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Research Article

EFFECT OF CHANGES IN COAL COMPOSITION ON AIR FUEL RATIO IN CFB BOILER

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ABSTRACT

This study focuses on the combustion process of coal in a Circulating Fluidized Bed (CFB) boiler, emphasizing the crucial role of the oxidation reaction between coal and combustion air. The design of the CFB boiler is meticulously conducted, incorporating calculations for fuel requirements, combustion values, air, and limestone demands, as well as addressing parameters such as combustion gases, solid waste production, fluidization speed, combustion efficiency, and boiler efficiency. To generate 75 tons/hour of steam, the optimized coal flow rate is determined to be 3.82 kg/s, utilizing coal particles with a size of 6 mm. The combustion process necessitates an air supply of 46.34 kg/s at a temperature of 130°C, with a fluidization velocity of 4.23 kg/s. The resulting gas flow rate from the combustion process is 50.14 kg/s, reaching a temperature of 1099.76°C. The ash flow rate is calculated to be 0.38 kg/s. The designed combustion process demonstrates impressive efficiency levels, with a combustion efficiency of 95%, and a boiler efficiency of 89%. These findings contribute to the understanding and optimization of CFB boiler systems, offering insights into efficient energy production from coal combustion.

Keywords: air, circulating fluidized bed boiler, coal, fuel, limestone.

INTRODUCTION

The coal combustion process in CFB boilers occurs due to the oxidation reaction between coal and combustion air that utilizes the initial combustion heat of the bed material. Parameters that affect combustion quality are coal composition, coal flow rate, coal particle size, air flow rate, air velocity and air temperature. A good combustion process will result in high combustion efficiency, while a poor combustion process will result in the oxidation of some of the carbon which produces toxic carbon monoxide. The process of burning coal will also have an impact on the quality of steam produced by the boiler. A poor combustion process will produce steam with poor quality as well. The purpose of this research is to analyze the effect of changes in coal composition on the Air Fuel Ratio, by paying attention to the calculation of the fuel required and the temperature of the combustion gas.Many studies have developed CFB technology. Research on CFB technology with lower energy consumption by redefining fluidization and lowering CFB combustion emissions to meet emission regulatory requirements [1]. Comprehensive CFD combustion model for 350 MW scale supercritical CFB boiler [2-4]. Biomass-fired fluidized bed (CFB) circulation boiler technology can reduce bed agglomeration, improve boiler efficiency, slagging on heating surfaces, and reduce NO_x emissions [5]. Denitrification transformation in 75 tons/hour capacity CFB boiler can reduce NO_x emission from about 220 mg/m3 to 180 mg/m3 [6]. Fluidized Bed Boiler (CFB) technology, developed to reduce NO_x emissions, is environmentally friendly [7-10].

LITERATURE REVIEW

Fuidized bed combustion

Fluidized bed combustion is one of the combustion systems in boilers that use bed material in the form of quartz sand in the process of burning coal, then the bed material is blown air so that fluidization occurs. Boiler types that apply fluidized bed combustion are bubbling fluidized bed (BFB) and circulating fluidized bed (CFB).

Circulating fluidized bed boiler

Circulating fluidized bed boiler (CFB) is the second generation of fluidized bed boiler, which is the latest version of bubbling fluidized bed boiler (BFB). Circulating means the circulation of unburned coal from the combustion chamber to the cyclone and then back into the combustion chamber. Fluidized means blowing primary air to keep the bed material and coal floating in the combustion chamber. Bed is a material in the form of quartz sand which is used as an initial medium for heat transfer from burning.

Coal combustion process

The process of burning coal occurs through several stages, namely: first heating and drying, devolatilization, volatile combustion, primary fragments, secondary fragments, charcoal combustion (Figure 1)

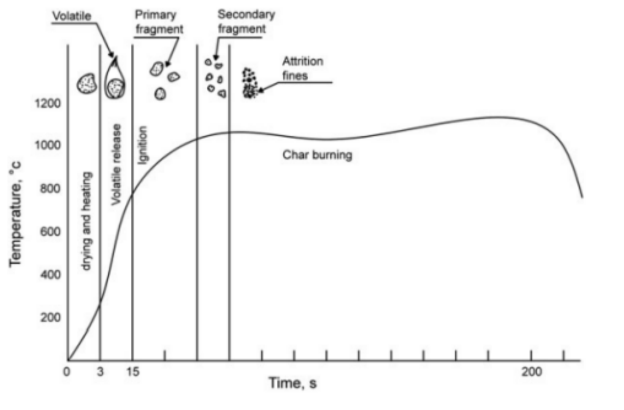

Figure 1 Coal combustion process [11]

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METHODS

The combustion process of coal in CFB boilers is carried out to produce complete combustion of coal by taking into account air parameters, fuel composition and combustion output in the form of solid waste and flue gas [12]. The calculation method of the combustion process includes the following parameters.

