Experimental study on integrated biomass pyrolysis and gasification process from teak wood waste: preliminary

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Abstract. This study aims to investigate the influence of teak wood waste column height on integrated biomass pyrolysis and gasification process. A design of new conversion process is developed in this study. Teak wood waste was compacted into a gasifier then a hollow like tube gap is inserted in the center of gasifier surrounded by char. Oxygen is passed in the inlet and was flown through the gap. When a flame was initiated, the gap was burned and temperature inside the gap was increased caused the pyrolysis of compressed teak wood happen. There were three different char column height investigated in this study, which are 50, 58 and 67 cm. Compactness of feedstock is set at 0.26 kg/m³. Water boiling test was conducted in order to find the fastest boiling time among the height variation. It is found that the higher the column, the faster the boiling time. Higher char column caused more gas produced due its higher feedstock mass. Furthermore, the gap between each teak wood chip in higher column has increased its ability to release the producer gas.

1. Introduction
Biomass refers to all matter that is produced biologically. It also defined as any organic matter such as wood, animal wastes, crops, etc. that could be used as an energy source. Biomass decomposes to its molecules while releasing heat and its combustion imitates the natural process. So, it could be said that energy produce from biomass is a form of renewable energy where it does not release the carbon monoxide when producing the energy [1]. Biomass is different with other renewable energy sources where it stores the energy in effective and natural ways. Moreover, biomass is the only renewable energy that not only could produce carbon but also capable to convert the fuels in solid, liquid and gaseous form [2].

Gasification, pyrolysis and combustion are the methods of thermochemical conversion of biomass. Due to its high efficiency, biomass gasification has gained the highest interest compared to pyrolysis and combustion technologies. Gasification is a process of transforming solid fuel into combustible gas [3]. The gas that is produced, knowns as producer gas, is a mixture some kinds of gas such as carbon monoxide, carbon dioxide, hydrogen, methane and nitrogen. The original biomass is less versatile than the producer gas where the producer gas could be burnt in order to produce heat and steam or it could be used to produce electricity in gas turbines [4].

Barbuzza et al. has investigated gasification of wood biomass by using renewable hydrogen in order to produce the synthetic natural gas. Sabatier reaction, water gas shift and partial oxidation are the three process configurations that have been studied in the research, where the configurations has differentiated by their oxygen supplies. Electrolysis and/or gasification processes are used in the study [5]. Production of hydrogen energy through biomass (waste wood) gasification has introduced by the other researchers. They found that the wood waste can be successfully transformed to produce the combustible gas, known as producer gas consisting of methane, hydrogen, nitrogen, carbon monoxide, carbon dioxide, and water vapor by using an Imbert downdraft biomass gasifier [6]. The efficiency of modern wood biomass gasification technologies economically was investigated by Kozlov et al. They found that the most
promising gasification technology is the multistage thermal chemical biomass, where producing almost a tar-free generator. It is also competitive with other alternative technologies in terms of energy production [7]. Brand et al. examined the effects of biomass blends on pellet qualities and concluded that rice saw and Pinus spp. shavings are the two raw materials that affect the pellets’ properties most [8]. Surahmanto has explored the performance study of wood chips gasification stove. He investigated three factors that affect the stove performance, which are fuel consumption rate, combustion zone rate and specific gasification rate. From the study, it could be concluded that these three factors are interrelated. It is indicated that there was stable boiling temperature which is linearly proportional with the efficiency [9]. The using of palm starch solid waste with gasification modelling method has investigated by Muslim et al. The energy Gibbs minimum was utilized in the study. They found that the using of palm starch waste that has RDF 5 could be developed more due to its potential biomass energy [10].

There is a new design of biomass conversion process which offers lower energy consumption, called integrated biomass pyrolysis and gasification. Previously, a study of the integrated and gasification process using rice straw has been conducted [11]. However, the using of wood waste as feedstock have never been investigated. Therefore, this study focused on the experimental study on integrated biomass pyrolysis and gasification process from teak wood waste.

