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Production of Liquid Smoke From Bamboo Waste Using a Pyrolysis Reactor: Optimization and Kinetics Studies

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ABSTRACT

There are many ways for preserving wood through the use of agricultural or biomass waste like bamboo. Its utilization can be used as a safe natural wood preservative for the community. In order to obtain a qualified liquid smoke and consumed-safe it is necessary to engineer the condenser conduit pipes. As a consequence, this study needs a performance test of condenser conduit pipe on pyrolysis reactor device. The purpose of this study is to determine the performance quality of pyrolysis reactor device based on the optimum of long condenser conduit pipe and to determine the reaction order. In this study, the pyrolysis process of 2,5 kgs bamboo was using a pyrolysis reactor in optimum operating conditions, conducted with condenser conduit pipes size 23 cm, 33 cm, 43 cm, 53 cm, 63 cm and 73 cm at temperature of 250ºC for 2 hours. The results of this study indicate that the optimal liquid smoke yield is obtained from 23 cm long condenser conduit pipe (21.66%); the mass of lost material is 52.49% found in 73 cm pipe; the performance of the pyrolysis reactor is 206.25 found in 23 cm pipe g/hour.m; and the reaction occured was included as the first order of reaction.

Keywords : *Liquid smoke; pyrolysis reactor; condenser conduit pipe; the reaction order*

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ABSTRAK

Ada banyak cara untuk melestarikan kayu melalui penggunaan limbah pertanian atau biomassa seperti bambu. Pemanfaatannya dapat digunakan sebagai pengawet kayu alami yang aman bagi masyarakat. Untuk mendapatkan asap cair yang berkualitas dan dikonsumsi dengan aman, perlu merekayasa pipa saluran kondensor. Sebagai konsekuensinya penelitian ini membutuhkan tes kinerja pipa penghubung kondensor pada perangkat reaktor pirolisis. Tujuan dari penelitian ini adalah untuk menentukan kualitas kinerja perangkat reaktor pirolisis berdasarkan optimalnya pipa penghubung kondensor panjang dan penentuan orde reaksi. Dalam penelitian ini, proses pirolisis bambu berbobot 2,5 kg dengan menggunakan reaktor pirolisis dalam kondisi operasi optimal dengan ukuran pipa penghubung kondensor adalah 23 cm, 33 cm, 43 cm, 53 cm, 63 cm dan 73 cm pada 250ºC selama 2 jam. Hasil penelitian ini menunjukkan bahwa hasil asap cair yang optimal diperoleh dari pipa penghubung kondensor sepanjang 23 cm sebesar 21,66%; massa bahan yang hilang adalah 52,49% pada pipa 73 cm dan kinerja reaktor pirolisis adalah 206,25 pada pipa 23 cm g / jam.m; Dan reaksi yang terjadi termasuk dalam orde reaksi satu

Kata kunci: Asap cair; reaktor pirolisis; pipa penghubung kondensor; orde reaksi

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INTRODUCTION

Nowadays, many wood crafters use a dangerous wood preservative that causes irritation to human eyes and produces unpleasant odors during its preservation process; one example of wood preservative is formic acid usage. Wood materials without preservatives will damage their wood structure, make these woods easily weathered, and have no durability to termites. Termites attack wet wood and reduce the physical and mechanical properties of the wood. The wood cell components will be damaged since termites destroy the lignin. Thus, artisans need to apply or add preservatives to wood during the processing time.

Some ways to preserve wood, such as agriculture waste utilization or biomass utilization, will be applied to bamboo in this study. This type of wood is one example of wood leftover from building constructions which is very easy to find around people's settlements. Bamboo for all these times has only been thrown away as disposal waste to the surrounding environment where actually (this waste) can be utilized as liquid smoke [1]. It is the biggest cellulose producer (2-6 times larger) than pine trees in a hectare. Bamboo biomass can escalate 10 – 30 % per day. Bamboo trees can be harvested within four years, much faster than 8 – 20 years for wood easy-to-grow three types [2]. Using bamboo waste as a natural preservative ingredient can also answer problems about safe wood preservatives for woodcrafters. Bamboo contains of 49.3% cellulose, 23.9% hemicelluloses, 22.4% lignin, and 1.5% ash [3]. When a pyrolysis process takes place in bamboo, there is a hydrolysis reaction (among others), acetic acid, a little phenol from cellulose, and the production of phenol compounds from lignin hemicellulose becomes carboxylic, furfuran, and furan [4].

