

# Comparison of metallurgical coke and lignite coke for power generation in Thailand

Sudlop Ratanakuakangwan<sup>1,\*</sup> and Somkiat Tangjitsitcharoen<sup>1</sup>

<sup>1</sup>Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand

\*Corresponding author: Sudlop.Ra@student.chula.ac.th

**Abstract.** This paper presents and compares two alternatives of cokes in power generation which are the metallurgical coke with coke oven gas and the coke from lignite under the consideration of the energy and the environment. These alternatives not only consume less fuel due to their higher heat content than conventional coal but also has less SO<sub>2</sub> emission. The metallurgical coke and its by-product which is coke oven gas can be obtained from the carbonization process of coking coal. According to high grade coking coal, the result in the energy attitude is not profitable but its sulfur content that directly affects the emission of SO<sub>2</sub> is considered to be very low. On the other hand, the coke produced from lignite is known as it is the lowest grade from coal and it causes the high pollution. Regarding to energy profitability, the lignite coke is considered to be much more beneficial than the metallurgical coke in contrast to the environmental concerns. However, the metallurgical coke has the highest heating value. Therefore, a decision making between those choices must be referred to the surrounding circumstances based on energy and environment as well as economic consideration in the further research.

## 1. Introduction

According to Thailand energy situation in 2015, more than 60 percent of natural gas are used in the power generation which causes the dependency of one particular fuel. However, the Thailand Power Development Plan 2015-2036 (PDP2015) has formulated the policies focusing on fuel diversification by reducing the use of natural gas in power plant and increasing the clean coal and the alternatives energy [1].

Coke is a porous carbonaceous material that naturally has higher heating value than coal. There are two main types of coke which are the petroleum coke and the metallurgical coke. Petroleum coke or pet coke is a by-product of petroleum refining industry. It is usually used in power generation but it releases higher SO<sub>2</sub> in the air than other sources in contrast to metallurgical coke or met coke [2 - 3].

Met coke and coke oven gas (COG) are produced inside coke oven chamber from coking coal. COG is a source of energy and is generally used to preheat the blast furnace. Lately, it become more common that COG is employed in the gas turbine cogeneration for producing electricity which means that the production from coking coal yields both met coke and COG that both can be utilized in power generation [4].

On the other hand, the coke can also be made from long-flamed lignite coal. Making the lignite coke upgrades the quality of fuel which means that it will require less amount. Producing lignite coke might be another source of energy for the power generation in the near future [5].



The aim of this paper is to propose and compare the uses of different coals in power generation from metallurgical coke with coke oven gas and lignite coke as a fuel. Those alternatives will be considered based on energy and environment aspects.

## 2. Classification of coals

Coal has four major compositions which are fixed carbon, ash, volatile matters and moisture. The fixed carbon content represents the heating value (HV). The higher proportion of fixed carbon, the higher HV it has. According to coal components, coal can be divided into four types which are anthracite, bituminous, sub-bituminous and lignite. The approximate components of these coals are shown in Table 1 [5 - 6].

**Table 1.** Types of coal by components

<b>Components</b>	<b>Anthracite</b>	<b>Bituminous</b>	<b>Sub-Bituminous</b>	<b>Lignite</b>
Fixed carbon (%)	85 - 98	45 - 85	35 - 45	20 - 35
Ash content (%)	10 - 20	3 - 12	≤ 10	10 - 50
Moisture (%)	< 15	2 - 15	10 - 45	30 - 60
Sulfur (%)	0.6 - 0.8	0.7 - 4.0	< 2	0.4 - 1.0

Besides classification of coal compositions, coal can also be identified by application into two types, thermal coal and coking coal. Normally, the thermal coal is used in power generation because of its low cost and abundant sources around the world. On the other hand, the amount of coking coal is less which leads to higher cost and it has the caking property that is required for producing the steel. Therefore, the coking coal is the material for making metallurgical coke which is used in blast furnace for steel production [6].

## 3. Met coke production

In the process of coal carbonization to met coke, coking coal is heated within the range of 900°C to 1200°C without the absence of oxygen inside the coke oven chamber [7]. During this process, the volatile matters leave the coal mass which is called coke oven gas [4]. The energy consumed for coking process is about 3.5 GJ/ton of coke [8]. The transfer ratio from coking coal to met coke and COG is shown in the Table 2 [4].

