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Combustion reactivity of low rank coal by the mixture of candlenuts shell

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Abstract. Mixture of Low-Rank Coal (LRC) with Candlenuts Shell (CNS) has been carried-out to improve the quality of combustion. The quality of combustion is affected by combustion reactivity, thermal efficiency and combustion emission. This study investigated the effect of the mixture of CNS and LRC to find-out its combustion reactivity. An experimental study has been done to investigate the combustion reactivity of mixing LRC and CNS with the addition of CNS to LRC of 10%, 30%, 50%, 70% and 90% respectively. Testing methods including proximate and ultimate analysis following ASTM Standard and sample combustion in electric furnaces were applied with a combustion temperature of 500 ^{O}C, 625^{O}C, 750 ^{O}C and 875^{O}C respectively. Oxygen was used as an oxidizer in this experiment. The result of the experimental test shows that the addition of CNS into LRC generally increased its combustion reactivity. This fact indicates that adding CNS into LRC improves significantly the combustion quality of CNS and LRC mixture. The optimum addition of CNS into LRC to increase combustion reactivity is 10%.

Keywords. Low-rank coal, Candlenuts shell, Proximate Analysis, Ultimate Analysis, combustion reactivity

1. Introduction

Combustion is a rapid reaction of fuel and air as an oxidizer. Co-combustion of Coal mixed biomass is due to improving combustion reactivity, thermal efficiency and decreasing global warming effect. Indonesia has the potential of coal resources reaching 120 billion tons and reserves of 31 billion tons. Most of them (60%) are low-rank coal (LRC), Coal which has a calorific value of <5,000-6,000 kcal/kg, moisture content (30-40%) [1] and low ignition temperature [2].The use of coal as fuel in power plants and industries is the largest contributor to the global warming effect [3].In order to improve combustion reactivity of LRC, it is necessary to mix LRC with biomass that containing high volatile matters (VM), high oxygen (O_2) and low moisture (M) content.

Recently, previous studies investigated the effect of biomass mixed with coal in order to improve the quality of coal combustion, among others: Co-firing of coal with peat showed that the ash particles of the combustion product were smoother. This fact indicates that the reactivity of combustion and combustion is almost complete with the addition of peat into LRC [4]. The study of the effects of biomass addition of wheat and wood straws mixed into coal shows the decrease of NO and CO emissions and also reduces unburned carbon (UBC) [5], NO emissions from biomass combustion mixed with LRC coal using the oxy-fuel atmosphere obtained NO emission reduction [6]. The addition of biomass (corn stalk) into the coal increases the combustion rate of the fuel mixture [7]. The investigation on co-firing of coal with biomass through Thermo gravimetric and mass spectrometric (TG-MS) testing at temperature range 150-750 ^{0}C concluded that by increasing the addition of biomass into coal resulted in increased mass reduction in combustion and this suggests that there is an increase in reactivity combustion of a mixture of biomass with coal [8]. Performance evaluation of co-firing various kinds of biomass such as wood pellet, empty fruit bunch pellet, palm kernel shell, walnut shell with LRC in a 500 MWe coal-fired power plant is obtained maximum plant efficiency this is due to the torrified so as to increase grind ability of biomass before mixed with LRC [9]. The addition of biomass peanut husk and rise husk into Changzhi coal has implications for the decrease of ash fusion temperature [10].

Based on the description it is clear that actually biomass greatly improve the quality of coal combustion. Indonesia has the potential energy from biomass waste of 32,000 MW and which has been utilized only around 1740.4 MW [1]. One of the least optimal biomass used as a fuel in improving the quality of LRC is the Candlenuts Shell (CNS). According to data from the Indonesian Bureau of Statistics 2015, Indonesia's national candlenut production is 100,700 tons[11] and from this potential is 65,700 tons of candlenut shell waste. The potential of this CNS is large enough to be used as one of the fuels that can be co-fired with LRC.

The aim of this study is to obtain the characteristic of combustion reactivity of LRC mixture with CNS on various mixed compositions and combustion temperatures performed in a conditioned electric furnace.

