INDOOR AIR POLLUTION FROM BRIQUETTE-BURNING STOVES

SELINAWATI T.D., RETNO DAMAYANTI AND HERNI KHAERUNISA
R & D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211
Ph. (022) 6030483, Fax (022) 6003373

ABSTRACT

Recently, the use of coal briquette has already been socialized to substitute the role of oil and firewood in the household and small industries. In general the use of coal briquette burning stoves for household and small industries purposes is often conducted indoors, with inadequate ventilation. Yet knowledge of emissions from coal briquette burning stoves and how to evaluate emission and exposure levels are very limited and need to be developed. Study of indoor air pollution was undertaken to evaluate SO_2, CO and NO_X concentrations and its exposure potentials coming from the utilization of coal briquette for household and small industries purposes. Its results were compared to the charcoal burning process. To estimate the indoor concentration and exposure potential, the single-compartment mass balance model was used. Results show that the total amounts of hourly emitted SO2, CO and NOx for 1 kg coal briquette burning vary from 5.32-14.71 mg kg^{-1}; 2.76-12.54 mg kg^{-1} and 112-288 mg kg^{-1}, respectively. While those emitted from charcoal burning are 0 mg kg^{-1}, 6.79 mg kg^{-1} and 201 mg kg^{-1}. The air exchange rate gives an effect to concentration level, peak indoor concentration and duration after the burning process. The hourly average concentrations of SO_2, CO and NO_X in the unventilated room are 22, 42 and 10 times, respectively higher than the used standards. While for charcoal burning, those were 0, 17 and 6 times, respectively.

1. INTRODUCTION

Indonesia has a diversity of mineral resources, spreading through out islands over the country. They include gas and oil, coal and base metals. It is estimated that Indonesian coal resources are about 50.6 billion tons (Suyartono, 2002). Since the energy crisis in 1970's, to fulfill national energy demand and in order to substitute petroleum fuel, coal has been selected as one of the alternative energies in the future.

Recently, the use of coal briquette has already been socialized to substitute the role of oil and firewood in the household and small industries. The aim of coal briquette utilization is to conduct environmental protection against de-forestry and to gain value added of low rank and fine coal. Along with those positive impacts, the utilization of coal briquette gives also negative ones to the environment. One of the negative impacts caused by coal briquette utilization is air pollution due to the emission from coal briquette burning. They include particulates and toxic gases such as sulfur dioxide (SO_2), nitrogen oxide (NO_2), carbon oxide (CO) and other organic compounds (Mangunwijaya, 1991). Adverse health effects of those gases are well known as to be significant risk in parts of using fossil solid fuels. In general the use of coal briquette burning stoves for household and small industries purposes are often conducted indoors with inadequate ventilation. In this condition, gas emits directly into the place and at the times of human occupancy. Therefore, the exposure of certain air pollution from these sources is often greater than those derived from large outdoor emissions.

Currently, knowledge of emissions from coal briquette burning stoves and how to evaluate emission and exposure levels is very limited and need to be developed. The study of indoor air pollution from briquette burning stoves was undertaken to evaluate and compare indoors SO_2, CO, and NO_x

concentrations and its exposure potentials coming from the utilization of coal briquette for household and small industries purposes.

2. MATERIALS AND METHODS

Fuel materials used in this study were:

- four kinds of coal briquette samples, namely Palimanan briquette (bagasse briquette - BB and rice husk briquette - BS); Lampung briquette (BL), and Tanjung Enim briquette (BT);
- marketable charcoal (AK) for comparison.

The first part of the study was to characterize samples by proximate analysis (water content, ash content, volatile matter and fixed carbon), caloric value and ultimate analysis (C, H, N, total sulfur and oxygen). Direct gas emission from a fuel-briquette-burning stove was measured using an apparatus as shown in Figure 1. A 1 kg fuel within a stove was burnt under a hood for 2 hours. Pollutant emission (SO_2, NO_x and CO) were measured using a multi gas monitor (ECOM-AC) at certain interval time. To estimate indoors pollutant concentrations over time, the single-compartment mass balance model (Zhang et.al., 1999) or a dilution chamber (Ballard-Tremeer, 1974) was used. In this model, they assume that all emitted gas from the stove is released indoors, well-mixed, and removed only by indoor/outdoor air exchange. No other gas sources are present.

