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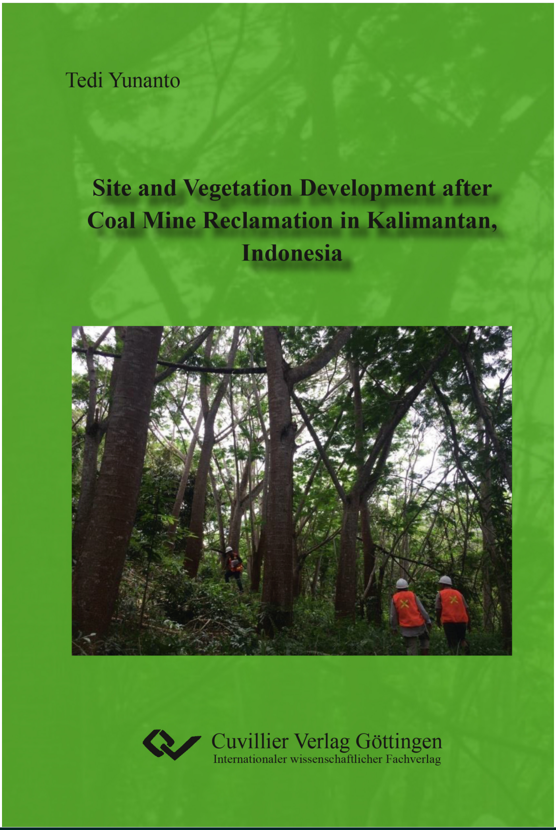
Site and Vegetation Development after Coal Mine Reclamation in Kalimantan, Indonesia



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1 Introduction

1.1 Coal

1.1.1 Definition

Coal is a rock composed of organic and inorganic materials, which contains 50% or more than 75% organic material (Fig. 1). The organic matter mostly consists of carbon (C), but is also comprised of hydrogen (H), oxygen (O), sulphur (S) and nitrogen (N). Besides organic matter, coal contains some inorganic compounds (minerals) and water (H_2O). Naturally, coal is formed from vegetation that has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years to ultimately form coal seams (World Coal Institute, 2005).

Fig. 1: Coal seam in PT Borneo Indobara, Tanah Bumbu Regency, South Kalimantan Province, Indonesia
Source: Directorate General Mineral and Coal (2018)

There are two principal phases in coal formation, namely the biochemical process of peatification and the geochemical process of coalification. The biochemical process of peatification is the initial stage of coal formation, the partially decayed organic matter is accumulated and stored in a flooded swamp area at a depth of approximately 0.5 m to

10 m below the surface water. The organic matter is converted into peat through the anaerobic activities of bacteria and fungi. Petersen *et al*. (2003) report that peat-forming conditions influence the abundance and thickness of coal seam.

The geochemical process is the most dominant procedure in the coalification stage. The coalification process produces a variety of coal rank, namely lignite, sub-bituminous, bituminous and anthracite. This stage involves an increase in temperature, pressure and time, which fundamentally raises the percentage of carbon content in the original organic matter. In contrast, the content of hydrogen and oxygen in the organic matter is reduced. Stach (1982), cited in Nursanto (2011), states that the most important factor in the coalification stage is the gradual increment of the geothermal gradient, burial depth and time.

1.1.2 Coal rank

Coal rank refers to the slow and natural process called “coalification", whereby buried plant material is turned into a drier, denser, harder and carbon-rich material (Schweinfurth, 2009). Based on this process, the five types of coal rank are: peat, lignite, sub-bituminous, bituminous and anthracite. Characterised by energy produced, coal is classified into two types: brown coal (lignite and sub-bituminous), which has a water content of 10 - 70% and calorific value of 7,000 calorie/gram (dry ash free); and hard coal (bituminous and anthracite), which has a low water content and calorific value of > 7,000 calorie/gram (dry ash free) (The National Standardization Agency of Indonesia, 1998).

