INDONESIAN MINING JOURNAL Vol. 15, No. 1, February 2012 : 33 - 41

THE USE OF SUB-BITUMINOUS COAL IN COMBINATION FIRING FOR TILE, BRICK AND LIMESTONE BURNING

SUMARYONO
R & D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211,
Ph. 022 6030483, fax. 022 6003373
e-mail: soemaryono@tekmira.esdm.go.id

ABSTRACT

Combination firing of firewood and bituminous coal was recommended to reduce firewood consumption and to increase energy efficiency. However, bituminous coal deposit in Indonesia has been depleted, therefore the use of sub-bituminous coal for combination firing should be promoted.

In this work the use of sub-bituminous coal for combination firing was investigated in tile, brick and limestone burning. The calorific value of the sub-bituminous coal was only 4.6% lower than the value of bituminous coal. The increase in energy efficiencies using sub- bituminous coal were lower than that of using bituminous coal. Compared with the use of firewood alone the increase in energy efficiencies using combination firing of firewood and sub-bituminous coal in tile, brick and limestone burning were 45.7, 53.6 and 28.3% respectively. While, in the use of bituminous coal, the increase were 70.8, 75.1 and 91.9% respectively.

In the combination firing, the firewood substituted by coal using sub-bituminous coal were smaller than the use of bituminous coal, i.e. for tile, brick and limestone burning, using sub- bituminous coal the substituted firewood were 47.7, 44.6 and 45.0% respectively while using bituminous coal there were 54.5, 50.0 and 66.0% respectively.

It was revealed that the superiority of bituminous coal come from its higher content of high hydrocarbon volatiles which produced higher radiative flame resulting more efficient burning processes.

Keywords: sub-bituminous coal, co-firing, tile-brick-lime burning

INTRODUCTION

Firewood is an important fuel for small and medium scales industries in Indonesia. The increase of fuel oil and gas prices, makes more industries consume fire wood that makes the cost of firewood increases. To reduce the firewood consumption, combination firing with coal was recommended. By this combination firing, the firewood consumption was reduced to less than 50% (Sumaryono 1992, Sumaryono 1997), by using bituminous coal. This firing method was practiced in brick and tile burning, limestone calcination and up to now in tobacco drying in Lombok. Coal was combusted in the form of lumpy coal or powdered into less than 0.5 mm. The combination firing was carried out in a furnace furnished with grate or no grate. In limestone calcination, the combination firing was carried out in a high turbulence combustion chamber using powdered coal. Higher energy efficiencies were achieved by the combination firing.

Because of the bituminous coal depletion in Indonesia in this moment, sub bituminous coal would be used in the combination firing with firewood. It is parralel with the government policy to increase the coal contribution in energy mix plan 2025 (Edy Prasodjo, 2011). The experiment on the use of sub bituminous coal was performed in tile, brick and limestone burning using the same kilns capacities those were used previously.

Received : 05 December 2011, first revision : 09 January 2012, second revision : 03 February 2012, accepted : February 2012

THEORETICAL BACKGROUND

The burning of tile, brick and limestone has been described elsewhere (Sumaryono, et al., 1992; Sumaryono, 1997). There are different characteristics in the combustion of sub-bituminous and bituminous coal. The steps of combustion process are:

Step 1: drying process of the coal. Normally, sub-bituminous coal contains larger moisture than the bituminous coal. Therefore it needs longer time for sub-bituminous coal to dry. After the moisture has been evaporated, the heat promotes devolatilization reactions of coal.

Step 2: the sub-bituminous coal emits more oxygenated volatile species than that of the bituminous coal which emits larger molecular weight hydrocarbons. The larger hydrocarbons are more difficult to combust than those of light hydrocarbons. In an improper combustion appliances burning of larger hydrocarbons emits more smoke than the burning of light hydrocarbons, indicating an incomplete combustion.

Step 3: the volatile combustion which is governed by the rate of volatiles mixing with oxygen. After the volatiles have been combusted, volatiles release is largely compleeted, and residual char is produced.

Step 4: the burning of residual char. The combustion of residual char is controlled by oxygen diffusion through the char particle and its temperature (Miller and Tillman, 2008).

The ratio of volatile matter with the fixed carbon of bituminous coal is lower than that of the sub-bituminous coal, therefore the residual char of bituminous coal has a lower porosity than that of the sub-bituminous coal. As a result, the sub-bituminous residual char is more reactive than that of bituminous coal, consequently the sub-bituminous residual char burns faster. The characteristics differences of sub-bituminous and bituminous coal in their combustion affect their combustion characteristics in their combination firing sistems as would be recognized in the following investigation.

