Analysis of phenol production technology from the waste of empty palm oil bunches: a review of methods and process efficiency

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Abstract. Empty palm oil bunches (EPB) are waste from the oil palm farming process that has not been widely utilized. This waste can be used as a raw material for the manufacture of phenols. There are various processes in making phenol from empty palm oil bunch waste, including pyrolysis and hydrothermal liquefaction. Pyrolysis is the process of decomposition of a material that occurs at high temperature, which produces three products, bio-oil, bio-char, and gas. The phenol content contained in bio-oil is taken using a liquid-liquid extraction process. This pyrolysis has advantage including compactness and relative simplicity, fuel flexibility and clean carbon by product and low CO and CO_2 emissions. This literature study aims to explain the method of making phenol and become a reference in terms of the selection of the process in making phenol, especially from empty palm oil bunches.

1 Introduction

Indonesia, as the leading global producer of crude palm oil, generated approximately 46.82 million tons of palm oil in 2022 [1]. The production process, particularly the processing of Fresh Fruit Bunches (FFB), generates a substantial amount of solid waste known as Empty Palm Oil Bunches (EPB / *Tandan Kosong Kelapa Sawit in Indonesian*). It is estimated that each ton of FFB processed yields about 21% EFB [2], a potential waste volume of approximately 9.5 million tons in 2023. Research efforts have identified economically valuable chemical compounds within EFB waste, notably phenol, which can be found in concentrations as high as 28.30% [3].

The comparatively high need for phenol in Indonesia's chemical manufacturing sector is hindered by the country's inadequate indigenous output, which forces imports. In Indonesia, phenol have a significant role as both the primary and secondary raw material in

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a number of chemical industry sectors. Phenol is used in the production of medications, insecticides, antiseptics, and artificial coloring agents, all of which are useful for a wide range of chemical industrial applications. It is essential to have technology to turn EPB trash into phenol given the enormous potential of EPB waste in Indonesia and the efforts being made to lessen reliance on imported phenol.

2 Previous Research

Regarding phenols from empty oil palm bunches, there are numerous research. Pyrolysis is one of the research methods used in this study. The operating temperature is the research variable, and the results show that more bio-oil and phenol are produced at higher working temperatures.

Pyrolysis is the most widely used production method for phenol derived from bio-oil. Expired palm oil bunches are the raw material used in this method. In general, the pyrolysis process involves heating organic molecules without the need of chemicals or oxygen to break them down. Without oxygen present in the reactor, this method can convert biomass into liquid (bio-oil), gas products (syngas), and solid fuel (char) [4]. The following is the pyrolysis reaction [5].

$$C_{100}H_{120}O_{40} \leftrightarrow 66.976C + 6.203C_3H_8O + 17.136H_2O + 9.734H_2 + 3.852CO + 6.404CO_2 + 4.159CH_4$$

3 Materials and Method

The pyrolysis method of producing phenol with a zeolite catalyst. The pyrolysis process begins with the insertion of raw materials into the reactor, which is aided by a zeolite catalyst ZSM-5. The reactor is then filled with hot nitrogen gas. The four primary steps of organic material generation for phenol can be achieved naturally as follows.

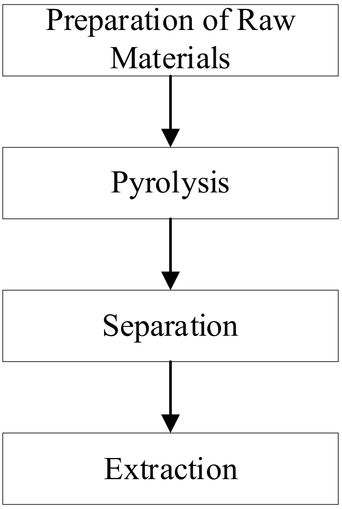

Fig. 1. Flow diagram for making phenol from empty palm oil bunches waste

3.1 Raw Material Preparation Stage

A dry raw material consisting of 26.51% lignin, 33.61% cellulose, 19.21% hemicellulose, 9% water, and 1.61% ash is used to make empty palm fruit bunches. The material is supplied to a rotary cutter for size reduction, followed by a bucket elevator and a hammer mill for more size reduction and smoothing. The purpose of this process is to increase the surface area and hasten the reactions that take place during the pyrolysis step. After being reduced in size, the empty oil palm bunches are screened to ensure that the size entering the reactor is consistent.