Under this assumptions, the indoor pollutant concentration during briquette burning can be determined using the following formula:

$$C(t) = \frac{F\,E_f}{VS}\left(1 - e^{-St}\right) \qquad (1)$$

Where
F = fuel burn rate, kg h^{-1}
Ef = fuel-mass based gas emission factor, g kg^{-1}
t = time, h
V = volume of the room, m^3
S = air exchange rate or ventilation rate, h^{-1}

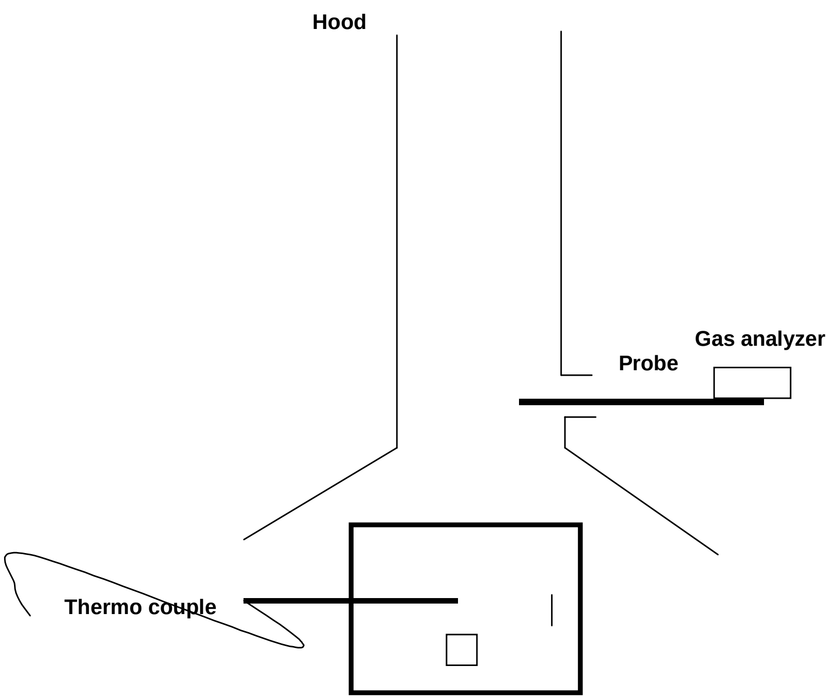

Figure 1. Schematic apparatus for gas emission determination

At time T when the burning process was stopped, a pollutant concentration reaches its maximum, following the formula:

$$C_{max} = \frac{FE_f}{VS}(1 - e^{-ST}) \qquad (2)$$

Averaged concentration (C_{avg}) for entire burning process duration can be calculated from the following equation:

$$C_{avg} = \frac{FE_f}{VS}\left[1 + \frac{1}{ST}(e^{-ST} - 1)\right] \qquad (3)$$

Pollutant exposure estimation was made according to the method described by Lioy (1990). A pollutant exposure for a person who stays in a room throughout the entire burning process duration (t from 0 to T) is

$$E = \frac{FE_t}{VS}\left(T - \frac{1}{S}(1 - e^{-ST})\right) \qquad (4)$$

4. RESULTS AND DISCUSSION

4.1 Material Characterization

The ultimate and proximate analyses were conducted to fuel materials to be studied. Results are presented in Table 1 and show that moisture contents of used fuels are relatively low. They range from 5.46 to 11.81 % as they are usually in equilibrium condition with the ambient relative humidity bio-fuel has a moisture content about 20%. The moisture in the fuel acts as a heat sink, lowering the combustion efficiency and promotes the formation of smoke. Ash content of the studied material has a value ranging from 1.43 % to 22.34%.

The lowest value is shown by charcoal sample (AK) and the highest is shown by husk briquette (BS). This matter is probably due to the AK was made from wood with its ash content about 0.5 % while the BS was made from coal mixed with husk which containing ash content about 20 - 25 %. Ash acts as a heat sink in the same way as moisture.

A volatile matter is a fuel component. When burnt, it will change into a vapor. In this study, the volatile content of the studied fuel has a value that range from 24.74 to 76.72 %. While the fixed carbon, namely the un-burnt fuel component varies from 11.69 % to 52.23 %. Data of the ultimate analysis show that S and N contents in fuel samples vary from 0.30 to 1.07 % and 0.38 to 0.92 %, respectively. These elements represent as components having a negative impact to the environment because in a burning process they will react with

Table 1. Results of ultimate and proximate analyses for studied materials

No.	Parameter	Unit	Fuel				
			AK	BB	BS	BT	BL
1.	Moisture content	%	10.16	7.25	5.46	5.81	11.81
2.	Ash content	%	1.43	18.36	22.34	17.22	11.25
3.	Volatile matter	%	76.72	45.22	43.76	24.74	37.69
4.	Fixed carbon	%	11.69	29.17	28.44	52.23	39.25
5.	Carbon, C	%	78.84	48.27	50.4	59.35	57.49
6.	Hydrogen, H	%	3.42	4.7	4.79	3.81	5.69
7.	Nitrogen, N	%	0.38	0.7	0.92	0.85	0.87
8.	Sulfur, S total	%	0.58	1.07	0.8	0.5	0.3
9.	Oxygen,O	%	15.35	26.9	20.75	18.27	24.4
10.	Caloric value	Kal	6970	4516	4905	5411	5565