Peat is not classified as a type of coal; however it can be used as a source of energy. This type of coal is the precursor to coal formation and displays the basic properties of key herbal components. Peat is usually porous and has a high water content (greater than 70%) and a very low calorific value, such as the natural peat’s water content in Hokkaido, Japan, which is approximately 115 - 1,570% (Khaidir and Yasufuku, 2014).

Lignite is also known as brown coal. Lignite is the lowest grade of coal and is usually used as fossil fuel for power plants. Generally, lignite or brown coal is a very soft coal and contains approximately 35 - 70% water; however, in some areas, lignite has a water content as low as 11%, for example in Turkey (Amirabedin *et al*., 2014). Furthermore, sub-bituminous coal is commonly used to generate heat for steam-electric power plants. Sub-bituminous is also an important raw material resource for making aromatic hydrocarbons for the synthetic chemical industry. Sub-bituminous contains less carbon, has a high water content and is a less efficient source of heat compared to other bituminous types. Imad *et al.* (2014) report that the mean calorific values of sub-bituminous measured at Makarwal, Kallar Kahar and Dandot in Pakistan were as high as 6,801, 5,624 and 6,415 Btu/lb or 3,781, 3,127 and 3,566 kcal kg^{-1} (1 Btu/lb = 0.555927 kcal kg^{-1}), respectively.

Bituminous coal is a solid mineral, which is black and sometimes dark brown in colour. Often used to generate heat for steam-electric power plants, bituminous contains 68 - 86% carbon (C), and has a water content of 8 - 10% by weight and a relatively high calorific value. For example, the heating value of bituminous in the Galandrud and Central Alborz regions of northern Iran is 7,430 - 8,880 kcal kg^{-1} (Ardebili *et al.*, 2015).

Anthracite is the highest grade of coal, containing 86 - 98% carbon (C) (Takanohashi, 2016). It also has a water content less than 8%. This type of coal has a hard structure and a shiny surface and is often used for household and industrial purposes.

1.1.3 The use of coal

Over recent decades, coal has become one of the most important energy sources used by developed countries. In general, coal is also used by various developing countries, especially by those that do not have petroleum resources. Coal is still one of the cheapest forms of energy and is well suited for developing countries such as Indonesia, China and India. In general, coal is widely used as a fossil fuel that is usually crushed and then burned in a furnace using a boiler. Around 51% of Indonesia's energy derives from coal (Centre for Energy and Mineral Resources Data and Information of Indonesia, 2013). It also powers other industries, such as the chemical, paper, plastics, metal, steel, ceramics, coal tar and fertiliser industries (Sun, 2010). The leaders of worldwide coal production are not limited to only one continent. Currently, the five largest coal producing countries in the world are China, United States (US), India, Australia and South Africa. The coal generated is largely used within the country of production: only 18% of coal production is aimed at the international coal market.

Coking coal, also known as metallurgical coal, is commonly used in the steel making process and is different from the thermal coal used to generate electricity (Anglo American, 2008). There are two principal raw materials when producing steel: iron ore and coke. Coke is used to convert iron ore into molten iron. The quality of coke is determined by the quality of the coking coal used (Sun *et al*., 2012), as well as the operating conditions of the coking plant. There are several factors that affect the quality of coke, such as the grade (rank) of coal, composition, mineral content and the ability of coal to soften when heated. It takes roughly 1.5 tons of metallurgical coal to produce a ton of coke.

The act of converting coal into a gas product rich in elements of CO and H_2 allows the coal to be used as a fossil fuel in the chemical industry. Since 1792, the gas generated from the coal gasification system has been widely used as a source of lighting. Alongside technological advances, there is also the intention to produce synthetic liquid fuels from low-grade coal (Shevyrev *et al*., 2015). There are several advantages to the application of gasification technology, namely the reduced dependence on oil-utilisation, the increased value of coal, a greater number of work opportunities and a boost to the national economy.

One of the success stories of the coal gasification system is the coal, oil and gas corporation of South Africa, otherwise known as SASOL, which currently produces 55 million Nm^3/day of synthetic gas and 150 thousand barrels of synthetic oils per day using the Fischer-Tropsch synthesis process. Furthermore, through the Fischer-Tropsch process, the gasification process can produce methanol; during which the methanol can be mixed into direct fuel or converted into gasoline.