Bamboo has lignin and phenolic acid content where lignin acts as an antibacterial, antifungal, and antiviral component while phenolic acid acts as an antioxidant [5]. Liquid smoke resulting from bamboo has a high yield number (62.89 %) compared to other types of wood. The vast potential of bamboo forest in almost 2 million hectares will result in more than 3.8 tons/hectare/year [6]. Within its production process, the yield from bamboo production from furniture and craftmanship products, 60 % and 40 % of them will become waste [7]. Some of those waste is just burnt down until it can not be utilized into liquid smoke.

Liquid smoke can preserve wood due to acidic and phenol compounds, which can control bacterial growth. Liquid smoke contains some chemical compounds, such as preservatives, antioxidants, disinfectants, and a biopepticide [8].

Liquid smoke is a product of combustion or burning process from direct or indirect pyrolysis which condensed out from the materials (coming from lignin, hemicellulose, cellulose, and other carbon compounds) with the use of heat or high temperature through a closed chamber combustion process, or airtight (no oxygen) condition, by employing pyrolysis reactor device [9]. A *pyrolysis reactor* is a tool that is used to produce liquid smoke by assembly lines of pyrolysis tubes, condenser conduit (connector) pipe, tar catcher, condenser, and liquid smoke container. Condensor conduit pipe to pyrolysis reactor plays an essential part for producing a more considerable amount and more qualified yields because tar resultant which came out through reactor connector pipes must be released (pushed out) to reduce tar level from liquid smoke being produced. Since tar is very dangerous to human health, the more tar amount which able to release from the product, the better the quality of liquid smoke as tar product, and proven can be used as food preservatives. The raw material and the process of liquid smoke making also affect the pyrolysis process [10]**.** To obtain a qualified and safe (to be consumed) liquid smoke requires engineering conduct that possesses optimum working performance to these condensor conduit pipes. Thus, it is necessary to perform the pipes connected to the pyrolysis reactor device in this research.

According to previous research, a 50 cm Condensor conduit pipe can produce device work performance of 1.24 g/(hour.m) with 13.45 % missing components**,** where the highest percentage of liquid smoke is 1.3 % during 2 hours pyrolysis time [11]. Meanwhile, Rita Dwi Ratnani et al. stated that a 3 m length Condensor conduit pipe would produce device work performance of 2.44% phenolic compound during 4 hours pyrolysis time at a temperature of 400°C [12]. A tool performance test will be carried out to measure the device work performance to determine the reaction order, liquid smoke yield, total missing material, and device performance for this research.

The novelty of this study is that there has been no occurrence found between reaction order from condenser connecting pipe length to the result of liquid smoke, which allows an optimal pyrolysis reactor performance to be measured.

According to the information above, the researcher is interested in examining substitutes for non-food preservatives that are safe for the community and biomass as raw material for liquid smoke because these materials have loaded waste that is easy to find utilized further.

This research aims to determine the work performance quality of the pyrolysis reactor toward the length of condenser conduit pipes and determine the order of the reaction rate. This study emphasizes the importance of understanding the reaction order because the reaction rate speed is associated with utilizing lignin and cellulose in coconut shells into liquid smoke. The reaction kinetics data will affect the basis of the design of a pyrolysis reactor in producing liquid smoke, so it is expected that there will be no errors in the design.

LITERATURE REVIEW

Bamboo is one of the raw materials that can be used as liquid smoke. Bamboo contains of cellulose (42.4-53.6%), lignin (19.8-26.6%, 1.24-3.77%), ash (1.24-3.77%), silica (0.10-1.78%), cold water solubility (4.5-9.9%) and hot water solubility(5.3-11.8%, 0.9-6.9%) [13]. Bamboo is one material with high cellulose content that can produce cellulose 2-6 times larger than pine in a hectare. The increase rate in bamboo biomass per day is 10-30%, while the increase rate in other wood tree biomass is only 2.5%. Bamboo can be harvested in 4 years, a much shorter time when compared to 8-20 years of other fast-growing types of wood trees [14].

Liquid smoke is a vapor condensate liquid produced by wood pyrolysis containing main constituent compounds of acids, phenols, and carbonyls due to thermal degradation from the components of cellulose, hemicellulose, and lignin. Liquid smoke possesses compounds that potentially can be antibacterial [15], and it is also a preservative due to its ability to be an antioxidant and biopesticide [16].

