Journal of Mechanical Engineering Research & Developments (JMERD)

ISSN: 1024-1752 (Print)
CODEN: JERDFO

DOI: http://doi.org/10.26480/jmerd.01.2019.116.121

RESEARCH ARTICLE

THE EFFECT OF ADDING CANDLENUT SHELL INTO THE LOW-RANK COAL ON COMBUSTION PERFORMANCE

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ARTICLE DETAILS

Article History:

Received 1 January 2019
Accepted 22 February 2019
Available online 7 March 2019

ABSTRACT

The potential of coal in Indonesia approximately 151 billion tons, there are 61% of Low-rank coal (LRC), which has a Higher Heating Value (HHV) of 5,100-6,100 kcal/kg and Moisture content of 30-40%. Combustion of the LRC contributes to global warming due to its CO_2 emission. The LRC has also a low igl (CNS). The combustion performance of LRC mixed with CNS was investigated by determining its combustion efficiency and the impact on combustion gas emission including Carbon Dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxide (NO_x), and Sulfur Dioxide (SO_x). This study was conducted by adding CNS into LRC of 10%, 30%, 50%, 70%, and 90%, respectively. The characteristic of the specimen is obtained from proximate and ultimate analysis based on ASTM standard. The combustion performance of mixing LRC and CNS was investigated in the electric furnace combustors with the burn-out temperature of 500, 625, 750, and 875 ^oC respectively. The combustion oxidant used oxygen which was supplied constantly. The combustion gas emissions were measured by using Thermoline MRU Air Fair VARIO plus test apparatus. The result shows that the addition of CNS into the LRC improves combustion performance significantly. The results show that the addition of 10% of CNS into the LRC yield the combustion efficiency varies in the range of 0.92 – 14.42%. The addition of CNS into the LRC has a significant impact on reducing CO_2, CO, NO_x and SO_x emissions. For example, adding 10% CNS into the LRC can reduce SO_x emission of 16.80%, and adding 90% CNS of 80.67% with combustion temperature of 500 ^oC. Improving the combustion performance by increasing combustion efficiency and reducing gas emissions will reduce global warming and also decrease slagging and fouling of combustion apparatus due to decrease of Sulfur content in the CNS and LRC mixtures.

KEYWORDS

Low-rank coal, Candlenuts shell, Low-Rank Coal, Proximate and ultimate analysis, Combustion performance

1. INTRODUCTION

Mixing a coal with biomass is applied to improve the combustion quality of the coal. The combustion quality is affected by combustion reactivity, combustion efficiency and combustion gas pollutant including greenhouse gas (GHG) namely Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxide (NOx), and Sulfur Dioxide (SOx). The use of coal as fuel in power plants and industries contribute largely to the global warming effect [1]. The coal that is widely used in power plants is Low-rank coal (LRC). The LRC has many disadvantages such as high moisture, sulfur and nitrogen contents. Also, it has low ignition temperature [2]. In order to improve the quality of the LRC, this type of coal could be mixed with biomass to reduce moisture, sulfur and nitrogen contents. The potential of coal resources in Indonesia is approximately 151 billion tons. 61% of the coal resources is LRC, which has a Higher Heating Value (HHV) of 5,100-6,100 kcal/kg and Moisture content of 30-40% [3].

The effect of addition biomass into the coal including olive kernel, sawdust, almond shell and municipal sewage mixed with coal have been investigated by using a pilot scale incinerator in order to reduce toxic emissions. It was found that adding all the types of biomass significantly reduces polychlorinated dibenzo-p-dioxide (PCCDFs) and dibenzofurans (PCDFs) emission [4]. The addition of palm shell to LRC with a ratio of 1:1 in fluidized bed boiler with boiler efficiency of 66% and steam temperature 450 oC increased the combustion efficiency up to 90% [5]. Co-firing of coal with peat showed that the ash particles of the combustion product were smoother. This fact indicates that the addition of peat into LRC improved combustion reactivity [6]. Addition of wheat and wood straws into coal showed the decrease of NO and CO emissions and also reduce unburnt carbon (UBC) [7]. NO emission from combustion of LRC mixed with biomass using the oxy-fuel atmosphere was reduced [8]. The addition of corn stalk into the coal increased the combustion rate of the fuel mixture [9]. The addition of 10-25% of Hydrocombustionly Treated Empty Fruit Bunch (HT-EFB) to coal has resulted an increase in power generation of 40% and also has an impact on the decrease in the environmental impact of using coal fuel [10]. Furthermore, co-firing of coal with raw and torrefied biomass fuel of corn straw and rice husk yields a significant reduction of gas emissions such as CO2, NOx, SOx and HCl [11].