**Table 2.** Transfer ratio from coking coal to met coke and COG

<b>Coking Coal (ton)</b>	<b>Met Coke (ton)</b>	<b>COG (m<sup>3</sup>)</b>
1	0.7	354.2

As a result of the met coke process, the percentage of fixed carbon inside coke will be increased due to the reduction of volatile matters and moisture. Referring to the use of high grade coking coal, the estimated components of coking coal and met coke are illustrated in Table 3 [3, 9 - 11].

**Table 3.** Components of coking coal and met coke

<b>Components</b>	<b>Coking coal<sup>3</sup></b>	<b>Met coke<sup>4</sup></b>
Fixed carbon (%)	55.35	87.65
Ash content (%)	8.99	8.85
Volatile matters (%)	27.83	0.75
Moisture (%)	7.83	2.75

<sup>3</sup> Average data from [3] and [9]

<sup>4</sup> Average data from [10] and [11]

## 4. Lignite coke production

The Lignite is pulverized and fed into the heating boilers using fluidized bed technology through drying, pyrolysis and partial gasification process. The volatile matters that vaporizes from the lignite

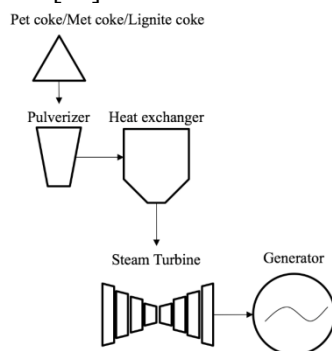
can be obtained above the bed. It has rich thermal energy that will be burned to maintain the high temperature inside the boilers. It is estimated that 1 ton of lignite can generate the thermal energy of 6,276 MJ. The lignite coke or thermocoke which is the solid residue left under the bed is gathered. The amount of thermocoke obtained compared to the input of lignite is in the ratio of 4:1. Hence, both lignite coke and thermal energy are produced in the same boiler [5]. The components of lignite and lignite coke are expressed in Table 4 [5].

**Table 4.** Components of lignite and lignite coke

Components	Lignite (Input)	Lignite coke (Output)
Fixed carbon (%)	20 - 22	74.2
Ash content (%)	7 - 8	8.2
Volatile matters (%)	45 - 48	10
Moisture (%)	33	7.6

### 5. Comparison of pet coke, met coke and lignite coke

Pet coke is the by-product obtained from oil refinery. Due to its low cost and high heating value, it is usually used in power generation. Power generation of pet coke, met coke or lignite coke is done by sending one of them which is pulverized into fine particles and then sent into a furnace with air for a combustion. Thermal energy from the furnace is used to heat water into steam to rotate the turbine to generate electricity as shown in Figure 1 [12].



**Figure 1.** Simple power generation process from pet coke, met coke or lignite coke.

The characteristics which are determined the usability of coke in power generation are the components and the hardness. Hardgrove Grindability Index (HGI) is a measurement of the hardness of coke. The lower index means the higher grinding energy is required for that particular coke before used in power generation. Normally, pet coke's HGI lies between 35 and 45 [13].

HGI can be calculated using the following formula;

$$\text{HGI} = 105 - R (1.16 + 0.002R) 0.4A \quad (1)$$

Where R is the summation of the percentage of volatile matters and moisture. A is the percentage of ash content [14]. Using the components of met coke and lignite coke, the HGI of them is calculated in the formula (1). The characteristics of pet coke, met coke and lignite coke are shown in Table 5.

**Table 5.** Characteristics of pet coke, met coke and lignite coke

Components	Pet coke <sup>5</sup>	Met coke	Lignite coke
Ash content (%)	0.3 - 5.0	8.85	8.20
Volatile matters (%)	8 - 15	2.75	10.00
Moisture (%)	2 - 10	0.75	7.60
<b>HGI</b>	<b>35 - 45</b>	<b>91</b>	<b>36</b>

<sup>5</sup>From [15]

With the similarity of the components and HGI of pet coke, met coke and lignite coke shown above, the met coke and lignite coke both can be used as a fuel in power generation as well as the pet coke with the different heating contents.

## 6. Monitoring of energy and environment hazard

### 6.1 Energy profitability

Tables should be centred unless they occupy the full width of the text.

The Higher Heating Value (HHV) or Gross Calorific Value (GCV) of coal can be calculated by following formula;

$$\text{HHV (MJ/kg)} = 37.777 - 0.647M - 0.387A - 0.089VM \quad (2)$$

Where M, A, VM are the percentage of moisture, ash, and volatile matters inside the coal, respectively. As the components mentioned above, the HHV of coking coal, met coke, lignite, lignite coke and pet coke are calculated using formula (2) as shown in Table 6 [16].

