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Gas Emissions from Mixed Coal-BCF Derived Fuel Burned in Industrial Boilers

Emisi Gas dari Bahan Bakar Campuran Batu Bara–BCF yang Digunakan pada Boiler Industri

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ABSTRAK

***Emisi Gas dari Bahan Bakar Campuran Batu Bara–BCF yang Digunakan pada Boiler Industri**. PT. X adalah industri tekstil yang menggunakan bahan bakar batu bara dalam jumlah besar untuk mengoperasikan boiler, yang menghasilkan abu dasar dalam jumlah besar dan dianggap sebagai limbah B3. Dilakukan uji coba awal (initial trials) untuk menggunakan kembali bottom ash yang dicampur dengan agregat kompos dari limbah padat, sehingga menghasilkan biofuel yang disebut sebagai briket biomassa coal fuel (BCF), sebagai bahan bakar pendamping. Uji coba emisi dilakukan menggunakan MRU Optima 7. Dari hasil uji coba emisi, diketahui bahwa konsentrasi SO_2 dari penggunaan 100% batu bara adalah 150 mg/Nm3, sedangkan konsentrasi SO_2 dari penggunaan bahan bakar batu bara dengan substitusi 10% BCF adalah 498,8 mg/Nm^3. Konsentrasi NO_2 dari pembakaran 100% batu bara adalah 174,2 mg/Nm^3, sedangkan dari pembakaran bahan bakar campuran adalah 370,3 mg/Nm^3. Konsentrasi SO_2 dan NO_2 tidak dikoreksi terhadap oksigen sebesar 6% karena di dalam Lampiran IV Permen LH No 7 tahun 2007 hal tersebut hanya disyaratkan untuk konsentrasi partikulat. Penggunaan BCF sebagai agregat untuk pembakaran batu bara tidak menurunkan emisi SO_2 dan NO_2. Faktor emisi SO_2 pembakaran 100% batu bara adalah 6,295 g/kg dan faktor emisi SO_2 pembakaran batu bara dengan substitusi BCF 10% adalah 31,09 g/kg. Sedangkan faktor emisi NO_2 dari 100% pembakaran batu bara adalah 7,31 g/kg dan faktor emisi NO_2 pembakaran batu bara dengan substitusi 10% BCF adalah 23,31 g/kg. Emisi SO_2 dan NO_2 dari pembakaran bahan bakar campuran batu bara dan BCF menghasilkan emisi yang lebih tinggi dibandingkan pembakaran batu bara saja. Walaupun emisinya lebih tinggi tetapi konsentrasi emisinya masih di bawah standar emisi nasional saat ini, yakni 750 mg/Nm^3 untuk SO_2 bahan bakar batu bara, 701,43 mg/Nm^3 untuk SO_2 bahan bakar campuran, 825 mg/Nm^3 untuk NO_2 bahan bakar batu bara, dan 816,91 mg/Nm^3 untuk NO_2 bahan bakar campuran. Hasilnya dapat digunakan sebagai bukti ilmiah dampak kualitas udara penggunaan co-fuel untuk aplikasi boiler industri.*