Fuel rrequirement

Fuel combustion requirements are the amount of fuel required for each unit of time in the combustion process for the steam generation process under the desired conditions.

Table 1: Comparison of PC and CFB boiler

		CFB (%)	
Items	**PC**	**Optimistic**	**Pessimistic**
Moisture in limestone	-	0.06	0.10
Calcination	-	1.02	1.69
Sulfation credit	-	-1.60	-1.60
Unborned carbon	0.25	0.50	2.00
Heat in dry flue gas	5.28	5.57	5.60
Moisture in fuel	1.03	1.03	1.03
Moisture from H2 burning	4.16	4.19	4.19
Radiation and convection	0.03	0.30	0.80
Moisture in air	0.13	0.14	0.14
Sensible heat in boiler ash	0.03	0.09	0.76
Bottom ash	0.05	-	-
Fan power credit	-0.25	-0.75	-0.40
Pulverized credit	-0.20	-	-
Total loss	**10.81**	**10.55**	**14.31**

It is assumed that the losses that occur in the boiler are an optimistic state of 10.55%, so that the maximum efficiency of the CFB boiler is 89.45%, then the fuel requirement can be calculated using the following equation [13]:

$$\dot{m}_c = \frac{\dot{m}_s \times (h_s - h_f)}{HHV \times \eta_b} \quad (1)$$

Fuel calorific value

Calorific value is the amount of energy that can be produced in the combustion process per unit mass of fuelder to form a perfectly homogeneous solution. Prepare six samples each from each variation of the solution

High heating value (HHV)

The upper combustion value is the combustion that produces liquid-phase $H_2O_2O_{.222}$

$$HHV = 33823 \times C + 144249 \times (H - O/8) + 9418 \times S \quad (2)$$

Lower heating value (LHV)

The lower combustion value is the combustion that produces vapor-phase H_2O.

$$LHV = HHV - 22604\, H - 2581\, M_f \quad (3)$$

Air requirement

Air demand is the amount of air required for complete combustion of coal based on the chemical content in the coal.

$$\dot{m}_{air} = \dot{m}_c \times \left[\left(11.53 \times C + 34.34 \times \left(H - \frac{O}{8}\right) + 4.34 \times S\right) \times EAC\right] \quad (4)$$

Air Fuel Ratio

Air Fuel Ratio (AFR) is the ratio between the combustion air flow rate and the fuel flow rate.

$$AFR = \frac{\dot{m}_{air}}{\dot{m}_c} \quad (5)$$

Air velocity

The combustion air velocity in the combustion chamber is asfollows:

$$v = \frac{\dot{m}_a}{A_{bed} \times \rho_a} \quad (6)$$

Combustion gases

Combustion gases consist of Nitrogen, water vapor, carbon dioxide, sulfur dioxide, oxygen and fly ash.

$$\dot{m}_g = \dot{m}_c \times N_2 + H_2O + CO_2 + SO_2 + O_2 + fly\ ash \quad (7)$$

$$N_2 = N + 0,768 \times M_a \quad (8)$$

$$H_2O = 9 \times H + M_a \times X_m + M_f \quad (9)$$

$$CO_2 = 3,66 \times C \quad (10)$$

$$SO_2 = 2 \times S \quad (11)$$

$$O_2 = O + 0,2315 \times M_a \times (EAC - 1) \quad (12)$$

$$Fly\ ash = ac \times ASH \quad (13)$$

Force Dragmbar 2.3 Force balance on a particle moving in an upward gas strea When a fluid flows over a stationary or moving particle with a velocity higher than the velocity of the upward-moving particle, the particle experiences upward fluid drag, as well as being subjected to buoyancy and downward gravitational forces. Buoyancy force and fluid resistance oppose the effects of gravity.

$$\dot{m}_c \times g = \dot{m}_c \times \frac{\rho_a \times g}{\rho_c} + C_D \times \frac{6 \times (v - U_s)^2 \rho_a}{8 d_c} \quad (14)$$