2. Material and Method

2.1. Material

LRC derived from Sangatta, Coal mining in East Kalimantan, Indonesia and CNS obtained from the plantation of the people in Tinambung, West Sulawesi, Indonesia. The raw materials of LRC and CNS are as shown in figure 1, and figure 2.

Figure 1. Low-Rank Coal (LRC)

Figure 2. Chandelnut Shell (CNS)

2.2. Method

The CNS sample was firstly cleansed from the inherent impurities and then dried with dry torrefaction method at 250-300 ^{O}C for 30 minutes in electric furnace [12], each of LRC and CNS sample was milled by separate crusher with particle size 40-60 mesh [13], both of them CNS samples and the LRC is mixed in the mixing machine for 30 minutes, this is intended to allow the sample mixture to be

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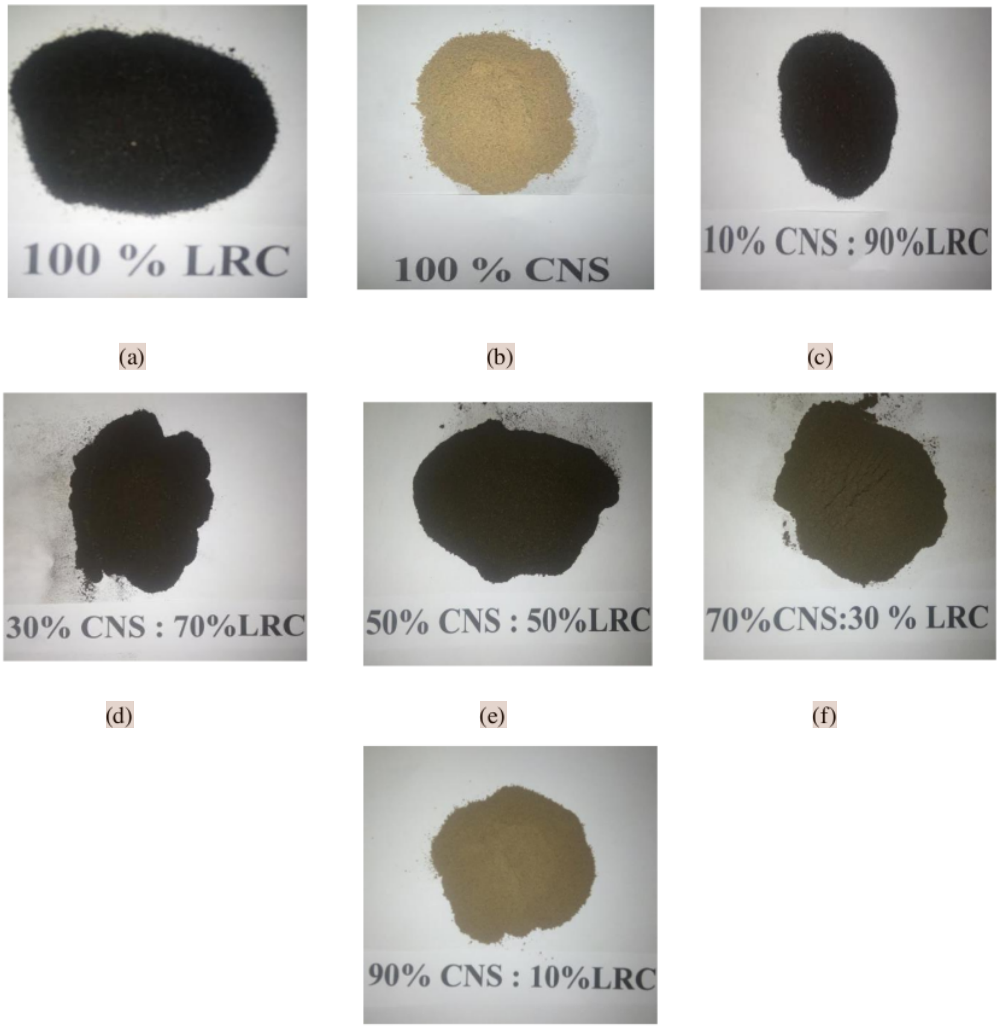
homogeneous. The composition of CNS addition to LRC was 10%, 30%, 50%, 70% and 90%, respectively by mass basis as shown in figure 3(a-g).



