LIQUID SMOKE PRODUCTION FROM PALM KERNEL SHELL PYROLYSIS: COMPARING COLD AIR AND CONVENTIONAL CONDENSATION METHODS

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***ABSTRACT*:** Gas condensation is one of the problems in the liquid smoke production process. Uncondensed gas will have an impact on the liquid smoke produced and air pollution. Here, several methods are applied to determine the percentage level of liquid smoke produced by the gas condensation process. The condensation method uses conventional normal water, gas condensation using cold water, and gas condensation using cold air. The raw materials used are oil palm shells with a size of -4+5 mesh, a pyrolysis temperature of 300-400^{0}C, and a liquid smoke production process for 300 minutes. Based on the test results, gas condensation occurs optimally in the cold air method, with the results of 22% liquid smoke, 64% charcoal, and 14% non-condensed gas. Compared with the condensation of the standard water method, the condensation method of cold air is superior to 36.36% for liquid smoke to minimize air pollution by up to 48%. The results of this study indicate that temperature and fluid effect the effectiveness of the gas condensation process, thereby increasing the yield of liquid smoke and reducing air pollution during the liquid smoke production process.

KEY WORDS: Liquid smoke; palm kernel shell; pyrolysis; gas condensation methods.

1. INTRODUCTION

Indonesia is among the few countries with a vast area; over 50% of its territory is utilized to enhance community welfare. One significant way this is done is through oil palm plantations that produce Crude Palm Oil, generating more than 43% of waste [1]. In 2013, records indicated that Indonesia had 10.6 million hectares of oil palm plantations, which increased to 13.7 million hectares by 2020 [2]. 6.000 tons of palm kernel shells are produced annually from 100.000 tons of fresh fruit bunches (FFB), 12.000 tons of fibre, and 23 tons of empty fruit bunches. The waste must be managed into a valuable and economical product, such as liquid smoke, to minimize the production of waste that can damage the environment [3]. The process of recycling waste into liquid smoke, which is environmentally friendly with a variety of combustion techniques to maximize yields, has been carried out by several studies [4]–[6].

One type of solid waste from the palm oil processing industry that needs proper management is palm kernel shell, which can generate significant benefits [7], [8]. Depending on their content, palm kernel shells have varying amounts of lignin, hemicellulose, and cellulose. Palm kernel shells contain 29.4% lignin, 27.7% hemicellulose, and 26.6% cellulose[3].

Liquid smoke is generated through condensation from the combustion of materials containing lignin, cellulose, hemicellulose, and various carbon compounds [9], [10]. Liquid smoke has many benefits, including as a latex clotting fluid, preservatives, biopesticides, neutralizing soil acids, improving soil quality, killing pests, insect repellents, accelerating growth on roots, stems, tubers, fruit, flowers, and leaves [11], [12]. Researchers have studied liquid smoke using palm kernel shells, as demonstrated by sources [13]–[22] and others.

Pyrolysis is the decomposition of organic compounds through a heating process, either white or with no oxygen [23]. It is said to be an organic thermal decomposition that can cause the formation of volatile compounds. The pyrolysis process generally ranges from 200^0C to 500^0C [24].

In general, condensation changes the fluid phase from gas to liquid by releasing heat into the environment. Volatile organic compounds are a significant source of air pollution, and the condensation process effectively addresses this issue [25]. The condensing process using a refrigeration system to form entropy has been carried out by [26]. In the process of producing liquid smoke, researchers use conventional water for condensing [16], [21], [22], [24], [27]–[29]. The process of condensing smoke into liquid smoke is conducted conventionally using water, which is then continuously circulated with a pump. While making liquid smoke, gas still escapes to the environment because the water temperature increases due to the condensing process [28].

Refrigeration transfers heat from one place to another, from a low to a higher temperature. In this process, heat is absorbed and release[30]d [30][31]. Businesses primarily utilize refrigeration systems in commercial equipment for freezing and food preservation, making them significant energy consumers [32] [9][33].

This research will discuss several methods for condensing pyrolysis gases in producing liquid smoke, namely the gas condensation method using cold air (C_{ca}), the gas condensation method using cold water (C_{cw}), and the gas condensing method using normal water (C_{nw}). Producers must use these methods to increase the productivity of liquid smoke while minimizing air pollution during the production process.

