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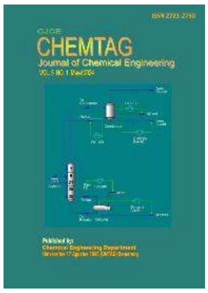

BENZENE PRODUCTION FROM NATURAL GAS IN ARUN GAS FIELD: PROCESS DESIGN AND ECONOMIC EVALUATION

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Abstract

This study designs a benzene production plant from natural gas in the Arun Gas Field, Aceh, Indonesia, with a focus on sustainability and economics. The plant could support Indonesia's government efforts in achieving the Enhanced Nationally Determined Contribution and carbon credit objectives. Using DWSim simulation, the processes modeled consists of natural gas purification, dehydroaromatization reaction, and benzene separation. The results demonstrate high efficiency in producing benzene with a purity of 99.5%-wt. Economic analysis indicates that the investment in this plant is financially viable, with an internal rate of return of 12.2%, a payback period of 7.6 years, and an 8.93% return on investment. By combining sustainability and economic profitability, this research provides a foundation for the implementation of an environmentally friendly and sustainable benzene production plant in the Arun Gas Field.

Keywords: *Benzene; DWSim; Economic analysis; Natural gas; Sustainable production*

Abstrak

Penelitian ini merancang pabrik produksi benzena dari gas alam di Lapangan Gas Arun, Aceh, Indonesia, dengan fokus pada keberlanjutan dan ekonomi. Pabrik ini dapat mendukung upaya pemerintah Indonesia dalam mencapai Kontribusi yang Ditentukan Secara Nasional yang Ditingkatkan dan tujuan kredit karbon. Menggunakan simulasi DWSim, proses yang dimodelkan melibatkan penyulingan gas alam, reaksi dehidroaromatisasi, dan pemisahan benzena. Hasilnya menunjukkan efisiensi tinggi dalam memproduksi benzena dengan kemurnian 99,5%-berat. Analisis ekonomi menunjukkan bahwa investasi dalam pabrik ini layak secara finansial, dengan tingkat pengembalian internal sebesar 12,2%, periode pengembalian modal selama 7,6 tahun, dan tingkat pengembalian investasi sebesar 8,93%. Dengan menggabungkan keberlanjutan dan profitabilitas ekonomi, penelitian ini memberikan dasar untuk implementasi pabrik produksi benzena yang ramah lingkungan dan berkelanjutan di Lapangan Gas Arun.

Kata Kunci: *Benzena; DWSim; Analisis keekonomian; Gas alam; Produksi berkelanjutan*

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1. Background

The Arun gas field is located near Lhokseumawe in the Aceh province of Indonesia and was discovered by Mobil Oil Corporation in 1971 [1]. Recently, there has been new development in the area known as the Peusungan B Gas Field Development Plan, located approximately 7 km from Lhokseumawe Beach [2]. Once operational, this gas field is expected to produce natural gas from 14.5 million to 19.4 million cubic feet per day (MMSCFD) for over 13 years [3].

Natural gas can be processed into various chemical compounds, one of which is benzene. Benzene is widely used in the manufacturing industry to produce consumer goods such as clothing, packaging, pharmaceuticals, cosmetics, and agricultural chemicals [4]. In 2022, Indonesia imported 2.2 million tons of benzene, estimated to have an import value of up to 2.7 billion US dollars [5]. By using natural gas as a raw material for benzene production, it is hoped to increase the independence of chemical production domestically.

In addition, with the enactment of carbon credits by the Indonesian government, industries are required to produce low-emission products. Low-emission chemical plants are one of the points in the Enhanced Nationally Determined Contribution (ENDC) proposed by the government to the UN Framework Convention on Climate Change (UNFCCC) [6]. The price of carbon credits in Indonesia is currently set at Rp69,600 ($4.45) per metric ton [7], which becomes an additional operational cost for factories and is potentially going to increase in the coming years. Therefore, it is important to consider the design of a low-emission benzene plant in support of government policy.

This research aims to carry out benzene production plant design from Aceh's natural gas. This research consists of simulation using DWSim, analysis of operating parameters, carbon emission analysis, and economic analysis consisting of the calculation of net present value (NPV), internal rate of return (IRR), and payback period.

2. Research Methods

This study includes a literature review, determination of the process basis, process simulation, and economic analysis.

2.1. Literature Review

The literature review is the initial stage of this research. At this stage, researchers collect and study various literature sources relevant to the design of the benzene industry, CO2 emissions, related chemical reactions, related separation processes, and process equipment design. The results of the literature study are summarized and form the basis of the plant design in this study.

