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Jyoti Prakash Kar
National Institute of Technology Rourkela, Odisha, India

Sakdillah, M.M
Kampus Gunung Kelua Jln. Sambaliung No.9 Samarinda 75119, Indonesia

Tommy Trides, S.T., M.T
Kampus Gunung Kelua Jln. Sambaliung No.9 Samarinda 75119, Indonesia

Correspondence:
Sakdillah, M.M
Kampus Gunung Kelua Jln. Sambaliung No.9 Samarinda 75119, Indonesia

Study of Coal Water Fuel Ratio (AFR) Using Stoikiometry Method in PT. TARA in Kutai Kartanegara District of East Kalimantan Province in Indonesia.

Sakdillah, M.M, Tommy Trides, S.T., M.T

Abstract
Air Fuel Ratio (AFR) is the ratio of the amount of air and fuel in the combustion process in units of mass or volume. In this study, Air Fuel Ratio (AFR) stoichiometry measured by calculating the amount of substance, chemical reaction equivalence, and air mass required in the combustion process of coal. Research data obtained by proximate analysis, namely inherent moisture, ash content, volatile matter, and fixed carbon. Ultimate analysis consist of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). Data processing of this study based on each basis of coal analysis report, namely as received, air dried, dry, and dry ash free. AFR stoichiometry analysis is carried by calculating the amount of substances for each element, chemical reaction equivalence, and calculating the amount of combustion oxygen. Because the AFR analysis of this study used mass units, the calculation of the amount of air mass and the AFR value is based on the basis and chemical reaction. The results of this study showed that the type of coal based on proximate and ultimate analysis was lignite coal. The results of chemical reactions consist of $CHS+O_2$ and $CHONS+O_2$ which affect the AFR value due to the difference in the amount of oxygen in the chemical reaction equivalence. The air fuel ratio (AFR) value of $CHS+O_2$ and $CHONS+O_2$ as received basis 5.42 and 3.42, air dried basis 6.49 and 4.95, dry basis 8.09 and 7.23, dry ash free base 9.71 and 8.67.

Keywords: Air Fuel Ratio (AFR), Proximate, Stoichiometry, Ultimate

Introduction

Coal is one of the main fuels in PLTU (Pembangkit Listrik Tenaga Uap or if we translate in engglish may be Electric steam power plant) in Indonesia. Coal analysis is needed to determine the quality of coal that can be used in the PLTU or outside the PLTU design range (Samlawi, 2017). Coal burning at the PLTU requires an actual and theoretical analysis in order to produce maximum energy in the energy conversion process at the PLTU. Stoichiometry is closely related to chemical reactions, such as relative atomic mass, relative molecular mass, molar mass, and so on. Stoichiometry can be used to calculate the amount of air required for burning coal. Stoichiometric combustion calculation analysis is carried out first before the actual combustion occurs, because it affects the recommended air ratio. based on the quality of the coal used. The ratio of air and fuel that is not in accordance with the recommendations will affect the perfection of combustion.

Combustion that is not perfect will have an impact on the energy produced will not be maximal. Air Fuel Ratio (AFR) is the ratio of air and fuel. Actual AFR is obtained by testing combustion reactions that actually occur, while stoichiometric AFR is obtained by calculating combustion chemical reactions (Widodo et al., 2014). This research was conducted to determine the ratio of air and fuel (Air Fuel Ratio) with the method of stoichiometric calculations so that it can be used as a recommendation for burning coal.

Theoretical Basis

Coal is a very complex mixture of organic chemicals containing carbon, oxygen and hydrogen in a carbon chain. According to Law No. 4 of 2009 regarding minerals and coal,

coal is a sediment of organic carbon compounds that are naturally formed from plant residues and can burn (Arif, 2014).