2. MATERIAL AND METHOD

This study utilizes cold air from the evaporator in the refrigeration system. Palm shell raw materials will undergo a pyrolysis process in the combustion chamber. The resulting smoke will enter the cold storage room for the condensation process, air circulation in the cold storage is assisted by a fan with a speed of 5.4 m / s. The refrigeration machine used has a capacity of 1 HP, refrigerant type R-22. This study uses temperature parameters with an accuracy level of ± 0.5 ^{o}C, humidity with an accuracy level of ± 3% and pressure with a maximum pressure of 140 PSI. The results of liquid smoke will be tested in the laboratory to obtain the values of Hemicellulose, Cellulose, Water content, Lignin and Ash. The air in the cold storage is set to reach 15^{o}C.

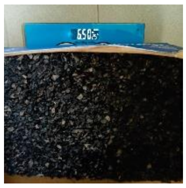
Oil palm shell waste that has been conditioned to a size of -4+5 mesh and dried in sunlight for 32 hours becomes material for making liquid smoke with various condensation modes. The conditioned palm kernel shell underwent laboratory tests, the results of which are in Table 1.

Table 1 shows the laboratory results of compounds on palm kernel shells from the palm oil industry located in South Sumatra Province, Musi Banyuasin Regency. The water content of this palm kernel shell looks low, namely 12.18%, this is because the sun has dried the oil palm shell. These results also show that the high lignin value reaches 76.22%.

Figure 1 shows the refrigeration cycle. The cycle consists of four main components: compressor, condenser, expansion, and evaporator. In addition, various safety and control devices save energy and keep the primary components safer [34].

Fig. 1. Smoke condensation using a low temperature air media refrigeration system

Table 1: Oil Palm Shell Compounds

Compound	Percentage (%)	Sample
Hemicellulose	2.68	
Cellulose	11.52	
Water content	12.18	
Lignin	76.22	
Ash	3.19	

Researchers will subject 10,000-gram palm kernel shells to a pyrolysis process at 300-400°C. The pyrolysis will produce gas that researchers will condense using three different methods: C_{nw}, C_{cw}, and C_{ca}.

Researchers frequently use water in the conventional gas condensation process, even today [5], [6], [22], [28], [35]. Additionally, they have carried out gas condensation using cold water, achieving a liquid smoke yield of 19% [36]. Researchers conduct the gas condensation process using water and cold air with a controlled refrigeration system, maintaining water and air temperatures at 15°C. This gas condensation process lasts for 300 minutes. The following diagram illustrates the gas condensation scheme.

Figure 2 shows the scheme of the conventional pyrolysis gas condensation process using water circulated using a pump without any special treatment for the water. The raw material for waste oil palm shells used is 10,000 g, with a pyrolysis temperature of 300-400^{0}C for 300 minutes.

Figure 3 shows a schematic of the condensation process of pyrolysis gas using controlled cold-water fluid by combining the refrigeration system. The water used for the condensation process of the pyrolysis gas will be cooled using the evaporator from the refrigeration system so that the water used is lower and controlled. A continuous pump keeps circulating the cold water.

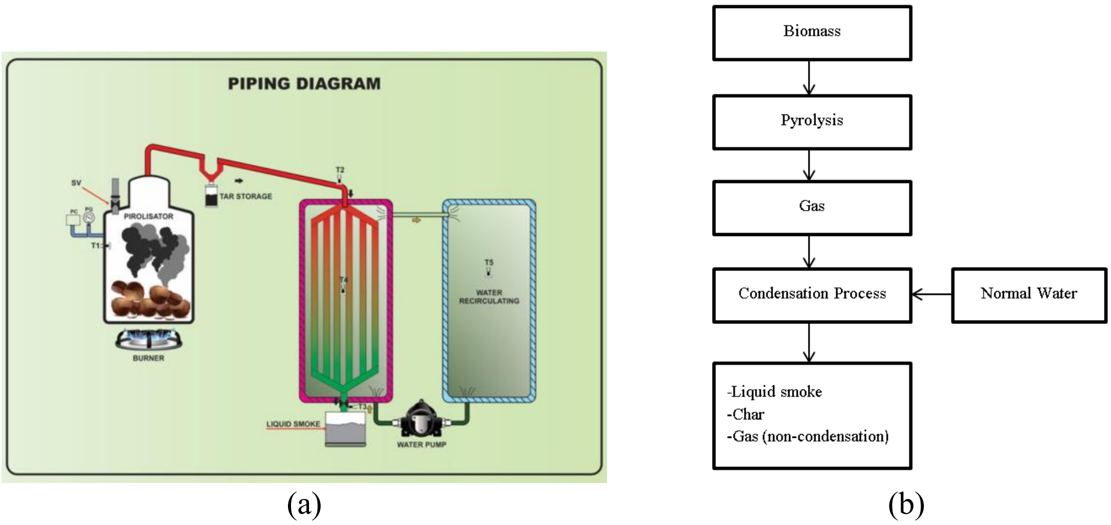


Fig. 2. Conventional gas condensation process using water (C_{nw}): (a) Piping Diagram (b) Flow chart