(g)

Figure 3(a-g), The sample of LRC, CNS and their blended.

The research method is done by experiment with the characterization of the sample consisting of Proximate Analysis to find out of thermal characteristic and Ultimate Analysis to obtain chemical characteristics, both of the measurement methods are based on the ASTM standard [14]. A 5-gram sample is placed in a cup sample suspended on a digital balance and then burned in an electric furnace by using oxygen as an oxidizer. The oxygen used in this experiment is taken from an 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 burning of each sample is carried out at temperatures: 500 ^{O}C, 625 ^{O}C, 750 ^{O}C, and

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875 ^{O}C [15]. The temperature setting is done by adjusting the flow of electricity with the electrical regulator. The test data taken decreases the sample mass to the constant mass of samples recorded on the digital balance and the flame temperature of the samples shown on the thermocouple panel. The experiment set-up of combustion as shown in figure 4.

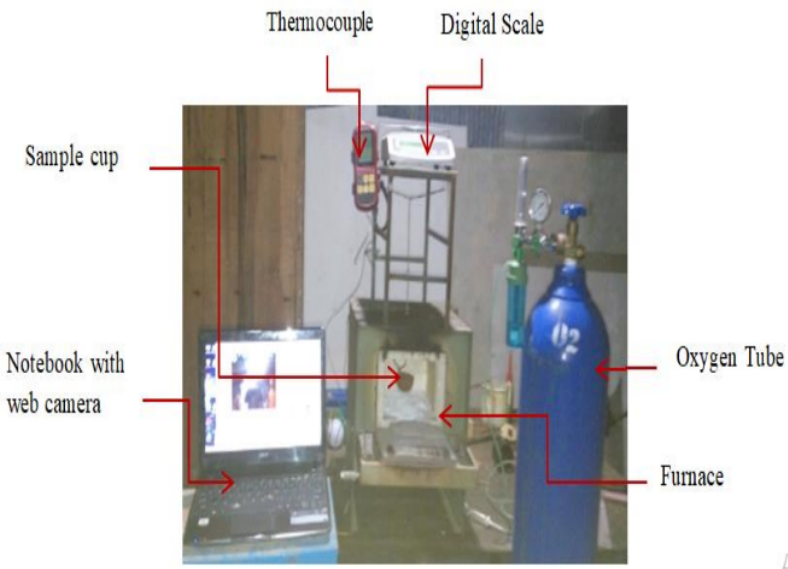

Figure 4, The experiment set-up

3. Results and discussion

3.1 The proximate and ultimate analysis

The proximate analysis is carried out to obtain thermal characteristics consisting of High Heating Value (HHV), Volatile Matters (VM), Moisture (M) Ash (A) and Fixed Carbon (FC) .The Ultimate analysis to obtain chemical characteristics consisting of Carbon C), Hydrogen (H_2), Nitrogen (N_2), Sulfur (S), and Oxygen content (O_2). Both of these tests are done following ASTM Standard. The test results are as shown in table 1.

Table 1, Proximate and Ultimate analysis

Proximate Analysis(%)adb	CNS 100%	LRC 100%	(LRC/ CNS): (90:10)%	(LRC/ CNS): (70:30)%	(LRC/C NS): (50:50)%	(LRC/ CNS): (70:30)%	(LRC/ CNS): (90:10)%	ASTM Standard
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	4936	5406	5329	5216	5187	5104	5049	D5865-12

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Ultimate Analysis (%) adb								
Carbon(C)	35,53	19,47	32,11	28,98	26,31	22,79	22,56	D5373-02
Nitrogen (N)	1,05	0,33	0,81	0,75	0,57	0,46	0,39	D5373-02
Hidrogen (H2)	9,72	15,49	10,36	11,97	13,11	14,43	14,68	D5373-02
Sulfur (S)	0,148	0,032	0,133	0,110	0,085	0,061	0,038	D 3177
Oxygen (O2)	51,17	64,21	54,64	56,64	58,59	61,18	61,80	by difference

3.2 Mass change analysis

3.2.1 The effect of composition of co-fuel on combustion behaviour

The sample mass changes are shown in figure 5(a-d).