Kata kunci: *briket, batu bara, cerobong, SO_2, NO_2.*

ABSTRACT

Gas Emissions from Mixed Coal-BCF Derived Fuel Burned in Industrial Boilers. The textile industry consumes a huge amount of coal to operate its boiler, resulting in large amounts of bottom ash, considered hazardous waste. PT. X conducted initial trials to reuse bottom ash mixed with solid waste compost to generate biofuel named biomass coal fuel (BCF) briquettes as co-fuel. Emission tests were carried out on the same stack and boiler at PT. X on a different day using MRU Optima 7., From the emission test results, the SO_2 concentration of 100% of coal burning was 150 mg/Nm^3. SO_2 concentration of coal fuel with a substitution of 10% BCF was 498.8 mg/Nm^3. The NO_2 concentration from 100% coal combustion was 174,2 mg/Nm_3, while from mixed fuel combustion was 370.3 mg/Nm^3. Note that oxygen corrections of 6% for the results of SO_2 and NO_2 concentrations were not carried out in the experiments. It is relevant only for particulate matter measurement as guided in the Regulation of the Minister of Environment No. 7 of 2007 Annex IV. Using BCF as an aggregate for coal combustion did not bring in lower emissions of SO_2 and NO_2. The emission factor for SO_2 from 100% coal combustion is 6,295 g/kg, while coal fuel with a substitution of 10% BCF is 31,09 g/kg. NO_2 emission factor from 100%, coal burning is 7,31 g/kg while the emission factor of NO_2 in coal fuel with a substitution of 10% BCF is 23,31 g/kg. The emissions of SO_2 and NO_2 from the burning of mixed fuel of coal and BCF yielded higher emissions than the burning of coal alone. Even though the emissions were higher, but the emission concentrations were still below the current national emission standards. The results can be used as scientific evidence of the air quality impact of using co-fuel for industrial boiler applications.

Keywords: briquettes, coal, stack, SO_2, NO_2.

1. Introduction

In supporting the production process, the textile industry usually uses coal-fired boilers as an energy source. The consumption of coal fuel in the textile industry is carried out in large quantities, up to 27 tons/day. Burning coal in a *boiler* causes combustion residue, one of which is bottom ash. The textile industry tries to use bottom ash as an alternative fuel, so-called Biomass Coal Fuel (BCF) briquettes, to solve the problem of bottom ash waste generated, with a composition of BCF briquettes 60% bottom ash and 40% mixed waste.

In its utilization, BCF briquettes that the textile industry has produced will be used as fuel and coal, or in other words, it is also known as co-firing. Referring to Suganal & Hudaya (2019), co-firing is the process of burning two types of fuel that are carried out on the same combustion device. Then as comparative data, experiments were also carried out with only the use of coal. Government Regulation No. 22 of the year 2021 stated that bottom ash as co-firing is allowed with technical approval from regulators after specific tests.

Using coal or briquettes as *boiler* fuel can produce emissions in the form of particulate and gaseous compounds. Based on Minister of Environment Regulation No. 7 of the year 2007, stipulates the quality of emission from stationary source emissions using coal fuel. The regulation stated that the only gas compounds measured are NO_2 and SO_2, in addition to the measurement of emissions in particulates, pollutants are generally toxic (Sugiarto *et al*., 2019).

In this study, the emission-quality standard used is the Regulation of the Minister of Environment No. 7 of the year 2007 attachment IV concerning the use of coal fuel and attachment VII concerning the use of co-firing fuels (90% coal and 10% BCF), according to the two experiments conducted. Appendix IV is used because this experiment focuses on gaseous pollutants from coal combustion, using the strictest Quality Standards for Coal. The impact caused by SO_2 and NO_2 can cause death to humans and animals and cause plants to be wilt and acid rain, which can damage property, such as buildings and other public facilities (Budiyono, 2010). (Suganal dan Hudaya, 2019).

There are negative impacts caused by SO_2 and NO_2 from the combustion of coal and BCF briquettes, so data and information are needed regarding gas emissions resulting from the fuel combustion process in the boiler when using coal or BCF briquettes. This study's purpose was limited to measure the concentration of SO_2 and NO_2 emissions from the use of coal fuel substituted with

10% BCF and compare it with the emission concentration of coal only. This study is done to see the quality of emissions resulting from the use of BCF, whether the emissions are worse or not. In the future, toxic air pollutants such as particulate matter, heavy metals such as mercury, arsenic etc., polyaromatic hydrocarbons (PAHs), and dioxin should be carefully measured.

2. Methods

Briquette is an energy source usually made from biomass which can be used as an alternative fuel. Briquettes can be made with compositions or raw materials that are easy to find, such as coconut shells, rice husks, husk charcoal, wood dust (sawdust), corn cobs, and leaves (Pratama *et al*., 2018).