Coal classification is a grouping based on the characteristics of coal, such as the type of coal, the carbon-hydrogen ratio, flying substances, and others (Speight, 2005). According to Sukandarrumidi (2008), based on PP (PP is Peraturan Pemerintah or if we translate in engglish Regulation From Goverment) No,45 of 2003 which was renewed by PP.No.9 of 2012 concerning Fee on Types of Non-Tax State Revenues that apply to the mining and energy department in the general mining sector states that the classification of coal in Indonesia is divided into four types:

Table 1: Classification of coal according to SNI (Sukandarrumidi, 2008)

CLASS	Calorie Value, KCal / Kg
Low	≤ 5100
Midle/Medium	5100 - 6100
High	6100 - 7100
Very High	≥ 7100

Coal quality is a chemical and physical characteristic of coal that affects its function. Coal analysis is reported by proximate and ultimate analysis (Thomas, 2013). Proximate analysis of coal is testing for moisture, ash, volatile matter, and fixed carbon with a series of standard testing methods. (Speight, 2005). Ultimate analysis is an analysis performed to determine the percentage by weight of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). The carbon determination in the test includes organic carbon and carbonate minerals. Hydrogen determination includes hydrogen present in organic matter and hydrogen in the moisture content of coal (Speight, 2005).Stoichiometry is the study of quantitative relationships of reagents and reaction products in chemical reactions. The units given for both the reagent and the reaction product are moles, grams and liters (for gas). Moles are used to calculate the number of reaction products formed in a chemical reaction. The coefficient in a chemical reaction is the same as the number of moles of each element in a chemical reaction (Chang, 2010).

$$mol = \frac{mass\ (gram)}{Mr\ or\ Ar} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

A chemical reaction is the process of changing an element or compound into one or more new compounds. Chemical formulas use chemical symbols to denote a chemical reaction process. Chemical equilibrium occurs when the rates of forward and reverse reactions are equal and the concentrations of reactants and products no longer change over time. Physical equilibrium is the equilibrium between two phases of the same substance (Chang, 2005).

Coal Combustion Reaction:

4CHONS + 7 (O2 + N2) ◊ 4CO2 + 2H2O + 4SO2 + 9N2…. ………………………………….… ……….2

Elemen of Coal Combustion Reaction:

$C + O_2 \rightarrow CO2$..3

$2H + 0,5\ O_2 \rightarrow H_2O$...4

$S + O_2 \rightarrow SO2$...5

Combustion is a chemical reaction that occurs between combustible material and oxygen at a certain volume and temperature. The elements in fuel that can form a combustion reaction with oxygen are carbon, hydrogen, and sulfur (Samlawi, 2017). Air fuel ratio (AFR) is the ratio of the amount of air to fuel in mass or volume (Widodo et al., 2014). The actual AFR is obtained from the ratio of the air mass and the mass of the fuel needed (Darise and Djafar, 2018). Stoichiometric AFR is obtained from the amount of atomic balance in a Combustion reaction (Widodo et al, 2014). Air mass calculations are performed before calculating the AFR value using the total moles of oxygen, the amount of oxygen in the air, and the molar mass of air. The stoichiometric AFR and actual AFR values are calculated using the same formula, namely the mass of air and mass of fuel at combustion. The formula for calculating the AFR value is as follows:

$$Air\text{-}Mass = mol\ O_2 \times \frac{100\%\ Air\ mole}{21\%\ OXYGEN\ mol} \times Air\ molar\ mass \ldots 6$$

$$AFR = \frac{Air\ Mass}{Mass\ of\ fuel} \ldots\ldots\ldots\ldots\ldots\ldots 7$$

Methodology

Introductory stage

The preliminary stage carried out in this research is a literature study conducted as a starting point for determining the concept and research design. Through this activity, the necessary data were obtained from various references regarding the study of coal Air Fuel Ratio (AFR) using the stoichiometric method.

Data Collection Stage

The data collection stage carried out in this study were:

1. Sample Preparation

Sample preparation is the preparation of samples in such a way that they become samples that are ready to be tested and analyzed. The standard used is ASTM.