3.2 Pyrolysis Process

Reactor feed is supplied with screened and empty oil palm bunches. With the aid of a catalyst, a fluidized bed reactor is utilized in the quick pyrolysis process. Subsequently, nitrogen will be introduced into the reactor, serving as a tool for combustion within the reactor. In this reactor, empty palm oil bunches are heated to 500°C under 1 atm of pressure and via the reactor jacket. This reaction's fundamental idea is to break down empty palm oil bunches into smaller molecules, which then turn them into charcoal, ash, and gas. To separate the contained particles from the gas mixture, the gas will be supplied into the cyclone and the charcoal and ash will be transported to the char. Subsequently, the gas mixture is passed through a filter bag in order to extract the remaining particles. After that, the gas travels to the condenser, where it is heated to 95°C for condensation.

3.3 Separation Process

The separation stage is where bio-oil is obtained. After condensing in the condenser, the gas flows to the knock-out drum where it will be separated using gravity. The gas in the form of CO, CH_4, H_2, CO_2, and N_2 will be sent to the burner later, while the bio-oil will enter a liquid phase and sink to the bottom.

3.4 Extraction Process

The bio-oil that is produced will be combined with the solvent in a mixer. Following the mixing of the bio oil and solvent, the mixture is poured into a decanter in order to separate the phenol from the insoluble bio-oil. Subsequently, the phenol is introduced into the evaporator, which evaporates the impurities, including water, to purify the phenol. The evaporation process's output is subsequently pumped into a cooler to lower its temperature, after which it is kept in a storage tank.

The research approach used in this study is a literature review, in which information about phenols was gathered from earlier studies published in books and journals. The flow diagram in Figure 1 models every action, from problem formulation to decision-making, and is meant to clarify the necessary procedures. The primary goal of literature studies is gathering references from the literature that will be brought up in discussion. The data collected in the second step, data collecting, comes from earlier studies. All collected data will be handled such that it is easy for readers to understand and comprehend in the third step of data processing. The analysis and evaluation phase is the fourth. The three primary goals of the analytical procedure are to identify different purification compounds used in the phenol-making process, identify phenol parameters based on SNI, and understand different manufacturing processes. Subsequently, an evaluation was conducted to identify the phenol production technique that yielded the greatest results while adhering to SNI. Compilation is the last phase. Conclusions from the discussed data results can be made after examination and evaluation.

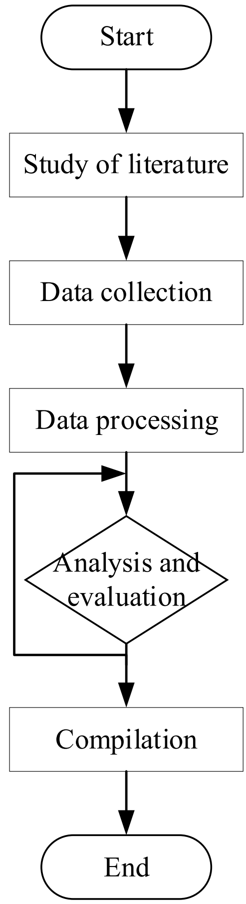

Fig. 2. Research block diagram

4 Findings and Discussion

There are two processes that can be used to produce phenol from biomass: pyrolysis and hydrothermal liquefaction. At moderate temperatures (200–400 °C) and high pressure (10–25 MPa), hydrothermal liquefaction (HTL), also known as hydrous pyrolysis, is a thermochemical depolymerization process used in a closed reactor to transform wet biomass into crude oil and chemicals[6].The thermochemical breakdown of biomass into a range of beneficial compounds is known as pyrolysis. Without oxygen present in the reactor, the pyrolysis process transforms biomass into liquid (bio-oil), gas products (syngas), and solid fuel (char)[4].