The composition of BCF briquettes consists of 40% mixed waste and 60% bottom ash. The bottom ash used is bottom ash which comes from the combustion of coal in the boiler. Meanwhile, the waste used comes from urban waste and waste from the Saguling Dam.

When measuring SO_2 and NO_2 gas emissions, the Center for Pulp and Paper uses the MRU Optima 7, which refers to the IK-Paskal-LU.MU-03 method for SO_2 and IK-Paskal-LU.MU-01 for NO_2, the method is based on work instructions belonging to the Pulp and Paper Center (Balai Besai Pulp dan Kertas-Bandung).

Measurements were made on the same boiler and stack, with two experimental arrangements have been made: 1) 100% coal burning, and 2) 90% coal + 10% BCF briquettes. The two experiments' results were compared with the emissions stipulated in the Minister of Environment Regulation Number 7 of 2007, attachment IV and attachment VII.

The combustion and emission tests for each fuel are carried out at different times. For the use of 100% coal, combustion and emission tests were carried out on 26 February 2020, while the use of 90% coal and 10% BCF was carried out on 9 March 2020. BCF is only used as much as 10% because it has been assessed from the BCF data produced that this number does not affect the boiler's performance, so the lowest amount is taken, namely 10%. Each emission test is carried out for 1 hour, with data obtained in the form of SO_2 and NO_2 concentrations from each of the emission tests carried out.

In this experiment for gas emission, no oxygen correction is carried out because it refers to the Minister of Environment Regulation No. 7 of the year 2007 that oxygen correction is only done for particulate emissions only. The MRU Optima 7 manual book is equipped with electrochemical sensors for O_2, CO, NO, NO_2, NO_x, SO_2, temperature, and exhaust gas velocity. The MRU Optima 7 is combined with an extraction probe to fit into the stack; the MRU Optima 7 analyzer's internal gas pump will extract a portion of the flue gas from the stack and analyze it using an electrochemical sensor. The thermoelement in the probe tube also measures the temperature of the gas. The results of the measurement of gas emissions in the chimney will be recorded directly in the tool in ppm units (Hintz, 2020).

Finding the core flow will assist in finding the optimal measuring point in the stack. The maximum exhaust gas temperature can identify the core flow. At high reaction times, the analyzer displays the exhaust gas temperature trend. The ways to position the probe in the core flow are as follows:

1. Insert the probe tube slowly into the stack
2. Position the probe when it has reached the maximum exhaust gas temperature
3. The maximum temperature is reached when the sigma on the MRU Optima 7 display disappears, and the sigma with a "beep" stops. One bar is equal to 1°C.
4. After the core flow is achieved, attach the probe to the probe cone, and the measurement results will appear on the screen.

Apart from emission concentration data, secondary data is also used, such as coal characteristic data and BCF. In contrast, the actual oxygen concentration data is not used because the gas parameter emission does not require oxygen corrections.

Based on the concentration value obtained from the emission test results, the emission factor calculation for each parameter can be performed. In calculating the emission factors for NO_2 and SO_2 gases, some supporting data is needed, such as:

- P = fuel consumption in tonnes/day
- Q = stack discharge in m^3 /second
- T = length of sampling time in Second
- K = concentration of parameters in units of mg/Nm^3.

There are three calculation phases:

1. Calculate the variable A (mg/d) using the formula

$$A = K \times Q \quad \text{..(1)}$$

2. Calculate the variable B (gram) using the formula

$$B = A \times H \quad \text{... (2)}$$

3. Calculate the emission factor (g/kg) using the formula

$$Emission\ factor = \frac{B}{P_{Total}} \quad \text{..................(3)}$$

Comparing data used emission factor data from the literature Atmospheric Brown Clouds - Emission Inventory Manual (ABC-EIM) (Shrestha *et al*., 2013).

