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Coconut Shell Liquid Smoke Production Quality from Size and Power Using Microwave-Assisted Pyrolysis

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Abstract. Coconut shell waste causes environmental pollution around the community. Therefore, it is necessary to have more optimal processing to produce valuable products using a microwave-assisted pyrolysis process. This study uses microwave-assisted pyrolysis (MAP) for the production of liquid smoke from coconut shells using different power (300, 450, 600 W) and sizes (1 mm, 2 mm, 3 mm). The results of this study show that the highest yield for 300 W power at 2 mm size by 22.85%, for 450 W power at 3 mm size by 28.52%, for 600 W power size 3 mm by 28.67%, while the optimal size for liquid smoke is 3 mm size by 31.95% at 450 W power.

1. Introduction

Indonesia is one of the countries with coconut plantation commodities. It has an area of around 3,653,167 ha and can produce as much as 2,870,739 tons. Almost 99% of the site is smallholder plantations, growing 98.87% of the total production in Indonesia [1]. Coconut is a folk plant used by the community in their lives [2]. The increase in coconut production also causes several waste problems caused, such as coconut shells, which cause environmental pollution and impact public health. Currently, coconut shell waste has not been optimally utilized. Coconut shells are generally used for handicrafts, as fuel, and to manufacture activated charcoal

Coconut shells have the potential to become liquid smoke. Liquid smoke can be used as a biopesticide because liquid smoke contains phenol compounds that act as antioxidants and acidic compounds that act as antibacterials. Coconut shell is classified as a hardwood type with a more lignin content of 29.4% than cellulose 26.6%, producing phenol compounds and acid compounds in the pyrolysis process [3]. The next problem is the appearance of pests on rice plants. Indonesia is one of the third countries after China and India to consume rice as a staple food [4]

The problem that arises with the presence of rice productivity is pests. Pests can harm farmers, especially with Indonesia's decreasing rice productivity. To avoid pests, farmers use chemical pesticides. This causes environmental pollution and public health, so biopesticides are needed to control pests in rice plants. One of the safe materials to use for biopesticides is liquid smoke because it comes from biomass materials. The liquid smoke resulting from the pyrolysis process contains phenol compounds of about 90.75% [5]. Typically, liquid smoke can be produced using a conventional pyrolysis reactor. An effective pyrolysis process produces liquid smoke using a microwave [6]. A microwave absorbent is necessary to expand the heating rate in the pyrolysis process. The reactor temperature will stabilize with minimal energy input through microwave irradiation when solid residues are dropped directly into the heated absorbent. Activated carbon as an absorbent can help reduce the toxic content of harmful gas phase products [7]

Adding carbon and activated carbon is an excellent microwave absorber that shows a high capacity to absorb and convert microwave energy into heat. Anissa et al. stated that microwave technology could reduce the reaction time of pyrolysis and improve the quality of value-added products obtained from the biomass of pine wood saws [8]

The production cost of bio-oil and biochar from microwave catalytic pyrolysis can be decreased because catalyst combinations significantly improve catalytic performance. [9].

Microwaves can efficiently heat carbon materials (e.g., carbon, charcoal, activated carbon), generally being an excellent microwave absorb [10]. Recently, the microwave-assisted pyrolysis process used an absorber to help increase the heating rate. Energy will enter minimally through microwave irradiation so that the temperature in the reactor in the microwave will be more stable when solids residues mix with the absorber when heated

In pyrolysis, biomass heating will go through two simultaneous heating mechanisms, namely irradiation and microwave conduction, with increasing high temperatures of the absorber [11]. The heating of biomass will raise its temperature instantly continuously or semi-continuously through the reactor from the microwave. Previous studies have shown that microwave-assisted pyrolysis (MAP), classified as mid-level pyrolysis, can reach the level of fast microwave-assisted pyrolysis (fMAP) through heating using an absorber so that maximum results will be obtained with high-quality products [12]. It is possible to improve poor heating efficiency caused by low-loss raw materials by including a microwave absorber, a material that is amenable to microwave heating [13]. A microwave absorber is added to the material to speed up the heating process on pyrolysis [14]. The microwave will encounter intermolecular frictional force, producing heat [15]. A good absorber material is a material that has a high absorption of microwaves resulting in stability at high temperatures and high oxidation resistance [16]

