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Research article

Techno-Economic Analysis of Linear Low-Density Polyethylene Plant Using Sclairtech Process Optimized by Heat Integration

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Abstract: Polyethylene (C2H4)n is a crucial industrial material in the plastics industry, produced via ethylene polymerization. The rising demand for Linear Low-Density Polyethylene (LLDPE) and advancements in process technology make the establishment of an LLDPE plant in Indonesia feasible. This paper aims to evaluate the feasibility of such a plant using the Sclairtech process. The heat exchanger network is designed using the Temperature Interval and Composite Curve Methods. The economic feasibility analysis, performed using the study estimate method with bare module costs, shows significant utility savings through heat integration, reducing utility costs from USD 3,933 to USD 1,510 per hour. The plant's Payback Period (PBP) is 3.21 years, with a net present value (NPV) of USD 250.48 million, an internal rate of return (IRR) of 16%, and a breakeven point of 31.04%. Sensitivity analysis indicates the plant remains profitable despite a 65.22% increase in raw material costs and a 100% reduction in product prices. Based on the Heat Integration design and economic analysis, the LLDPE plant using the Sclairtech process is deemed economically viable.

Keywords: Heat integration system, Linear low-density polyethylene, Sclairtech Process, Techno-economic analysis.

1. Introduction

Polyethylene $(C_2H_4)_n$ is classified as a fundamental industrial product in the plastic industry, produced through ethylene polymerization [1]. Various polymerization technologies are available, each with distinct advantages and limitations. The high-pressure process has a high production rate but requires significant energy consumption and expensive equipments for high-pressure resistance. The slurry process is relatively low-cost but has a limited product range [2]. The gas-phase process is simple and low-cost, but it has issues with heat removal, which can cause reactor fouling and affect product quality [3]. The solution process offers a broad product range and excellent polymer properties but involves challenges with solvent handling and is more complex than other processes [4].

The global demand for polyethylene continues to grow steadily. In 2014, worldwide polyethylene consumption was estimated at 84 million tons, marking a 3.8% increase from the previous year [5]. Global market data from Chemorbis showed that polyethylene's valuation reached USD 114.79 billion in 2021 and is predicted to continue growing by 2030. The high valuation is attributed to polyethylene's durability and strength. The growing industries in various sectors, such as food and beverage, are driving the demand for polyethylene to be used in bottles, food packaging, and more [6].

One type of polyethylene is Linear Low-Density Polyethylene (LLDPE), a linear polymer with several short branches [7], [8], [9]. LLDPE is produced through the copolymerization of ethylene with short-chain α-olefins, such as 1-butene, 1-hexene, or 1-octene, using Ziegler-Natta catalysts [10], [11]. The global LLDPE market forecast presented by *Databridgemarketresearch* indicates that the LLDPE market across all continents increases annually, reaching a value of USD 60.73 billion by 2029 (Global Linear Low Density Polyethylene (LLDPE) Market – Industry Trends and Forecast to 2029, 2022). The polyethylene market in Indonesia experienced significant growth in 2020. The selling price of LLDPE reached USD 1,152 per ton. This represents a price increase of 5 to 6% from the previous period [6].

The combination of high domestic demand and the availability of advanced production technologies presents a compelling case for establishing a local LLDPE production facility. Among the available technologies, the Sclairtech process is notable for its operational efficiency and product versatility. Therefore, the objective of this paper is to evaluate the techno-economic feasibility of constructing an LLDPE production plant in Indonesia using the Sclairtech process.

2. Materials and Methods

2.1. Process Technology Consideration

Ethylene polymerization involves various types of process technologies. This paper evaluates the feasibility of the Sclairtech process. The Sclairtech process was chosen because it has the shortest residence time compared to other processes, resulting in shorter reactor transition times. The transition time between reactors influences reactor stability; the shorter the transition time, the more stable the reactor becomes. This occurs because longer residence times require the reactor to maintain the reaction temperature below the sticking temperature, which limits the amount of ethylene reacting and leads to a larger volume of unreacted material remaining in the reactor for extended periods. A shorter transition time also enables the reactor to produce a full range of products using a single catalyst, thus conserving energy by avoiding plant shutdowns due to catalyst changes. Additionally, the lower process temperature of the Sclairtech system enhances the economic efficiency of the production process [13].