Notes : All concentrations were calculated on air-dried basis
AK : Charcoal
BB : Bagase briquette
BS : Rice husk briquette
BT : Tanjung Enim briquette
BL : Lampung briquette

oxygen and produce SO_2 and NO_X. Calorific value determination points out that the studied fuels retain calorific value from 4516 to 6970 calories.

4.2 Gas Emission

In this study, an experiment was carried out in a room with a volume of 6 x 4 x 3 m^3 (72 m^3) using a ceramic stove with 1 kg fuel (charcoal or briquette). Burning process (T) took was 2 hours. Total emission for the three pollutants (SO_2, NO_x and CO) were calculated using the following equation:

$$M_E = \left[\int_{t=0}^{T} C_M \, v_{fuel} \, dt \right]$$

Where
M_E is the mass of pollutant (g)
T is the test duration (s)
C_M is the pollutant concentration at time t (g/m^3)
V_{fuel} is the flue flow rate (m^3/sec)

Results are shown in Figure 2. Pollutant emission from burning process are directly related to the used fuel composition. From Figure 2, it can be seen that the emitted pollutants from the coal briquette burning are more than that of charcoal burning. There is no SO_2 emitted from the charcoal burning, while SO_2 emitted from coal briquette varies from 32 to 14.71 mg. The emitted NO_x and CO are 2.76 - 12.54 mg and 112 - 288 mg, respectively.

4.3 Indoor Pollution and Exposure Estimation

With assumption that pollutant gases are well-mixed in the 72 m^3 room where 1 kg of fuel was burnt for 2 hours in a ceramic stove, the room concentrations of SO_2, CO, and NO_x were calculated using equations (1). An air rate exchange (S) of the room was calculated using the formula derived from equation (1) for two known concentrations, C1 and C2 (measured at time t_1 and t_2) as follows:

$$S = \frac{\ln|C_1(t_1)| - \ln|C_2(t_2)|}{t_2 - t_1}$$

Results of this calculation give S value of the experiment from 2 h^{-1} to 8 /hour.

Calculation of CO concentration as a function of time was done for BB fuel and for levels of air exchanges rate S (2 h^{-1}, 4 h^{-1}, 6 h^{-1} and 8 h^{-1}). The results are shown in Fig 3. It can be seen that the air change rate S gives an effect to concentration level, peak indoor concentration and duration after the burning process is stopped. For S = 2 h^{-1}, peak concentration of indoor CO is 1.844 mg/m3 and remains at elevated concentration for a hour after the burning process is stopped. On the one hand, for S=8 h^{-1}, the peak concentration of indoor CO (0.418 mg/m3) was reached very quickly about 20 minutes. After the burning process was stopped, the indoor CO concentration decreased to zero within 20 minutes. Table 2 shows the C_{max} and C_{avg} during the burning process that were calculated using equations (2) and (3).

To access the potential exposures to emission gases produced from fuel burning, equation (4) was used to estimate pollutant exposure (E) for a person who stays in the room during the entire burning process. Results are shown in Table 3.

It is shown that estimated 1-h average SO_2, NO_x and CO concentrations in the 72 m^3-unventilated rooms could be 22, 42 and 10 times, respectively higher than the used standards. While those for charcoal burning were 0, 17 and 6 times, respectively. From this experiment, it is suggested that the use of briquette-burning stoves as well as charcoal stoves should be have chimneys, hoods or exhaust fans.

5. CONCLUSION AND SUGGESTION

5.1 Conclusion

In general, coal briquette used in this study has moisture content and volatile matter less than that of charcoal. Their ash and their fixed carbon contents were higher. The total amount of SO_2, NO_x and CO hourly emitted for 1 kg coal briquette burning varies from 5.32 to 14.71 mg, 2.76 to 12.54 mg and 112 to 288 mg, respectively; while those emitted from charcoal burning are 0 mg, 6.79 mg and 201 mg.