Pyrolysis is the process of thermochemical conversion from organic materials into carbon (char), liquid, and gas materials by heat process in high temperature with the absence of oxygen [17]. Lignocellulosic biomass contains hemicellulose, lignin, and cellulose [18]. Lignin occurs at a low temperature (160-170°C) to high temperature (about 900°C), while hemicellulose is formed at a temperature of 200 to 400^0C then followed by cellulose formation [19].

A condenser is a heat exchanger that condenses fluid or converts steam into liquids. A 200 cm pipe coil was the same material designs of the condenser room into a cylinder-shaped reactor without a lid. Further, a room with no pipe coil is filled with cooling water, equipped with a drain pipe to regulate the circulation of the cooling water. In addition to cooling, the condenser also serves to accelerate the condensation process of liquid fumes coming out from the pyrolysis reactor. Some factors that affect the capacity of the condenser are: 1) The surface area of the heat transfer includes the diameter of the condenser pipe, the length of the condenser pipe and the characteristics of the condenser pipe, 2) The cooling airflow is natural convection or forced flow by the fan, and 3) The difference in cooling air between the refrigerant and outdoor air.

METHOD

Materials

The research method employed in this study is an experimental laboratory method. The selected raw ingredients for this study are bamboo taken from the Malang City area and LPG gas as the fuel for the pyrolysis process. The instrument for this research is a pyrolysis reactor.

The process starts with a pyrolysis process using bamboo material where 3 kgs of cleaned bamboo were sized down (8-10 cm) and put inside the pyrolysis reactor that has a variety of condenser conduit pipes length (23,33,43,53,63, and 73 cm) and heated in temperature of 250^0C for two hours. When the process ends, it will produce three types of fractions: 1) charcoal as the solid fraction; 2) tar as the heavy fraction and; 3) smoke and methane gas as the light fraction. Then, the light fractions will have flowed into condensation pipe until this process gained liquid smoke, whereas the methane gas remains as uncondensed gas (can be utilized as fuel). After the liquid smoked out from the condensor, its yield and tar produced were calculated.

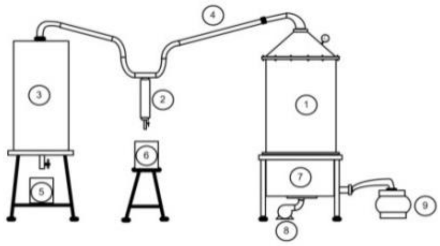

Figure 1. Set of Pyrolysis Reactor Device

The series of devices used are shown in Figure 1 as the pyrolysis reactor, and the method of pyrolysis process employed in this research is the slow pyrolysis method.

Reaction Kinetics Method

Reaction kinetics is the study of the speed at where the reaction occurs. In this condition, changes of yield amount in the reaction will affect the rate of the reaction while the kinetic aspect includes the reaction order and the reaction rate constant of the liquid smoke yield is using the linear regression method through the equation of :

$$r = k\,[A]^n \quad \ldots\ldots (1)$$

Where r = rate, k = reaction rate constant, [A] = substance concentration, n = reaction order.
Pyrolysis reaction with bamboo waste will break down cellulose into heterogeneous reaction on biomass as in the reaction equation:

$$\underset{\text{Cellulose}}{3(C_6H_{10}O_5)} \rightarrow \underset{\text{water vapor + tar+ carbondioxyde+ methane+ hydrogen+char}}{8H_2O+C_6H_8O+3CO_2+CH_4+H_2+8C} \quad \ldots\ldots (2)$$

According to these reactions the reaction rate equation can be made as follows:

$$r = k[C_6H_{10}O_5]^3 \quad \ldots\ldots (3)$$

At the reaction rate, as the reaction increases or the reagents decrease per unit of concentration, the rate concerning the gas speed through the condenser pipe is viewed as an increase in the amount of yield. This result shows that the rate is identical to the number of yields so that a linear regression will be formed as the equation below:

$$y = ax + b \quad \ldots\ldots (4)$$

The Device Work performance

The working device performance is calculated (mainly) based on distillate weight that accommodated for every pyrolysis process resulting from the condenser by applying the formula of:

$$\text{Work performance of the device (g/hour.m)} = \frac{weight\ of\ liquid\ smoke\ that\ accomodated\ (g)}{pyrolysis\ time\ (hour)\ x\ condensor\ lengthr\ (m)} \ldots\ldots (5)$$

RESULTS AND DISCUSSIONS

The analysis for the liquid smoked results which have been obtained are displayed in picture below:

Determination of the order of the reaction

The kinetic aspect of bamboo pyrolysis products to the pyrolysis reactor performance is evident through the relationship between the condenser length and the yield produced as a product. Analysis for determining the reaction order can be done by applying a linear regression approach, where the result is displayed in figure 2 as follow.

