Co-combustion characteristics of low-rank coal mixed with candlenut shell by using Thermogravimetry analysis - differential thermal analysis

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Abstract: CNS is one of the plantation wastes that can be used as alternative fuel which can be mixed with LRC. The research aims to obtain thermal and chemical characteristics of LRC – CNS mixing and the impact of adding CNS into LRC on combustion characterization. An experimental test was conducted to obtain thermal characteristics by using proximate and ultimate analysis based on ASTM standard. Combustion characteristics are obtained by using differential thermal analysis (DTA) and thermal gravimetry analysis (TGA) by using air as an oxidant. The Composition of CNS mixtures with LRC are 10, 30 and 50 respectively. The result of CNS mixed with LRC generalized improves the quality of the fuel mixture by the increase combustion reactivity, and this has an impact on increasing differential internal energy. The optimum addition of CNS into LRC was obtained of 10%.

Keywords: candlenut shell, low- rank coal, proximate analysis, ultimate analysis, combustion reactivity.

1. Introduction

The world’s energy needs are increasing at this time, but energy use is only focused on fossil energy such as oil, coal, and gas which are limited in number with fluctuating prices. In general, power plants use coal as fuel. Indonesia’s coal resource potential is 151 million tons. Of this potential, there are 86.4% are low-rank coal (LRC), which has higher heating value (HHV) 5,000-6,000 kcal kg\textsuperscript{-1}, and moisture content of 30 to 40% [1]. LRC resource potential is very large in its use as fuel in power generation. But the facts show that LRC has many disadvantages such as moisture content, sulphur, and nitrogen content which is still quite high. Moreover, LRC has a low combustion temperature. Based on this fact, it has implications for the low combustion efficiency and combustion reactivity [2]. Burning coal, for example, the LRC contributes to an increase in CO\textsubscript{2} emissions, which is twice as much as CO\textsubscript{2} emissions per unit of heat energy. Similarly, high sulphur (S) and nitrogen (N\textsubscript{2}) content will contribute to the amount of combustion gas emissions such as CO\textsubscript{2}, NOx, and SOx. Therefore, a formulation is needed to minimize the negative effects of burning LRC.
The most common formulation is mixing LRC with biomass which aims to improve the quality of coal combustion.

Some research results that use biomass as coal companion fuel. Bertrand et.al. [3] conducted a study on the effect of adding biomass of wheat straw, and wood mixed to coal showed a decrease in NO emissions, and CO also reduced carbon that was not burned by unburned carbon (UBC). Testing of NO emissions from combustion of biomass mixed with various types of coal rank using an oxy-fuel atmosphere obtained a decrease in NO emissions [4]. The possibility of decreasing NO is due to the low Nitrogen content in biomass. Then Ghenai et.al. [5] by using computational fluid dynamics (CFD) simulations presented a decrease in NO\textsubscript{x} and CO\textsubscript{2} emissions with variations in biomass mixture into coal. An interesting thing that has been simulated by Hutrindo et al. [6-7] i.e. the addition of peat into the LRC mixture which increases the combustion rate and finer combustion ash particles. This positive combustion result is probably due to the volatile matters (VM) content in the peat being greater than the VM in the LRC, while the moisture (M), and ash (A) content in the peat is smaller than in the LRC. Furthermore, the addition of palm shells with LRC at a ratio of 1:1 to fluidized bed boilers (FBB) with combustion air of 5.2 kg/kg, obtained the amount of steam produced 4.3 kg of steam kg\textsuperscript{-1} of fuel and boiler efficiency of 66% with temperature steam of 450 °C, combustion efficiency increases up to 90% [8].

From the description of the utilization of the biomass mixture with coal, it shows an increase in the quality of the combustion. One of the biomass wastes that have not been widely studied is its use as a renewable energy source and is used as a companion to coal for joint combustion, which is candlenut shell (CNS). Based on data from the Central Bureau of Statistical Data (BPS) [9] in 2015 the production of the Republic of Indonesia’s national candlenut was 100,700 tons. From this amount of production, it will produce 65,700 tons of CNS waste. This CNS waste has the potential to be used as fuel which can be mixed with LRC to improve the quality of LRC combustion.