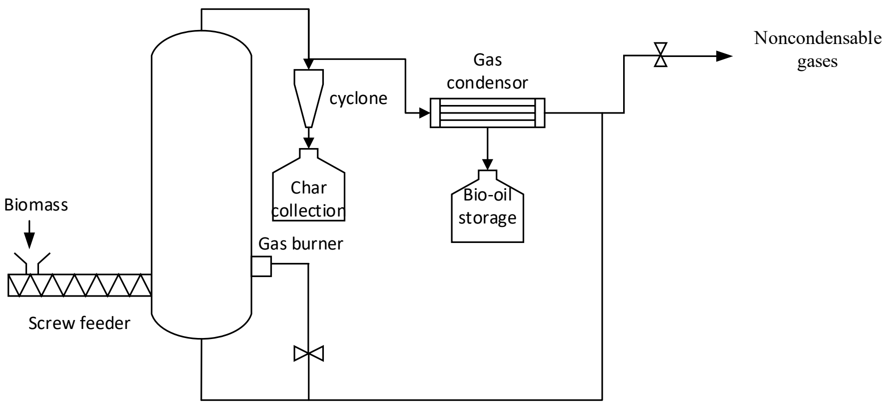

Fig. 3. A basic method of pyrolysis

Pyrolysis is the thermochemical breakdown of organic molecules by heating them without the presence of oxygen. Three products are obtained from the pyrolysis process: char, non-condensable gas, and condensable gas (bio-oil). There are two categories of pyrolysis: slow pyrolysis and quick pyrolysis. Fast pyrolysis is the pyrolysis method that is employed if the desired result is bio-oil, which is a gas that may be condensed. In the meantime, slow pyrolysis is the pyrolysis method that is employed if char is the desired result[29].

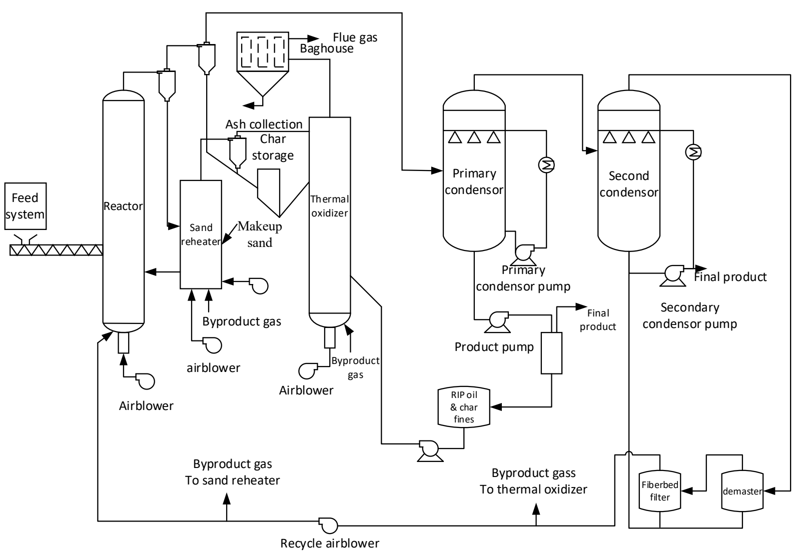

Fig. 4. A basic method of pyrolysis [30]

According to the above illustration, biomass is fed into a fixed bed reactor where it is heated to pyrolysis temperature, which is the point at which the decomposition process takes place. To separate the char and gas, condensed gas, uncondensed gas, and char exit the reactor and go into the cyclone. While the gas from the cyclone enters the gas condenser to separate condensed gas from non-condensed gas, the char created is kept in a char reservoir. Condensed gas undergoes a phase transition and becomes liquid, commonly referred to as bio-oil. Condensed gas is recycled and utilized as fuel to heat the gas used in the pyrolysis reactor in the meantime[29].

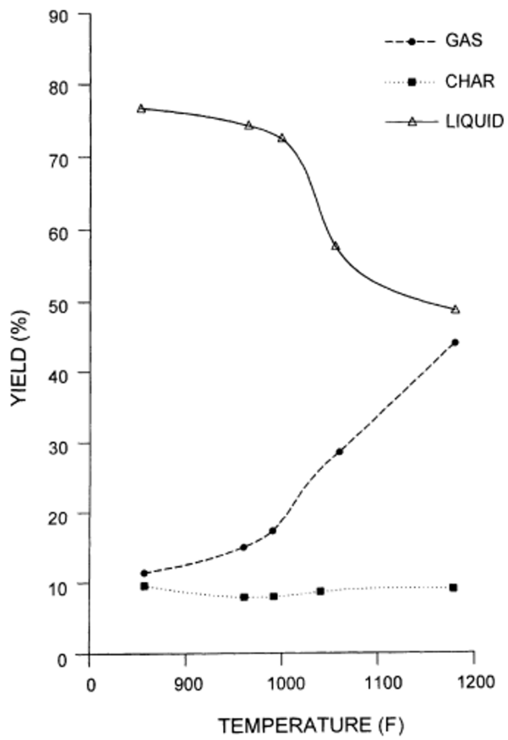

Fig. 5. Effect of temperature on gas, char, and liquid yield [30]

To get pyrolysis results according to the desired needs, change several parameters in the pyrolysis process. A low ultimate temperature, a lengthy residence time, and a slow heating rate (<0.01-2.0°C/s) are necessary to maximize the generation of char. A high heating rate, a medium end temperature (450°C –600°C), and a brief gas residence time are utilized to optimize the yield of liquid.°CLong gas residence durations, high end temperatures (700°C –900°C), and medium to moderate heating rates are employed to enhance gas production[29].