EXPERIMENTAL METHOD

Kilns

The testing of sub bituminous coal conducted in combination firing were accomplished in tile, brick and lime burning kilns.

a. Tile burning
   Up draft kiln, capacity of 15.6 ton tile. Furnace volume of 4.7 m^3 of 2 units grateless furnaces, fired from 2 sides of the kiln proceeded into the kiln centre.

b. Brick burning
   Up draft kiln, capacity of 70.4 ton brick. Furnace volume of 5.0 m^3 of 5 units grateless furnaces, fired from 2 sides of the kiln proceeded into the kiln centre.

c. Lime calcination
   Up draft kiln, inner diameter of 3.0 m and the depth of 7.0 m, which was an underground kiln. The capacity of kiln was 100 ton CaCO3, furnished with a hemisphere combustion chamber at the bottom of the kiln. A small hole for the access of the combustion air and the fuel was made on the combustion chamber. The high velocity air entered this small hole, produced a high turbulence condition within the combustion chamber that rendered a high rate combustion of coal and firewood.

Combustion Method

a. Tile and brick burning
   Combination firing of firewood and lumpy coal for tile and brick burning was performed in grateless furnace (Figure 1). The pile of firewood in the furnace acted as grates for coal combustion. In this combination firing, there is a mutual cooperation of :
   - firewood combustion
   - coal volatile flame
   - char combustion

   The firewood combustion initiates the combination firing, and initiates coal volatile burning which then increases the temperature. The combustion of residual char stabilizes the combustion process.

Figure 1. Combination Firing of Coal and Firewood in A Grateless Furnace

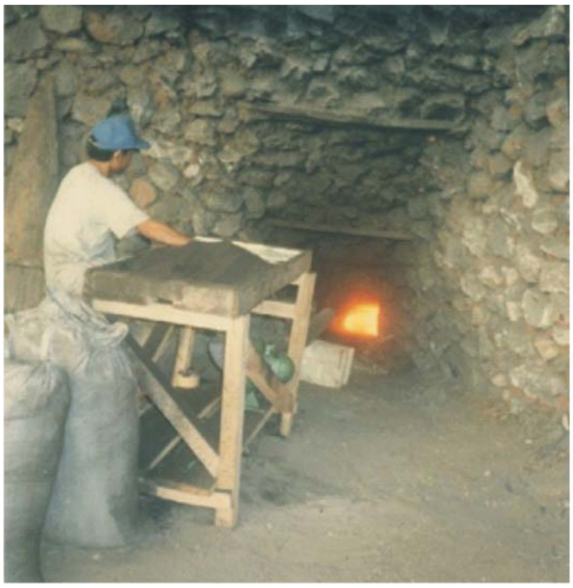

Figure 2. Feeding Into The Combustion Chamber

b. Limestone Calcination
Combination firing of firewood and coal for limestone calcination was performed in a high turbulence combustion chamber. Coal, crushed to be less than 0.5 mm particle size sucked into this chamber by the draught produced the hot limestone bed in the kiln. A suddent change in air velocity in the very small opening in the combustion chamber wall and within the chamber itself produced high turbulence condition.

The turbulence intensity was increased by the presence of firewood set irregularly within the chamber (Sumaryono, 1997). Figure 2 shows the feeding of powdered coal, carried by an air blower into the combustion chamber opening and then it was sucked into the chamber by the draught in the kiln.

Materials

The proximate analysis and calorific value of coal and firewood used are presented in Table 1.

Testing to Use Sub Bituminous Coal

The testings to use sub-bituminous coal for combination firing using firewood and coal were performed in the burning of tile, brick and lime stone calcination, using the same kiln at the same capacity as there were carried out the experiments using firewood and bituminous coal (Sumaryono, et al., 1992 and Sumaryono, 1997). The sub-

Table 1. Proximate Analysis of Coal and Firewood, in air dried basis (a.d.b)

Parameter, unit	Sample				
	Bituminous Coal*)	Sub Bituminous Coal	1st Class Firewood	2nd Class Firewood	4th Class Firewood
Moisture, %	5.1	19.10	15.03	18.83	43.20
Ash, %	17.5	2.16	0.59	0.62	0.36
Volatile Matter, %	39.2	40.65	75.20	71.80	50.24
Fixed Carbon, %	38.2	38.09	9.18	8.75	6.20
Calorific Value, kcal/kg	6040	5745	4000	3788	2618

*) used in the former experiment (Sumaryono, et al., 1992 and Sumaryono, 1997)

bituminous coal used has the calorific value close to the bituminous coal calorific value which was 5745 kcal/kg compared with 6040 kcal/kg for bituminous coal. This may reduce the effect of the difference of heating value of the coals.

