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Design and Construction of a Reactor Device for (Thermal Catalytic Cracking) of Waste Cooking Oil

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Article Info	Abstract

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His study discusses the design and development of a thermal catalytic cracking reactor for converting waste cooking oil into bio-oil as an alternative renewable energy source. The reactor is designed with a semi-batch system equipped with an electric heater, a stirring motor, and a circulation pump. The catalyst used is Ni/Al_2O_3 with a mass of 2.4 grams, and the input volume of waste cooking oil is 2000 mL. The cracking process was carried out at temperatures ranging from 150°C to 250°C for a duration of 4 hours. Experimental results show that the bio-oil yield increased with temperature, reaching the highest yield of 780 mL at 250°C. The total electrical energy consumed by the device was 6,004,800 Joules, while the thermal energy used in the reaction process was 1,221,000 Joules. The energy efficiency of the system was calculated to be 20.33%. These results indicate that the reactor is capable of performing thermal conversion with moderate efficiency and has the potential for improvement through better thermal insulation and heat distribution systems.

1. INTRODUCTION

The increasing global demand for energy has emerged as a critical challenge for nations worldwide, including Indonesia. The reliance on fossil fuels as the primary energy source is under considerable pressure due to both the declining reserves and the adverse environmental impacts associated with their use. As a developing country with a large population, Indonesia is experiencing rapid growth in energy consumption, particularly within the transportation and industrial sectors. This condition has intensified dependence on imported petroleum-based fuels, which poses a potential threat to national economic stability. Reducing such dependence can be achieved through the utilization of biodiesel, as its feedstock remains abundantly available for large-scale development (Asthasari, 2008).

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through the utilization of biodiesel, as its feedstock remains abundantly available for large-scale development (Asthasari, 2008).

In parallel, Indonesia also generates a substantial amount of waste that has not been optimally utilized. One of the most abundant and widely distributed types of waste is used cooking oil, originating from households as well as the food industry. According to data from the Ministry of Environment and Forestry, Indonesia produces millions of liters of used cooking oil annually. Although waste cooking oil is essentially a byproduct of frying processes, its conversion into bio-oil has not yet been widely implemented (Chen, 2017). Furthermore, several studies have revealed that repeatedly used cooking oil contains harmful compounds, such as free fatty acids (FFA), peroxides, and polycyclic aromatic hydrocarbons (PAHs), which are carcinogenic and may increase the risk of degenerative diseases (Uzwatania, 2017).

Bio-oil is the product of pyrolysis or thermal cracking of hydrocarbon-containing materials, such as waste cooking oil. One of the most widely developed methods is thermal catalytic cracking, a process in which long hydrocarbon chains are broken down into lighter compounds with the aid of high heat and catalysts. This process can yield bio-oil with characteristics similar to diesel or gasoline, depending on the processing conditions and the type of catalyst employed. Not only is this method effective in processing waste, but it is also relatively simple and does not require additional chemicals, as in the case of transesterification. Nevertheless, only a limited portion of society is aware that waste cooking oil can be transformed into value-added products with significant economic potential (Bezergianni, 2010).

Among the effective methods for converting waste cooking oil into bio-oil is catalytic cracking, which involves breaking down complex compounds into simpler molecules through the application of heat and catalysts. In this study, nickel (Ni) metal catalysts activated with NaOH solution were employed. However, the success of catalytic cracking largely depends on the equipment used. The catalytic cracking apparatus must be capable of maintaining a consistently high temperature, ensuring optimal contact between the oil and the catalyst, and incorporating a separation system to isolate bio-oil from residues or by-products. Therefore, there is a pressing need for the design and development of a simple, efficient, and integrated laboratory-scale catalytic cracking unit that can serve as a preliminary model for advancing waste-to-fuel conversion technology. In order to optimize the reutilization of waste cooking oil, further processing is required to improve its quality (Nasrun et al., 2017).

In this study, nickel (Ni) metal catalysts activated with sodium hydroxide (NaOH) were employed to enhance the stability of bio-oil by reducing its oxygen content and increasing the hydrocarbon fraction during the conversion of waste cooking oil into bio-oil. The activation with NaOH is intended to increase the surface area and porosity of the metal, thereby accelerating the breakdown of waste cooking oil molecules into lighter bio-oil compounds. Nickel (Ni) was selected as the catalyst due to its porous structure, which allows the reaction to proceed more efficiently, and its relatively more economical performance compared to activated carbon-based catalysts. However, the cost of Ni metal remains relatively higher than that of copper (Cu) or other activated carbon catalysts, which may increase the overall production cost.