The emission factors in Table 1 are used to estimate coal emission factors in general based on ABC-EIM.

3. Results and Discussion

The fuels used are coal and BCF briquettes. The amount of fuel used can be seen in Table 2.

The characteristics of each fuel can be seen in Table 3.

3.1. SO_2 and NO_2 Concentrations

3.1.1. Sulfur Dioxide (SO_2)

SO_2 concentration emission data for coal combustion and coal + 10% BCF can be seen in Table 4.

Referring to Sukandi *et al*.(2018), fuels with a high calorific value produce lower

Table 1. Emission Factor (ABC-EIM)

Coal Type	Emission Factor (kg/Tj)	
	SO_2	NOx
Lignite	130 CS_{fuel}	300, 564[d], 433[b,1]

Source: Shrestha *et al*., 2013
Information:
CS = sulfur content
b, 1 = average value for pulverized coal-fired boiler (uncontrolled)
d = Kato and Akimoto, 1992. Derived by assuming average calorific values, as given in the IEA Energy Statistics and Balances for non-OECD Countries (IEA, 1998).

Table 2. Amount of The Fuel Consumption

Boiler	Amount of Coal Fuel Before Substitution of BCF (ton/day)	Total Fuel After Substitution 10% BCF (ton/day)	
		Coal	Biomass Coal Fuel (BCF)
Experiment 1: Fire tube *boiler*	7	-	-
Experiment 2: Fire tube *boiler*	-	6,3	0,7

Table 3. Fuel characteristics

Sample	Moisture content (%)	Ash content (%)	Calorific value (cal/g)	Volatile matter (%)	Fixed carbon (%)	Total sulfur (%)	Nitrogen (%)
Coal	23,15	2,65	5.223,00	37,00	37,13	0,24	0,19
Coal + 10% BCF	21,57	7,69	4.950,78	35,54	21,26	0,28	0,87

Source: Indonesian Institute of Science (LIPI), 2020

Table 4. SO_2 concentration

Sampling date	Coal (mg/Nm^3)	Coal + 10% BCF (mg/Nm^3)	Quality standard
26-02-2020	150,00[1)]	-	750,00[2)]
09-03-2020	-	493,90[1)]	701,43[3)]

Data source: [1)] Center for Pulp and Paper, 2020
[2)] *Regulation of The Minister of Environment no. 7, attachment IV, 2007*
[3)] *Regulation of The Minister of Environment no. 7, attachment VII, 2007*