The observations of the perfomance test include the fuel composition and the energy efficiencies. For energy efficiency the calculation of the specific heat of tile and brick (Cp) is 0.224 kcal/kg. The dissociation energy of $CaCO_3$ is 1,086 kcal/kg of CaO product.

RESULTS AND DISCUSSION

Results

Tile Burning

Tile burning test was carried out in an up-draft kiln containing 10,000 tiles or 15.6 ton. By combination firing the temperature of the furnace was 900°C and the tile bed at the top was 700°C.

Experiments of the tile burning by firewood and sub-bituminous coal combination firing resulted the consumption of 4,600 kg fourth class of firewood and 840 kg sub-bituminous coal in 15 hours process. It took longer time and consumed more fuel to obtain a temperature of 700°C at the top of tile bed in the kiln, compared with the use of bituminous coal with nearly the same heating value.

The comparison of fuel composition consumed in tile burning using firewood only and combination of coal – firewood is presented in Table 2.

Table 2. Fuel Consumption in 15.6 ton Tile Burning

No.	Fuel	Weight (kg)	Moist. (kg)	Vol. Matter (kg)	Fixed Carbon (kg)	Total Calorie (kcal)	Energy Efficiency (%)
1.*)	Firewood	8,800	3,801	4,421	545	23,038,400	17.5
2.	Firewood Sub-bit. Coal	4,600 840	1,984 160	2,308 341	284 320	12,026,045 4,825,800 16,851,845	25.5
3.*)	Firewood Bit. Coal	4,000 650	1,710 33	1,989 255	245 248	10,462,000 3,926,000 14,388,000	29.9

*) Sumaryono, et al., 1992)

From the experimental data in Table 2 it is clear that energy efficiency increases significantly by burning process using combination firing method. However the increase in energy efficiency was lower when sub-bituminous coal was used, compared with that by using bituminous coal.

Brick Burning

Brick burning test using sub-bituminous coal was performed in an up-draft kiln of 32,000 bricks or 70.4 ton. By combination firing the temperature of furnace was 900°C and the temperature of the bricks bed at the top was 600°C. The burning of 32,000 bricks consumed 7,200 kg second class of firewood and 850 kg sub-bituminous coal in 36 hours process. More fuel was consumed using sub-bituminous coal compared with that by using bituminous coal combined with the second class of firewood. The comparison of fuel composition consumed in brick burning using firewood only and combined fuels is presented in Table 3.

Nearly the same with the result of tile burning, the experiment in brick burning revealed that energy efficiency increased significantly by burning process using combination firing method. The increase in energy efficiency was lower when sub-bituminous coal was used, compared with that by using bituminous coal.

Lime Calcination

Lime calcination test using sub-bituminous coal was accomplished in an up draft kiln containing 100 ton of $CaCO_3$ described in the former paper (Sumaryono, 1997). The calcination of 100 ton

Table 3. Fuel Consumption in 70.4 ton Brick Burning

No.	Fuel	Weight (kg)	Moist. (kg)	Vol. Matter (kg)	Fixed Carbon (kg)	Total Calorie (kcal)	Energy Efficiency (%)
1.*)	Firewood	13,000	2,448	9,334	1,137	49,244,000	27.4
2.	Firewood Sub-bit. Coal	7,200 850	1,356 161	5,169 345	630 323	27,273,600 4,883,250 32,156,850	42.1
3.*)	Firewood Bit. Coal	6,500 600	1,224 30.6	4,667 235	568 229	24,622,000 3,624,000 28,246,000	48.0

*) Sumaryono, et.al., 1992)

limestone to produce quicklime consumed 27,500 kg first class of firewood and 8,500 of kg sub-bituminous coal in 138 hours process. Paralel with the result of tile and brick burning, the use of sub-bituminous coal combined with first class of firewood consumed more energy compared with that by using bituminous coal. The comparison of fuel composition consumed in lime calcination using firewood only and combined fuels is presented in Table 4.

