# Coal Gasification and Coal Microscopic Characteristics in Tanjung Baru, Lahat Regency, South Sumatera

## Basuki Rahmad, Sugeng Raharjo, Ediyanto, and Gerhana Prasetya Putra

Department of Geological Engineering, Faculty of Technology Mineral, Universitas Pembangunan Nasional
"Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta 55283 Indonesia

*E-mail*: b_rahmad2004@yahoo.com; basukirahmad@upnyk.ac.id

### *Abstrak*

*The location of research is located in the Tanjung Baru Area, Lahat Regency, South Sumatera. The Geological setting of the Tanjung Baru Area in the South Sumatra Basin is included in the Muara Enim Formation the age is Middle Miocene to Late Miocene. Coal in the Tanjung Baru Area, has a calorific value of 5089-5321 Kcal / kg and is rank High in Bituminous Volatile C-High Volatile Bituminous B according to the ASTM classification. Average quality (proximate test) of Muara Enim Formation coal: total sulphur 0.36-1.49% (adb); 1.28-2,5% ash (adb); inherent moisture 9-11% (adb); volatile matter 38.7-42.4% (adb); fixed carbon 45.5-47.9% (adb), total moisture 28.1-28.8% (Ar); relative density 1.28. Coal Charactersitics of Coal Tanjung Baru the macerals average are vitrinite (92,4% vol.); liptinite (2.9% vol.); inertinite (5,7% vol.). Each macerals or group macerals has different physical and chemical properties. The variation of composition microscopy showed the changes of plant communities or coal facies leading to varies of coal quality, with a average vitrinite reflectance value 0.47-0.58, generally the coal rank is subbituminous-bituminous. Coal gasification is the process of converting coal into synthesis gas. One of the gas produced is a flammable methane gas. Gasification is raw fuel, in this case coal is partially oxidized to produce a product called combustible gas. The main product from the gasification product is synthesis gas or syngas, consisting of Carbon Monoxide (CO), Hydrogen (H$_2$), Methane (CH$_4$), Carbon Dioxide (CO$_2$) and Nitrogen (N$_2$).*

*Keywords: coal, macerals, gasification, synthesis gas, CO, H$_2$, CH$_4$, CO$_2$, N$_2$*

## Introduction

Gasification is a process that convert carbonaceous materials, such as coal, petroleum, petroleum coke, or biomass, into carbon monoxide and hydrogen (Wikipedia, 2006). The gaseous products are further processed for use as an energy source or as a material for the production of a variety of chemiclas and/or liquid fuels. Coal gasification as a power generation technology is gaining popularity due to the ready global availability of the raw material (coal), as well as positive environmental issue associated with this technology over other combustion technologies. To ensure optimal process efficienc, an in-depth understanding of the coal properties influencing gasification behavior is required. Gasification performance is dependent on coal type (organic/coal microscopic characteristics and inorganic composition) and gasifier configuration, both of which are discussed in the following discussion, the former in more detail. Alternative gasification technologies are briefly discussed.

Although it has now generally ben replaced by natural gas, manufactured gas (or town's gas) of medium specific energy has been produced in many areas by traditional carbonization of coal in special types of retorts. Town's gas, however, is only one of a range of fuels of differing compositions and specific energies that can be obtained from coal. Depending on the type gasifier and the conditions of gasification, gas produced from coal can be used in virtually all applications where natural gas or fuel oil is including utility boilers, industrial boilers, gas turbines, brick kilns, iron ore processing, steel treatment furnaces, glass furnaces and reciprocating internal combustion engines. Modem gasification is mainly directed towards producing either synthesis gas (syngas) a mixture of CO and H$_2$, or synthetic natural gas (SNG), consisting solely of methane. Syngas can be used to make a variety of product, such as methanol, while synthetic natural gas can be fed directly into natural gas grid systems to supply the domestic, industrial and electric utility markets.