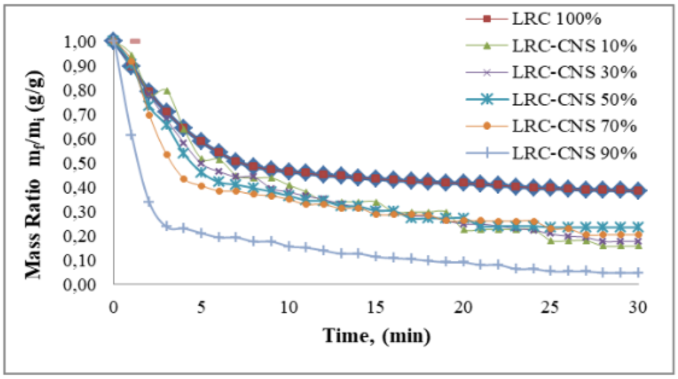

Figure 5(a), Combustion history of LRC mixed CNS at combustion temperature of 500 ^{O}C.

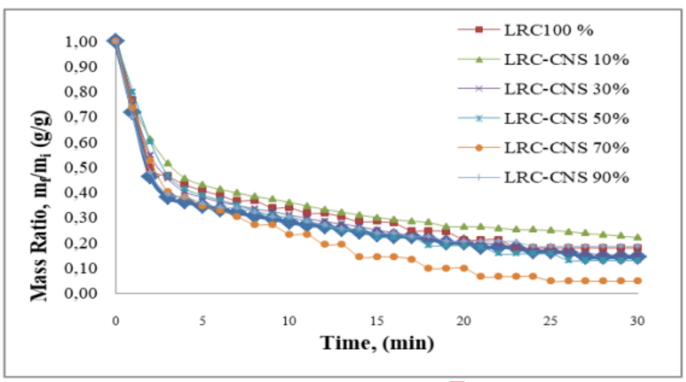

Figure 5(b), Combustion history of LRC mixed CNS at combustion temperature of 625 ^{O}C

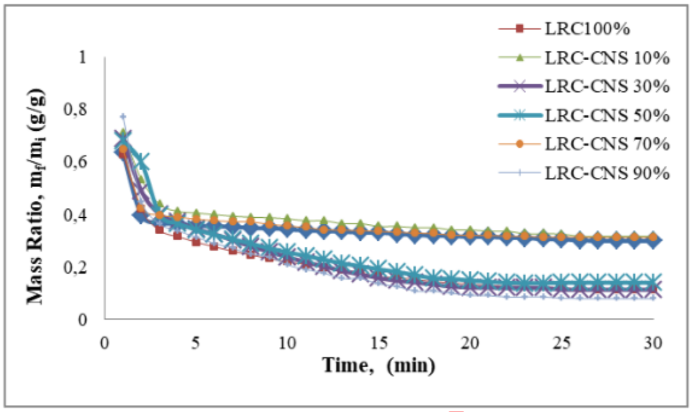

Figure 5(c), Combustion history of LRC mixed CNS at combustion temperature of 750 ^{O}C.

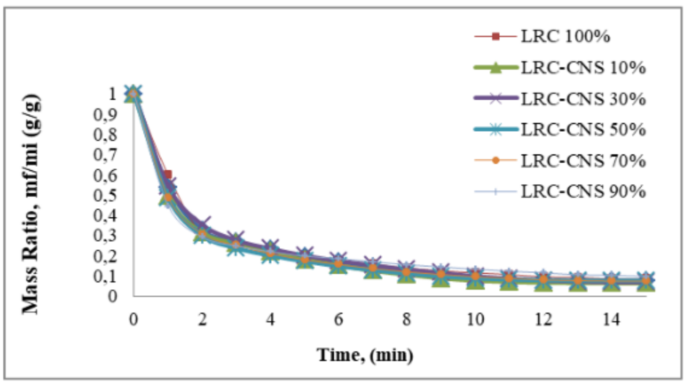

Figure 5(d), Combustion history of LRC mixed CNS at combustion temperature of 875 ^{O}C.