Liquid smoke is produced by incomplete combustion involving the decomposition of polymer constituents into low molecular weight organic compounds due to the influence of heat, which includes oxidation, polymerization, and condensation reactions. The cooling medium used in the condenser is water that is flowed through *an inlet* pipe that comes out as the result of incomplete combustion and then flows through the condenser and condenses into the smoke distillate. Smoke particles have a diameter of 0.1µm. The density of the smoke can be determined by the proportion of solids and liquid particles in the gaseous medium. Liquid smoke is a mixture of wood smoke dispersion in water made by condensing liquid smoke from pyrolysis. The base material and the pyrolysis temperature influence the liquid smoke from this pyrolysis. Twelve components are found in the coconut shell's liquid smoke, mainly from the thermal degradation of wood carbohydrates, such as ketones of about 6.53%, carbonyl, and acids of about 2.98%, as well as furan and pyran derivatives of about 3.02%. The liquid smoke of coconut shells contains 28 components derived from the thermal degradation of lignin. Those components are phenols 24.11%, guaiacol and its derivatives 36.58%, syringol and its derivatives 18.26% and alkyl aryl ether 8.5% [17]. The addition of magnetic ZnFe2O4 will improve the efficiency of the pyrolysis process. It shows that the content of C 4-C_{12} increased by 3.5%, and the content of C_{18}^{+} decreased by 4.1%, and this shows that magnetic nanoparticles have good catalytic [7]. The purpose of this study is to determine the optimal size of raw materials and microwave power in the manufacture of liquid smoke using the microwave-assisted pyrolysis method

2. Materials and Methods

Raw Material

Coconut shells are obtained from the Dampit Malang area, East Java, Indonesia. Further cleaning is carried out and cut by 1mm, 2mm, and 3 mm, then dried in the sun until completely dry. Another ingredient is activated carbon as an absorber used in the mixture of ingredients in the microwave.

Research Methods

This research began with the pyrolysis process using raw materials in the form of coconut shells. At first, the shells of raw materials that have been cleaned and ground vary (1 mm, 2 mm, 3 mm), and each variation of the impact was taken 50 grams to be mixed with an activated carbon absorber of 5%. Then it was put in the microwave, with a power of (300, 450, 600 watts) for as long as (5,10,15,20,25.30 minutes). The process obtained the solid fraction in the form of charcoal, the heavy fraction in the form of Tar, and the light fraction in the form of smoke and methane gas. The light fraction would flow into the condensation pipe so that liquid smoke was obtained while the methane gas remained an uncondensed gas