2. Proximate Analysis

Proximate analysis is performed to determine moisture, ash content, volatile matter, fixed carbon, and calorific value in coal. The standard used in this study is ASTM.

3. Ultimate Analysis

The ultimate analysis was conducted to determine the percentage of carbon, hydrogen, oxygen, nitrogen and sulfur in coal. The standard used in this study is ASTM.

4. Secondary Data

Secondary data in this study include the percentage of oxygen in the air, the molar mass of air, and the relative atomic mass (Ar).

Discussion and Analysis Stage

At the data discussion stage, data processing is carried out, namely:

1. Analysis of the amount of elemental coal.
2. Analysis of the combustion reaction.
3. Analyze the amount of combustion oxygen
4. Air fuel ratio analysis.

Results and Discussion

Proximate Analysis

Proximate analysis was performed after sample preparation using ASTM standards for determination: *moisture*, *volatile matter*, *ash content*, and *fixed carbon*

Table 2 Results of the proximate analysis

	As Received	Air Dried	Dry	Dry Ash Free
IM (%)	16,49	19,74	-	-
Ash (%)	11,18	13,39	16,68	-
VM (%)	32,47	38,88	48,44	58,14
FC (%)	23,38	27,99	34,87	41,86

The results of each parameter on a different basis can be obtained by conversion, because in general proximate analysis uses an air dried basis. Other basis conversion calculations are as follows.

$$IM_{(ar)} = IM_{ad} \times \frac{100-M_{ar}}{100-M_{ad}}$$
$$= 19,74 \times \frac{100-32,97}{100-19,74}$$
$$= 16,49\ \%$$

$$Ash_{(ar)} = Ash_{ad} \times \frac{100-M_{ar}}{100-M_{ad}}$$
$$= 13,39 \times \frac{100-32,97}{100-19,74}$$
$$= 11,18\ \%$$

$$VM_{(ar)} = VM_{ad} \times \frac{100-M_{ar}}{100-M_{ad}}$$
$$= 38,88 \times \frac{100-32,97}{100-19,74}$$
$$= 32,47\ \%$$

$$FC_{(ar)} = FC_{ad} \times \frac{100-M_{ar}}{100-M_{ad}}$$
$$= 27,99 \times \frac{100-32,97}{100-19,74}$$
$$= 23,38\ \%$$

Coal classification can be seen by comparing the value of each test parameter with coal classification according to SNI, ASTM, and the value of proximate analysis according to Speight (2005).

Table 3 Results of proximate analysis based on Speight (2005) and research data.

	Lignite	Subbituminous	Air Dried
IM (%)	25 - 45	10 - 25	19,74
Ash (%)	3 - 15	3 - 10	13,39
VM (%)	24 - 32	28 - 45	38,88
FC (%)	25 - 30	30 - 57	27,99

Coal classification according to SNI and ASTM uses the calorific value for low rank coal. In the preliminary report data, the calorific value of coal for the as received basis is 4237 kcal / kg, while the classification based on ASTM uses the unit btu / lb, for this reason conversion is required with the following calculations.

1 kcal = 3,96567 btu
1 kg = 2,20462 lb

$$1\ \text{kcal/kg} = \frac{3,96567\ btu}{2,20462\ lb} = 1,7655\ \text{btu/lb}$$
$$4237\ \text{kcal/kg} \times 1,7655\ \text{btu/lb} = 7480,42\ \text{btu/lb}$$

The results of the proximate analysis based on air dried based on Speight (2005) are included in the lignite category. The calorific value of 4237 kcal / kg based on SNI includes low calorie coal (lignite) and a calorific value of 7480.42 btu / lb based on ASTM including lignite A coal, so it can be concluded based on the results of proximate analysis and the calorific value of coal used for air fuel ratio analysis (AFR) belongs to the lignite type.

Ultimate Analysis

Ultimate analysis is carried out to determine carbon, hydrogen, oxygen, nitrogen and sulfur. The oxygen analysis in the ultimate test was carried out by subtracting the total percentage of ash, carbon, hydrogen, nitrogen and sulfur, for a total of 100 percent.