2. Methods
The integrated biomass pyrolysis and gasification process happened in a biomass stove which also called gasifier. Firstly, the waste teak wood with desired mass and height was divided into three parts. The first part was poured into the gasifier chamber, then the first load barrier disc was put into the gasifier. The second wood part, second load barrier disc, and third wood part were then stacked like the first part. The load barrier discs were used in order to maintain the shape of the wood and avoid the wood from collapsing. Finally, the top cover was assembled and connected into the pressing unit. The wood then pressed until reaching the desired column height. The small and large center pipes then were removed from the chamber, so there is a gap that tube-like in the middle of feedstock, called as an alley. The oxygen will entered through gasifier inlet and flown into the gap along the chamber. Fire was initiated by put a flame paper into gasifier inlet so that there is fire inside the alley. This fire caused temperature inside the alley was increased so that the pyrolysis of compressed teak wood happen (pyrolysis temperature has been reached). The experimental procedures were illustrated in figure 1. There were three different char column height investigated in this study, which are 50, 58 and 67 cm. Compactness of feedstock is set at 0.26 kg/m$^3$. 


3. Results and Discussion
Before testing the biomass stove, we conducted a simple test on how much the energy needed to boil water from ambient temperature using commercial liquefied petroleum gas (LPG) available in Indonesia. Time and temperature of water was recorded before heating, during and after boiled by a minute interval. Mass reduction of LPG gasses used along experiment was also recorded. The mass reduction then converted into energy released by multiply the calorific value of commercial LPG, which is 11.254.61 Kcal/Kg [12]. The energy released by LPG in boiling 1500 mL water was depicted in figure 2 and the formula for energy release depicted in figure 3. The energy released by LPG in boiling 1500 mL water then assumed equal with energy needed to boil 1500 mL of water. In this study, energy needed to boil 1500 mL of water by LPG is equal to energy need to boil 1500 mL of water by biomass, which
formulation was written in figure 3. As seen in the picture, energy released by fuel (or needed to boil water) is a function of temperature.

![Energy released by LPG in boiling 1500 mL water](image)

**Figure 2.** Energy released by LPG in boiling 1500 mL water

![Formulation of energy release by LPG in boiling 1500 mL water](image)

**Figure 3.** Formulation of energy release by LPG in boiling 1500 mL water

Water boiling test was conducted in order to find the fastest boiling time among the height variation. Water with volume of 1500 mL and in room temperature condition was put in a kettle. After the fire from biomass stove was stable, the kettle then was placed on the stove. Time and temperature were measured and recorded every sixty seconds until the water boiled. There were five repetitions done for each column height's variation. The results of the experiments were depicted in figure 4. Results showed that the highest column, 67 cm, obtained the fastest boiling time among the others. It could be said that the higher the column, the faster the boiling time. Higher char column caused more gas produced due
its higher feedstock mass. Furthermore, the gap between each teak wood chip in higher column has increased its ability to release the producer gas. After obtaining the data of temperature for each variation, the energy released by biomass was calculated by using formula in figure 3. The energy released by biomass was depicted in figure 5.

![Temperature vs Time Graph](image1)

**Figure 4.** Experimental result of water boiling test for column height variation

![Energy vs Time Graph](image2)

**Figure 5.** Energy released by biomass to boil 1500 mL of water
4. Conclusion
Investigation on column height effect on boiling time of integrated pyrolysis and gasification biomass using teak wood as feedstock has been done. Based on the results of research and discussion that has been delivered, it can be concluded the column height affects the boiling time. The highest column obtained the fastest boiling time among the other column height variation. More producer gas generated and higher capability in releasing producer gas are the reasons why the highest column height obtained the best results.

Acknowledgments
The authors would like to acknowledge the “Universitas Negeri Yogyakarta, Indonesia” for providing financial support through a sponsored research project.

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