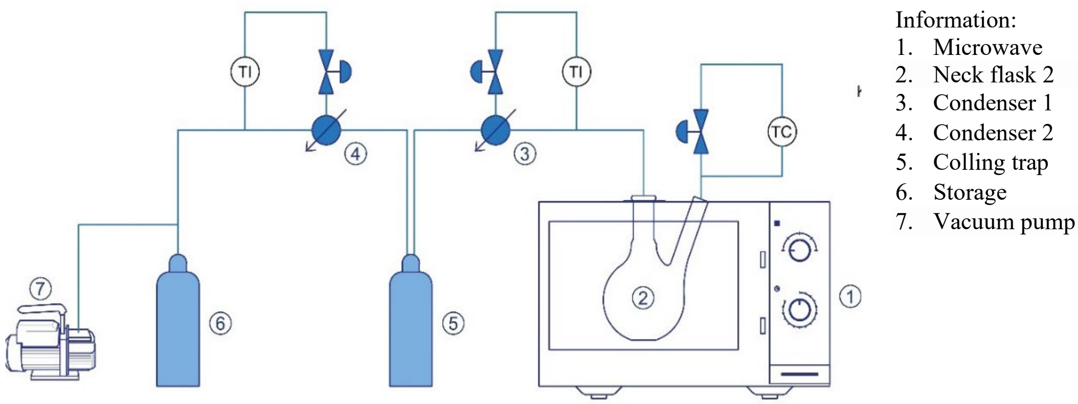

Figure 1. Microwave-assisted pyrolysis device circuit scheme

3. Results and Discussion

This research used the microwave-assisted pyrolysis method to make liquid smoke. The technique with microwave-assisted pyrolysis used an activated carbon absorber with a coconut shell size (1mm, 2mm, 3mm) and heating time (5, 10, 15, 20, 25, 30 minutes), and power (300 watts, 450 watts, 600 watts). The analysis test used the gravimetric method to obtain density results from liquid smoke. The parameter used is the percentage yield. The data can be seen in Table 1 in the following observations:

3.1. Microwave-Assisted Pyrolysis Method against heating temperatures

Table 1. The relationship of liquid smoke to the heating temperature in the method microwave-assisted pyrolysis at 300 watts

No	Raw Material Size	Heating Temperature (°C)	Yield (%)
1	1 mm	116	4.65
2		126	8.37
3		141	12.09
4		146	14.13
5		155	15.99
6		174	18.22
1	2 mm	92	6.60
2		93	10.38
3		95	14.15
4		105	16.98
5		122	19.81
6		130	22.83
1	3 mm	82	1.33
2		89	3.22
3		93	7.01
4		100	8.90
5		116	10.80
6		121	12.12

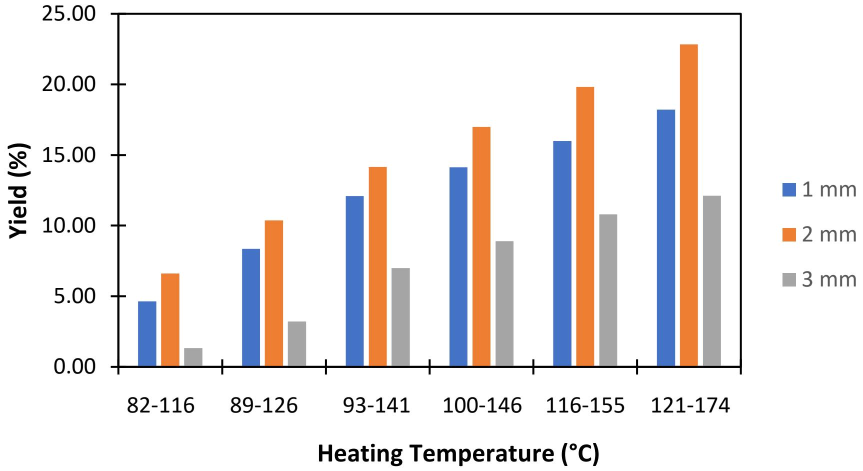

Figure 1. The relationship between liquid smoke yield to heating temperature using microwave-assisted pyrolysis method at 300 watts of power

Figure 1. indicates that the higher the heating temperature, the higher the volume of liquid smoke produced. The difference in heating temperature will cause a break in the hydrocarbon chain from the polymer in the raw material. Subsequently, the yield of liquid smoke differs at each temperature change due to the power variance carried out in the pyrolysis process and the power used. This will affect the result of liquid smoke to the reaction temperature that is increasing, and the microwave power increases. It is because the random motion of the molecules gets more extensive with increasing temperature. The increasingly sizeable spontaneous movement of molecules leads to increasingly large collisions between molecules. As the heating temperature increases, the smoke emitted will increase, so the yield of liquid smoke will rise. A material size of 1 mm produces a faster and more liquid smoke yield than 2 mm and 3 mm. This is related to the surface area because the heat propagation rate is more rapid, producing more liquid smoke yields under stable condenser water conditions. Since microwaves can penetrate the material and store energy, heat can be generated from all parts of the material simultaneously, so microwave heating will take place quickly. In microwave heating, the temperature on the (bulk) part of the material is higher on the surface, and this can be seen in the results of liquid smoke that comes out first than Tar