Based on the combustion history of LRC mixed CNS in Figure 5 (a-d) it can be seen that basically, combustion consists of two zones. They are evaporation of moisture and the devolatilization zone occurs at the beginning of combustion and continues in about 4 minutes and the charcoal burning zone that occurs thereafter. The evaporation zone and devolatization are shorter in time, compared to longer charcoal zones, depending on the Fixed Carbon content in the fuel. The addition of CNS to the LRC increases the combustion rate, but due to the smaller content of Fixed Carbon from CNS than the LRC, it has implications for the shortness of the charcoal combustion.

In general, the addition of CNS into the LRC shows a larger decrease in the ratio of mass reduction of the sample. This suggests that the implications of adding CNS to the LRC increase the reactivity of combustion. The greater the addition of CNS into the LRC results in increased reactivity of combustion. This indicator is indicated by the increasing ratio of mass reduction of the sample. Some studies of coal combustion with biomass results increasing combustion reactivity [14-19]. This fact shows that as a result of the VM, H, and O_2 content on the CNS is higher than in the LRC, and the M content on the CNS is lower than the LRC, based on proximate and ultimate analysis as presented in Table 1.

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3.2.2 Effect of Temperature on combustion behaviour

In order to find out of the impact of combustion temperature on the decrease of sample mass, it is plotted correlation between the behaviour of decreasing sample mass to the combustion of combustion temperature inside the furnace, as in figure 6(a-e).