**Table 6.** Higher Heating Value of coal and coke

Components	Coking coal	Met Coke	Lignite <sup>6</sup>	Lignite coke	Pet coke <sup>7</sup>
Ash content (%)	8.99	8.85	7.50	8.20	2.65
Volatile matters (%)	27.83	0.75	33.00	7.60	11.5
Moisture (%)	7.83	2.75	46.50	10.00	6.00
<b>Higher Heating Value (kJ/kg)</b>	<b>26,755</b>	<b>32,506</b>	<b>9,385</b>	<b>28,796</b>	<b>31,846</b>

<sup>6</sup> Average from Table 3.

<sup>7</sup> Average from Table 4.

The energy profitability is calculated by the differentiation of energy input required and energy output of both process. The energy input is consisting of coal and energy required for the carbonization processes. The energy output is including coke type, by-product and excess energy output. The energy profitability is shown in Table 7.

**Table 7.** Energy profitability between met coke and lignite coke

		Properties	Met Coke	Lignite coke
<b>Energy Input</b>			<b>Coal</b>	
	Coal Type		Coking coal	Long-flamed Lignite
	Coal HHV (kJ/kg)		26,755	9,385
<b>Energy Output</b>			<b>Energy</b>	
	Energy Input <sup>8</sup> (kJ/kg coal)		2,975	1062.5
			<b>Coke</b>	
	Coke Type		Met Coke	Lignite coke
	Coke HHV (kJ/kg)		32,506	28,796
	Amount (kg/kg coal)		0.7	0.25
			<b>By-product</b>	
	By-product		Coke oven gas	-
	By-product HHV (kJ/m <sup>3</sup> )		19,900	-
	Amount (m <sup>3</sup> /kg coal)		0.3542	-
			<b>Energy</b>	
	Energy Output (kJ/kg coal)		-	6,276
	<b>Net Energy Profitability (kJ/kg coal)</b>		<b>73</b>	<b>3028</b>

<sup>8</sup> Estimated from [8]

The net energy profitability of the met coke is obtained about 73 kJ/kg of coal while the lignite coke's is 3028kJ/kg as shown in Table 7. Thus, the production of lignite coke is considered to be more profitable in the energy aspect.

### 6.2 Environmental hazard

Coal is considered to be highly-polluted fuel as the high proportion of ash and SO<sub>2</sub> emission. SO<sub>2</sub> which is determined by sulfur content in coal is one of the main environmental problems of coal fired power plant. For example, if all coal fired boilers use low-sulfur coal (less than 0.6 percent) instead of high sulfur coal (more than 3 percent), SO<sub>2</sub> emission would be decreased by 1.5 Mt/year [17].

Regarding to the assumption that does not consider the SO<sub>2</sub> treatment due to the complexity of its process, the sulfur content in coke directly affects the SO<sub>2</sub> emission. Pet coke has the highest sulfur content within the range of 3% to 8% [15]. Met coke tends to have lower sulfur with 0.675% by average weight [3,9] than lignite coke that has the potential to have more sulfur due to the higher proportion of its source from lignite but still less than pet coke.

As mentioned above, it is understood that met coke has the highest heating value as shown in Table 6. Also, met coke emits less SO<sub>2</sub> as compared to lignite coke and pet coke. The comparison of heating value and SO<sub>2</sub> emission is concluded in Table 8. Thereby, met coke is the best alternative under the consideration of heating value and environmental hazard.

**Table 8.** Comparison of heating value and SO<sub>2</sub> emission

Heating Value	SO <sub>2</sub> emission
Met coke > Pet coke > Lignite coke	Met coke < Lignite coke < Pet coke

## 7. Conclusions

This paper proposed and compared alternatives using conventional coal types in a new way under two considerations which are environmental hazard and energy aspect. The first option is to use coking coal in carbonization process in coke oven to produce metallurgical coke and coke oven gas in order to use them in power generation. Another one is to use lignite coke that created from the lowest grade of coal that is lignite. Referring to energy profitability, the production of lignite coke is considered to be more beneficial than met coke in contrast to environmental hazard. Therefore, a decision making between those two choices must consider the specific heating value. Both alternatives increase their heating value which means that they will be needed less number of coke to generate the same amount of power. Met coke has the highest heating value while the lignite coke's is the lowest. For environmental viewpoint, met coke is also inclined to emit the least SO<sub>2</sub> emission. However, an economic evaluation will be considered for the final decision to select which alternatives in the further research.

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