Lime Calcination

Lime calcination test using sub-bituminous coal was accomplished in an up draft kiln containing 100 ton of $CaCO_3$ described in the former paper (Sumaryono, 1997). The calcination of 100 ton limestone to produce quicklime consumed 27,500 kg first class of firewood and 8,500 of kg sub-bituminous coal in 138 hours process. Paralel with the result of tile and brick burning, the use of

Table 4. Fuel Consumption in 100 ton $CaCO_3$ Calcination

No.	Fuel	Weight (kg)	Moist. (kg)	Vol. Matter (kg)	Fixed Carbon (kg)	Total Calorie (kcal)	Energy Efficiency (%)
1.*)	Firewood	50,000	7,510	37,600	45,900	200,000,000	27.2
2.	Firewood Sub-bit. Coal	27,500 8,000	4,133 1,528	20,680 3,252	2,524 304	110,000,000 45,960,000 155,960,000	34.9
3.*)	Firewood Bit. Coal	17,000 6,000	2,555 306	12,784 2,352	1,560 2,292	68,000,000 36,240,000 104,240,000	52.2

*) Sumaryono, et.al., 1997)

Nearly the same with the result of tile burning, the experiment in brick burning revealed that energy efficiency increased significantly by burning process using combination firing method. The increase in energy efficiency was lower when sub-bituminous coal was used, compared with that by using bituminous coal.

sub-bituminous coal combined with first class of firewood consumed more energy compared with that by using bituminous coal. The comparison of fuel composition consumed in lime calcination using firewood only and combined fuels is presented in Table 5.

Table 5. Fuel Consumption in 100 ton $CaCO_3$ Calcination

No.	Fuel	Weight (kg)	Moist. (kg)	Vol. Matter (kg)	Fixed Carbon (kg)	Total Calorie (kcal)	Energy Efficiency (%)
1.*)	Firewood	50,000	7,510	37,600	45,900	200,000,000	27.2
2.	Firewood Sub-bit. Coal	27,500 8,000	4,133 1,528	20,680 3,252	2,524 304	110,000,000 45,960,000 155,960,000	34.9
3.*)	Firewood Bit. Coal	17,000 6,000	2,555 306	12,784 2,352	1,560 2,292	68,000,000 36,240,000 104,240,000	52.2

*) Sumaryono, et.al., 1997)

Discussion

From the experiment data presented in Table 2; 3 and 4 some interesting tendencies are recognized.

1. Compared the combustion using firewood only and combination firing of firewood and coal, there is a tendency of firewood reduction. For brick burning from 13,000 kg to 6,500 kg or 50% reduction. For tile burning from 8,800 kg to 4,000 kg or 54.5% reduction and for lime burning from 50,000 kg to 17,000 kg or 66% reduction.

   It is interesting that the tendency is parallel with the coal combustion quality in the kiln. The worst combustion condition is in brick burning kiln, since the raw brick contains higher water content. The water vapour reduces the draught of the up draft kiln, therefore the velocity of combustion air is reduced so the rate of coal combustion is low. In tile burning kiln, the raw tile contains less water content, so that the draught in tile burning kiln is better. A higher velocity of combustion air makes a better coal combustion in tile burning. The best coal combustion condition is in the lime calcination kiln since in this kiln coal is combusted in the form of powder in a high turbulence condition. This condition guarantees a high rate coal combustion. The best coal combustion condition in lime burning makes the highest reduction of firewood consumption.

   The coal substitution in combination firing or firewood reduction compared with the use of firewood alone in the burning process is 600 kg for 6,500 kg firewood or 9.2% in brick burning, and 650 kg for 4,800 kg firewood or 13.5% in tile burning. In lime calcination 6,000 kg of coal substitutes 33,000 kg firewood or 18.2%. The more the substituted of firewood, the higher the percentage of coal is required. It indicates the important role of firewood in the combination firing. It is a mutual cooperation.

   The use of sub-bituminous coal substituted less firewood than the use of bituminous coal in the combination firing. In the brick burning (Table 3), the use of 850 kg of sub-bituminous coal reduced 5,800 kg of firewood or 6.82 kg firewood for 1 kg sub-bituminous coal consumed. Based on the same calculation, the substitution of firewood using sub-bituminous coal in the brick, tile and lime burning were 6.82; 5.0 and 2.81 kg of firewood respectively for 1 kg of coal consumed. Whereas the values were 10.8; 7.4 and 5.5 kg of firewood respectively for 1 kg of bituminous coal consumed. This meant that bituminous coal substituted more firewood than that the use of sub-bituminous coal in this combination firing. This may be realized more clearly in the calculation presented in Table 6 below, that reveals, the firewood substitutions by coal using sub-bituminous coal for tile, brick and lime burning are 47.7, 44.6 and 45.0% respectively while the substitutions using bituminous coal are 54.5, 50.0 and 66.0% respectively.