Addition of biomass improves significantly the quality of coal combustion.

The potential energy from biomass waste is 32,000 MW in Indonesia and has been utilized only around 1,740.4 MW . The potential biomass to be mixed with LRC to improve its combuation performance is Candlenuts shell (CNS). Based on the data from the Indonesian Bureau of Statistics 2015, Indonesia's national candlenuts production is 100,700 tons [12]. It produces 65,700 tons of candlenuts shell waste. This research investigates the effect of adding CNS into the LRC on combustion peformance by determining its combustion efficiency and the impact on combustion gas emission including Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxide (NOx), and Sulfur Dioxide (SOx).

2. MATERIAL AND METHODS

In order to find-out the thermal and chemical properties, the raw material and their mixtures are firstly characterized based on ASTM Standard.

2.1 Specimen Preparation

The LRC was from Sangatta, Coal mining East-Kalimantan, Indonesia, and the CNS was from plantation in Tinambung, West-Sulawesi, Indonesia. The raw materials of the LRC and CNS are as shown in Figure 1 and Figure 2.

Figure 1: Low-rank Coal (LRC)

Figure 2: Candlenut Shell (CNS)

The CNS specimen was firstly cleansed from the inherent impurities and then dried with dry torrefaction method at 250-300 oC for 30 minutes in electric furnace [13]. The LRC and CNS specimens were milled by separated crusher with particle size 40-60 mesh [14]. Furthermore, the LRC and CNS are mixed in the mixing machine for 30 minutes to be homogeneous. The composition by mass of addition of CNS to LRC was 10%, 30%, 50%, 70%, and 90%, respectively. The characterization of raw material and their mixtures of the specimens is carried-out through proximate and ultimate analysis based on ASTM standards [15]. Proximate analysis is intended to obtain thermal characteristics namely the content of Volatile Matters (VM) based on ASTM D 3175 standard, Moisture (M) content based on ASTM D 3173 standard, and Ash (A) content based on ASTM D 3174 standard, and measurements of HHV based on ASTM D 5865-12 standard using the Adiabatic Bomb Calorimeter PARR 1261. The ultimate analysis is carried-out to measure the chemical constituents using Leco CHN 628 Series Machine. The standard used was ASTM D5373-02 using infrared. Measurement of Carbon (C), Hydrogen (H2) and Nitrogen (N) content using ASTM D 5373-02 standard. Measurement of sulfur content (S) based on ASTM D 3177 standard. The results of the characterization of raw materials (LRC and CNS) and their mixtures are presented in Table 1.

Table 1: Proximate and Ultimate analysis of specimen and their mixture

Proximate Analysis (%) adb	CNS	LRC	CNS /LRC (10/90)	CNS/LRC (30/70)	CNS/LRC (50/50)	CNS/LRC (70/30)	CNS/LRC (90/10)	ASTM Standard Method
Volatile Matters (VM)	63.00	39.80	42.25	47.20	51.51	56.99	62.03	D 3175
Moisture (M)	6.72	15.15	14,10	12.15	10.56	8.51	6.93	D3173
Ash(A)	0.47	2.38	1.95	1.55	1.34	1.08	0.53	D3174
Fixed Carbon (FC)	28.69	42.67	41.70	39.10	36.59	33.42	30.31	by difference
HHV (kcal/kg)	4,936	5,406	5,329	5.216	5,187	5,104	5,049	D 5865-12
Ultimate Analysis (%) adb								
Carbon(C)	19.47	35.52	32.11	28.98	26.31	22.79	22.56	D5373-02
Nitrogen (N)	0.33	1.05	0.81	0.75	0.57	0.46	0.39	D5373-02
Hydrogen (H2)	15.49	9.92	10.36	11.97	13.11	14.43	14.68	D5373-02
Sulfur (S)	0.032	0.148	0.133	0.110	0.085	0.061	0.038	D 3177
Oxygen (O2)	64.21	51.17	54.64	56.64	58.59	61.18	61.80	by difference

