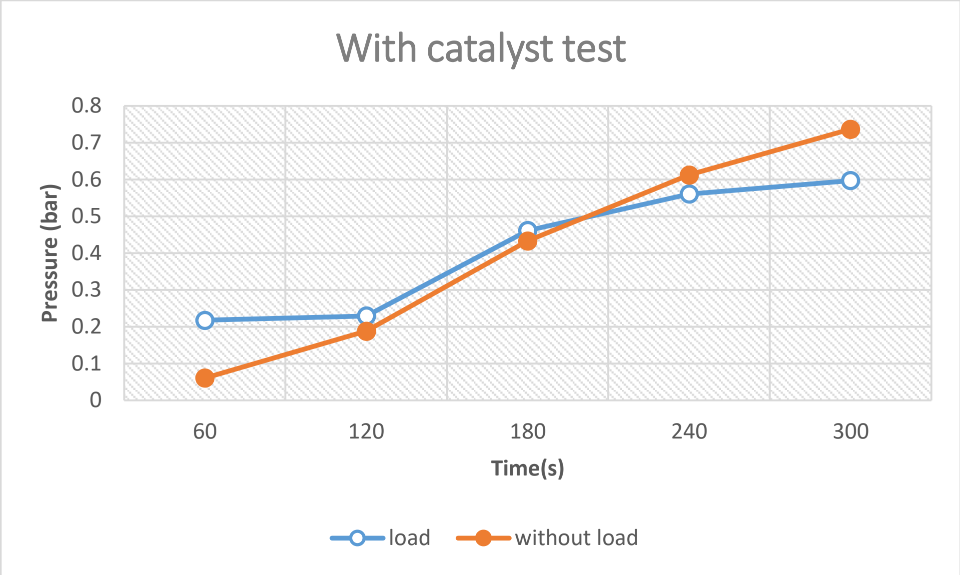

Figure 4: Comparison catalyst test load and without load

Table 4 (b): Hydrostatic pressure without catalyst test

No.	Input Pressure (bar)	Holding time (s)	Pressure drops (bar) - load	Pressure drops (bar) – without load
1.	0.8	60	0.4932	0.1151
2.	0.9	60	0.7365	0.2172
3.	0.9	60	1.029	0.3025
4.	0.8	60	1.035	0.6223
5.	1	60	1.475	0.6683

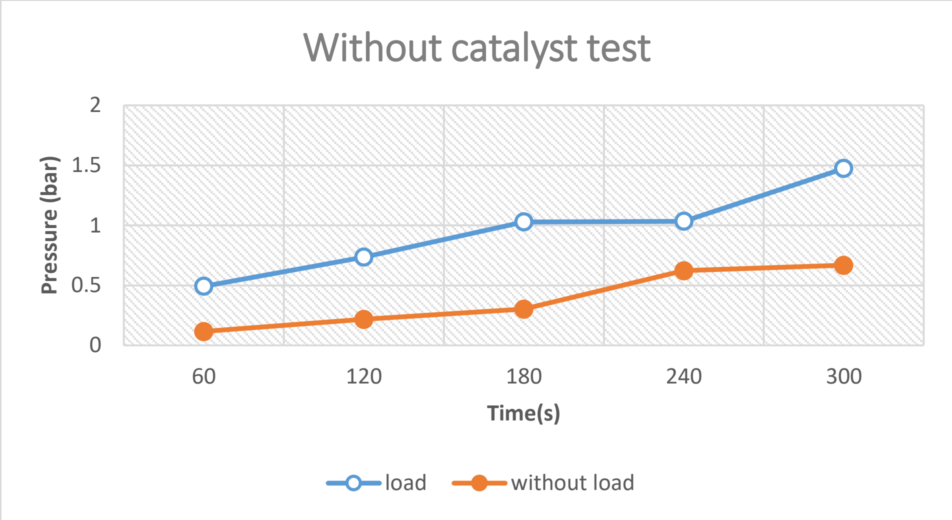

Figure 5: Comparison without catalyst test load and without load

The pressure drop test, like all tables and figures, was designed to simply observe the difference in force per unit area between two levels of a fluid-carrying network. Pressure drops occur when frictional forces caused by flow resistance act on a fluid as it falls through the multistage reactor. The hydrostatic pressure test can be performed with or without a load. The former indicates the presence of HDPE plastic in the multistage reactor, whereas the latter indicates that no HDPE plastic was inserted into the multistage reactor.

4. Conclusion

This study proves that the reactors on a small scale can only withstand the following temperatures and must not exceed the set rate as it will affect the rate of temperature and pressure drop. Hence, the portable multistage pyrolysis reactor of black oil was able to fabricate and function properly based on the design and analysis involves, and the objective have been achieved.

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