Candlenut (Aulerius molucca) is a plantation that grows in tropical regions such as Indonesia. The use of CNS as a renewable biomass fuel source has been used for a long time by a small proportion of rural communities for household needs in Indonesia as a substitute for wood charcoal. Preliminary research into the effects of mixing CNS with CNS charcoal formed into pellets has been carried out to test the CO emission content [10]. The test results showed CO emissions decreased by only adding 25% CNS. Further on the addition of CNS, Tambunan et al. [11] conducted an experiment by mixing CNS and CNS charcoal in an electric furnace. The recorded data shows the combustion temperature reaches 400°C with combustion air velocity 0.4 m s\textsuperscript{-1}. As a result, the maximum power obtained is 46.08 Watts in the composition of 3:1 between CNS and CNS carbonated charcoal [11].

Based on the research results of mixing various types of biomass with coal, as described above which can improve the quality of combustion, and utilize the potential of candlenut as a combustion additive, it is interesting to test CNS mixing with LRC in terms of the right composition to improve combustion quality. It is expected that this experiment will increase VM content and decrease M, N, and S as the main characteristics of increased combustion quality. This experimental method is carried out by mixing CNS into LRC with various compositions, and then the mixing results are characterized to obtain thermal properties and chemical properties by standard ASTM. Furthermore, the mixture sample is tested by TGA-DTA by using air as an oxidizer.

2. Materials and methods
The LRC using in this experimental test is collected from the Sangatta coal mine of East Kalimantan of Indonesia, and the CNS is collected from Tinambung Village, West Sulawesi of Indonesia. Preparation of sampel LRC and CNS were previously cleaned from the material/dirt attached and
then dried by the sun heating for 1 day. The CNS was pretreatment through dry torrefaction in an electric furnace with a temperature of 350 °C for 30 minutes [12]. LRC and CNS are milled separately on crusher with particle size of 40-60 mesh [13-14]. Both materials are mixed in the mixing machine with the percentage addition of CNS into LRC are 10, 30, 50, 70 and 90% respectively. The above sample is tested through a proximate analysis and ultimate analysis. Both of the analysis were conducted based on the ASTM standards [15]. To find out the co-combustion characteristics of the sample, it is tested by using Thermogravimetry and differential thermal analysis (TGA-DTA) Lynseis type STA PT 1600. The sample used was 22 mg by using atmospheric air of 0.5 L min\(^{-1}\) as an oxidizer.

3. Result and discussion
3.1. Proximate and ultimate analysis
The thermal and chemical characteristics are presented in Table 1 by using proximate and ultimate analysis, based on ASTM Standard was adopted from Patabang et.al. [16].

Table 1. Proximate and ultimate analysis of sample, adopted from Patabang et.al. [16]

| Sample mixture       | VM %adb | M %adb | A %adb | FC %adb | HHV (kcal kg\(^{-1}\)) |
|----------------------|---------|--------|--------|---------|------------------------|
| CNS 100%             | 63.00   | 6.72   | 0.47   | 28.69   | 4936                   |
| LRC 100%             | 39.80   | 15.15  | 2.38   | 42.67   | 5406                   |
| LRC/CNS (90/10)%     | 42.25   | 14.10  | 1.95   | 41.70   | 5329                   |
| LRC/CNS (70/30)%     | 47.20   | 12.15  | 1.55   | 39.10   | 5216                   |
| LRC/CNS (50/50)%     | 51.51   | 10.56  | 1.34   | 36.59   | 5187                   |
| LRC/CNS (30/70)%     | 56.99   | 8.51   | 1.08   | 33.42   | 5104                   |
| LRC/CNS (10/90)%     | 62.03   | 6.93   | 0.53   | 30.31   | 5049                   |

| Sample mixture       | Nitrogen | Hydrogen | Sulphur | Oxygen |
|----------------------|----------|----------|---------|--------|
| LRC 100%             | 1.05     | 9.72     | 0.148   | 51.17  |
| CNS 100%             | 0.33     | 15.49    | 0.032   | 64.21  |
| LRC/CNS (90/10)%     | 0.81     | 10.36    | 0.133   | 54.64  |
| LRC/CNS (70/30)%     | 0.75     | 11.97    | 0.110   | 56.64  |
| LRC/CNS (50/50)%     | 0.57     | 13.11    | 0.085   | 58.59  |
| LRC/CNS (30/70)%     | 0.46     | 14.43    | 0.061   | 61.18  |
| LRC/CNS (10/90)%     | 0.39     | 14.68    | 0.038   | 61.80  |

