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Integrating Coal Gasification into Gas Engine Power Plant: A Techno Economic Study at PLTMG Bangkanai

Imam Suwandi, Jenny Rizkiana & Hafis Pratama Rendra Graha

Chemical Engineering, Faculty of Industrial Technology, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
Email: imamsuandi@gmail.com

Abstract. Indonesia aims to achieve a 29% emission reduction by 2030 by reducing its reliance on coal-fired power plants. Gas-fired power plants offer a cleaner option with lower CO_2 emissions compared to coal-fired power plants (PLTU). The Bangkanai Gas Engine Power Plant (PLTMG) with a capacity of 310 MW currently operates with a capacity factor (CF) of only 28.47% due to limited gas supply. The gas demand at PLTMG Bangkanai is 66.04 BBTUD, while the available gas supply is only 20.33 BBTUD. On the other hand, Indonesia has substantial coal reserves, especially on Kalimantan Island, totaling 14 billion tons. This study investigates the technology of converting coal into Synthetic Natural Gas (SNG) to address the gas supply shortage at PLTMG Bangkanai. The coal-to-SNG process includes coal gasification, water gas shift (WGS) reaction, and methanation reaction. The modeling was performed using Aspen Plus software. The gasifier design used is an entrained-flow gasifier with a coal feed rate of 120 t/h, a gasifier temperature of 700 °C, and a pressure of 1 bar. The simulation results show that the SNG product has a high heating value (HHV) of 45.58 MJ/kg and a total gas production of 46.04 BBTUD, which is sufficient to meet the gas shortage at PLTMG Bangkanai of 45.72 BBTUD. The economic analysis for coal-to-SNG processing, including the gas pipeline to the power plant, reveals a CAPEX of US$ 102,120,735 and OPEX value is US$ 107,542,643 per year. The IRR value obtained was 16.18% and the payback period was 5.14 years assuming the SNG selling value was 7.5 USD/MMBTU.

Keywords: *Coal, Gasification, PLTMG Bangkanai, SNG*

1 Introduction

Energy consumption for power electricity generation in Indonesia until 2023 is still dominated by coal (39.69%), oil (29.91%), gas (17.11%), and renewable energy (13.29%) [1]. Although the government has set a target for renewable energy to account for 23% of the energy mix by 2025, coal remains the primary source, with projections of 30% in 2025 and 25% in 2050 [2]. This dependence contradicts Indonesia's commitment to reducing greenhouse gas emissions by 29% by 2030 and achieving Net Zero Emissions by 2060 [3]. As an alternative, Gas Engine Power Plants (PLTMG) offer a cleaner option with lower CO_2

emissions compared to coal-fired power plants (PLTU). However, PLTMG Bangkanai, with a capacity of 310 MW, only operates at a Capacity Factor (CF) of 28.47% due to limited gas supply. The gas demand for PLTMG Bangkanai to achieve 100% CF is 66.04 BBTUD, while the current gas supply is only 20.33 BBTUD, resulting in a gas supply shortage of approximately 45.72 BBTUD. This gas shortage at PLTMG Bangkanai can be mitigated by utilizing gas fuel produced from coal gasification technology, which is proven and widely implemented. Moreover, the location of PLTMG in Central Kalimantan has substantial coal reserves. According to [7], Kalimantan has coal resources of 92 billion tons with reserves of 14 billion tons. This approach aligns with the Indonesian government's program to support the downstream development of mineral and coal products.

This study aims to analyze the use of Synthetic Natural Gas (SNG) derived from the coal gasification process as a solution to optimize the performance of PLTMG Bangkanai, enhance the reliability of the Kalimantan power system, support coal downstream programs, and provide an alternative energy source.

2 Methodology

In this study, a techno-economic analysis will be conducted for the use of SNG from gasification as gas fuel at the PLTMG Bangkanai. The scheme used is that the SNG plant is located in the PT Pada Idi mining area where this mine is the closest mine to the power plant which is about 37 km away. Furthermore, the syngas or SNG results are transferred through a gas pipe. The process that occurs at the SNG plant is simulated using Aspen Plus software. The process diagram at the SNG plant is shown in Figure 1.