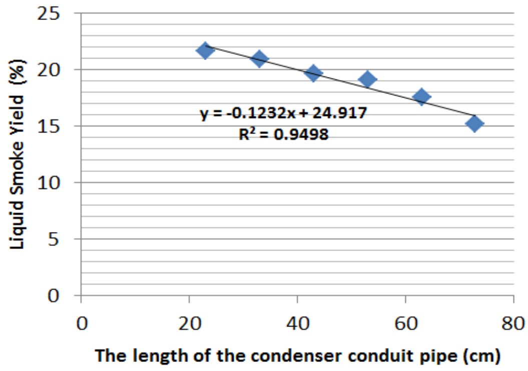

Figure 2. Liquid Smoke Yield Test Kinetics Results against the Length of the Condenser

Figure 2 shows the regression equation in the form of y =-0.1232x + 24,917. The equation shows that the reaction order of the pyrolysis of liquid smoke as a wood preservative is -0.1232. Whereas the speed constant is obtained by 24,917 = 6,63,1010. The reaction order of -0.1232 showed no effect of the condenser length on the reaction rate in the liquid smoke yield, because the values are between order 0 and 1. Thus, it can be interpreted as there is an increase in the reaction rate of the liquid smoke yield to the condenser length because the reaction is not in exact order 0 (zero) so it also does not directly proportional to the yield of pyrolysis with Condensor length because the reaction also does not exist in order 1. The reaction will be ordered as 1 when the reaction rate is directly proportional; however, if the reactor concentration has 0 order to concentration changes, thus these changes will not affect the reaction rate [20].

According to the regression data in Figure 2, it shows the linearity of the relationship between the length of the condenser and the liquid smoke yield can be stated as accurate. When the correlation coefficient is positive, the two variables have a direct relationship. The correlation value will be categorized as very strong when the value of R2 = 0.75 - 0.99 [21].

Figure 2 presents the reaction order determined based on the regression equation. The method can be applied when the reaction order is identified, so its order can be shown in Figure 3 by plotting the relationship between [A] and [Vr] from equation $r = k\,[A]^{1}$, which shows a straight line as displayed in figure 3 below.

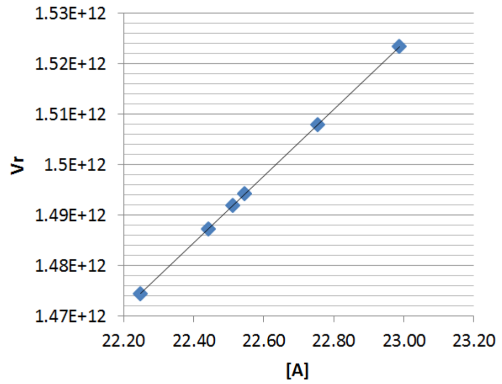

Figure 3. Chart of Order One

Figure 3 shows the first-order reaction of the liquid smoke pyrolysis reaction from bamboo waste. First-order equations are linear equations. Therefore the reaction rate can be interpreted as directly proportional to the yield rate.

Liquid Smoke Yield

The liquid in the form of a liquid smoke yield is produced in the pyrolysis process from gas condensation as a result of the degradation of volatile components of the biomass. The liquid smoke yield has a high percentage result.