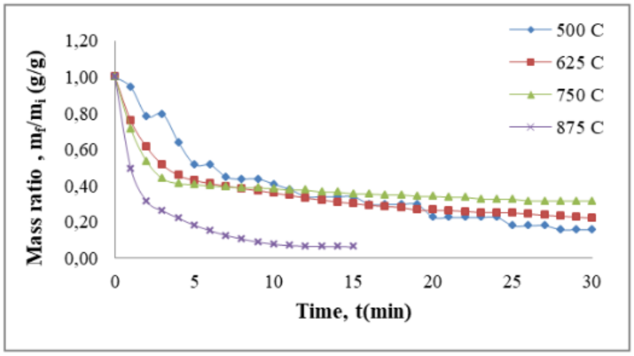

Figure 6(a), Combustion history on the addition of CNS 10%

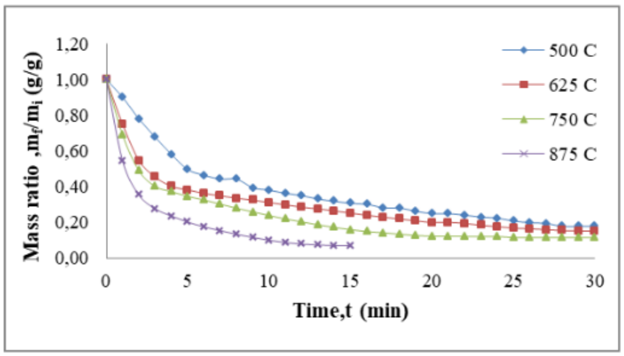

Figure 6(b), Combustion history on the addition of CNS 30%

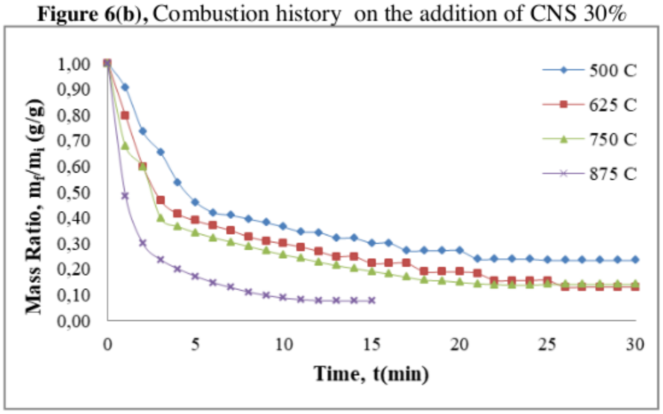

Figure 6(c), Combustion history on the addition of CNS 50%

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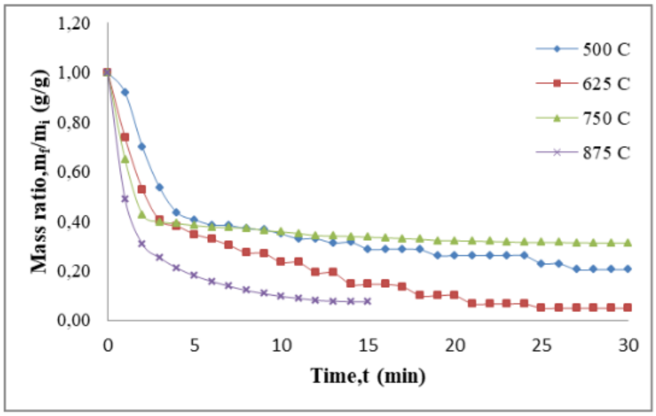

Figure 6(d), Combustion history on the addition of CNS 70%

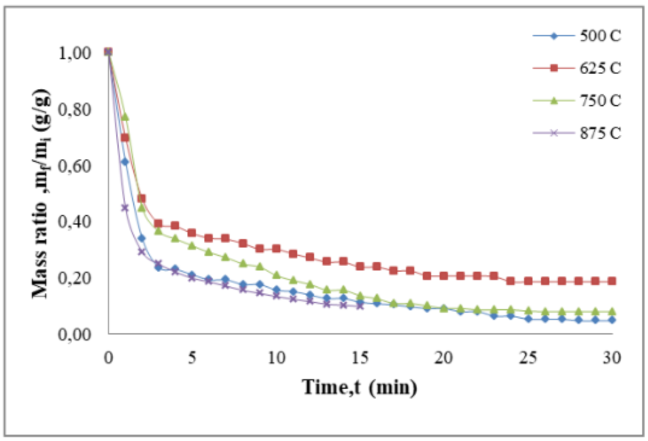

Figure 6(e), Combustion history on the addition of CNS 90%

Based on the behaviour of the mass decrease to the combustion temperature inside the furnace then the following is obtained. The higher sample combustion temperature resulted in a larger decrease in sample mass ratio indicated the higher the reactivity of the combustion. As a comparison of the effects of biomass type i.e. Japanese cedar, rice straw, and seaweed, the performance of LRC has a significantly impact on co-gasification, either at high combustion temperatures even at low combustion temperatures [18].

3.2.3 Reactivity of combustion

The reactivity of combustion based on maximum average of loss mass and the initial weight of sample according to the formula below [19]

$$R = \left(\frac{-1}{W_o}\right)(dW/dt) \quad (1)$$

Where (dW/dt) the maximum average of mass loss, and W_o is the initial mass of sample (g).

The results of the reactivity calculation of sample combustion are presented in figure 7(a-d).

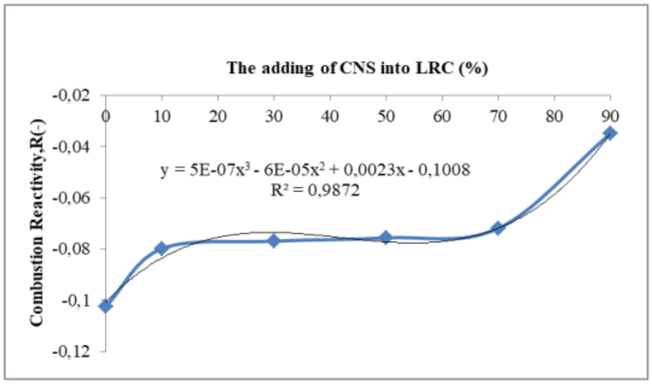

Figure 7(a), The combustion reactivity of the sample at combustion temperature of 500^{O}C