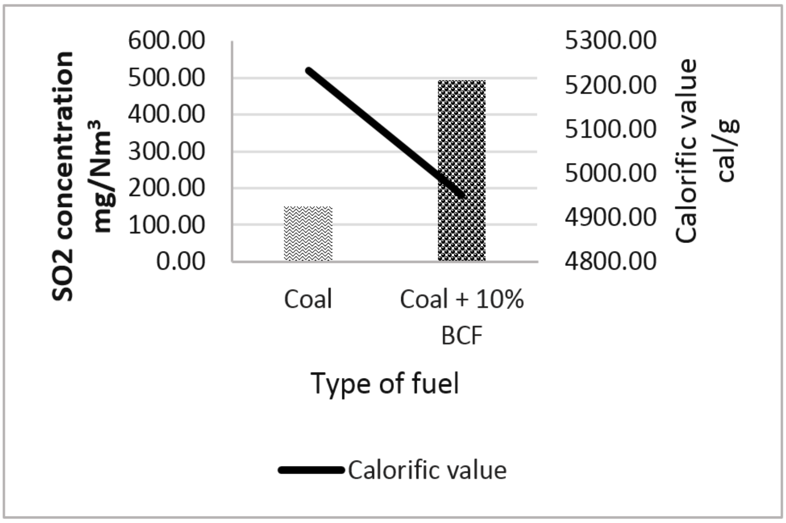

Figure 1. Graph of SO_2 Concentration and Calorific Value

gas emissions than fuels with low heating values. As shown in Figure 1, it can be seen that the black line in the image shows a low calorific value in coal fuel + BCF, the SO_2 concentration produced by burning coal with a heating value of 5223 cal/g resulting in an SO_2 concentration of 150,00 mg/Nm^3. Meanwhile, coal + 10% by burning with a heating value of 4950,78 cal/g produces an SO_2 concentration of 493,90 mg/Nm^3. It is known that based on Ge (2001), the SO_2 concentration for coal briquettes is 701 mg/Nm^3. This concentration is relatively greater than the SO_2 concentration at PT. X.

Then an analysis is carried out based on the characteristics of each fuel. It can be seen in Table 2 that the sulfur content in coal and coal + 10% BCF affects the high or low SO_2 concentration. The sulfur content in coal is 0,24%, while the sulfur content in coal briquettes is + 10% BCF which is 0,28%. The transformation of sulfur in coal is also affected by the combustion temperature (Hou *et al*., 2018). The combustion temperature can be seen in Table 5.

Table 5. SO_2 concentration and burning temperature

Fuel	SO_2 (mg/Nm³)	Temperature (°C)
Coal	150,00	900 - 1100
Coal+10% BCF	493,90	1200 - 1300

According to Hou (2008), when the combustion temperature reaches 300°C, SO_2 begins to form. Along with the increase in combustion temperature, SO_2 will gradually rise and reach its peak at a temperature of around 1100°C. While the use of coal + 10% BCF, the temperature tends to increases to 1300°C. A sulfur oxidation reaction occurs during combustion to produce SO_2. In general, the reaction to sulfur dioxide gas (SO_2) formation is as follows (Nugrainy *et al*., 2015; Yunita & Kiswandono, 2017).

$$S + O_2 \rightarrow SO_2$$

$$SO_2 + O_2 \rightarrow 2\ SO_3$$

The amount of SO_3 gas is usually not more than 10% of the amount of SO_2 formation.

3.1.2. Nitrogen Dioxide (NO_2)

The emission concentrations of NO_2 for both experiments are presented in Table 6.

According to Sugiarto (2019) and Fardiaz (1992), NO_2 emissions are influenced by the nitrogen content and volatile matter in the fuel formed during the combustion process. Based on the nitrogen content and volatile matter data in Table 3. These two characteristics do not significantly affect emissions because the value of the content is inversely proportional to the concentration value of NO_2.

The NO_2 concentration in coal is smaller than the NO_2 concentration in coal + 10% BCF. The NO_2 concentration of coal was 174,20 mg/Nm³ while the NO2 concentration of coal + 10% BCF was 370,30 mg/Nm³. It is known that based on Komariah (2013), the NO_2 concentration for coal is 159,64 mg/Nm³. This concentration is almost equal to that of NO_2 coal concentration at PT. X.

As is well-known, nitrogen will burn only at high temperatures. Referring to the EPA (1999), NO_x will quickly be formed from molecular nitrogen in the air, mixed with fuel. The nitrogen in the air will be oxidized together with the fuel and become NO_x during the combustion process.

A high heating value results in lower gas emissions compared to fuels that have a low heating value. As shown in Figure 2, it can be seen that the black line in the image shows a low calorific value in coal fuel + BCF, the NO_2 concentration produced from burning coal with a heating value of 5223,00 cal/g resulting in a NO_2 concentration of 174,2 mg/Nm³. Meanwhile, burning coal + 10% BCF with a heating value of 4950,78 cal./g produces a NO_2 concentration of 370,30 mg/Nm³.