Combustion efficiency

Combustion efficiency in boilers is the ability of the burner to burn all the fuel that enters the combustion chamber.

$$\eta_c = \frac{\dot{m}_g \times C_p \times \Delta T}{\dot{m}_c \times HHV} \quad (15)$$

Boiler Efficiency

Boiler efficiency is a quantity that shows the relationship between the supply of energy into the boiler and the output energy produced by the boiler:

$$\eta_b = \frac{\dot{m}_s \times (h_s - h_f)}{HHV \times \dot{m}_c} \quad (16)$$

The combustion process

The combustion process in the CFB boiler combustion chamber is carried out using Lignite type coal with the following composition:

Table 2: Coal ccomposition

Ultimate Analysis (%)	
Carbon Content	41.4
Hydrogen Content	3.2
Oxygen Content	13.6
Sulfur Content	0.1
Nitrogen Content	0.6
Ash Content	5.1
Moisture Content	35.9
Total	**100**

The boiler used as the object of design is the boiler of PLTU Surge with a steam generation capacity of 75 tons/h. The parameters used are as follows:

Table 3: Boiler operating parameters existing

Parameter	Value	unit
Combustion air temperature	130	°C
Combustion air pressure	1,3	Bar
Feed water temperature	10	°C
Feed water pressure	66.7	Bar
Feed water enthalpy	634.7	kJ/kg
Main steam flow rate	75	T/h
Main steam temperature	485	°C
Main steam pressure	48	Bar
Enthalphy of main steam	3392	kJ/kg

Simulation

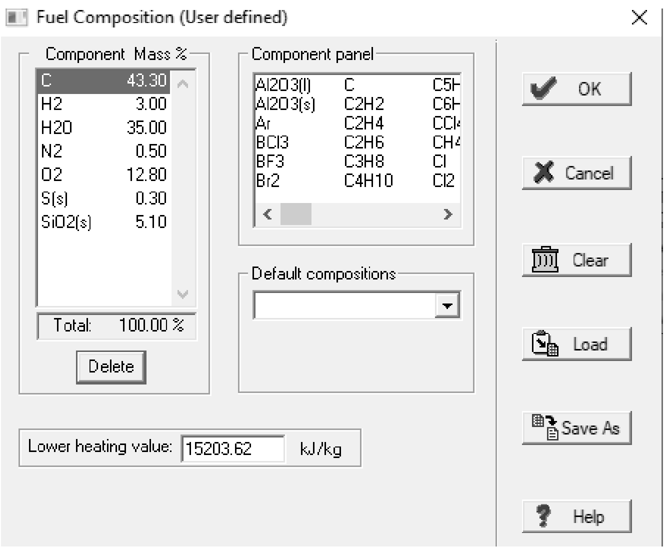

Figure 2 Coal composition input process in the application

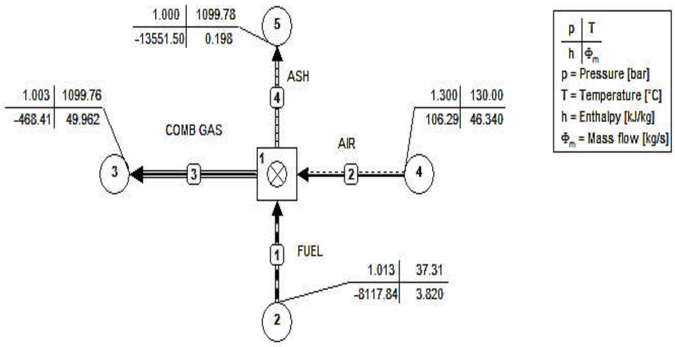

Figure 3 Coal combustion process

Based on the coal combustion process using application, the combustion gas temperature is obtained at 1099.76 °C.

RESULTS AND DISCUSSION

The results of the calculation process using equations 1-16 are tabulated in Table 4.

Table 4: Parameter calculation result

Parameter	Value	unit
Fuel flow rate	3.82	kg/s
HHV of fuel	16803.8	kJ/kg
Fuel LHV	15203.6	kJ/kg
Fuel particle size	6	Mm
Air flow rate	46.34	kg/s
Air temperature	130	°C
Fluidization velocity	4.23	m/s
Air Fuel Ratio	12.13	kg/kg
Combustion gas flow rate	50.15	kg/s
Combustion gas temperature	1099.76	°C
Combustion efficiency	95	%
Boiler efficiency	89	%

The results of the design of the coal combustion process are able to meet the design criteria, where the fluidization speed of the design results is obtained at 4.23 m/s while the standard is 4-6 m/s. AFR design results obtained amounted to 12.13 kg / kg while the standard value is 11.5 kg / kg.