2.2 Experimental Set-up

A 5-grams specimen was placed in a cup specimen suspended on a digital scales and then burned in an electric furnace combustors using oxygen as an oxidizer. The oxygen used in this experiment was supplied from a pure oxygen tube by adjusting the oxygen flow rate in the oxygen gas regulator. The amount of oxygen used in combustion is 0.5 L/min.

The combustion of each specimen is carried-out at temperatures 500, 625, 750 and 875 oC respectively [16,17]. It is due to the pyrolysis temperature of biomass is greater than 400oC. The temperature setting was carried-out by adjusting the flow of electrical current with the electrical regulator. The flame temperature of the specimens is measured by using a thermocouple temperature recorder. The experimental set-up is shown in Figure 3.

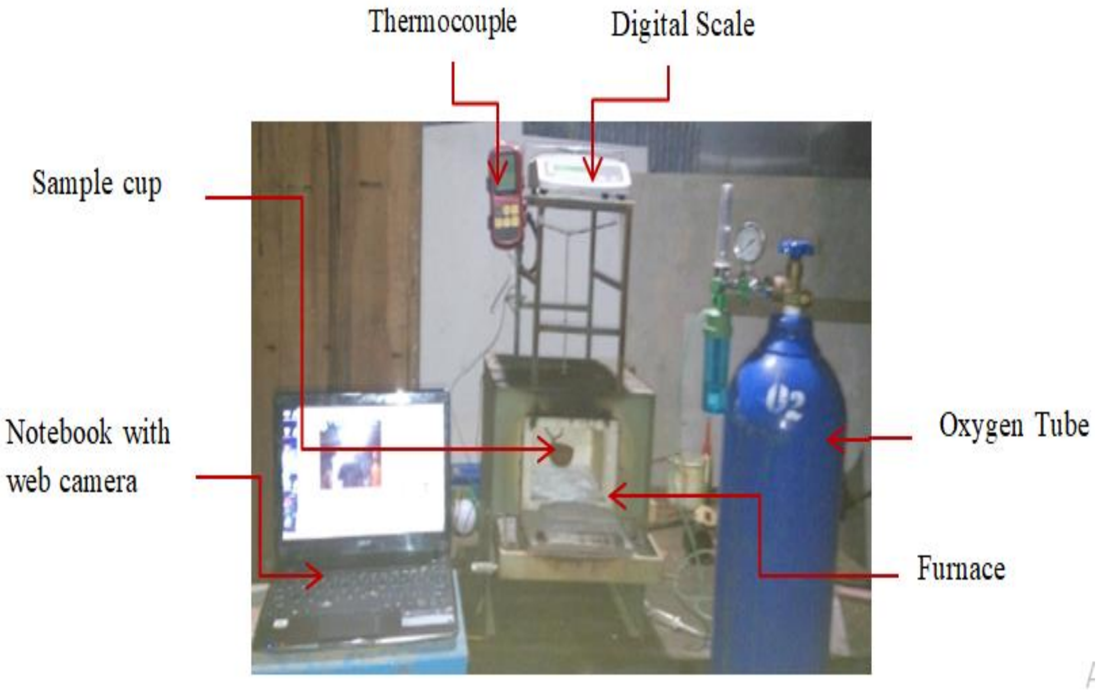


Figure 3: The experimental set-up

Measurement of combustion gas emissions including of CO2, CO, NOx and SOx was carried-out with combustion of 80 grams of specimen in a Thermoline muffle furnace. The specimens were burned with the combustion temperatures of 500, 625, 750 and 875 oC respectively by flowing oxygen into the furnace in accordance with the needs of each specimen mass. Combustion gas emissions were measured directly by using Emission Monitoring Systems of MRU Air Fair VARIO plus industrial models as shown in Figure 4.