The calorific value is influenced by moisture content, fixed carbon, and ash content. High water content can reduce combustion temperatures and make it

Table 6. NO_2 concentration

Sampling date	Coal (mg/Nm³)	Coal + 10% BCF (mg/Nm³)	Quality standard
26-02-2020	174,20[1)]	-	825,00[2)]
09-03-2020	-	370,30[1)]	816,91[3)]

Data source: [1)] Center for Pulp and Paper, 2020
[2)] *Regulation of The Minister of Environment no. 7, attachment IV, 2007*
[3)] *Regulation of The Minister of Environment no. 7, attachment VII, 2007*

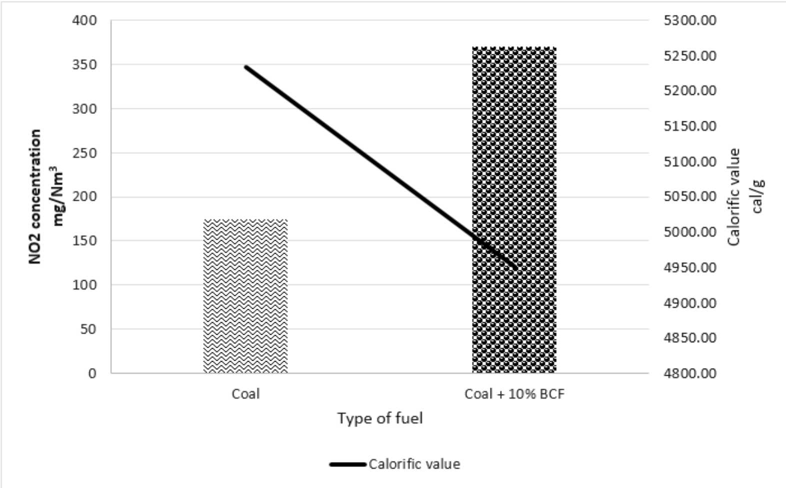

Figure 2. Graph of NO_2 Concentration and Calorific Value

difficult to ignite (Himawanto, 2003). The ash content in the fuel plays a role in reducing the calorific value, which lowers the fuel quality. The ash contained in solid fuel is a non-combustible mineral (Yuwono & Setiawan, 2009). Fixed carbon which is low in fuel, will reduce the calorific value and vice versa (Sudiro, 2014). This statement is by the relationship between calorific value and fixed carbon in coal and the BCF used.

The release of NO increases drastically with increasing combustion temperature (Hou *et al*., 2018). The combustion temperature can be seen in table 7.

The formation of NO from N_2 occurs mainly by the formation of thermal NO, as in the following reaction:

Table 7. NO_2 concentration and burning temperature

Fuel	NO_2 (mg/Nm³)	Temperature (°C)
Coal	174,20	900 - 1100
Coal + 10% BCF	370,30	1200 - 1300

$O + N_2 \leftrightarrow NO + O$

$N + O_2 \leftrightarrow NO + O$

$N + OH \leftrightarrow NO + H$

In the first reaction, thermal NO formation occurs at about 1500°C. The formation of N_2O occurs when the combustion temperature reaches 800 - 900°C. During the combustion process, all nitrogen contained in coal will be released as a gas.

According to Hou (2018), NO_2 will start to be produced at a combustion temperature of 300°C and will increase gradually as the combustion temperature increases with a peak temperature of 1100°C. While coal + 10% BCF, the temperature tends to continue to increase to 1300°C. The reaction to the formation of NO is a byproduct of the combustion process (Ilahi & Nugroho). The reaction for the formation of NO_2 begins with the formation of NO.

$2 N + O_2 \rightarrow 2 NO$

$2 NO + O_2 \rightarrow 2 NO_2$

3.2. Emission Factor

3.2.1. Sulfur Dioxide (SO_2)

From the calculations carried out, it is known that the SO_2 emission factor is as in Table 8.

Table 8. SO_2 Emission Factor

Coal (g/kg)	Coal + 10% BCF (g/kg)	ABC-EIM (g/kg)
6,30	31,09	0,69

In the ABC-EIM literature, the emission factor value of 0,69 g/kg for lignite coal type with a sulfur content is 0,24%. The emission factor from coal and coal + 10% BCF has an emission factor value that is higher than the emission factor value in ABC-EIM literature.