This study also takes into account the pretreatment of waste cooking oil prior to its conversion into bio-oil. Since waste cooking oil often contains solid particles and impurities that may hinder the reaction process, a purification step was carried out using filter paper and a vacuum pump (Kacang, 2020).

The purification process operates on the principle of separation based on density differences, allowing heavier impurities to be efficiently separated from the oil. Through this method, the waste cooking oil used in the reactor becomes cleaner, enabling the production of higher-quality bio-oil.

The heating process within the thermal catalytic cracking reactor utilizes a heater to raise the temperature of the waste cooking oil until it reaches the reaction temperature, typically in the range of 350–450 °C. This step is crucial, as at such temperatures, the chemical structure of triglycerides present in waste cooking oil begins to decompose into shorter-chain hydrocarbon compounds, such as bio-oil and gas.

The heat source in this apparatus is an electric heater, which may consist of ceramic heating elements or heating coils surrounding the outer wall of the reactor tube. The heater operates on the principle of converting electrical energy into heat through electrical resistance. The generated heat is then transferred by conduction through the reactor’s metal walls into the waste cooking oil, while a portion of it is also transferred through thermal radiation.

The outcomes of this study will be analyzed based on several key parameters, including bio-oil yield, viscosity, density, and chemical composition. These evaluations aim to determine whether the produced bio-oil possesses characteristics suitable for application as an alternative fuel or as a feedstock in the chemical industry. It is expected that a more effective method of bio-oil production from waste cooking oil can be achieved through the utilization of Ni-based catalysts activated with NaOH. However, a challenge that arises is the need for an additional separation process to isolate the product from the catalyst mixture (Gryglewicz, 1999). Despite this, bio-oil remains a promising candidate due to its relatively stable price, environmental safety, and natural biodegradability (Wimardiyanti, 2023).

2. METHODS

The functional approach describes the roles of each component in the waste cooking oil processing system for bio-oil production. The equipment design consists of a filtration tank, stirring motor, reactor converter, separator, heater, water pump, and storage container. This functional approach is applied to ensure that each component of the thermal catalytic cracking (TCC) reactor can effectively perform its role in converting waste cooking oil into bio-oil.

The structural approach is a design method that emphasizes the physical form, arrangement, dimensions, and interrelationships among the components of a system or device. Its objective is to ensure that all components are assembled ergonomically, robustly, and in a manner that supports the safe and efficient operational functions of the equipment.

In the design of the thermal catalytic cracking reactor for waste cooking oil, the structural approach is applied to ensure that the physical configuration of the apparatus aligns with its intended functions, operational efficiency, and ease of maintenance and operation.

3. RESULT AND DISCUSSION

Results: Reactor Catalytic Cracking Operation Test In this study, a series of experiments were conducted to investigate the effect of reaction temperature on the efficiency of bio-oil production from waste cooking oil using a thermal catalytic cracking reactor. The experiments were carried out with a feedstock volume of 2 liters of waste cooking oil, 4 grams of NaOH-activated activated carbon catalyst, and a reaction time of 4 hours. The only variable altered was the reaction temperature, which ranged from 150 °C to 250 °C at intervals of 30 °C. The outcomes were recorded in terms of the volume of bio-oil produced, from which the yield was subsequently calculated.

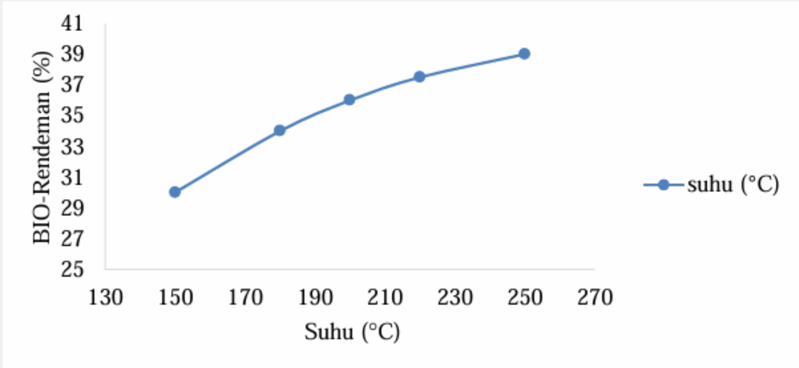
Tabel 4.1 Hasil dari Efisiensi Suhu dan Volume *Bio-Oil*

No.	Volume Minyak jelantah (ml)	Berat Katalis (gram)	Suhu Pemanasan (°C)	Waktu (jam)	Volume Bio-Oil (mL)	Rendemen (%)
1	2000	4	150	2	600	30
2	2000	4	180	3	680	34
3	2000	4	200	4	720	36
4	2000	4	220	6	750	37,5
5	2000	4	250	8	780	39