Table 5: Comparison of calculated parameters with existing ones

Parameter	Existing	Calculation	Unit
Fuel flow rate	4.3	3.82	kg/s
Air flow rate	48.2	46.06	kg/s
Air Fuel Ratio	11.21	12.13	kg/kg
Combustion efficiency	92	95	%
Boiler efficiency	81	89	%

Based on the table, by designing the coal combustion process, the coal consumption can be reduced from 4.3 kg/s to 3.82 kg/s. A decrease in coal consumption will result in a decrease in energy consumption. The decrease in energy consumption results in an increase in boiler efficiency and combustion efficiency [14-16].

Effect of changes in coal composition on fuel requirements

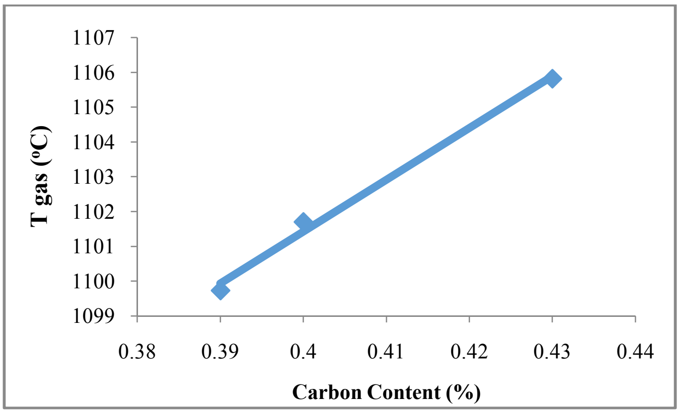

Figure 4 Coal carbon content against combustion gas temperature

Based on the graph in Figure 4, it can be seen that the higher the carbon content in coal, the higher the combustion gas temperature will be. This happens because the highercarbon content, it will produce more CO_2 so that the heat generated from the combustion process will be higher, so that the temperature of the combustion gas will be higher.

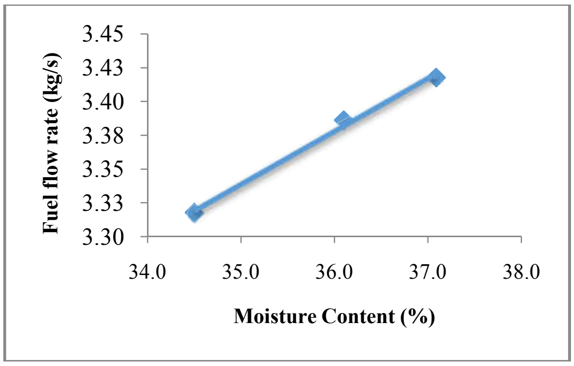

Figure 5 Coal Moisture Content against Fuel Flow Rate

Based on the graph in Figure 5, it can be seen that the higher the moisture content in coal, the higher the coal required for the combustion process. This happens because high moisture content consumes higher heat, where the heat of combustion will be used first to evaporate the moisture or water content in the coal before finally burning the coal, so the coal needed will be more.

Effect of Changes in Coal Composition on AFR

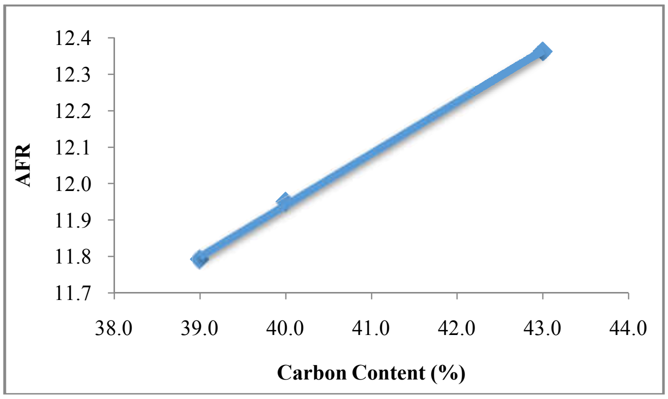

Figure 6 coal carbon content against AFR

Based on the graph of coal carbon content against AFR, it can be seen that the greater the carbon content in coal, the AFR required for the combustion process will be greater. This happens because the higher the carbon value in coal, the higher the oxygen required for the combustion process, so the air requirement will be higher [17-18].