Coal can be converted into solid, liquid or gas products when undergoing the process of pyrolysis, during which the material undergoes thermal treatment during the absence or near absence of oxygen (Rađenović, 2006). The amount of products produced depends on the temperature and type of coal used during the pyrolysis process. At high temperatures, coal undergoing a pyrolysis or refining process will produce coal liquids, i.e. coal tar or light crude oil. Meanwhile, it will also produce elements of hydrogen, methane, ethylene, carbon monoxide, carbon dioxide, hydrogen sulphide, ammonia and nitrogen. Some chemical products can be produced from coal by-products, such as coal tar which, when purified, can be used in the manufacturing of other chemicals, such as creosote oil, naphthalene, phenol and benzene (Jiang *et al*., 2007). Ammonia gas generated from the heating of coke coal can be used to manufacture ammonia salts, nitric acid and agricultural fertilisers. Furthermore, thousands of different products can be produced from coal by-products such as soaps, aspirin, solvents, dyes, plastics and fibres, rayon and nylon.

1.2 Coal mining system

1.2.1 Surface mining

The two main systems of coal mining are surface mining and underground mining. Currently, underground mining produces approximately 60% of worldwide annual coal production, although some coal is produced by countries using a surface mining system. Open-pit mining in Australia produces approximately 80% of coal production compared to roughly 67% in the US (World Coal Institute, 2005). In contrast, more than 95% of coal production in China is produced through underground mining.

Generally, the selection of coal mining methods is highly dependent on: a) regional geological conditions such as overburden layer characteristics, coal rock characteristics, and geological and hydrological structures; b) coal seams and deposit forms; and c) economic and technological considerations.

The surface mining system is a means of extracting minerals, such as coal, iron ore, and stones, whereby workers are in direct contact with the air and external climatic conditions. Based on tonnage and field application, open-pit and open-cast mining techniques are widely used in surface mining (Hartman, 1987). The open-pit and open-cast methods apply a conventional mining cycle in order to extract coal or minerals. In general, the surface mining system exerts drilling and blasting operations in order to damage rocks (overburden), followed by the excavation and hauling of overburden. To expose the mineral layer, disassembled layers of overburden are subsequently transferred or transported to a disposal area. In this method, the process of stripping and mining of mineral deposits is carried out from one or more sequences of benches. Meanwhile, in open-cast mining, the disassembled layers of overburden are not transported to the disposal area, but rather taken and hauled directly into an adjacent mined-out panel (Hartman, 1987). The process begins with tree removal, land clearing, soil removal, overburden removal, extraction of mining commodities and land reclamation. Meanwhile, the many benefits of open-pit mining are as follows: lower costs, healthier and safer, more efficient and effective in terms of mechanical equipment, lower risks of explosion due to methane gas and an overall higher coal output.

1.2.2 Underground mining

Underground mining is a mining system, whereby workers and mining work activities are in indirect contact with the air and external climatic conditions. The underground mining system, in its application, is strongly influenced by several aspects, i.e. the strength, physical or mechanical properties of the sediment, the slope of sludge and the thickness of the sediment. The underground mining system accounts for only 4% of mined non-metallic ores, 13% of excavated metals and 42% of coal products (Hartman, 1987).

The underground mining system is divided into three methods: unsupported, supported and caving methods. Unsupported methods are the most widely used underground mining systems: almost 80% of the mineral production of the US comes from this underground system. Today, the supported method is scarcely used, while caving methods are increasingly popular (Hartman, 1987).

One of the unsupported methods is the room and pillar mining method. In this method, the openings of the mine area are conducted orthogonally and at regular intervals in a mineral deposit. In addition, for natural support they are usually flat-lying (or not far from), tabular and relatively thin forming rectangular or square pillars. Because of the mineral's natural condition, the room and pillar method is ideally suited to the underground production of coal commodities (Hartman, 1987).