2.2. Process Description

The LLDPE production process using the Sclairtech technology involves four main stages: feed preparation, polymerization reaction, product separation, and product finishing [4]. The details of each stages are explained below:

- **Feed Preparation:** Ethylene, 1-octene (comonomer), and cyclohexane (solvent) are pre-treated to achieve optimal conditions of temperature and pressure. The use of Ziegler-Natta catalysts is crucial for controlling the polymer chain structure and branching.
- **Polymerization Reaction:** The core reaction occurs at a temperature of 300°C and a pressure of 138 bar. Ethylene and the comonomer undergo copolymerization in the presence of the catalyst to form LLDPE. The reactor design ensures optimal mixing

and heat transfer to maintain stable reaction conditions and minimize unreacted monomer content.

- **Separation and Purification:** The reaction mixture is directed to a separation unit where unreacted monomers and solvents are recovered and recycled. The product stream is further purified to remove catalyst residues and other impurities.
- **Finishing:** The purified LLDPE is pelletized or granulated to produce a final product that meets industry specifications for downstream applications.

A detailed process flow diagram (Figure 1) illustrates the overall process, including major equipment and stream directions.

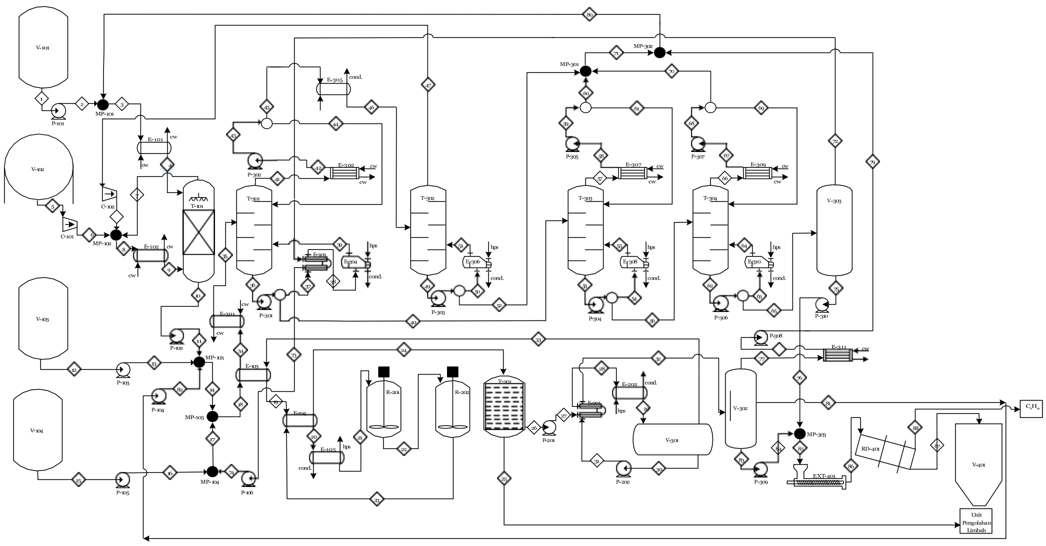


Figure 1. Process flow diagram of LLDPE plant using Sclairtech Process.

2.3. Heat Integration Design

To enhance energy efficiency, a Heat Exchanger Network (HEN) was designed by integrating hot and cold process streams to maximize internal heat recovery and minimize external utility requirements. The design methodology followed two key analytical techniques:

- **Temperature Interval Method:** This method was employed to identify the pinch point and determine the Minimum Energy Requirement (MER) for both heating and cooling utilities.
- **Composite Curve Method:** Composite curves were constructed to visualize the interaction between hot and cold streams, helping to optimize the heat exchange matches and quantify the utility savings.