Figure 2. Conventional gas condensation process using water, smoke from the pyrolyzer flows into the cooling chamber for condensation, the cooling process is carried out conventionally using water without special treatment. Circulating water uses a pump with a water flow capacity of 1300 liters / hour.

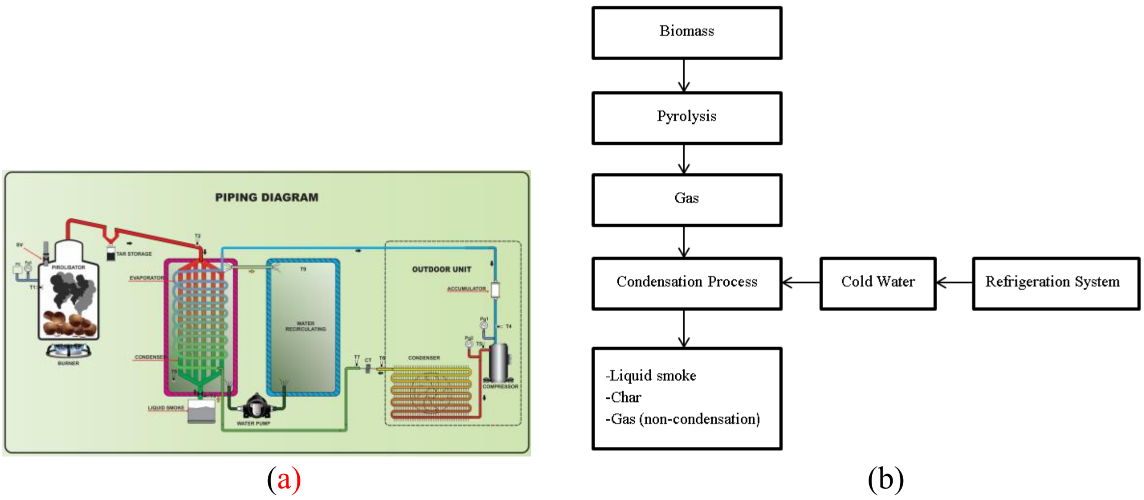
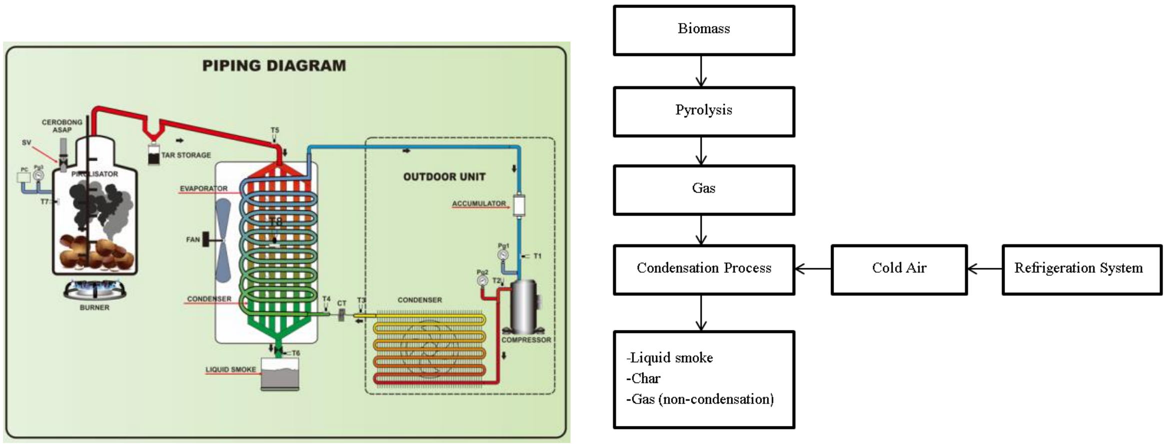


Fig. 3. Gas condensation process using cold water (C_{cw}): (a) Piping Diagram (b) Flow chart

Figure 3. Gas condensation process using cold water, smoke from the pyrolyzer flows to the cooling chamber for condensation, the water used for the condensation process is cooled using an evaporator through a refrigeration system to obtain a temperature of up to 15°C with a water flow rate of 1300 liters/hour.