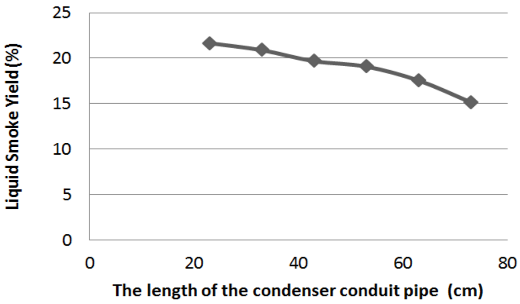

Figure 4. Result of Liquid Smoke Yield

Yields are the amount of liquid smoke accommodated from the pyrolysis process. Figure 4 shows that the longer the condenser connecting pipe, the lower the yield of liquid smoke formed. The yield of bamboo liquid smoke in 23 cm condenser conduit pipe is higher than the yield from other condenser conduit pipes because, during the pyrolysis (burning) process, the water content inside bamboo also evaporates at 100°C. It undergoes condensation when water vapor passes through the condenser, increasing the amount of liquid smoke condensate produced. The composition of liquid smoke yield obtained depends on the condensation system. Liquid smoke will produce at maximum capacity when an optimal cooling process occurs and is aided by water as a cooling medium, so the heat exchange occurs quickly. The condensation process can optimally happen when the water in the cooling system is drained continuously and pushes the temperature in the cooling system not to rise [22]. Liquid smoke differences will exist with reason more to the temperature during the pyrolysis process, the water content contained in bamboo, and the length of the condenser conduit pipe.

The Mass of Loss Material

Pyrolysis of bamboo produces charcoal, condensed and uncondensed gas. The condensed gas will turn into liquid, while the uncondensed gas is released into the air. In the pyrolysis process, there is charcoal from bamboo leftover from combustion, and the mass of material lost from the pyrolysis process is called weight loss (%).

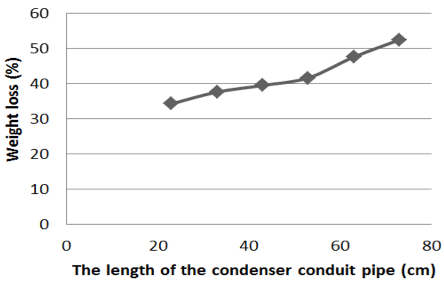

Figure 5.The Lost Material Mass

Figure 5 shows that the percentage of the mass of material lost in the 23 cm condenser conduit pipe is 34.32%, which is considered a smaller value than the 73 cm condenser connecting pipe with 52.49%. The different percentage was obtained due to lots of steam released through the exit of tar and liquid smoke in the pyrolysis process. In the 73 cm condenser conduit pipe, the liquid smoke that has been condensed passed the saturation point and made a lot of mass of material in the liquid smoke were lost. The amount of lost material mass dramatically affects the yield produced. The higher the yield produced, the lower the mass of bamboo material lost due to pyrolysis. Conversely, the lower the yield, the higher the mass of the lost bamboo material.

Pyrolysis Device Performance

The length of the condenser conduit pipe affects the pyrolysis reactor performance because it experiences a residence time in the condensation process to the rate of heat transfer in the condenser pipe that converts the gas phase into a liquid phase.

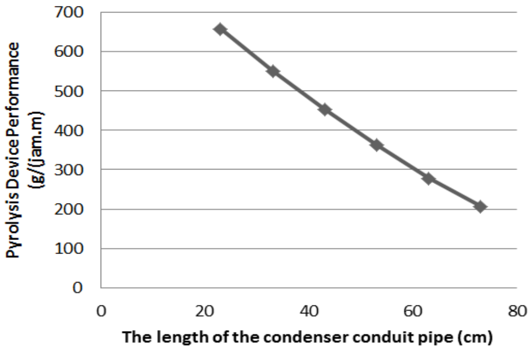

Figure 6. The Working Performance of Pyrolisis Reactor Device

Figure 6 shows that the longer the condenser conduit pipe size, the lower the pyrolysis reactor performance. Conversely, the shorter the condenser conduit pipe size, the higher the performance of the pyrolysis reactor tool produced.

From the 23 cm condenser conduit pipe, the high result of device performance is found. The high performance is influenced by the yield of liquid smoke produced and the mass of material lost. The pyrolysis device performance is high when the yield is abundant and the mass of lost material is slight. The shorter the condenser conduit pipe, the higher the device performance because the steam produced from the shorter condensor conduit pipe will make the heat transfer rate faster.

CONCLUSION

The highest or the optimum result of liquid smoke yield is 21.66% which took place in 23 cm condenser conduit pipe, whereas the optimum result of lost material mass is 52.49% which happened in 73 cm condenser conduit pipe. Then, the optimum liquid smoke performance is 206.25 g/hr found in a 23 cm condenser conduit pipe, and the reaction that occurs in the pyrolysis reactor is included as the first-order reaction.

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