The air exchange rate gives an effect to concentration level, peak indoor concentration and duration after the burning process. Hourly average SO_2,

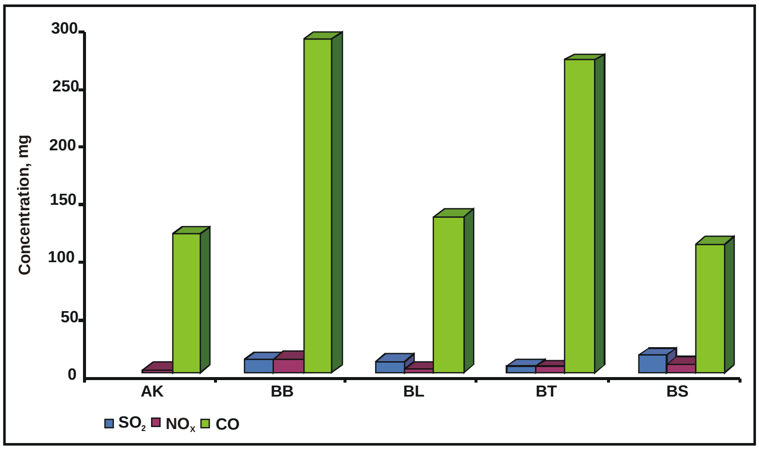

Figure 2. Total amount of SO_2, NO_x and CO emission

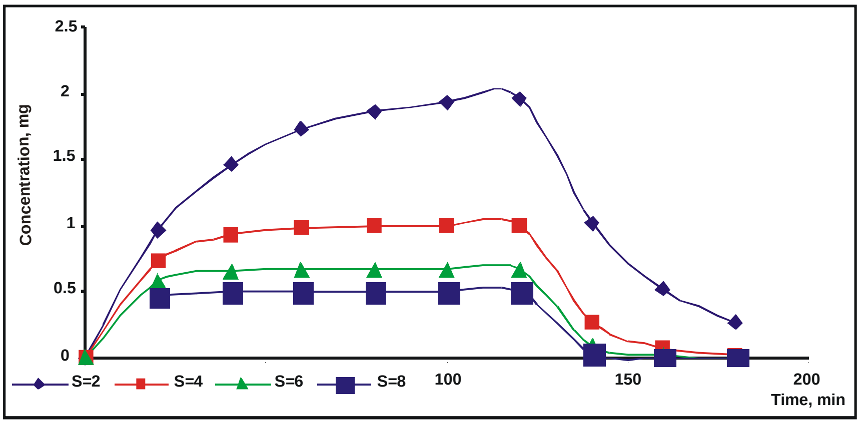

Figure 3. Calculated CO indoor concentrations coming from BB burning for variation values of S

Table 2. Maximum and average concentrations of gas emission from fuel burning

Fuel	F kg/h	Ef (g/kg)			C_{max} (mg/m^3)			C_{avg} (mg/m^3)		
		SO_2	NO_x	CO	SO_2	NO_x	CO	SO_2	NO_x	CO
BB	0.89	13.05	14.09	324	0.04	0.044	1.844	0.02	0.022	500
BS	0.93	15.82	6.94	120	0.051	0.022	0.387	0.026	0.011	194
BT	0.84	6.34	5.68	322	0.019	0.017	0.938	0.009	0.008	469
BL	0.77	11.96	4.38	175	0.012	0.012	0.469	0.016	0.006	234
AK	0.59	0	4.68	204	0	0.01	0.418	0	0.005	209

Table 3. Gas emission hourly exposure

Fuel	Exposure (h-mg/m^3)		
	SO_2	NO_x	CO
BB	23.21	25.06	576
BS	29.39	12.89	223
BT	10.64	9.54	540
BL	18.4	6.75	270
AK	0	5.52	240
TLV (WHO)	00.90*	0.32	40

*Note: * = Philipines standard*

NO_x and CO concentrations in the unventilated room are 22, 42 and 10 times, respectively higher than the used standards. While those for charcoal burning were 0, 17 and 6 times, respectively.

5.2 Suggestion

It is not recommended to use charcoal or coal briquette-burning stoves in the lack ventilation room. The briquette-burning stoves and the charcoal stoves should have adequate chimneys, hoods or exhaust fans.

REFERENCES

Ballard-Tremeer, G. 1997. *Emissions of Rural Wood-Burning Cooking Devices*, http://ecoharmony.com.

Lioy, P.J., 1990. Assessing Total Human Exposures to Contaminants, *Environmental Science Technology 24*, 938-945.

Mangunwijaya, 1991. The Development of Environmental Management for Mining Activities in Indonesia, Paper Presented at The *Seminar on Mining Activities and Environment Management*, Bandung, July 2-4, 1991.

Suyartono, 2002. *Indonesian Coal Utilization and Its Environmental Issues*, Directorate of Mineral and Coal Technique.

Zhang et.al, 1999. Carbon Monoxide from Cook Stoves in Developing Countries: 2. Exposure Potentials, *Chemosphere: Global Change Science 1, 367-375*.