Table 2. The relationship of liquid smoke yield to heating temperature in the method Microwave-assisted pyrolysis at 450 watts

No	Raw Material Size	Heating Temperature (°C)	Yield (%)
1	1 mm	98	1.86
2		118	3.72
3		138	5.58
4		154	9.30
5		168	11.16
6		184	21.20
1	2 mm	104	5.64
2		118	9.40
3		133	16.92
4		146	22.56
5		151	24.44
6		173	27.82
1	3 mm	112	9.51
2		133	15.21
3		143	19.02
4		153	22.82
5		163	26.62
6		176	28.52

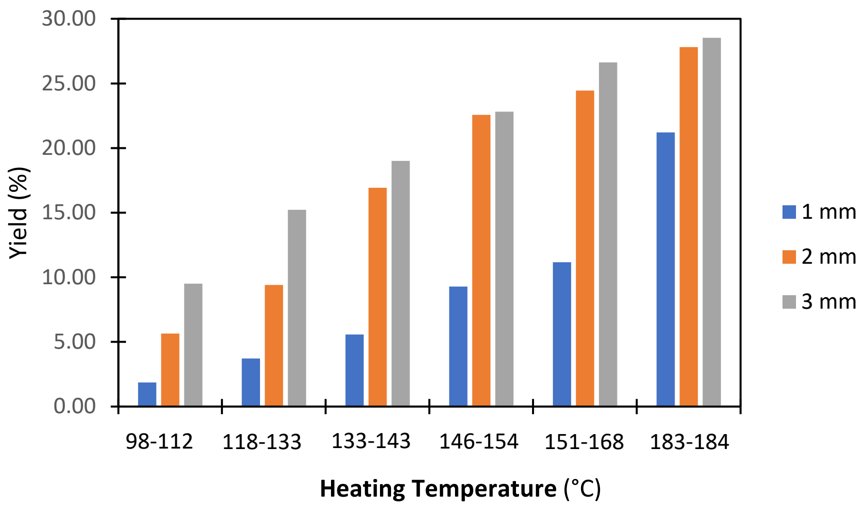

Figure 2. The relationship between liquid smoke yield to heating temperature using microwave-assisted pyrolysis method based on 450 watts of power

Figure 2. shows that the higher the heating temperature, the higher the yield of liquid smoke produced is due to the greater the amount of smoke produced at high temperatures so that the smoke condensed into liquid smoke is more significant. It also affects the power used. The interaction of charged particles in the material with the electric field of electromagnetic radiation causes the materials to heat up. The heat generated from this interaction is mainly caused by two factors, namely polarity and electron movement. In polar molecules, such as water, the electric field of microwaves causes the formation of permanent dipoles, and it induces the dipole to rotate according to the electric field of the return ball.

The movement of these molecules generates frictions between molecules that rotate to produce heat. In solid materials, the interaction of charged particles with an electric field causes electrons to move freely. Because the electron cannot change the phase of the electric field, the movement of the electron will generate heat. In addition, because the wave will propagate in the heating chamber, the greater the volume of the heating chamber, the less the microwave power will be. As a result, microwave power is reduced, and the highest temperature (peak temperature) will be lower. A power of 450 watts will increase, and the temperature will be higher than the power of 300 watts. Because the microwave power will increase because the wave will spread to fill the heating chamber, resulting in a larger volume of the heating chamber so that the temperature will be higher.