The production of benzene from natural gas has been the subject of various studies. One study comprehensively reviews the production of benzene from petroleum-related gas, which contains a large amount of methane, presented in another study [8]. Another study presents a systematic global optimization-based process synthesis framework for producing aromatics from natural gas [9]. The process flowsheet for producing benzene from shale gas based on the methane dehydroaromatization reaction pathway is discussed in another study [10]. These studies collectively highlight the potential of natural gas as a viable raw material for benzene production through various technology approaches.

The dehydroaromatization reaction of natural gas to produce benzene is a low-emission reaction pathway. The chemical reaction equation for this reaction is as written in equations (1) and (2).

$$6CH_4 \leftrightarrow C_6H_6 + 9H_2 \quad (1)$$

$$3C_2H_6 \rightarrow C_6H_6 + 6H_2 \quad (2)$$

2.2. Process and Plant Overview

Figure 1 shows the overall process of benzene production from natural gas. First, the natural gas is purified from impurities (water, carbon dioxide, and hydrogen sulfide) using a 12-column pressure swing adsorption [11]. Then, the natural gas is preheated to 800°C and reacted in a dehydroaromatization reactor [12]. After that, the hydrogen produced in the reactor is separated using a membrane [13]. Finally, benzene is separated from other gases using a flash drum to produce benzene with a purity of 99.5% by weight.

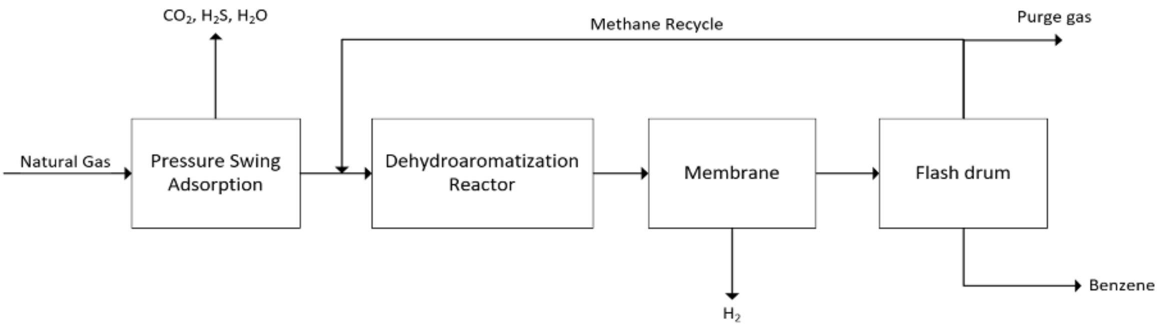

Figure 1. Process flow diagram of natural gas to benzene

2.3. Process Modelling and Simulation

The modeling and simulation of this plant's mass and energy balance were developed using the DWSim v8.6.8 process simulator. DWSim is an open-source chemical process simulator. This process simulator is reported to have a simulation result difference with other process simulators of less than 5% [14]. In addition, several studies have conducted petrochemical-based plant simulations using DWSim software and have reported good accuracy levels [15], [16].

One of the advantages of using DWSim is that users can program unit operations using Python scripts. Python is an easy-to-understand, open-source language that has recently been widely used in academia and industry. This makes DWSim versatile for solving complex process problems.

Greenhouse gas emitted from this plant is calculated using emission factor The carbon emissions from this plant are calculated based on the emission factor set by the Indonesian government through the Ministry of Energy and Mineral Resources. The emission factor is calculated based on the amount of energy used by the plant, which is 0.87 metric tons of CO2 equivalent per megawatt-hour (mtCO2e/MWh) [17].

2.4. Economic Analysis

The economic analysis of this benzene plant from natural gas includes Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PB), and Rate of Investment (ROI). NPV reflects the value of the project and is used in capital budgeting and investment planning to investigate the profitability of investment projections or projects [18]. Meanwhile, IRR is used to reveal the attractiveness of a project and predict the likelihood of generating profit. ROI is used to measure the efficiency or profitability of an investment. The Payback Period indicates the duration required for an investment to generate an amount equivalent to the initial investment [19]. The calculation of economic analysis uses the equations written in equations (3), (4), and (5).

$$\mathrm{NPV} = \sum_{n=1}^{n=T} \frac{\mathrm{CF}_n}{1+i^n} - \mathrm{TCI} \quad (3)$$

$$\mathrm{PB} = \mathrm{FC} + \frac{I}{\mathrm{P+D}} \quad (4)$$

$$\mathrm{ROI} = \frac{\mathrm{C}}{\mathrm{TCI}} * 100\% \quad (5)$$

Where CF_n is the net cash flow during period T, TCI is the total capital investment, i is the discount rate, T is the number of time periods, FC is the fixed capital investment that can be depreciated, I is the interest on TCI over the estimated service life, P is the average annual profit, D is the average annual depreciation, and C is the net annual profit after tax. The economic analysis was calculated using a spreadsheet.