Figure 4: Thermoline MRU Air Fair VARIO plus

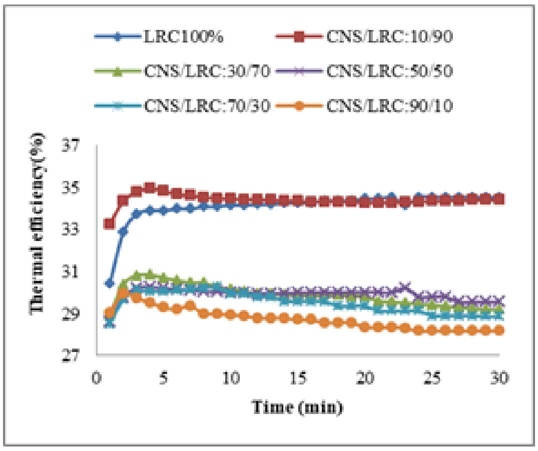
3. RESULTS AND DISCUSSION

3.1 Thermal Efficiency of Combustion

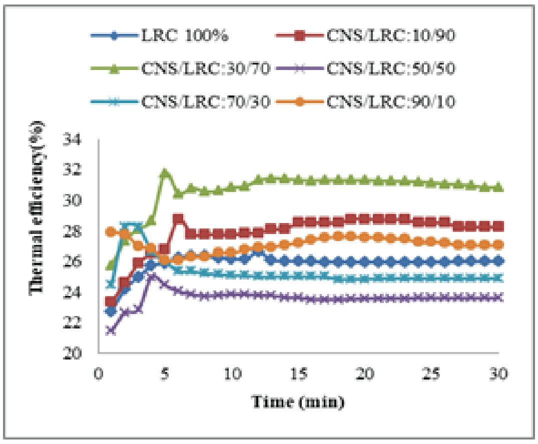
The combustion efficiency is the ratio of actual flame temperature of the specimen when it is burned to the adiabatic flame temperature of the specimen by the following equation

$$n_{th} = \frac{T_{act}}{T_{ad}} \text{ x } 100 \ \% \qquad (1)$$

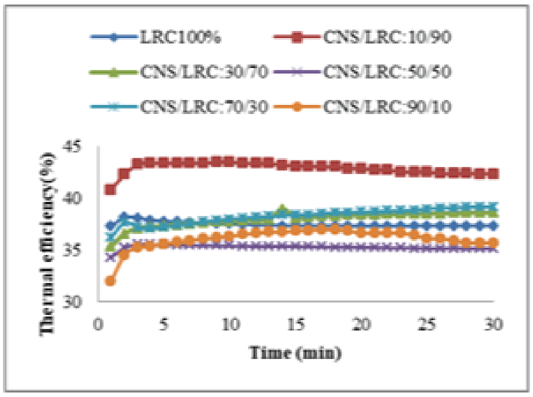
Where Tact is the actual flame temperature of the specimen (oC) and Tad is the adiabatic flame temperature of the specimen (oC).