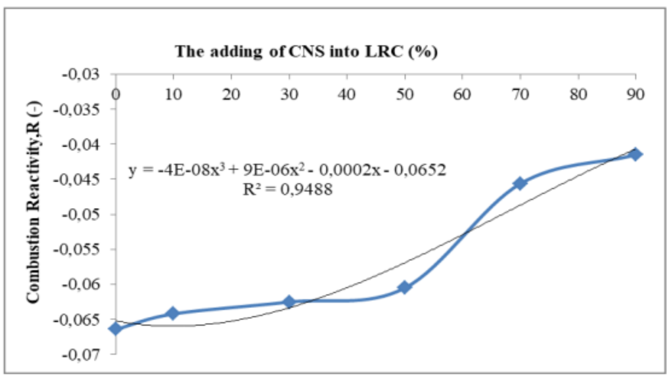

Figure 7(b), The combustion reactivity of the sample at combustion temperature of 625^{O}C

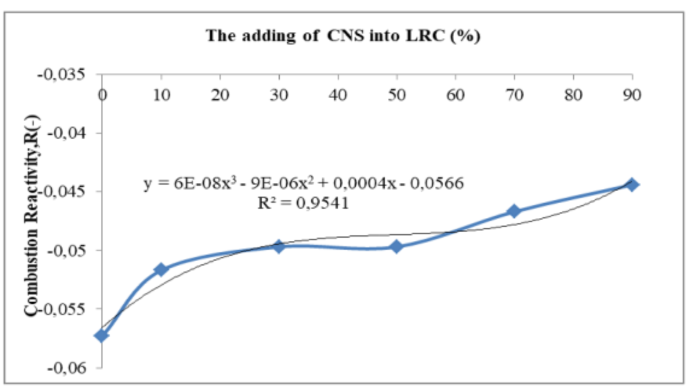

Figure 7(c), The combustion reactivity of the sample at combustion temperature of 750 ^{O}C

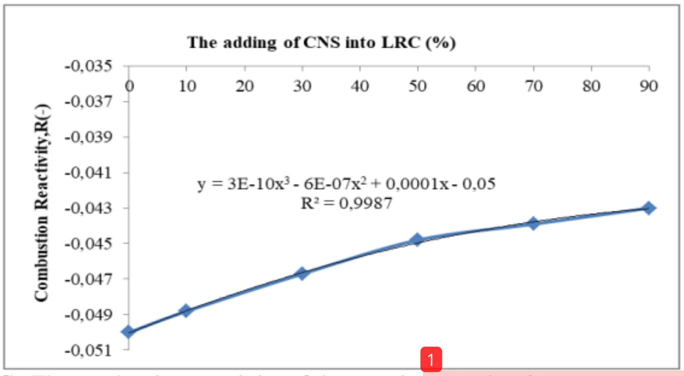

Figure 7(d), The combustion reactivity of the sample at combustion temperature of 875 ^{O}C

Based on the results of the calculation of combustion reactivity presented in Figure 7 (a-d), the increasing of CNS added into the LRC results in increased combustion reactivity. It can be presented based on the correlation equation between the addition of CNS into the LRC to the combustion reactivity number following the equation of the power three polynomials, as presented in figure 7 (a-d) From the results of combustion reactivity, a significant increase in combustion reactivity is obtained by adding 10% CNS.

4. Conclusions

Based on the results of the combustion experiment as an impact of the co-firing of LRC with CNS then it can be concluded as follows:

1. Addition of CNS into the LRC shows an increase in the rate of loss sample mass, indicating that there is a significant increase in reactivity of combustion.
2. Increased sample combustions temperatures have implications for increased reactivity of combustion
3. The optimum of CNS added into LRC is obtained at 10%.

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