

# Processing of Coal into Coke with the Pyrolysis Method

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**Abstract**— The utilization of coal as a direct fuel can cause environmental problems, such as solid waste in the form of fly ash (flyash). This study aimed to process coal into coke using the pyrolysis method in the hope of increasing the quality and efficiency of coal while ensuring its environmental safety. The research was conducted in three stages. The first stage involved crushing and sieving the coal, testing its proximate and ultimate properties, and analyzing its calorific value. In the second stage, the coal was prepared and subjected to pyrolysis using a set of pyrolysis tools. The pyrolysis process was conducted at approximately 400°C, using a stainless reactor with a volume capacity of 16 liters. The pyrolysis continued until no more liquid smoke was produced. Finally, in the third stage, the resulting coke product was crushed and tested for its proximate and ultimate properties, including moisture content, ash content, volatile matter, fixed carbon, total sulfur, and calorific value. The results demonstrated that the quality of coal could be improved by processing it into coke using the pyrolysis method. This improvement was evident in the reduced water content, decreased volatile matter, increased fixed carbon content, and enhanced calorific value of the coke product.

**Keywords**— coal; pyrolysis; coke

## I. Introduction

Indonesia's final energy consumption continues to increase in line with increasing economic activity in all sectors, including industry, transportation, households and commercial. Based on Indonesia's 2017-2021 energy balance data from the Central Bureau of Statistics (BPS), the percentage of final energy consumption by energy source in 2017-2021 experienced an average increase of 2.12%. Indonesia's final energy consumption in 2021 will reach 4,768,794 terajoules. The average consumption of energy in Indonesia in 2017-2021, namely fuel (43.27%) is the highest energy consumption followed by electricity (18.81%), coal (15.54%), LPG and gas refineries (7.32%), and Primary Biomass Energy (5.38%). Based on

these data, coal is one of the most widely used fuels for energy consumption in Indonesia [1].

Coal is a natural resource that is abundantly available. Coal reserves in Indonesia are very abundant compared to petroleum, the Ministry of Energy and Mineral Resources records Indonesia's total untouched coal reserves of 31.7 billion tons in 2021 with the largest number of reserves found in Palu, Sumatra and Kalimantan Island and a small portion is in Sulawesi, Papua. and Java [2]. Based on these data, the availability of coal in Indonesia is more than the availability of oil and natural gas. However, its use is still focused on the energy sector and is rarely used as raw material for the chemical industry.

Coal is a deposit of carbonaceous organic compounds that are formed naturally from plant residues and can be burned. Coal has several types, namely anthracite, bituminous, sub-bituminous and lignite. The distribution of coal types is divided into primary energy producing sources and secondary energy producing sources [3].

The use of coal for domestic purposes (Domestic Market Obligation/ DMO) continues to increase, recorded in 2013 the utilization for DMO was 72 million tons, in 2014 it was 76 million tons, in 2015 it was 86 million tons and in 2016 it was recorded 91 million tons. Until now, the use of coal in Indonesia, both for energy and non-energy purposes, is not competitive compared to petroleum, it is still limited to direct combustion in the cement industry, iron and steel industries, pulp and paper, other industries. covering textile, food, tile, brick and manufacturing factories as well as heat energy and fuel

for power plants (PLTU) as well as export needs. Apart from this, coal is also used in the form of briquettes to meet the needs of households and small industries. Although Indonesia has not yet implemented coal utilization technology like other developed countries, it is hoped that in the future it will be able to develop coal utilization technology which can contribute to the chemical and petrochemical industries given the increasing price of petroleum and the dwindling amount of petroleum reserves. as stated by the World Energy Council (WEC) in 2013 estimates that the world's oil reserves are only sufficient for the next 56 years [4].

Until now, coal production activities in Indonesia have only been digging and selling, for this reason it is necessary to increase added value as has been done in other countries, including China which has converted coal into jet fuel. Increasing the added value of coal in Indonesia can be done by processing coal with the pyrolysis process [5].

Utilization of coal as a direct fuel in the form of powdered solids can cause environmental problems from solid waste in the form of fly ash (flyash). A study that examined the water quality of the Cisadane River, Tangerang City, based on the use of coal in Indonesia as a direct fuel, has a negative effect on the environment [4].

Pyrolysis is a technology that can provide solutions to optimize the use of coal that is safe for the environment. Therefore, the utilization of coal must be further increased, one way that is quite potential and can reduce the negative impact on the environment is to convert coal into an environmentally friendly fuel. The technology that can convert coal into gas, liquid and solid fuels that is feasible to develop is the pyrolysis process [4].