Table 1. Types of Phenol Production Method

Materials	Method dan Variable	Temperature Process (°C)	Catalyst	Phenol	Bio-Char (%)	Bio-oil (%)	Gas (%)
Empty oil palm bunches [7]	Pyrolysis; temperature process	500 550 600	-	-	29,39 32,71 30,58	40,73 43,01 45	29,86 24,26 24,41
Empty oil palm bunches [8]	Pyrolysis; temperature process	300 350 400	-	-	38,35 34,71 33,33	4,78 4,32 6,49	23,85 25,53 26,91
Empty oil palm bunches [9]	Free fall pyrolysis; catalyst weight	-	Ni/NZA	-	-	30,27	-
Empty oil palm bunches and palm oil shells [10]	Pyrolysis; temperature process	400 500 600	-	-	45,28 30,66 32,77	25,86 24,85 29,16	28,86 44,49 38,08

Empty oil palm bunches [11]	response surface methodology (RSM); conversion percentage	554-568	-	-	-	62,21	-
Coconut shell [12]	Liquid-liquid extraction; temperature extraction & mixing speed	-	-	90,25	-	-	-
Empty oil palm bunches [13]	Pyrolysis; temperature process	100 150 245	-	0,67- 3,87	-	4 29,63 100	-
Empty oil palm bunches [14]	Pyrolysis; temperature process	--	Lempung gambut	--	-	-	-
Empty oil palm bunches [15]	Pyrolysis; sample size & hydrogen gas pressure	-	-	15,24	-	-	-
Empty oil palm bunches [16]	Pyrolysis; temperature process, nitrogen gas flow rate, and steam flow rate	350 475 600	-	24,09	-	-	-
Empty oil palm bunches [17]	Pyrolysis; temperature process	300 400 500 550 600 700	-	11,21	34,37 28,47 25,27 21,2 25,33 24,2	40 41-42 45-46 41-42 49 55,53	-
Corncob [18]	Liquid-liquid extraction; temperature process and mixing speed	-	-	66,31	-	-	-
Empty oil palm bunches [19]	Fast pyrolysis; temperature process	400 500 600	--	-	~50 50 ~18	~15 27 ~26	40 23 ~60
Empty oil palm bunches [20]	Pyrolysis	-	-	68,15	-	-	-
Empty oil palm bunches [21]	Pyrolysis; temperature process	300 400 500 600	-	51,91	40,87 ~39 ~32 26,65	32,62 ~38 43,80 38,41	22,52 ~25 ~30 32,06
Empty oil palm	Pyrolysis; temperature process	350 400 450	-	2,18 2,26 3,63			

bunches [22]							
Empty oil palm bunches [23]	Pyrolysis	-	-	7,76	-	-	-
Pine wood [24]	Pyrolysis ; amount of catalyst	-	Mo / Lempung			41,36 61,89	
Sugarcane bagasse [25]	Pyrolysis catalytic	-	HZSM-5 zeolite	-	-	40,83	-
Palm shell [26]	Pyrolysis : ratio catalyst/biomass	-	NIMo/ ZSM-5	-	-	68,6	-
Palm fronds [27]	Pyrolysis; catalyst variations	-	Mo/NZA	-	-	54,7	-
Empty oil palm bunches [28]	Pyrolysis; temperature process	-	HZSM-5	23,74	-	55,975	-

5 Conclusion

Based on this review, it can be concluded that the best method for making phenol is the fast pyrolysis process with the help of the ZMS-5 catalyst because the time required is relatively short and produces high levels of phenol, environmentally friendly because the pyrolysis method does not release harmful gases into the environment. The disadvantage of this method is that the pyrolysis process is complicated and requires high operational costs and investment. The best method for extracting phenol compounds from bio-oil is using the extraction method because it can provide a higher yield of phenol products.

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