## Process and Methods For Coal Gasification

Gasification is defined as the reaction of solid fuels with air, oxygen, steam, carbon dioxide, or a mixture of these gasses at temperatures exceeding 800$^o$C in reducing environment where the air : oxygen ratio is controlled. Heat and pressure break apart the chemical bond in the molecular structure of the coal, setting in motion chemical reactions

Prosiding Seminar Nasional Teknik Kimia "Kejuangan"
*Pengembangan Teknologi Kimia untuk Pengolahan Sumber Daya Alam Indonesia*
Yogyakarta, 14 - 15 Juli 2020

ISSN 1693-4393

with the steam and oxygen (Coal Utilization Research Council, 2006). The yield is gaseous product suitable for use as : an energy source, or as a raw material (syngas) for the production of chemicals, liquid fuels, or other gaseous (Collot, 2006), or a combination of these. Reffered to as synthesis gas (or syngas), this primarily consists of carbon monoxideand hydrogen. The chemical composition of the gas produced depend on coal composition and rank, coal preparation (specifically particle size distribution and ash content), gasification agent (oxygen : air : steam ratios), gasification conditions (heating rate, residence time, temperature, pressure), and plant configuration (flow geometry, feed form, mineral behavior, syngas cleaning).

It is generally assumed that the gas phase in a gasifier is controlled predominantly by the equilibrium of the water-gas shift reaction, of which the amount of carbon present in the gas phase is the important driver. Thus, an understanding of the carbon conversion process is essential for calculating water-gas shift reactions and gas concentrations and is key in predictive gasification modelling (Harris et al., 2006). At higher temperature under pressure, a greater degree of carbon conversion occurs, and the extra carbon in the gas phase affects the equilibrium in the reaction such that the CO and $H_2$ levels are higher at the expense of $CO_2$. The study of fundamental coal gasification reactions is gaining momentum as the popularity of gasification as a coal conversion process increases.

Most gasifiers can be grouped in one of three groups according to the type of reactor bed in which the coal is gasified, namely: (1) fixed bed or moving bed, (2) fluidized bed, or (3) entrained flow gasifiers (King, 1981; Collot, 2002, 2006; higman and van der Burgt, 2003 in Suarez-Ruiz and Crelling, 2008). Others types of gasifiers have been developed but are not yet near commercialization. Examples include rotary kiln gasifier and molten bath gasifiers (Collot, 2002, 2003 in Suarez-Ruiz and Crelling, 2008). The design of gasifier affects its ability to handle particular feedstocks and the condition in which the feedstock can be fed into the vessel, oxidant and steam requirement, and gas outlet temperature and composition, as summarized in Table 1. The select the optimum gasification process for a specific application, important factors need to be considered, including feedstock characteristics, quality requirement for clean gas, the quality of waste products, operating characteristics, and environmental legislation.

The chemical and physical properties of a coal are directly related to gasifier behavior, and detailed analyses of coal are for predicting gasification performance when a specific coal source or mixtures of coal resources are to be gasified.

**Table 1.** Operating parameters for generic types of gasifiers (compiled from SFA Pacific, 2000; Simbeck et al., 1982 in Suarez-Ruiz and Crelling, 2008)

| | Fixed/moving bed | Fluidized bed | Entrained bed |
|---|---|---|---|
| Depiction | | | |
| Preferred feedstock | Lignite, reactive bituminous coal, wastes | Lignite, bituminous coal, cokes, biomass, wastes | Lignite, reactive bituminous coal, petcokes |
| Coal feed size (mm) | <50 | <6 | <0.1 |
| Ash content | No limitation slagging type <25% preferred | No limitation | <25% preferred |
| Operating temperature (°C) | Co-current 700–1200 Counter-current 700–900 | Dense <900 Circulating <900 | 1500 |
| Scale | co-current <5 MW$_t$ counter-current <20 MW$_t$ | Dense 10<MW$_t$<100 Circulating 20<MW$_t$<? | >100 MW$_t$ |
| Exit gas temperature (°C) | 420–650 | 920–1050 | ±1200 |
| $CO_2$ in dry raw gas | 26–29 | 18 | 6–16 |
| $CH_4$ in dry raw gas | 8–10 | 6 | <0.3 |
| $H_2$/CO ratio | 1.7–2.0 | 0.7 | 0.7–0.9 |
| Ash conditions | Dry/slagging | Dry/agglomerating | Slagging |
| Tars produced | co-current - low counter-current mod-high | intermediate | absent |
| Key distinguishing characteristic | Hydrocarbon liquids in the raw gas | Large char recycle | Large amount of sensible heat energy in the hot raw gas |
| Key technical issue | Utilization of fines and hydrocarbon liquids | Carbon conversion | Raw gas cooling |