(a) (b)

Fig. 4. Gas condensation process using cold air (C_{ca}): (a) Piping Diagram (b) Flow chart

Figure 4. Gas condensation process using cold air, smoke from the pyrolyzer flows to the cold storage for condensation, The air in the cold storage is cooled using an evaporator from the refrigeration system. Air circulation in the cold storage is assisted by a fan with an average speed of 5.4 m/s and the temperature in the cold storage is maintained at 15°C.

3. ANALYSIS

Researchers will calculate the results of the liquid smoke obtained using 100% of the total weight of the raw material. They will divide this value into liquid smoke, tar, charcoal, and gas.

$$m_s = m_l + m_c + m_g = 100\% \quad (1)$$

$$m_l(\%) = \frac{m_l(gr)}{m_s(gr)} x\ 100\% \quad (2)$$

$$m_c(\%) = \frac{m_c(gr)}{m_s(gr)} x100\% \quad (3)$$

$$m_g(\%) = \frac{m_g(gr)}{m_s(gr)} x100\% \quad (4)$$

The equation above shows the percentage calculations for palm oil, liquid smoke, charcoal, and gas. m_s is the percentage for the number of palm shells used, m_l is the percentage amount of liquid smoke obtained, m_c is the percentage amount of charcoal left over from the pyrolysis process, and the percentage amount of unconspired gas, measured in mg, represents gas that cannot transform into liquid smoke, allowing it to escape into the environment and cause pollution.

4. RESULTS AND DISCUSSION

In this study, researchers carried out three different gas condensation methods: condensation using plain water (C_{nw}), condensation using cold water (C_{cw}) by combining the refrigeration system with cooling water, and condensation using cold air (C_{ca}) by integrating the refrigeration system with cooling air.

Table 2: Results of production of liquid smoke by various condensation methods

Mass	C_{nw}	C_{cw}	C_{ca}
	g	g	g
Liquid Smoke	1056	1951	2204
Char	6200	6300	6400
Gas	2744	1749	1396

Table 2 shows that each gas condensation in the liquid smoke production process with the condensation method using ordinary water (C_{nw}), cold water (C_{cw}), and cold air (C_{ca}) is superior to the gas condensation process using cold air media with the result of 2204 liquid smoke, and 1396 g of gas. It is due to the help of the evaporator from the refrigeration system, which can lower the air temperature while controlling the resistance of the air used for gas condensation; besides that, the type of fluid used dramatically affects the heat release process, both air and water. While the conventional gas condensation system using water media without special treatment is not optimal, the water temperature will increase during production.

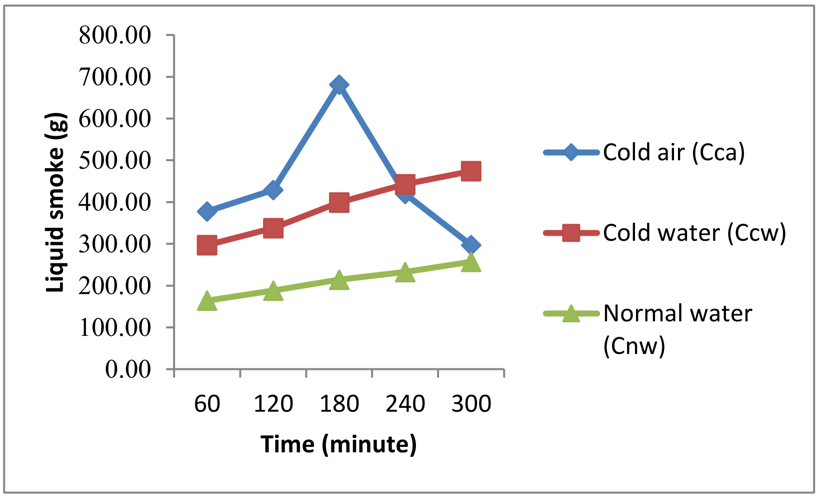


Fig 5. Achievement of liquid smoke production with a variety of condensation methods