3.2. The characteristics of combustion
The characteristics of combustion by using TGA-DTA of 100% of LRC is presented in Figure 1 while The characteristics of combustion by TGA-DTA of 100% of CNS is presented in Figure 2. The characteristics of combustion by TGA-DTA of adding 10% of CNS into 90% of LRC is presented in Figure 3. The characteristics of combustion by TGA-DTA of adding 50% of CNS into 50% of LRC is presented in Figure 4.
Figure 1. The TGA-DTA record of sample of 100% of LRC

Figure 2. The TGA-DTA record of 100% of CNS.
Figure 3. The TGA-DTA record of 10% of CNS mixed with 90% of LRC.

Figure 4. The TGA-DTA record of 50% of CNS mixed with 50% of LRC.
3.3. Thermogravimetry analysis (TGA)
Based on the results of the TGA, the sample combustion area includes 3 zones, according to the stages in the combustion process, namely the zone of demoisturization, devolatization, and char combustion zone [17]. In the demoisturization zone the water vapor in the sample is released, and this zone is characterized by a gradual reduction in sample mass, after all steam has been evaporated, then it is followed by a devolatization zone, where volatile matters samples start coming out of the sample, and this is characterized by reduced sample mass rapidly, and then the sample starts burning.

The higher the VM in the sample, the sample flame will be more stable, because one of the functions of the VM is to maintain the stability of the fuel, then the charcoal (fixed carbon) combustion zone. In this zone, the higher the FC content in the fuel, the longer the combustion time of charcoal, so on the contrary the smaller the FC content in the sample, the shorter the combustion time.

In the LRC combustion test 100% charcoal combustion ranges from 200 minutes, while in combustion of CNS 100% combustion of charcoal ranges from 115 minutes, as well as the addition of CNS into the LRC. The greater the addition of CNS to the LRC, the shorter the combustion time of charcoal. For example, in the addition of 50% CNS, the duration of burning of charcoal is around 110 minutes. Besides that the duration of burning the VM is increasing. As the results of the initial research using an electric furnace conducted by Patabang et. al. [18] which presented an increase in combustion reactivity. The results of the thermogravimetry test strengthen the initial research by using an electric furnace that can condition the combustion.

3.4. Differential thermal analysis (DTA)
The DTA test results presented different energy activation rates for each sample. From the DTA graph, the endothermic and exothermic conditions were observed alternately, and the energy change value in the 100% of LRC sample was 0.38 µV, while the CNS 100% energy change value was 0.66 µV, this indicates that the energy change activation value of the CNS greater than LRC, so that the addition of CNS into LRC has implications for increasing the value of energy changes. These results are consistent with the results of the initial research by using an electric furnace which is conditioned to determine the combustion reactivity, where the addition of CNS into the LRC increases the combustion reactivity [16]. The increase in reactivity is due to the greater VM, O$_2$, and H$_2$ content in the CNS than in the LRC. This has implications for improving the quality of LRC combustion. The effect of adding CNS to the LRC by 10% has significant implications for increasing energy activation and increasing mass changes increasing optimal combustion reactivity.

4. Conclusions
Based on the characterization of the addition of CNS into the LRC, it can be concluded. The proximate analysis has presented the addition of CNS into the LRC increases the combustion reactivity due to the increase of Volatile Matters and the decrease of Moisture, and Ash content in their mixture. The ultimate analysis has presented the addition of CNS into LRC to reduce Nitrogen and Sulphur. The increasing addition of CNS into LRC further decreases Nitrogen and Sulphur content. This will significantly contribute to the decrease of these NOx and SOx content from combustion emission. The addition of CNS to the LRC has implications for the quality of combustion consisting of increased combustion reactivity, combustion efficiency, and reduction of combustion emissions. The optimum addition of CNS into the LRC is 10%.
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