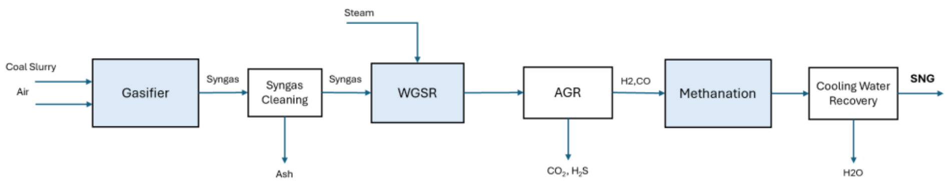

Figure 1 Schematic of SNG production process from coal gasification

The gasifier capacity is calculated based on the output of the SNG produced which will be used to cover the gas supply shortage at the PLTMG Bangkanai of 45.72 BBTUD. The coal to SNG process is simulated using Aspen Plus to determine the capacity and operating parameters of the gasifier, WGSR, Methanation and other utilities to obtain the amount of SNG product needed by the power plant.

The coal used in the simulation is coal originating from Kalimantan with the type low rank coal (lignite-subbituminous) with the results of proximate analysis and ultimate analysis shown in Table 1.

Tabel 1 Proximate and Ultimate Analysis of Coal

Characterization	wt.%, adb	wt.%, db
Proximate Analysis		
Moisture in analysis	13.67	
Ash content	6.43	7.76
Volatile Matter	41.73	48.33
Fixed Carbon	39.40	45.64
Ultimate Analysis		
C	58.14	67.34
H	6.11	4.58
N	0.98	1.14
O	16.65	19.28
Total Sulphur	0.78	0.92
Gross Caloric Value (kcal/kg)		4,073.60

2.1 Simulation Model in Aspen Plus

In the modeling of coal gasification technology used is the entrained flow gasifier type, where coal slurry and air feed are used to convert coal into syngas. The entrained flow type gasifier was chosen because it has been widely used. The modeling flowsheet on aspen plus is shown in figure 2.

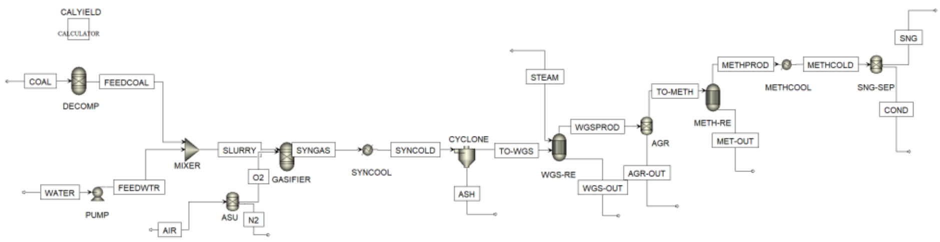

Figure 2 Flowsheet Modelling in Aspen Plus

The high temperature used in the gasification process allows the kinetic barriers to be ignored, where the gas mixture exiting the gasifier approaches equilibrium conditions. Therefore, the gasification process can be modeled accurately using a thermodynamic approach [5]. In this study, a global equilibrium approach was used by ignoring the complexity of the gasifier hydrodynamics. Other assumptions in the model include: Steady state, WGSR (Water-Gas Shift Reaction) and methanation (Methanation Reaction) reactors as isothermal-equilibrium reactors, The gasification reactor is modeled as an adiabatic RGibbs reactor. In addition, the coal drying process is not included in this model. The RGibbs reactor was chosen because of its ability to handle three phases (gas, liquid, solid) in chemical equilibrium conditions, predicting the composition of the equilibrium syngas through minimization of Gibbs free energy. This reactor based on the principle of minimizing Gibbs free energy has been widely used to model gasification reactions [5]. The potential species that may be formed in the RGibbs reactor include: H_2O, N_2, O_2, H_2, C (graphite), CO, CO_2, CH_4, H_2S, NH_3, COS, HCl, and Cl_2. The diversity of these species allows simulation of various types of syngas depending on the input parameters. Modeling of coal into Synthetic Natural Gas (SNG) in aspen plus includes five process hierarchies, namely: feed preparation (SLURRY), gasification (GASIFIER), Water Gas Shift Reactor (WGS-RE), acid gas removal (AGR), and methanation reactor (METH-RE). This simulation uses coal slurry feed and air gasification agent. Aspen Plus cannot handle non-conventional substances, and coal is a non-conventional solid with a complex macromolecular structure [45, 46]. Therefore, the coal stream needs to be hypothetically decomposed into reactive compounds, namely its corresponding constituents (such as C, H_2, N_2, O_2, S, Cl_2, and H_2O) based on their proximate and ultimate analyses. This process is carried out in the yield reactor (DECOMP block). The yield distribution for this reactor has been defined in the calculator block. These expressions determine the mass flow rates of the components in the FEEDCOAL stream. Slurry is then formed by mixing the FEEDCOAL stream with the FEEDWTR inlet stream in the MIXER mixing block, and is fed to the next process stage via the SLURRY stream.