The implementation of HEN led to a significant reduction in steam and cooling water consumption, improving the sustainability and cost-effectiveness of the plant's thermal energy management system [14].

2.4. Economic Feasibility Analysis

The techno-economic analysis of the LLDPE plant was conducted under a set of defined financial and operational assumptions:

- **Project Parameters:** Construction begins in 2024 with a 2-year build period. The operational analysis covers a 10-year lifespan, assuming 346 working days per year.

- **Financial Assumptions:** The analysis includes a corporate tax rate of 22%, a minimum acceptable Return on Investment (ROI) of 16%, and a loan sourced from First National Bank with an interest rate of 10.27%.
- **Methodology:** A study estimate level of accuracy was applied using the bare module cost approach. This approach balances simplicity and accuracy for early-stage feasibility assessments.

Key economic indicators calculated include the Payback Period (PBP), Net Present Value (NPV), Internal Rate of Return (IRR), and Break-Even Point (BEP). In addition, a sensitivity analysis was conducted to evaluate the project's robustness under fluctuations in raw material costs and product prices [15].

3. Results and Discussion

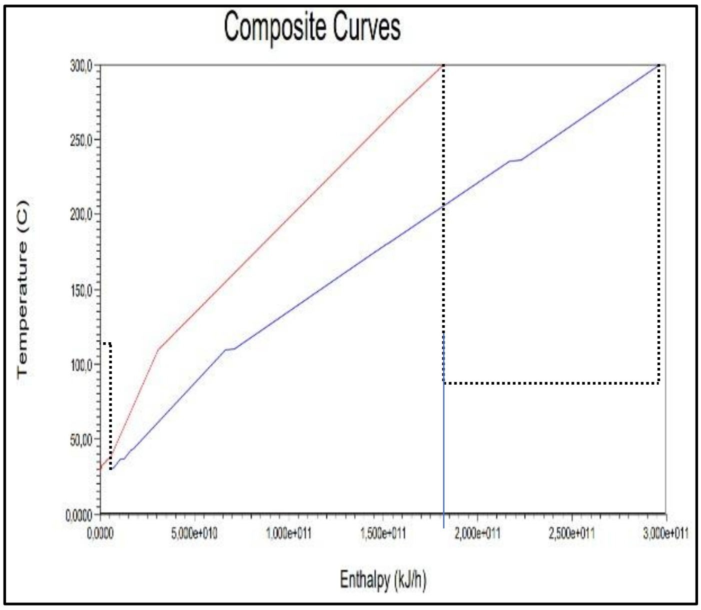
3.1. Heat Integration System

The implementation of a Heat Exchanger Network (HEN) significantly improved the thermal efficiency of the LLDPE plant designed using the Sclairtech process. Heat integration is a critical aspect of process optimization, particularly in energy-intensive industries such as petrochemicals. By integrating hot and cold process streams, the HEN enables the recovery and reuse of heat that would otherwise be wasted, thereby reducing dependence on external utility systems.