2. It is a clear difference revealed from this experiment in the use of bituminous or sub-bituminous coal in the coal-firewood combination firing. The difference in calorific value (Table 1), the sub-bituminous coal has 4.9% lower calorific value than that of the bituminous coal, however the energy efficiency decreases sig-

Table 6. Substituted Firewood in Combination with Sub-Bituminous and Bituminous Coal

Commodity	Firewood Consumption in Firewood Firing	Firewood Consumption in Firewood Sub-Bituminous Coal Combination	Substituted Firewood	Firewood Consumption in Firewood Bituminous Coal Combination	Substituted Firewood
	Kg	Kg	%	Kg	%
Tile	8,800	4,600	47.7	4,000	54.5
Brick	13,000	7,200	44.6	6,500	50.0
Lime	50,000	27,500	45.0	17,000	66.0

nificantly when sub-bituminous coal is used in the combination firing. Lower increase in energy efficiencies were obtained when sub-bituminous coal was used in the combination firing rather than the use of bituminous coal as it is showed in Table 7 below. Compared with the use of firewood alone the increase in energy efficiencies using combination firing of firewood and sub-bituminous coal in tile, brick, and lime burning were 45.7, 53.6 and 28.3% respectively. While in the use of bituminous coal, the increase were 70.8, 75.1 and 91.9% respectively.

Since the difference in calorific value is only 4.9%, the higher energy efficiency using bituminous coal may come from the difference in hydrocarbon characteristics. The bituminous coal has more higher hydrocarbons than the sub-bituminous coal, which has more oxygenated species (Miller and Tillman, 2008). The combustion of higher hydrocarbon emits luminous flame having high radiative flame.

In coal carbonization experiment using Rexco process, the bituminous coal and sub- bituminous coal were carbonized (Sumaryono 1994). The sub-bituminous coal produced only 0.8% tar and the bituminous coal produced 4.5% tar, this meant that the sub-bituminous coal has lower large molecule hydrocarbon volatiles.

It is interesting that the decrease in energy efficiency is more significant in lime calcination. It may be explained that the combustion temperature in lime calcination using powdered coal is higher than that in tile and brick burning, in average of 1,200°C compared with 800°C in tile and 750°C in brick burning. At higher temperature, radiative heat transfer is more important (Lienhard IV and Lienhard V, 2006), therefore the luminous flame emitted by higher molecular weight hydrocarbons liberated by bituminous coal plays significant role in the energy efficiency of calcination process. In this situation, sub-bituminous coal's inferiorities become obvious.

3. In the combination firing there is a mutual cooperation of firewood and coal, especially high rank coal. In the last century, Europeans fireman burned high rank coal by previously sprayed the coal with water. By this mean the

Table 7. The Increase in Energy Efficiency Using Combination of Firewood with Sub-Bituminous and Bituminous Coal

Commodity	Energy Efficiency, Firewood alone	Energy Efficiency, Sub-Bituminous – Firewood Combination	Increase in Energy Efficiency	Energy Efficiency, Bituminous – Firewood Combination	Increase in Energy Efficiency
	%	%	%	%	%
Tile	17.5	25.5	45.7	29.9	70.8
Brick	27.4	42.1	53.6	48.0	75.1
Lime	27.2	34.9	28.3	52.2	91.9

smoke emission was reduced which meant that the combustion of volatiles especially high hydrocarbons was improved. It may be explained that at high temperature H2O produces radicals improving the combustion of coal volatiles (Liston Setiawan, et.al., 2009). In this combination firing, much water vapour is produced from firewood. In the brick, tile and lime burning, the smoke emission is negligible, indicated a complete and clean combustion.

Another evidence was revealed in a coal combustion on a travelling grate (RBU, 2005) (Figure 3). A bituminous coal and a lignite were combusted on this grate (Table 8).