Tabel. 4.2 Energi yang digunakan pada *Reaktor Catalytic Cracking* yang digunakan pada produksi untuk proses *Bio-Oil.*

No.	Komponen	Daya (Watt)	Lama Operasi (Jam)	Energi (Wh)	Energi (kWh)
1	Heater	400	4	1600	1600
2	Pengaduk	14	4	56	0,056
3	Pompa	3	2	6	0,006
	Total			1662	1662

Effect of Reaction Temperature on Bio-Oil Yield Efficiency The results indicate that reaction temperature has a significant effect on the yield of bio-oil. Increasing the reaction temperature from 150 °C to 250 °C led to an increase in the volume of bio-oil produced, from 600 mL to 780 mL, corresponding to a yield increase from 30% to 39%. This finding demonstrates that the cracking process is more efficient at higher temperatures, as triglyceride molecules in waste cooking oil are more readily broken down into shorter-chain hydrocarbon compounds that are volatile in nature. The higher the temperature, the faster the reaction rate, which in turn promotes the formation of more condensable liquid products that can be collected as bio-oil.



Gambar 4.1 Grafik kenaikan suhu dan Rendemen Bio-Oil proses Alat *Reaktor Thermal Catalytic Craking.*

In this study, the process involved heating waste cooking oil using an electric heater at various temperatures and durations. The feedstock consisted of 2000 mL of waste cooking oil with the addition of 4 grams of catalyst, while the reaction temperature was varied from 150 °C to 250 °C. The heating duration ranged from 2 to 8 hours. The resulting bio-oil was then measured in terms of its volume and yield. For instance, from 2000 mL of waste cooking oil, a bio-oil volume of 780 mL was obtained, corresponding to a yield of 39%.

Experimental data show that the yield increases with both rising temperature and longer heating duration. At 150 °C with a heating time of 2 hours, the yield reached only 30%. However, at 250 °C with a heating time of 4 hours, the yield increased to 39%. This result indicates that temperature is a critical factor in accelerating the cracking reaction and facilitating the evaporation of light fractions from waste cooking oil.

In addition to temperature and the presence of a catalyst, heating time also influences the outcome. A heating duration that is too short does not allow sufficient evaporation of the oil fractions, while excessively long heating may cause the degradation of compounds into gases, thereby reducing the liquid bio-oil yield. Thus, yield is not only a quantitative indicator of the amount of bio-oil produced but also reflects the energy efficiency and overall success of the waste-to-fuel conversion process.

Electric Energy Usage in the Catalytic Cracking Reactor Based on the analysis of electric energy consumption required by the catalytic cracking device in the process of converting used cooking oil into bio-oil. The purpose is to determine how much electric energy the system requires during the process and how efficient it is in relation to the yield produced. The system consists of several main components that use electric energy, namely a heater as the heat source, a stirrer motor for mixing, and a pump for flow circulation. The processing time used during the experiment was 2 hours.

Energy is a key element in the design and operation of engineering equipment, including waste oil processing systems. The choice of energy type, conversion efficiency, and its utilization control significantly influence the overall performance of the system. By understanding the fundamental concepts of energy and its various forms, it is possible to design systems that are optimal, safe, and sustainable. The main components of this system consist of two heating elements, one stirrer motor, and one pump.

4. CONCLUSION

Based on the results of research and testing of the thermal catalytic cracking reactor designed to process used cooking oil into bio-oil, several conclusions can be drawn, This device serves as a preliminary model in the development of renewable waste processing technology and can be utilized for conversion processes with a capacity of up to 5 liters of used cooking oil per cycle. The external heating system employs electric heating elements with a power range of 500–600 W, capable of reaching operational temperatures between 200–400 °C.

The reactor is equipped with heating elements (heaters) and a digital thermocouple and controller system, which effectively maintain the reaction temperature within the range of 150 °C to 250 °C. This supports the cracking process optimally and allows precise control of operating conditions according to the reaction requirements. Safety devices such as thermocouples and gas ventilation are applied to monitor temperature and pressure, ensuring that the process runs safely and stably.

Based on the experimental results, a bio-oil yield of 30% to 39% was obtained, with an increase observed as the temperature rose. This indicates that the reactor demonstrates good conversion efficiency. In addition, the device showed operational stability throughout reaction durations of 2 to 8 hours without disruptions in the heating or condensation systems, suggesting that the reactor design is reliable for continuous processing.

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