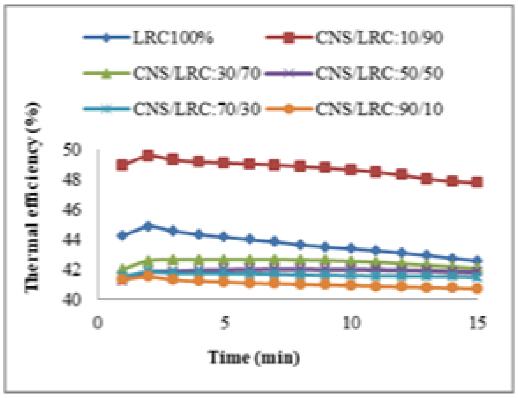
(a) Combustion temperature of 500 oC



(b) Combustion temperature of 625 oC



(c) Combustion temperature of 750 oC



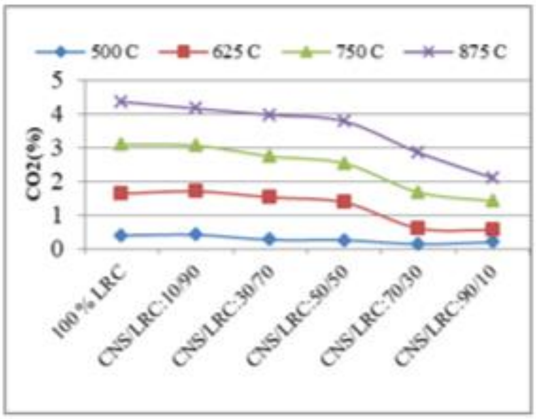
(d) Combustion temperature of 875 oC

Figure 5: Combustion efficiency history

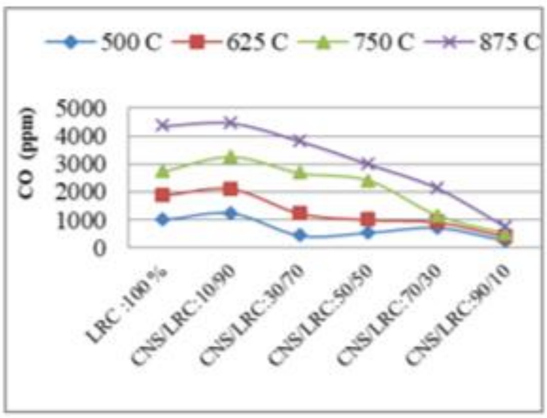
Combustion efficiency is strongly influenced by the flame temperature and CNS content of each combustion temperature as shown in Figure 5(a-d). The combustion of mixed LRC with CNS was carried out at temperatures of 500, 625, 750 and 875 oC, respectively. In the combustion temperature of 500 oC, combustion efficiency increased in the LRC mixed with addition of CNS of 10%, 30%, and 90% respectively. The combustion efficiency increased in the LRC mixed with CNS of 10% at combustion temperature of 625 oC. The combustion efficiency increased in the CNS addition of 10, 30 and 70% at combustion temperature of 750 oC. In addition, the combustion efficiency increased in the CNS addition of 10% and 30% at combustion temperature of 875 oC. These results show that the addition of 10% of CNS into the LRC generally yielded the combustion efficiency varies in the range of 0.92 – 14.42%. The maximum combustion efficiency increase of 14.42% obtained at the combustion temperature of 750 oC. Addition of CNS into the LRC greater than 30% generally did not increase combustion efficiency.

3.2 Gas Emissions from Combustion

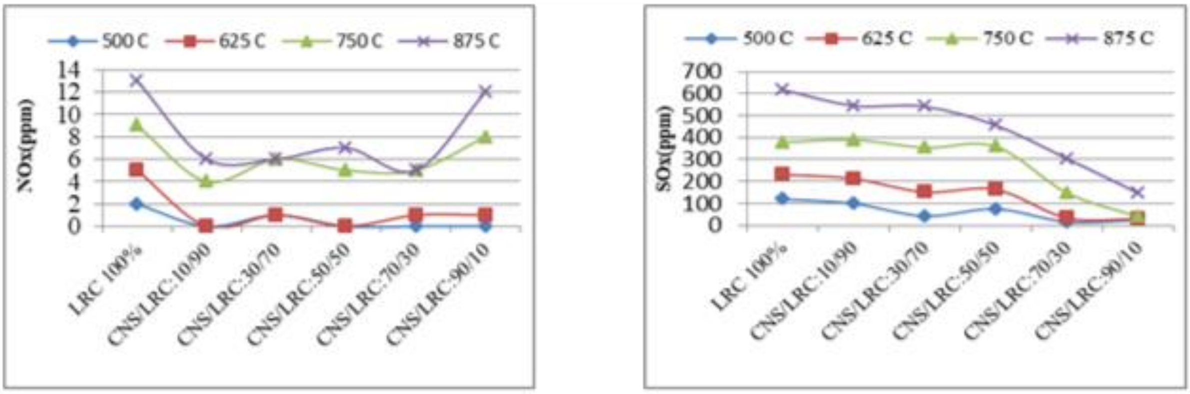
The results of measurements of gas emissions from combustion consisting of CO2, CO, NOx, and SOx are presented in Figure 6.