Table 4. Results of ultimate analysis.

	As Received	Air Dried	Dry	Dry Ash Free
Karbon (%)	38,09	45,61	56,83	68,21
Hidrogen (%)	3,01	3,60	4,49	5,38
Nitrogen (%)	1,11	1,33	1,66	1,99
Sulfur (%)	0,20	0,24	0,30	0,36

Coal classification can be seen by comparing the value of each test parameter with the ultimate analysis value according to Speight (2005).

Table 5 Results of ultimate analysis based on Speight (2005) and research data.

	Lignite	Subbituminous	Air Dried
Karbon (%)	35 - 45	55 - 70	45,61
Hidrogen (%)	6 - 7,5	5,5 - 6,5	3,60
Oksigen (%)	38 - 48	15 - 30	35,83
Nitrogen (%)	0,6 - 1	0,8 - 1,5	1,33
Sulfur (%)	0,3 - 2,5	0,3 - 1,5	0,24

In the ultimate analysis, the coal classification of this study was determined on the basis of air dried as in proximate analysis. Based on the value of each parameter, the coal used is included in lignite because the values of carbon, oxygen and sulfur are included in the lignite category.

Stoichiometric Analysis

Stoichiometric analysis on coal is carried out by calculating the amount of substance for each element and the equality of the combustion reaction of the element with oxygen. To calculate the amount of elemental substances used the value of the elemental mass and relative atomic mass (Ar).

Table 6. The amount of coal elemental substances

	As Received	Air Dried	Dry	Dry Ash Free
mol Carbon	3,174	3,801	4,736	5,684
mol Hidrogen	3,01	3,6	4,49	5,38
mol Oksigen	2,901	2,239	1,253	1,504
mol Nitrogen	0,079	0,095	0,119	0,142
mol Sulfur	0,006	0,008	0,009	0,011

The coal combustion reaction can be determined by equalizing the chemical reaction using the moles of each element that react with oxygen and produce the moles of oxygen required for combustion.

As received base coal element combustion reaction

$C + O_2 \rightarrow CO_2$

$3{,}174 + 3{,}174 \rightarrow 3{,}174$

$H + 0{,}25O_2 \rightarrow 0{,}5H_2O$

$3{,}01 + 0{,}753 \rightarrow 1{,}505$

$S + O_2 \rightarrow SO_2$

$0{,}006 + 0{,}006 \rightarrow 0{,}006$

Number of moles of combustion oxygen:

3,174 + 0,753+ 0,006 = 3,933

Overall coal burning reaction

$CHS + O_2 \rightarrow CO_2 + H_2O + SO_2$

$\mathbf{C_{3,174}H_{3,01}S_{0,006} + {}_{3,933}O_2 \rightarrow {}_{3,174}CO_2 + {}_{1,505}H_2O + {}_{0,006}SO_2}$

$CHONS + O_2 \rightarrow CO_2 + H_2O + N_2 + SO_2$

$\mathbf{C_{3,174}H_{3,01}O_{2,901}N_{0,079}S_{0,006} + {}_{2,482}O_2 \rightarrow {}_{3,174}CO_2 + {}_{1,505}H_2O + {}_{0,04}N_2 + {}_{0,006}SO_2}$

The result of the chemical reaction of combustion with the elements carbon, hydrogen, and sulfur that react with oxygen, the number of moles of oxygen is 3,933, while in the chemical reaction of burning coal as a whole, the number of moles of oxygen is 2.482.The amount of elemental substances is influenced by the percentage of elements obtained through ultimate analysis. This value will differ based on the basis used because the ultimate analysis results will differ based on the basis and affect the chemical reaction. In the stoichiometric analysis of combustion, the equality of chemical reactions is an important factor in determining the number of moles of oxygen. Unbalanced chemical reactions will affect the heat produced is not optimal. The difference in the amount of combustion oxygen substance based on the chemical reaction and the basis used can be seen in the following graph.