Table 9. SO_2 Emission Factor

Coal	Emission factor (g/kg)	Source
Coal	6,30	This study
Coal + 10% BCF	31,09	This study
Coal briquette (literature)	19,90	(Ge *et al*., 2001)
Coal ABC-EIM	0,69	(Shrestha *et al*., 2013)

Table 9 compares the calculated coal emission factors, coal-based literature, and coal + 10% BCF.

It can be seen in Table 9 that each fuel used from some literature has a different emission factor value. The coal briquette emission factor, which refers to the journal (Ge *et al*., 2001), has a value of 19,9 g/kg, which is smaller than the emission factor value in calculating the SO2 emission factor of PT. X for coal fuel is + 10% BCF, but bigger when compared to the value of the ABC-EIM coal and coal emission factors. The briquettes used in journals (Ge *et al*., 2001) are formulated briquettes.

3.2.2. Nitrogen Dioxide (NO_2)

The calculations carried out show that the NO_2 emission factor is as in Table 10.

Table 10. NO_2 Emission Factor

Coal (g/kg)	Coal + 10% BCF (g/kg)	ABC-EIM (g/kg)
7,31	23,31	0,01

Suppose the emission factor for coal is + 10% BCF and only coal compared to the ABC literature's emission factor value. In that case, the two emission factors exceed the ABC-EIM emission factor estimate for bituminous coal type is only 0,01 g/kg. The difference between the two emission factors is relatively much larger when compared to the ABC-EIM emission factors. Table 11 compares the calculated coal emission factors, coal-based literature, and coal + 10% BCF.

Table 11. NO_2 Emission Factor

Type of Fuel	Emission Factor (g/kg)	Source
Coal	7,31	This study
Coal + 10% BCF	23,31	This study
Coal (literature)	0,597	(Deru dan Torcellini, 2007)
Coal (ABC-EIM)	0,01	(Shrestha *et al*., 2013)

It is known that the NO_x emission factor for lignite coal is 5,97 g/kg. Based on Finlayson-Pitts & Pitts Jr (1986), the NO_2 content in NO_x is 10% and the NO_2 emission based in Der & Torcellini's (2007) is 0,597 g/kg. It can be seen in Table 9 above that the emission factor from the use of coal fuel + 10% BCF has the greatest emission factor value.

4. Conclusion

From these initial trials, the SO_2 concentration in coal fuel use is 150 mg/Nm^3, and the use of mixed fuel (coal + 10% BCF) is 493,90 mg/Nm^3. The NO_2 concentration in the use of coal fuel is 174,20 mg / Nm^3 while for the use of mixed fuels (coal + 10% BCF) is 370,30 mg/Nm^3. The factor that affects the value of gas emissions is the temperature at the time of combustion of the mixed fuel, which tends to increase. The SO_2 emission factor is simulated for coal fuel use as 6,30 g/kg, for the use of mixed fuel (coal + 10% BCF) is simulated as 31,09 g/kg. The NO_2 emission factor for coal fuel use is simulated as 7,31 g/kg, for mixed fuel (coal + 10%

BCF) is simulated as 23,31 g/kg. From the results of the initial trials for an emission test and analyzes that have been carried out, it is known that SO_2 and NO_2 emissions in the use of coal + BCF have a concentration or emission factor that is greater than the use of coal only, but the use of BCF can still be done because it still below the quality standard requirements of the Minister of Environment Regulation no. 7 of 2007. However, it is still needed efforts to assess the value of the resulting emissions. Further efforts are still required to collect more stack emission monitoring and statistical analysis on the variations. The composition of BCF to be added to the coal fuel should be varied to confirm the mixed fuel content's effect on the gas concentrations measured at the stack..

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6. Authorship

In this research, the first author collecting data and write the manuscript. Other co-authors revised the manuscript.

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