Pyrolysis can increase the efficiency of coal. Coal is pyrolyzed into various products with better use value. Pyrolysis converts coal into solid, liquid and gaseous products through a thermal pre-composition process under limited air conditions. The solid product produced from the coal pyrolysis process is coke.

The development of pyrolysis technology is one of the technologies to increase the added value of coal which

produces syncrude oil, high quality coal, and COG (Coke Oven Gas), where syncrude oil can be further processed into fuel or chemical products such as BTX (Benzene, Toluene, Xylene) [6].

Pyrolysis is a process of chemical decomposition of materials by heating in the absence of oxygen or a small amount of oxygen. Pyrolysis is an alternative technology for converting organic waste into biomass which can be used as an alternative fuel. With this pyrolysis technology we can handle organic waste, make the environment healthier so that it becomes a zerowaste activity and makes it a final product with added value. All products from pyrolysis can be used as environmentally friendly fuels [7].

In the pyrolysis process, coal is thermally cracked to produce fuel in the form of liquid, gas and solid (char). Gas and liquid fuels produced from the coal pyrolysis process no longer contain contaminants so that when used as fuel they do not cause environmental pollution problems due to fly ash [4]. Therefore, this study aimed to process coal into coke using the pyrolysis method in the hope of increasing the quality and efficiency of coal while ensuring its environmental safety.

## II. Research Methodology

### A. Materials

This study used a set of pyrolysis tools in the form of a reactor, heater, condenser, gas cylinder, thermocouple, temperature controller, pressure controller, and Erlenmeyer. The materials used in this study are coal as a raw material and LPG as an energy source.

### B. Methods

This research was conducted in the following 3 stages:

Phase I: Coal crushing, coal sieving, proximate and ultimate coal testing (moisture content, ash content, volatile matter, fixed carbon, total sulfur), and analysis of the calorific value of coal.

Phase II: Coal preparation, pyrolysis of coal using a pyrolysis kit. Pyrolysis was operated at  $\pm 400^{\circ}\text{C}$  using a stainless reactor with a reactor volume capacity of 16

liters. Pyrolysis is carried out until no more liquid smoke is produced.

Phase III: Crushing of coke products, proximate and ultimate testing of coke (moisture content, ash content, volatile matter, fixed carbon, total sulfur), and analysis of coke calorific value.

### III. Results and Discussion

The coal that was processed into coke was first crushed with a crusher to reduce the size of the coal from chunks to powder. Then, the coal was sifted to obtain fine-sized coal powder. The coal was further refined to meet the requirements as a sample for analysis of its proximate, ultimate, and calorific value. The crushed coal was subsequently analyzed for its proximate and ultimate content, including moisture content, ash content, volatile matter, fixed carbon, total sulfur. Additionally, its calorific value was determined through analysis. The results of coal testing can be seen in Table 1.

Table 1. Coal Testing Results

Parameter Testing	Test Results
Water content	10,09 %
Ash Content	10,31 %
Flying Substance	39,34 %
Bonded Carbon	40,26 %
Total Sulfur	2,008 %
Calorie Value	6053 kkal/kg

The coal to be pyrolyzed was crushed using a crusher to reduce its size. The purpose of reducing the size was to enhance the heat contact with the coal and facilitate the formation of liquid smoke, as well as to facilitate the evaporation of substances and the escape of volatile matter.

Pyrolysis is a process of decomposition of the compounds that make up the material into several organic compounds through a dry combustion reaction without oxygen. This reaction takes place in a pyrolysis reactor that works at a certain temperature and time [8].

This research processes coal into coke using a set of pyrolysis tools arranged as shown in Figure 1.

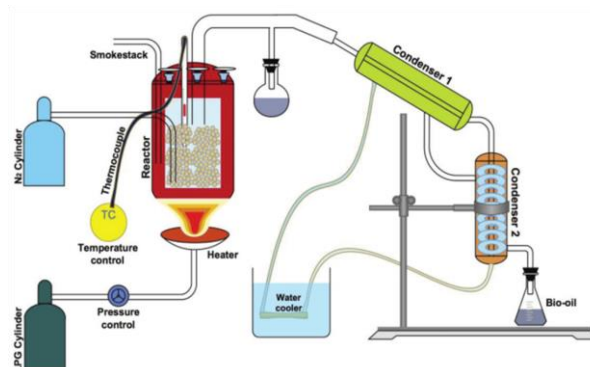


Figure 1. Series of Pyrolysis Equipment [9]

The pyrolysis process was conducted at approximately 400°C, which was determined by adjusting the heat capacity of the pyrolysis tool utilized in this study. Coal pyrolysis generates three types of products: liquid smoke, tar, and coke. Among these products, coke was the most abundant, while the amounts of liquid smoke and tar produced from the coal pyrolysis process were relatively small. Subsequently, the resulting coke was subjected to analysis to assess the impact of pyrolysis on the quality of coal during the conversion into coke. The test results for the resulting coke products are presented in Table 2.