(a) CO2 emission



(b) CO emission



(c) NOx emission

(d) SOx emission

Figure 6: The history of gas emission

CO2, CO, NOx, and SOx emissions are strongly influenced by chemical constituents and combustion temperatures in each co-fuel as shown in Figure 6. Increasing combustion temperature contributed to the gas emission of CO2. Addition CNS into the LRC reduced CO2 gas emission. For example, adding 10% CNS into the LRC can reduce CO2 emission of 5%, and adding 90% CNS of 39.02% with combustion temperature of 500oC. The increasing of CNS addition implicates to the greater reduction of CO2 emissions. The maximum reduction in CO2 emissions was obtained at CNS addition of 90% with combustion temperature of 625oC which is 72.09%. Some previous studies have investigated the reduction of CO2 emission by addition of biomass into the coal [18-20].

Similarly, addition CNS into the LRC reduced CO gas emission. For example, adding 10% CNS into the LRC can reduce CO emission of 21%, and adding 90% CNS of 80.19% with combustion temperature of 500oC. The maximum reduction in CO2 emissions was obtained at CNS addition of 90% with combustion temperature of 750oC which is 91.81%.

NOx emission decreased only at combustion temperature of 500 and 625oC. Decreasing NOx at the combustion temperature of 500oC vary from 50 to 100% and at the combustion temperature of 625oC vary from 66.67 to 100%. However, the opposite condition appeared at the combustion temperature of 750 and 875oC. It is due to increasing of NOx index at the high temperature as stated by a researcher [21].

The decrease of NOx emission is caused by the nitrogen content in the CNS less than that of in the LRC based on ultimate analysis as shown in Table 1.

As the results of previous study informed that NOx emission will reduce if Nitrogen content in the fuel is low [22,23]. Reduction of NOx emission will prevent of acid rain, formation of smog, and damage to plants.

Finally, SOx gas emission was also decrease with addition of CNS into the LRC. For example, adding 10% CNS into the LRC can reduce SOx emission of 16.80%, and adding 90% CNS of 80.67% with combustion temperature of 500 oC. The maximum reduction in SOx emissions was obtained at CNS addition of 90% with combustion temperature of 625 oC which is 95.57%. Some previous studies have also shown reduction of SOx gas emission by adding biomass into the LRC. An example, studies on combustion of torrefied biomass, eucalyptus pellets with bituminous and lignite coal show the decreasing of SO2 gas emission [24,25]. The reduction of SOx gas emission due to the sulfur content in the CNS is very small compared with that of in the LRC based on the ultimate analysis results as shown in Table 1. This fact will affect to decrease in slagging and fouling due to decrease of Sulfur content in the CNS and LRC mixtures.

In generally, it can be formulated that the addition of CNS to LRC has a significant impact on reducing CO2, CO, NOx, and SOx emissions.

4. CONCLUSIONS

The addition of CNS into the LRC generally improves combustion efficiency and reduces emissions of combustion gases. Combustion efficiency generally increases with the addition of CNS by 10% into the LRC vary from 0.92-14.42%. However, the addition of CNS above 30% into the LRC generally does not increases its combustion efficiency. In addition, CO2, CO, NOx, and SOx emissions are strongly influenced by chemical constituents and combustion temperatures in each co-fuel. The addition of CNS into the LRC has a significant impact on reducing CO2, CO, NOx , and SOx emissions.

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