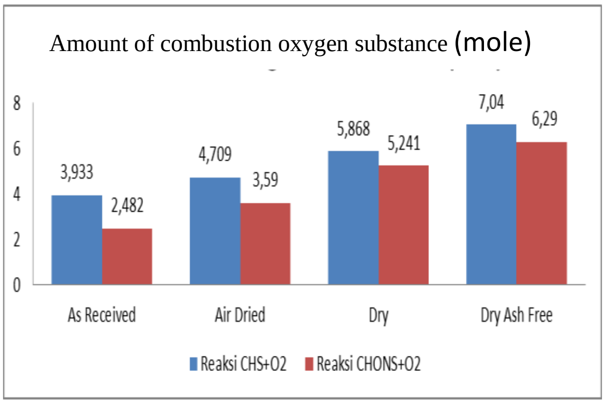

Fig. 1: The difference in the amount of combustion Oxygen.

Analysis of Air Fuel Ratio (AFR)

To determine the air demand for coal combustion, an air fuel ratio analysis is needed. The number of moles of oxygen on each used basis must be converted to mass units. The difference in the mass value of combustion air based on the chemical reaction and the basis used can be seen in the following graph.

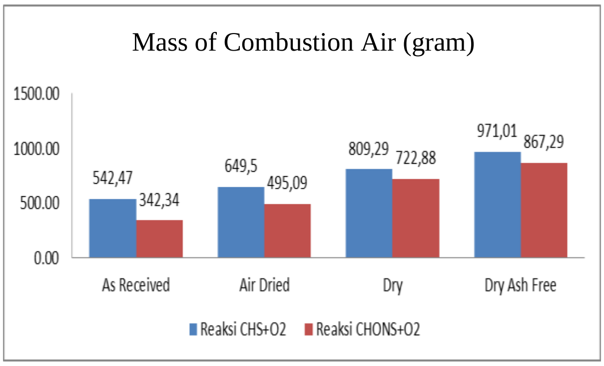

Fig. 2: The difference in the mass of combustion Air.

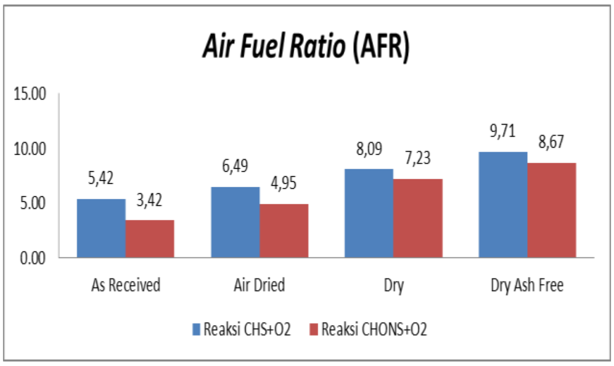

Fig. 3: The difference in the value of the air fuel ratio (AFR

The difference in the value of the air fuel ratio (AFR) based on the chemical reaction and the basis used can be seen in the following graph The amount of combustion oxygen substance and air mass will affect the value of the air fuel ratio (AFR). In the results of the calculation of the value of the amount of oxygen, air mass and AFR experience the same pattern, namely a decrease in the value based on the reaction and an increase in the value based on the basis used. The decrease in the value of the amount of oxygen, air mass, and air fuel ratio (AFR) in the CHONS + O2 combustion reaction is caused by the percentage of oxygen present in coal, so for chemical reaction equality, the mole value of oxygen for coal combustion will be smaller than the value it should be. Whereas in the CHS + O2 combustion reaction, the oxygen contained in coal is not used in the calculation because it cannotundergoes combustion, so that it does not affect the equality of the chemical reaction and the mole value of combustion oxygen does not decrease.The increase in the amount of combustion oxygen substance on each basis is caused by the percentage of the chemical element of coal. In the results of the proximate and ultimate analysis, all coal parameters have increased due to the basis, because each base has different parameters. For example, on an as received basis there is a total moisture value which is the amount of surface moisture and inherent moisture. If using air dried basis, surface moisture value will not be used, so the percentage of other parameters will be greater than as received basis. This factor also affects the chemical elements in the ultimate analysis of coal.