In complete gasification, coal reacts with a gasifying agent, such as steam or oxygen. The organic material is converted into gas and ash is left as a residue, usually in the form of either dry powder or molten slag depending on the gasifier system. Study of the fate of the elemental carbon in the coal provides a convenient way to monitor the gasification reactions and to compare the gasification rates of different coals.

Two of these ractions, the water gas reaction and the Boudouard reaction are endothermic. To gasify 1 t of carbon by the water gas process requires an amount of heat equivalent to burning a further 0.29 t of carbon, while in the Boudouard reaction, which plays an important role in blast furnace operations, an additional 0.40 t of carbon is required.

Gasifiers may be classified on the basis of the method used to generate heat for the gasification reactions. In autothermal gasifiers, the heat required as generated in the reactors by using steam dan oxygen as the gasifying agent. The oxygen causes combustion of part of the coal and thus provides reaction heat, while the steam reacts with the other part of the coal to form water gas. Autothermal reactor types include fixed bed, fluidized bed and entrained bed gasifiers.

Allothermal processors are those in which the heat required for the gasifications reactions is generated external to the reactors. This heat can be provided by external combustion chambers burning coal gases or cabonization products, and is transferred to the gasifier by superheated stream, stream-gas mixtures or solid heat carriers. Another concept under development uses a high temperature nuclear reactor to heat helium gas which is fed to the gasifier. This system eliminates to need to use any 'external' coal for heat generation purposes.

Many different systems of gasification have been developed over the years, and some of these are currently in commercial operation. Others are under development with the object of achieving higher thermal efficiencies and lower levels of capital investment. These gasifiers differ from each other with respect to the following features:
a.  The type and rank of coal which can be used;
b.  The size distribution of the coal;
c.  The gasifying agent (e.g. steam – oxygen, steam – air, hydrogen);
d.  The flow pattern of the reactants and products;
e.  The residence time of the coal;
f.  The reaction temperature and pressure

## Discussion

As is well known, coal is a heterogeneous mixture of organic and inorganic constituents, and it is from the organic component that syngas is generated during gasification. The inorganic component has a significant impact on gasifier performance, where certain minerals can act as catalysts, other as inhibitors, depending on the gasification technology and the type of mineral.

Gasification of coal occurs in two stages, namely: (1) rapid pyrolysis devolatilizing the coal and char formation, and (2) char reaction. If the heating rate is slow, devolatilization is followed by gasification; if the heating rate is fast, the two processes may occur simultaneously .

All the will go through a pyrolysis stage during conversion, when gases and higher hydrocarbons are released. Refer to Gavala (1982) and Berkowitz (1985) in Suarez-Ruiz and Crelling (2008) for in-depth discussions on coal pyrolysis.

Devolatilization occurs between 350°C and 800°C, and the rate is dependent on the heating rate, particle size, pressure, and reaction with the gasification agent.

The water-gas shift, Boudouard, and hydrogenation reactions govern the overall conversion rates during the char reaction stage; refer to Higman and van der Burgt (2003) in Suarez-Ruiz and Crelling (2008) for models describing these reactions. The rate of the gasification reaction is influenced by the particle siz, internal surface area, and morphology (structure) of the char, and char consumption is the controlling process in gasification.

The subsequent rate of char combustion will significantly influence the release of the heat, temperature profiles, char burnout characteristics, and unburned carbon in the ash.

Gasification performance is dependent on the type of the coal and gasifier configuration. Typically, the most relevan coal properties are elemental composition (organic and inorganic), surgace characteristics and porosity, and intrinsic reactivity (van Heek and Muhlen, 1986 in Suarez-Ruiz and Crelling, 2008), but the importance of coal properties will differ depending on the different gasifier designs.