3 Results dan Discussion

3.1 Simulation Result

The results of the modeling simulation on Aspen Plus for coal processing into SNG through coal gasification are expected to produce SNG with specifications that are appropriate or close to the natural gas that has been used so far and the amount needed to cover the gas supply shortage at the Bangkanai PLTMG. Meanwhile, the results of the modeling simulation on Aspen Plus obtained SNG with the composition and specifications as shown in Table 2.

Tabel 2 SNG Composition results from simulation

No	Composition		Mole Fract.	Mass Fract.	Mass Flow (kg/h)
1	Methane	CH_4	0.8628	0.7858	34,897.97
2	Carbon Monoxide	CO	0.1179	0.1875	8,326.55
3	Hydrogen	H_2	0.0028	0.0003	13.99
4	Nitrogen	N_2	0.0166	0.0264	1,170.63

The HHV value of SNG is calculated using equation (1).

$$HHV_{SNG} = \sum_{i=1}^{k} X_i . HHV_i \quad (1)$$

X= mass fraction, i= each gas.

The HHV values for methane and hydrogen are shown in Table 3.

Tabel 3 High Heating Value (HHV) gas specie based on the content of SNG

No	Composition		HHV (MJ/Nm3)	HHV (MJ/kg)
1	Methane	CH_4	39.78	55.53
2	Carbon Monoxide	CO	12.62	10.10
3	Hydrogen	H_2	12.77	141.80
4	Nitrogen	N_2	-	-

By using formula (1) and HHV data for each gas component in SNG, the HHV value of SNG is 45.58 MJ/kg. The SNG pressure of 42 bar is the output pressure from the SNG plant which will then be used for transport to the power plant through piping and by taking into account the pressure drop so that the gas pressure can meet the criteria in the power plant, which is a minimum of 4 bar. If the gas pressure in the power plant is too large, a reducer can be used to reduce the gas pressure. The amount of gas needed in PLTMG Bangkanai is according to table 1, which is 45.72 BBTUD. The amount of energy produced from SNG can be calculated from the multiplication of mass flow and HHV of SNG equation (2).

$$P = m_{SNG} . HHV_{SNG} \quad (2)$$

P is the energy produced, m is the mass. The mass flow of SNG is 44,409 kg/h, so with equation (2) the energy from SNG is 2,023,966 MJ/h or equivalent to 46.04 BBTUD. This amount can cover the shortfall in the amount of gas for the Bangkanai PLTMG which is 45.72 BBTUD.

The data on the temperature and pressure conditions of the reactor and stream used in the simulation so that the specifications and amount of SNG are obtained according to the needs are shown in table 4.

Tabel 4 Temperature and Pressure Parameter of Reactors and Streams

Reaktor	T (°C)	P (bar)
GASIFIER	700	50
WGS-RE	250	49
AGR	250	49
METH-RE	350	42

Stream	T (°C)	P (bar)	Mass Flow (t/h)
COAL	30.00	1.00	120.00
FEED WATER	30.00	5.00	55.92
OKSIGEN	30.00	1.00	12.67
STEAM	250.00	49.00	27.00
SLURRY	37.00	5.00	175.59

To obtain the amount and specifications of SNG that meet the needs of the PLTMG Bangkanai, feed with a coal flow of 120 t/h is required.

3.2 Economic Analysis

3.2.1 Cost Analysis of SNG Plant

The economic analysis of the SNG Plant in this study uses an approach with existing research references. The CAPEX analysis refers to research conducted by Y. Yu, I. L. Chien, 2015 [11], while the OPEX analysis refers to the Great Point Energy report, 2007 [12]. The economic items analyzed include capital investment, fixed operating and maintenance costs (Fixed O&M costs), and variable operating and maintenance costs (Variable O&M costs). The values obtained from the references then need to be equated with the values in 2025 assuming an inflation rate of 3.5%. The cost calculation for the SNG plant is shown in table 5.