Table 3. The relationship of liquid smoke yield to heating temperature in the method Microwave-assisted pyrolysis at 600 watts

No	Raw Material Size	Heating Temperature (°C)	Yield (%)
1	1 mm	158	3.70
2		205	5.55
3		210	7.39
4		215	9.24
5		221	11.09
6		232	14.42
1	2 mm	135	4.07
2		154	7.78
3		170	9.63
4		187	11.48
5		198	13.33
6		209	15.19
1	3 mm	113	7.64
2		137	13.38
3		151	17.20
4		163	21.02
5		176	24.84
6		191	28.67

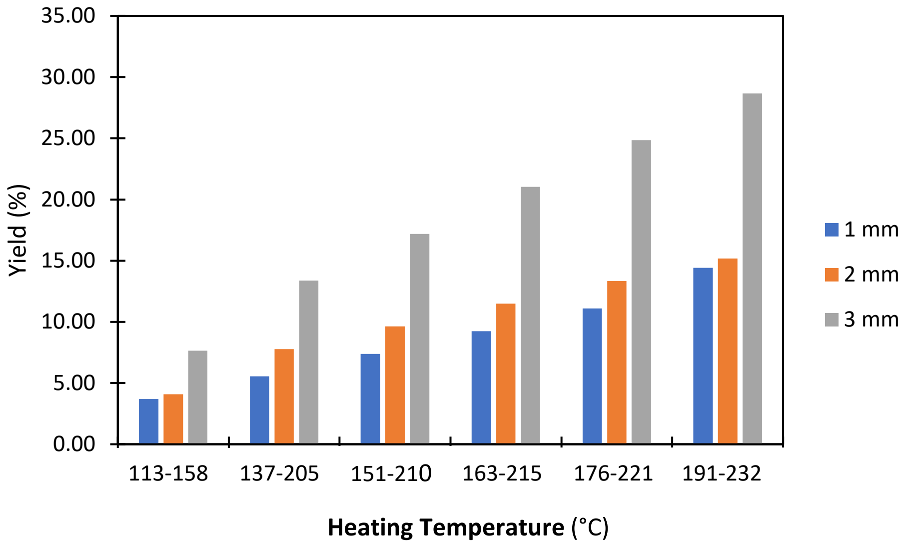

Figure 3. The relationship between liquid smoke yield to heating temperature using microwave-assisted pyrolysis method based on 600 watts of power

Figure 3. shows that the higher the heating temperature, the greater the yield of liquid smoke produced. This is as a result of microwave technology is a modern technology that makes thermal energy by rapid movement and rotation of polar molecules by rubbing against each other. Microwave irradiation induces a thermal, electric field, and other nonthermal effects in substances. Thermal effects convert electromagnetic energy into thermal energy to generate heat. The nonthermal effect causes rotation and polarization of dipole molecules, increasing the frequency of collisions between

molecules that generate heat through friction and heat transfer from the inside of the substance to the outside. The frictional force between the molecules produces heat. The forces increase the diffusion rate of internal water from the interior to the surface of the object. In addition, mechanical action and thermal effects increase the fluidity of water, which further accelerates movement

3.2. Microwave-Assisted Pyrolysis Method against particle size

Table 4. The relationship of particle size to yield (%) liquid smoke in power 300 W, 400 W, and 600 W

No	Raw material size (mm)	Power (Watt)		
		300	450	600
1	1 mm	18.22	21.20	14.42
2	2 mm	22.83	27.82	17.41
3	3 mm	12.12	31.95	30.58