The following analyses must be performed for appropriate characterization of coal: proximate, ultimate aand sulphur analysis, particle size distribution, thermal fragmentation (atmospheric pressure), Fischer Assay/Gray-king assay for tar or oil production, caking propensity (swelling index), reactivity, analysis of pore size and surface area of chars, and determination of petrographic properties (rank by vitrinite reflectance, maceral, microlithotype and mineral group analysis, degree of weathering, and char morphology).

Coal microscopic characteristics enables the optical consideration of coal and carbon via which the evolution of char structures, and hence the changes during the carbon conversion process, can be determined. The maceral content significantly affects char formation, which is also affected by the role of temperature, pressure, residence time, and particle size (Zhou et al., 2000 in Suarez-Ruiz and Crelling, 2008), so more detailed discussion of coal microscopic characteristics are:
a.  Rank determination. Vitrinite reflectance analysis is required to determine the rank of a coal (lignite, subbituminous, bituminous, coking, or anthracite). Coal rank affects hydrogen and oxygen ratios as well as gasifier performance. Char morphology formation is largely rank dependent.

b.  Macerals, microlithotype, and mineral group analyses conducted on coals for gasification are based on the ISO standards for petrography. All three analysis are useful in comparing new coal feeds to current sources, determining blend composition, organic and inorganic associations, major mineral groups, and any anomalies that may arise from the chemical analyses or coal performance during gasification. Parent coal properties significantly influence the resultant char formation (Wagner and Jouber, 2005; Harris et al, 2006 in Suarez-Ruiz and Crelling, 2008), and, as with combustion, char morphology can be predicted from the initial maceral and microlithotype composition. Char type has a significant impact on pyrolysis and gasification, and coals with a high volatile content generally have a lower char yield.

Vitrinite and inertinite differ in pyrolysis behavior, affecting the char yield and morphology. Wall et al., 2002, in Suarez-Ruiz and Crelling, 2008 demonstrated that the proportion of porous chas increased with with the increase in vitrinite content in the parent coal al all pressures, and the proportion of vitrinite in a particle will influence the porosity of the char particle. Megaritis et al., 2002, in Suarez-Ruiz and Crelling, 2008 concluded that the gasification of inertinite begins at a later stage than liptinite and vitrinite, and inertinitechars were found to have high gasification reactivity with a longer residence time. Liptinite and vitrinite convert rapidly during pyrolysis and exhibit plasticity, whereas inertinite retains its rigid, well-defined porous structure through the gasification zone. Wall et al., 2002, in Suarez-Ruiz and Crelling, 2008 also demonstrated that inertinite is capable of displaying high fusibility similar to vitrinite under condition of high pressure (15 atm). Similar results were reported for coal particls of 4 – 4.75 mm by Matsouka et al., 2005, in Suarez-Ruiz and Crelling, 2008.

Vitrinite is a result of the process of pembatubaraan humic material derived from cellulose ($C_6H_{10}O_5$) and lignin plant cell walls containing wood fibers such as stems, roots, leaves, and roots. Most of the vitrinite macral group originates from the acid-humic fraction of the humic core, in the form of dark compounds from complex compositions.The compound contains elements of carbon, oxygen, hydrogen and nitrogen. Vitrinite has a variety of heavy and soluble molecules, has an aromatic nucleus and contains functional groups of hydroxyl (-OH) and carboxyl (-COOH). The compound is formed during peatification and mouldering, even partially in the brown coal stage, mainly from plant cell walls in the form of lignin and cellulose. In addition to the original material, the formation and characteristics of humic acid are dependent on environmental conditions related to the redox potential value (eH) and pH (Figure 1, Table 2)