During the coal burning process at the PLTU, the AFR value is needed in order to produce maximum heat. After knowing the stoichiometric AFR value, it is necessary to review the actual AFR on the boiler. When the actual AFR value is greater than the stoichiometric AFR value, it will result in a lean mixture which means a shortage of fuel. When the actual AFR value is less than the stoichiometric AFR value, a rich mixture will result, which means excess fuel. This will have an impact on the heat energy produced and exhaust gases in the combustion process.

Conclusions

Based on the results of the analysis of the research that had been carried out, it can be concluded as follows:

1. Based on the results of the proximate analysis of air dried basis (inherent moisture 19.74%, ash content 13.39%, volatile matter 58.14%, fixed carbon 27.99%) and the ultimate analysis of air dried basis (carbon 45.61 %, hydrogen 3.6%, oxygen 35.83%, nitrogen 1.33%, sulfur 0.24%), the type of coal used is lignite.
2. The results of the chemical reaction of burning coal on an as received basis are:

$$C_{3,174}H_{3,01}S_{0,006} + {}_{3,933}O_2 \rightarrow {}_{3,174}CO_2 + {}_{1,505}H_2O + {}_{0,006}SO_2$$

$$C_{3,174}H_{3,01}O_{2,901}N_{0,079}S_{0,006} + {}_{2,482}O_2 \rightarrow {}_{3,174}CO_2 + {}_{1,505}H_2O + {}_{0,04}N_2 + {}_{0,006}SO_2$$

The chemical reaction results of burning coal on air dried basis are:

$$C_{3,801}H_{3,6}S_{0,008} + {}_{4,709}O_2 \rightarrow {}_{3,801}CO_2 + {}_{1,8}H_2O + {}_{0,008}SO_2$$

$$C_{3,801}H_{3,6}O_{2,2394}N_{0,095}S_{0,008} + {}_{3,5886}O_2 \rightarrow {}_{3,801}CO_2 + {}_{1,8}H_2O + {}_{0,048}N_2 + {}_{0,008}SO_2$$

The chemical reaction results of burning coal on a dry basis are:

$$C_{4,736}H_{4,49}S_{0,009} + {}_{5,868}O_2 \rightarrow {}_{4,736}CO_2 + {}_{2,245}H_2O + {}_{0,009}SO_2$$

$$C_{4,736}H_{4,49}O_{1,253}N_{0,119}S_{0,009} + {}_{5,241}O_2 \rightarrow {}_{4,736}CO_2 + {}_{2,245}H_2O + {}_{0,06}N_2 + {}_{0,009}SO_2$$

The results of the chemical reaction of burning coal on dry ash free basis are:

$$C_{5,684}H_{5,38}S_{0,011} + {}_{7,04}O_2 \rightarrow {}_{5,684}CO_2 + {}_{2,69}H_2O + {}_{0,011}SO_2$$

$$C_{5,684}H_{5,38}O_{1,504}N_{0,142}S_{0,011} + {}_{6,29}O_2 \rightarrow {}_{5,684}CO_2 + {}_{2,69}H_2O + {}_{0,071}N_2 + {}_{0,011}SO_2$$

3. The values of air fuel ratio (AFR) reaction of CHS + O2 and CHONS + O2 as received basis (5.42 and 3.42), air dried basis (6.49 and 4.95), dry basis (8.09 and 7,23), dry ash free basis (9.71 and 8.67).

Suggestions

1. For further research, the researcher recommends analyzing various kinds of coal samples in order to obtain supporting data that complements the results of this study

2. It is hoped that in future studies to analyze the effect of the type of coal on the value of air fuel ratio (AFR), so that this research can further develop.

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