3. Results and Disucussion

3.1. Plant Performance

The process that was reviewed, evaluated, and selected from the preliminary study was synthesized to construct an industrial-scale process. The process flow diagram of the main synthesized process is shown in Figure 2.

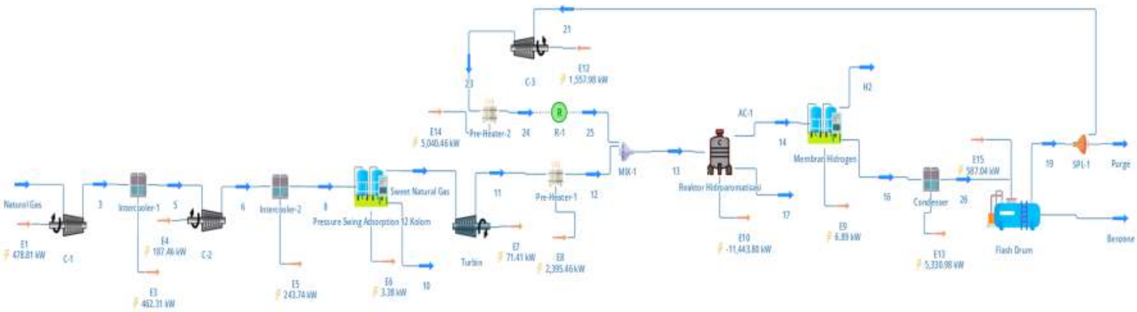

Figure 2. Simulation of natural gas to benzene using DWSim

The computational model of the plant was developed and simulated using DWSim v8.6.8, which was built based on the process described in the previous section, including natural gas purification, benzene production, and benzene separation.

Natural gas purification involves natural gas compression and adsorption processes. The natural gas is compressed in two stages to a pressure of 70 bar. Then, the natural gas undergoes adsorption in six stages until the impurity composition of the natural gas is below 100 ppm. Adsorption in DWSim is modeled using the Compound Separator model based on the previously mentioned study.

The benzene production process includes initial heating and dehydroaromatization reaction. The output from the natural gas purification system is expanded using a turbine until the pressure becomes 27 bar. The natural gas is then heated to 800°C and mixed with recycled methane. Then, the mixture is fed into an adiabatic reactor and the reaction occurs endothermically.

The energy required to run this plant comes from compressors, reactors, and utilities. The energy requirement of this plant is 246,179.52 kWh. Using the emission factor, the greenhouse gas emissions from this plant are found to be 214.18 metric tons of CO2 equivalent (MtCO2e).

3.1. Economic Analysis

The prices of equipment, piping, instrumentation, and buildings were estimated using sizing and price factors from Turton et al. [20]. The plant's operating costs were assumed to be a percentage of the investment cost based on Park et al. [19]. Meanwhile, profitability analyses such as NPV, IRR, PB, and ROI used the equations explained in the previous section for 20 years. A summary of the plant's economic calculation results and profitability analysis is presented in Table 1.

Table 1. Economic analysis of benzene from natural gas

Economic Parameter	Value
Capital expenses (IDR)	2,448,339,652,395.00
Operational expenses (IDR/year)	42,970,365,921.60
Revenue (IDR/year)	183,219,660,000.00
NPV (IDR)	43,048,332,635.40
IRR	12.2%
Payback period (year)	7.6
ROI	8.93%

The above economic analysis results indicate that this plant is quite economically feasible. The economic analysis of the design of a natural gas to benzene plant has been evaluated in several studies. One study assessed the economics of the process of methane to benzene using a catalytic membrane reactor model implemented in the Aspen Plus V9 process model. The research results show that the venture is profitable, with a profitability index of 1.17, an IRR of 35.5%, and an NRR of 18.2%. The calculated capital cost is $35,500 per barrel of benzene per day. In addition, this process remains economically attractive as long as the price of benzene remains above $470/ton or the price of hydrogen remains above $0.8/kg [21]. Another work presents the design and process analysis to convert shale gas into benzene based on the direct methane aromatization route [10]. These studies indicate that producing benzene from natural gas is a process that has good appeal.

4. Conclusion

In the context of developing a benzene production plant from natural gas in the Arun Gas Field, this research has successfully designed an overall process involving natural gas purification, dehydroaromatization reaction, and benzene separation. Simulations using DWSim show that this process can be run efficiently with high-purity benzene results.

From an economic perspective, the financial analysis shows that investment in this plant is quite profitable with a positive internal rate of return, a reasonable payback period, and a decent ROI. Therefore, this plant can be considered a financially adequate project and supports government policies related to sustainable production.

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