The inertinite group is thought to come from plants that have been burned (charcoal) and some are thought to be due to the oxidation process from other maceral or decarboxylation processes caused by fungi or bacteria (biochemical processes). With this process the inertinite group has a relatively high oxygen content, low hydrogen content, and an O/C ratio higher than the vitrinite and liptinite groups. Inertinite comes from the word "inert" containing basic elements that are not reactive and contribute to the blending of coking coal such as fusinite, semifusinite and sclerotinite maceral. Inertinite comes from cellulose and lignin from plant cell walls. These constituents undergo fusinitization during bonding (Taylor et al., 1998). The characteristic of inertinite is high reflectivity, little or no flouresense, high carbon content and little hydrogen content, strong aromatics due to several causes, such as charring, mouldering and destruction by fungi, biochemical gelification and plant fiber oxidation (Figure 1).
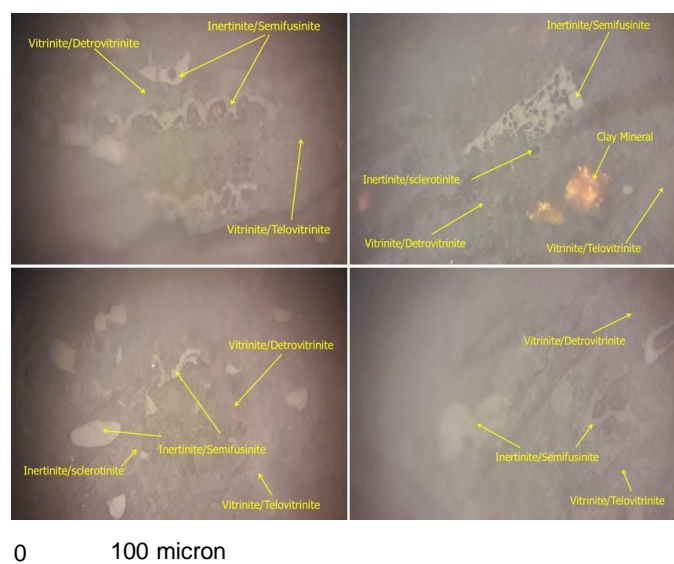


**Figure 1.** Coal Microscopic of Seam-B

**Tabel 2.** Coal Microscopic Composition of Seam-B

| Number Sampel (Seam) | Vitrinite % (Vol) | Liptinite % (Vol) | Inertinite % (Vol) | Mineral Matter % (Vol) | Refektan Vitrinite % (Vol) | Relative Density |
|---|---|---|---|---|---|---|
| B (1) | 91,7 | 2,4 | 5,8 | 1,8 | 0,48 | 1,3 |
| B (2) | 92,5 | 2,7 | 5,1 | 1,8 | 0,47 | 1,27 |
| B (3) | 92,9 | 1,6 | 4,9 | 1,6 | 0,52 | 1,25 |
| B (4) | 92,6 | 2,8 | 4,8 | 1,7 | 0,58 | 1,29 |
| B (5) | 92,9 | 0,9 | 3,7 | 1,9 | 0,54 | 1,28 |

As determined by van Heek and Muhlen (1986), and Zhuo et al., (2000) in Suarez-Ruiz and Crelling, 2008 fusain, due to its inert nature, does not exhibit any changes in size during pyrolysis, whereas vitrain exhibits considerable swelling, increasing the particle size two- to four-fold.

At 90 bar the retained their maximum size, but at lower pressure, the particle shrank again. At high pressures and heating rates for larger particles, the mass transfer to the outer atmosphere is inhibited, the product formed during pyrolysis (tars and volatiles) partially remain, and the grain is no longer capable of shrinking. Durain, containing high amounts of liptinite, exhibited significant shrinkage as the particles rapidly decayed during pyrolysis with the gases and tars escaping before the solidification of the outer shell (van Heek and Muhlen, 1986, in Suarez-Ruiz and Crelling, 2008.

The following proximate analysis must be performed for appropriate characterization of coal (Table 3)

**Tabel 3.** Proximate Analysis of Coal Seam-B

| Number Sampel (Seam) | Total Moisture % (a r) | Moisture Inherent % (adb) | Ash % (adb) | Volatile matter % (adb) | Fixed Carbon % (adb) | Total Sulphur (% adb) | Calorivic Value (adb) Kcal/Kg |
|---|---|---|---|---|---|---|---|
| B (1) | 28,1 | 9 | 1,8 | 38,78 | 45,5 | 0,36 | 5234 |
| B (2) | 28,5 | 9,2 | 1,1 | 41,8 | 47,9 | 1,27 | 5321 |
| B (3) | 28,8 | 9,4 | 1,9 | 42,4 | 46,7 | 1,25 | 5089 |
| B (4) | 28,6 | 10,1 | 2,5 | 40,6 | 46,2 | 1,49 | 5134 |
| B (5) | 28,9 | 11 | 1,28 | 41,5 | 45,9 | 1,28 | 5267 |