One of the underground systems included as the caving method used for coal extraction is the long-wall mining method. In this method, the exploitation method uses fairly flat-lying, thin, tabular deposits, in which a long face is built across a panel between sets of entries and retreated or advanced by narrow cuts, aided by the complete caving of the roof or hanging wall (Hartman, 1987).

1.2.3 Coal mining system in Indonesia

In Indonesia, coal exploitation generally uses an open-pit or open-cast mining method. Over 95% of coal mining companies that use surface mining systems are licensed by either the local or central government. According to regulations from the Ministry of Forestry (now known as the Ministry of Environment and Forestry - MoEF), the use of open-pit mining on protected forests is strictly forbidden (Law of Republic Indonesia No. 41, 1999). In general, the underground mining system used for coal production is usually illegally carried out by individuals. There are five verified coal mining companies that are using an underground mining system in Indonesia, namely PT Fajar Bumi Sakti, PT Gerbang Daya Mandiri and PT Gunungbayan Pratamacoal Block II in East Kalimantan, PT Bukit Asam in South Sumatra, and PT Merge Mining Industry in South Kalimantan.

Open-pit mining commences with tree removal (if forest area), land clearing, soil removal, overburden removal, coal getting and reclamation. Tree removal is a part of the land clearing phase of the mining operation. Referring to the MoEF's data from 2008 to March 2013, the total area of forest leased to the mining industry reached 2.9 million hectares. There are approximately 2.5 million hectares of forest used for mining survey/exploration and 380,000 hectares used for exploitation/production-operation (Forest Watch Indonesia (FWI), 2014). The mining company should undertake a forest inventory of tree species before harvesting trees (Fig. 2).

In addition to inventorying tree species, the company must collect natural seeds from the forest floor, then store and maintain them in its nursery. The stored seeds will be used during the reclamation process for future planting activities, or as a source of further seedlings (cuttings, grafting, etc.). Mining companies are allowed to use trees that have been logged in forest areas by applying to the MoEF for permission.

Fig. 2: Removal of trees in PT Tambang Tondano Nusajaya, Manado City, North Sulawesi Province, Indonesia
Source: Directorate General Mineral and Coal (2018)

Land clearing, which is carried out before mining operations can begin, includes tree removal and clearing of shrubs or reeds. Land clearing is influenced by several aspects, namely the growing tree's condition, soil bearing capacity, topography, rainfall, machinery requirements and costs. In order to establish good mining practices and safe conditions, land clearing should be conducted in accordance with the company's mining plan (only prospective areas are cleared). The area of land clearing should be marked with flags and the clearing activities should be carried out only during daylight, with the exception of those days when rainfall has occurred. Land clearing should be supervised by a qualified supervisor. Trees with < 30 cm in diameter can be felled with a dozer under normal conditions, whereas trees with > 30 cm diameter should be felled with a chainsaw. After land clearance, trees with > 20 cm diameter should be drawn and collected in a log yard, then calculated and reported to the MoEF.

The removal of soil then takes place after land clearing (Fig. 3). In general, the mining company removes the soil that consists of a mixture of topsoil and subsoil. Topsoil is an upper layer of soil that contains many essential nutrients for plant growth during the revegetation process. If the soil is not directly spread for reclamation activity, the mining company must maintain and manage the soil in a soil bank. In order for the amount of soil not to decrease or even disappear due to erosion and sedimentation, the soil bank should be encompassed by a cover crop. The mining company should also conduct deep soil tests, which can usually be accomplished by carrying out a test pit. This test is carried out using an excavator and digs the soil until the layer thickness is up to 2 m. Each soil horizon is documented to determine the depth of the soil that can be picked up and moved. In addition to using excavators, some mining companies exert soil drilling methods and use a Munsell Soil Colour Chart Book to determine the depth of the soil layer in order to prevent the loss of soil nutrients.

Fig. 3: Removal of soil in PT Borneo Indobara, Tanah Bumbu Regency, South Kalimantan Province, Indonesia
Source: Directorate General Mineral and Coal (2018)