Table 2. Coke Product Test Results

Parameter Testing	Test Results
Water content	1,11 %
Ash Content	11,20 %
Flying Substance	37,31 %
Bonded Carbon	50,38 %
Total Sulfur	2,216 %
Calorie Value	6888 kkal/kg

Based on research data in Table 1 and Table 2, a large decrease in water content was obtained from 10.09% to 1.11%. Pyrolysis reduces the water content of 8.98% in coal. This decrease was due to the evaporation of water during the pyrolysis process which condensed with liquid smoke. If viewed from the pyrolysis temperature at 400°C, all the water should have evaporated but in fact there was still water left, this was due to the water being

reabsorbed from the air during the product storage process [10].

Based on the research data presented in Table 1 and Table 2, there is no significant difference in the ash content. This was because when the same sample of coal and coke was burned under identical operating conditions, they would yield the same amount of ash. The coke retained the total ash content of the original coal after undergoing pyrolysis.

When viewed from the calorific value, the smaller the ash content, the higher the calorific value. From the research results, it was known that the calorific value of sawdust was higher than that of coal so that it has a small ash content even though the difference in calorific value was not significant [10].

Based on research data in Table 1 and Table 2, the volatile matter content decreased from 39.34% to 37.31%. This was caused by the loss of some of the volatile matter in the coke product after pyrolysis. Pyrolysis temperature of  $\pm 400^{\circ}\text{C}$  has been able to remove some of the volatile matter in coal.

Volatile matter comprises combustible gases like hydrogen (H), carbon monoxide (CO), and methane (CH<sub>4</sub>). The reduction in volatile matter is not substantial due to the relatively moderate pyrolysis temperature employed. This characteristic is beneficial for coke quality as a fuel source because volatile matter is an active component present in coal that generates energy or heat during combustion. Consequently, volatile matter acts as a catalyst, expediting the combustion process [11].

Based on research data in Table 1 and Table 2, there is a large increase in Fixed Carbon from 40.26% to 50.38%. The increase in Fixed Carbon occurred due to a decrease in water content and volatile matter content. The value of fixed carbon greatly affected the quality of a coal, because the higher the value of fixed carbon, the quality of the coal increased.

Fixed carbon is the amount of carbon contained in the remaining material after the volatile matter is removed. Fixed carbon content is the fraction of carbon (C) which is bound in products other than the fraction of water, ash

and volatile matter. The value of bound carbon content is obtained by calculating the sample weight (100%) minus the total moisture content, ash content and volatile matter content [10].

The research data from Table 1 and Table 2 indicate that there is no significant difference in sulfur content. Both coal and coke samples exhibited a sulfur content of approximately 2%. Sulfur content is a crucial factor as it has significant implications for environmental impact, particularly in terms of SO<sub>2</sub> emissions. Therefore, it is important to ensure that the sulfur content remains below the established threshold. Arman (2018) suggested that high sulfur content in coal can be mitigated by blending it with biomass materials like sawdust. This approach enables the sulfur content to meet the required criteria (SNI), such as achieving a sulfur content below 1%. Arman proposed a coal-to-sawdust biomass ratio of 25:75, resulting in a sulfur content below the specified threshold [10].

Based on research data in Table 1 and Table 2, there is a large increase in calorific value from 6053 kcal/kg to 6888 kcal/kg. The calorific value is the amount of heat that can be released by each kilogram of coal when it is completely burned. The increased calorific value makes coke products of higher quality to be used as fuel. High calorific value can increase the effectiveness and efficiency of fuel use.

#### **IV. Conclusion**

The quality of coal can be enhanced through the pyrolysis method, which involves processing it into coke using a stainless reactor at a temperature of approximately 400°C. This process yields several improvements, including a reduction in water content, a decrease in volatile matter, an increase in fixed carbon, and an elevation in calorific value. These changes serve as evidence for the enhanced quality of the resulting coke product compared to the original coal.

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