**Conclusion**

1. Coal gasification as a power generation technology is gaining popularity due to the ready global availability of the raw material (coal), as well as positive environmental issue associated with this technology over other combustion technologies
2. Gasification performance is dependent on coal type (organic/coal microscopic characteristics and inorganic composition) and gasifier configuration.
3. Gasification performance is dependent on the type of the coal and gasifier configuration. Typically, the most relevan coal properties are elemental composition (organic and inorganic such as coal maceral and coal rank), surgace characteristics and porosity, and intrinsic reactivity
4. Gas produced from coal can be used in virtually all applications where natural gas or fuel oil is including utility boilers, industrial boilers, gas turbines, brick kilns, iron ore processing, steel treatment furnaces, glass furnaces and reciprocating internal combustion engines.

**Acknowledgments**

**References**

Australian Standart-AS 2856-1986. Coal Maceral Analysis. Published by The Standart Association of Australian Standart House. NSW

Stach E, Mackowsky MTh, Teichmuller M, Tailor GH, Chandra D, Techmuller R. Stach's textbook of coal petrology 3th edition. Gebr. Borntraeger, Berlin-Stutgart. 1982: p.38-47

Suarez-Ruiz I, Crelling JC. Applied coal petrology. The role of petrology in coal utilization. Elsevier Ltd All rights reserved. 2008

Taylor GH, Teichmuller M, Davis A, Diessel CFK, Littke R, Robert P. Organic Petrology, Gebruder Borntraeger .Berlin .Stutgart 2008: 704

Ward CR. Coal Geology and Coal Technology, Blackwell Scientific Publications, Singapore. 1984: 134 – 138.

# Lembar Tanya Jawab

**Moderator**  :  **Aditya Kurniawan (UPN "Veteran" Yogyakarta)**
**Notulen**  :  **Yuli Ristianingsih (UPN "Veteran" Yogyakarta)**

1. Penanya  :  Aditya Kurniawan (UPN "Veteran" Yogyakarta)
   Pertanyaan  :  Untuk menghasilkan suhu dan tekanan tinggi apakah prosesnya dilakukan dengan insitu combustion atau diinjeksikan steam dengan tekanan tinggi sehingga tercapai temperatur gasifikasi yg diinginkan?
   Jawaban  :  Utruk mencapai temperatur yang diinginkan kita akan menginjeksikan suatu steam. Steam tersebut yang akan menghasilkan suatu tekanan dan tekanan tersebut yang akn menggerakan beberapa komponen-komponen fluida hidrokarbon sehingga terjadi sebuah migrasi hidrokarbon dan akhirnya akan disedot dan ditangkap ke atas.

2. Penanya  :  Aditya Kurniawan (UPN "Veteran" Yogyakarta)
   Pertanyaan  :  Bagaimana mitigasi gas yang diperoleh dari proses underground gasification agar tidak ada gas metana yang tersebar kemana-mana (dengan kata lain pengendalian gas loses)?
   Jawaban  :  Di underground ada system permeabilitas yaitu tempat untuk mengalirnya fluida agar bisa flowing. Kalo di underground ada yang namanya klit/ crack (retakan) yang berfungsi sebagai makro pori untuk permeabilitas. Yang akan diinjek ada di klit/ crack tersebut dan reaksi tekanan ada di klit tersebut. Klit tsb jika bertekanan maka fluida hidrokarbon akan mengalir melalui klit/ crack tersebut. Jika gasifikasi permukaan akan menggunakan sebuah reaktor untuk proses pirolisis. Dengan reactor pirolisis tersebut batubaranya diremuk menjadi butiran, dan gas tersebut ada di dalam butiran tersebut. Resiko mitigasi sangat rendah karena msih menggunakan tekanan rendah dikarenakan terjadi pada kedalaman rendah.