Effect of changes in coal composition on combustion gas temperature

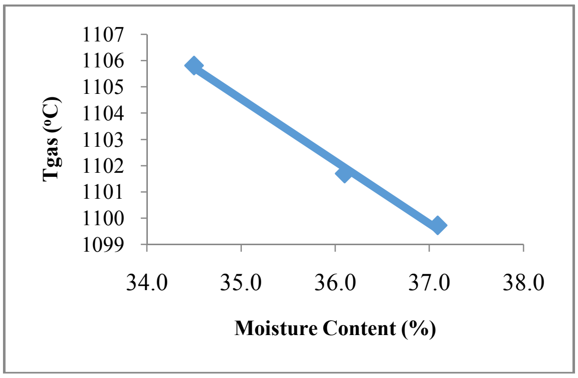

Figure 7 Coal moisture content against combustion gas temperature

Based on the graph, it can be seen that the higher the moisture content in coal, the lower the combustion gas temperature. This happens because the heat of fuel combustion is first used to evaporate the water content in the fuel before burning the fuel, so that the high moisture content in the fuel will make the combustion gas temperature lower.

CONCLUSION

In conclusion, the analysis of the coal combustion process in the Circulating Fluidized Bed (CFB) boiler, designed for a steam generation capacity of 75 tons/h, yields valuable insights into the optimal utilization of lignite-type coal. The key findings are summarized as follows:

1. For the specified steam generation capacity, the combustion process efficiently utilizes lignite coal with a particle size of 6 mm and a Higher Heating Value (HHV) of 16803.8 kJ/kg. The calculated coal flow rate is 3.82 kg/s, maintaining an Air Fuel Ratio (AFR) of 12.13 kg/kg. The combustion air flow rate is determined to be 46.34 kg/s, ensuring an excess air coefficient of 2.2 relative to the theoretical air demand. The fluidization velocity during combustion is optimized at 4.23 m/s. The resulting combustion gas rate is 50.14 kg/s, attaining a temperature of 1099.76 °C.
2. Variation in coal carbon content demonstrates distinct coal consumption requirements and AFR values. Specifically, coal with a carbon content of 39% demands 3.42 kg/s, requiring an AFR of 11.8 kg/kg. Similarly, coal with carbon contents of 40% and 43% necessitates 3.39 kg/s and 3.32 kg/s, respectively, with corresponding AFR values of 12 kg/kg and 12.4 kg/kg. The associated combustion gas temperatures range from 1099.73 °C to 1105.8 °C.

These conclusive outcomes contribute to the comprehensive understanding of coal combustion processes in CFB boilers, providing valuable data for the efficient and sustainable utilization of lignite coal in large-scale steam generation applications. The insights obtained from this study have implications for optimizing combustion conditions, enhancing energy efficiency, and minimizing environmental impact in similar industrial settings.

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NOMENCLATURE

ac : ash fraction, %
Ash : Amount of coal ash, mg
Cp : Heat capacity, kj/kg °C
g : Gravitational constant, m/s²
h_s , h_f : Enthalpy of steam, enthalpy of liquid, kJ/kg
$\dot{m}_c$: Mass of fuel, kg/s
$\dot{m}_g$: Mass of gas, kg/s
$\dot{m}_s$: Mass of steam, kg/s
M_a : Theoretical dry air mass, kg/kg$_f$
M_f : Coal moisture, kg/kg$_f$
NO_x : emission concentration, mg/Nm³
P : Pressure, bar
R : Constant of the perfect gas, L·bar·K⁻¹·mol⁻¹
t_s : Combustion period, s
t_{max} : Maximum combustion period, s
ΔT : Temperature different, °C
V : Furnace volume, m³
X_m : moisture fraction, %

Greek
ρ : Density, kg/m³
η_b : Efficiency of boiler, %
η_c : Efficiency of combution, %

Subscripts:

c : Coal
e : Exhausts
f : fuel

Abbreviation

AFR : Air Fuel Ratio
CFB : Circulating Fluidized Bed
CFD : Computational Fluid Dynamics
ECA : Excess Air Coefficient
HHV : High heating value, kJ/kg
LHV : Lower heating value, kJ/kg

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