Tabel 5 Economic Calculation Results

Cost Criteria	Cost (USD/MMBTU) 2015	Cost (USD/MMBTU) 2025
CAPEX	3.87	5.46

Cost Criteria	Cost (USD/MMBTU) 2007	Cost (USD/MMBTU) 2025
OPEX	3.92	6.40
- Feed stock (*)	0.63	1.76
- Catalyst	0.72	1.02
- By product revenue	(0.70)	(0.99)
- Fixed cost	1.12	1.58
- Financing	2.15	3.03
Total Cost		**11.86**

The feed stock value (coal) has been adjusted to the price of coal received, which is IDR 470/kg with a calorific value of 4073 kcal/kg. With an SNG production capacity of 46.04 BBTUD or equivalent to 16,804 BBTU/year, the economic calculations for CAPEX and OPEX in US Dollars (US$) and Rupiah (IDR) are obtained as shown in table 6 (1 US$ = Rp. 16,543,-).

Tabel 6 CAPEX and OPEX SNG Plant

Cost Criteria	USD/MMBTU	USD	IDR
CAPEX	**5.46**	**91,760,735**	**1,514,052,119,281**
- SNG Plant	5.46	91,760,735	1,514,052,119,281
OPEX/year	**6.40**	**107,542,643**	**1,774,453,607,421**
- Feed stock (coal)	1.76	29,554,315	487,646,200,437
- Catalyst	1.02	17,067,354	281,611,347,425
- By product revenue	(0.99)	(16,593,261)	(273,788,809,997)
- Fixed cost	1.58	26,549,218	438,062,095,995
- Financing	3.03	50,965,017	840,922,773,561

3.2.2 Cost Budgeting Gas Pipeline

The calculation of pipeline investment for gas transfer from the SNG plant to the Bangkanai PLTMG uses an estimated value referring to the gas pipeline project from PT. Perusahaan Gas Negara, Tbk (PGN) [13]. The pipeline cost is US$ 35,000 per km-inch for onshore pipelines and US$ 50,000 per km-inch for offshore pipelines. Additionally, the estimated cost for a compressor is US$ 2,300 per horsepower. The length of the pipe required is considered the same as the distance between the SNG Plant and power plant locations, which is 37 km (figure 3).

Figure 3 Distance between SNG Plant and PLTMG Bangkanai

The pipe diameter used is 8 inches (DN200) which from the pressure drop calculation estimate outlet pressure to PLTMG is 4 bar. Using the basic onshore pipeline price of US$ 35,000 per km-inch, a pipe length of 37 km, and a pipe diameter of 8 inches, the estimated value for pipeline investment is US$ 10,360,000,-.

3.2.3 Economic Analysis Coal to SNG

From the capex value of the SNG plant and piping, the total capex value required is USD 102,120,735. The calculation of the economic analysis for processing coal into SNG which is used as gas fuel at the PLTMG Bangkanai is shown in the table 7.

Tabel 7 IRR and Payback Period

Criteria	Unit	Value
Lifetime	year	20.00
Capacity Factor (CF)	%	80.00
Discount rate	%	10
Inflation rate	%	3
SNG price	USD/MMBTU	7.50
Cash Flow	USD/year	14,793,958
IRR	**%**	**16.18**
Payback Period	**year**	**5.14**

The selling price of SNG is assumed to be 7.5 USD/MMBTU to obtain an attractive IRR. With this price, it is still quite competitive with the price of natural gas that has been used so far, which is 5.6 USD/MMBTU. But the price of SNG will be cheaper when compared to the price of LNG which has a price range of 9-12 USD/MMBTU.

4 Conclusion

Coal processing technology into SNG through gasification, water gas shift reaction, and methanation stages can be implemented to meet gas needs at the Bangkanai PLTMG. The optimal SNG plant capacity is with a coal feed rate of 120 t/h which can produce SNG of 46.04 BBTUD with an HHV of 45,58 MJ/kg. The composition of SNG with a CH_4 content is 86.28% mole fraction and CO 11.79% is still within the fuel specifications permitted at the PLTMG, which is a minimum of CH4 70%.

In the economic analysis, the CAPEX value (SNG Plant and piping) for the using SNG for gas fuel in PLTMG Bangkanai is US$ 102,120,735. And CAPEX value is US$ 107,542. Assuming the selling price of SNG is 7.5 USD/MMBTU, the IRR value will be 16.18% and the payback period will be 5.14 years.

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