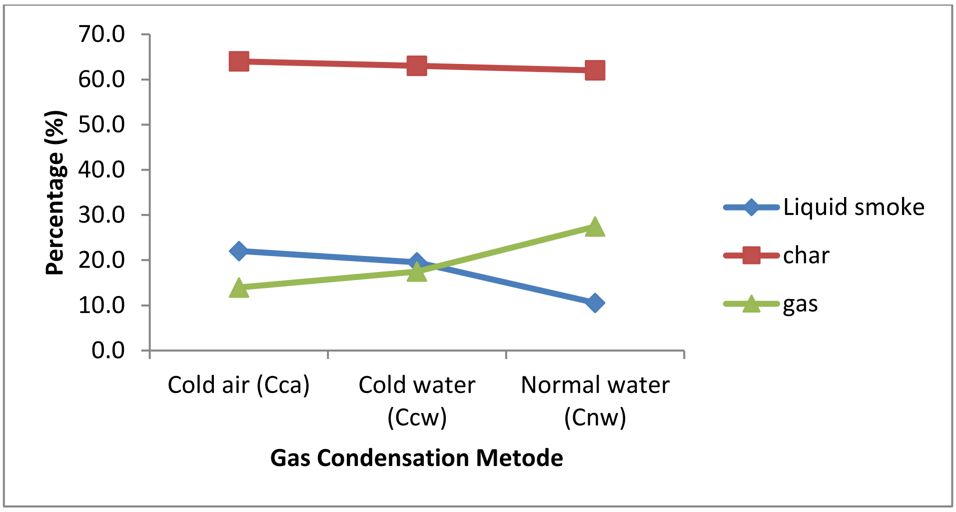


Fig 6. Condensing the gas resulting from pyrolysis in the production of liquid smoke

Figure 5 shows the maximum level of liquid smoke yield in the gas condensation method using cold air (C_{ca}) at 180 minutes from the total production for 300 minutes. The gas condensation process increases at 180 minutes and decreases thereafter because the moisture content in the palm oil shell evaporates to the maximum and decreases after 180 minutes. We have reduced the moisture content in the shell of the oil palm, and the achievement for evaporation has been minimal. Meanwhile, condensation using cold water takes longer to achieve the maximum results of liquid smoke. The condition of the palm shell used in the pyrolysis gas condensation process

remains consistent since the moisture content in the palm oil shell evaporates thoroughly and decreases after 180 minutes. The reduction happens because the moisture content in the oil palm shell has been minimized, and the evaporation efficiency has been low. Meanwhile, condensation using cold water takes longer to achieve the maximum results of liquid smoke. The condition of the palm shell used in the pyrolysis gas condensation process is the same.

Figure 6 shows some of the results of the pyrolysis gas condensation process in producing liquid smoke. The pyrolysis-derived condensed gas will decompose into liquid smoke, charcoal, and non-condensed (contaminated) gas. The results of liquid smoke obtained from each condensation process were using 22% cold air (C_{ca}) condensation, 19.5% cold water (C_{cw}), and 10.6% normal water (C_{nw}). On the other hand, 14% of the non-condensed gas used cold air condensation (C_{ca}), 17.5% used cold water condensation (C_{cw}), and 27.4% used normal water condensation (C_{nw}).

The amount of gas released into the environment can be minimal compared to other studies, which resulted in gas escaping as much as 22.9% [18], and 19% of the gas escaping with the same raw material, namely palm kernel shells [19]. While the phenol content in liquid smoke was 56.18% higher on average compared to research using conventional cooling at 13.49% [20], phenol value also reached 28.3% with 16% gas [21]. Another study also examined palm kernel shells using the pyrolysis method with microwave and conventional condensation, achieving 34.91% phenol and 37.69% passed gas [22]

5. CONCLUTION

Research results indicate that the gas condensation process from pyrolysis in liquid smoke production is more effective when using the gas condensing method with cold air. Evidence for this is found in the percentage of liquid smoke produced and the amount of non-condensed gas measured under the same raw material conditions for palm oil shells. The results of liquid smoke using the cold air (C_{ca}) method reached 22%, while the cold water (C_{cw}) method reached 10.6%. Thus, the fast and controlled heat transfer process increased gas condensing using the cold air (C_{ca}) method by 36.36% compared to the standard water method (C_{nw}). At the same time, it can also analyze the results of the gas that is not condensed or in other words, the gas escapes the environment, which causes pollution. The amount of non-condensed gas using the cold air method (C_{ca}) reaches 14%, while the non-condensed gas using the standard water method (C_{nw}) reaches 27.4%. Thus, the more gas that is not condensed, the higher the level of air pollution will be in the process of producing liquid smoke. Thus, the pyrolysis gas condensation method using cold air can minimize air pollution by as much as 48% compared to ordinary water condensation methods.

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