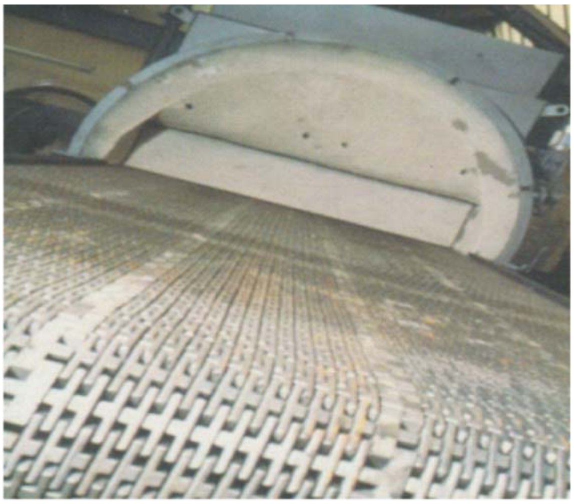

Figure 3. Travelling Grate

Table 8. Proximate Analysis of a Bituminous Coal and Lignite, air dried basic (a.d.b.)

Parameter, Unit	Sample	
	Bituminous Coal	Lignite
Moisture, %	1.95	35.87
Ash, %	3.56	13.03
Volatile matter, %	21.51	27.73
Fixed carbon, %	72.92	23.37
Calorifie value, kcal/kg	7,086	3,415

In the burning of lignite on this grate, unstable combustion was performed as the lignite has a high moisture content and a low calorific value. This fuel was broken into small particles, reducing the bed permeability, therefore the air supply through the fuel bed was inhibited. A different case was showed by bituminous coal combustion. Smoky flue gas was emitted from chimney, indicating incomplete combustion of the coal, especially the combustion of the coal volatiles. Bituminous coal volatiles containing more heavy hydrocarbons (Miller and Tillman, 2008) which are difficult to be combusted perfectly, rendering smoke emission. An interesting thing was showed in the combustion of a blend of 50 % bituminous coal and 50 % lignite. A stable and smokeless combustion was performed, indicating a more complete combustion of the volatiles. The moisture from lignite may play its role in this combustion process.

CONCLUSION

From this work it can be concluded, that:

1. Firewood substitution by coal in combination firing, increased with increasing burning temperature according to the sequence : brick, tile and lime burning, which temperatures were 700, 750 and 1,200°C respectively. The substitution by sub-bituminous coal was lower than that by using bituminous coal.

2. By using sub-bituminous coal in combination firing, compared with the use of firewood alone, the increase of energy efficiencies were lower than the use of bituminous coal in combination firing.

3. Since the sub-bituminous and the bituminous coal used had nearly the same calorific value, the superiority of bituminous coal over the sub-bituminous coal might come from the bituminous coal's higher content of high hydrocarbons that having more radiative flame.

REFERENCES

Prasodjo, E., 2011. Indonesian Coal Mining: Some strategic issues, Fifth Coal Trans: Coal Mining Operation and Upgrading, *Coal Conference*, Jakarta.

Setiawan, L., Umar, D.F., Kuswara, T., Hanafiah, N., Mahfud, A., 2009, Optimasi Teknologi Pembuatan dan Pembakaran CWF, *Laporan Intern tekMIRA Bandung*.

Lienhard IV, J.H., Lienhard V, J.H., 2006. *A Heat Transfer Textbook, 3rd Ed.*, Phlogiston Press, Cambridge, USA.

Miller, B.G., Tillman, D.A., 2008. *Combustion Engineering Issues*, Elsevier, Burlington.

RBU, 2005. *Boilers with automatic chain grate firing, Brochure*, Bekasi.

Sumaryono, Aslya, D., Hanafiah, N., 1992. Pengembangan Bahan Bakar Kombinasi Batubara – Kayu Untuk Pembakaran Bata/Genteng Dalam Tungku Tradisional, *Buletin PPTM, Bandung, Vol. 14 No. 8*, p. 1-11.

Sumaryono, 1994. Karbonisasi Batubara Pada Temperatur Rendah Dengan Sistem Rexco, *Proceeding Kolokium Hasil Kegiatan Penelitian Bidang Pertambangan Umum*, PPTP, Bandung, p. 175-185.

Sumaryono, 1997, Pembakaran Kapur Dengan Kombinasi Batubara – Kayu Dalam Tungku Berkala Dengan Rongga Pembakaran Berturbulensi Tinggi, *Seminar Nasional Fisika Terapan dan Lingkungan*, LIPI, Serpong, p. 55-61.