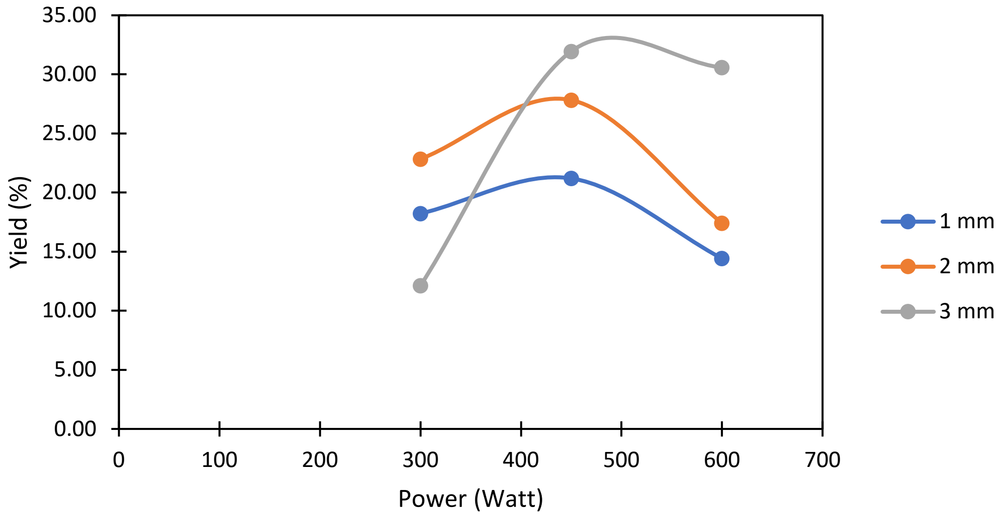

Figure 4. Relationship of Particle Size to Liquid Smoke Yield At Power 300 W, 450 W and 600 W

Figure 4. shows that at a power of 300 watts, the larger the particle size, the less the volume produced. A material length of 1 mm shows a more decreased yield when compared to 2 mm and 3 mm, which increases throughout the heating time. The influence of microwave fire on the material results in a lower yield of liquid smoke. The larger the surface area, the lower the decomposition rate of organic compounds, and the damage to the constituents of the material decreases so that the liquid smoke produced will be less when compared to a larger particle size because it has a larger surface area. During the thermal decomposition process, particle size influences the surface area of heat transfer contact between the material and the heat source. The smaller the particle size, the smaller the heat transfer surface and will decrease the heat transfer rate to the material surface. The consequence will decrease the rate of decomposition in the material and reduce the efficiency of pyrolysis, especially in need of a short period of stay

While at a power of 450 watts, it is seen that the volume of liquid smoke continues to increase at a size of 1 mm, 2 mm to 3 mm. The most significant liquid smoke yield is found at a length of 3 mm, which is 30.58%. Because, at this size, with a power of 450 watts, it produced a higher temperature of 146 ° C compared to a capacity of 350 watts at 102 ° C. The compounds evaporate at that temperature. The yield of liquid smoke is increasing at high temperatures because the amount of liquid smoke produced at high temperatures is getting bigger so that the smoke condensed into liquid smoke is getting bigger. At this temperature, it gets a relatively large amount of heat intensity. The temperature in the condenser water is still stable, so the smoke in the coconut shell will be more decomposed and condensed into liquid smoke—the more significant the power in the microwave, the more temperature.

At a power of 600 Watts, it tends to go down more (30.58%) and 300 Watts and 450 Watts. It is because, in the process of hot propagation on the entire surface of the particles, charcoal is formed so that it produces less yield. At a smaller particle size, there will be a faster heating process and run out faster to produce outcomes so that the results are less. The higher the power at optimal conditions, the lower the temperature so that the friction force between the molecules is reduced because there is no longer a friction force that appears. Microwave radiation will also decrease so that it will reduce the desire of polar molecules to make movements, and this causes the heat that appears less to transfer thermal energy to water in the heated material.

4. Conclusions

In this study, pyrolysis-assisted microwaves were processed based on material sizes and varying microwave power producing the highest yield at 300 Watts of power with a length of 2 mm of 22.85%. A power of 400 Watt with a size of 3 mm resulted in 28.52%, and a capacity of 600 watts with a length of 3 mm produced 28.67%. While the optimal size for liquid smoke is a size of 3 mm by 31.95% at a power of 450 Watt

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