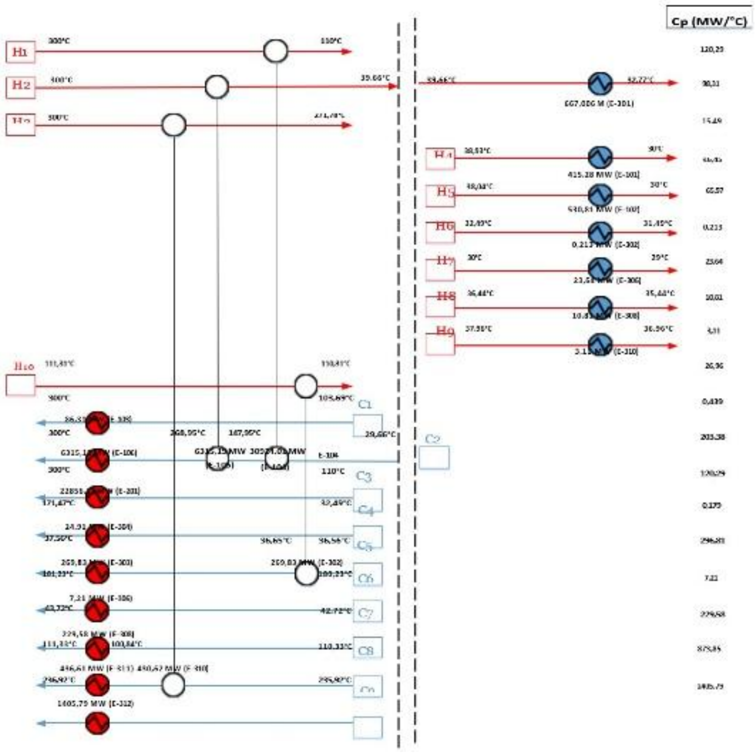
Prior to the integration of HEN, the plant's utility demands were substantial: high-pressure steam consumption reached 219,003.52 kg/h, and cooling water consumption was 2,901,315.08 kg/h. Following the HEN design, these demands dropped dramatically to 85,758 kg/h for steam and 23,821 kg/h for cooling water. This represents utility savings of over 60%, translating into a cost reduction of approximately USD 2,423 per hour, from USD 3,933 to USD 1,510. These savings have a direct impact on the plant's operating expenditure and overall economic viability.

The HEN was designed using the Temperature Interval Method and the Composite Curve Method. These approaches allow for systematic identification of the pinch point, which defines the minimum energy requirements and guides the placement of heat exchangers. Figure 2 presents the composite curve and grid diagram, which visualize the overlap between hot and cold stream enthalpy profiles and the optimal heat exchange matches, respectively [14].

Figure 2. (a) Composite curve; (b) Grid diagram of heat.



(a)



(b)

In total, four hot streams and four cold streams were successfully integrated. The data show the specific heat capacities and temperature ranges of each stream, along with their respective duties in megawatts. Notably, high-capacity exchangers such as E-104 and E-201 handled significant energy loads, contributing substantially to utility savings. The application of heat integration not only reduces energy costs but also lowers greenhouse gas emissions by decreasing fuel consumption in utility generation. This makes the process not just economically efficient, but also environmentally responsible.

3.2. Economic Feasibility

The economic analysis evaluated the financial viability of the LLDPE plant over a projected 10-year operation period, based on a set of realistic assumptions including a construction period of 2 years, 346 operational days per year, and a corporate income tax rate of 22%. Financial modeling also included a 10.27% loan interest rate from First National Bank and an acceptable internal return threshold of 16%, consistent with standard industry investment expectations. Key financial metrics derived from the analysis include:

- Payback Period (PBP): 3.21 years
- Net Present Value (NPV): USD 250.48 million
- Internal Rate of Return (IRR): 16%
- Break-Even Point (BEP): 31.04% of total capacity

These results suggest a feasible investment, with the project recouping its capital costs within just over three years, and generating significant positive net value thereafter. To further assess the robustness of the business model, a sensitivity analysis was conducted. The analysis simulated adverse market scenarios, such as a 65.22% increase in raw material costs and even a 100% reduction in product selling price. Remarkably, the plant remained marginally profitable under these extreme conditions. This resilience indicates a strong buffer against market volatility, particularly valuable in a commodity-driven sector like petrochemicals.

The cash flow diagram as seen in Figure 3 shows a steady upward trend in cumulative cash flow beginning in the third year of operation, confirming financial sustainability under baseline conditions. The results of this feasibility study strongly support proceeding with the investment in an LLDPE plant using the Sclairtech process in Indonesia, where demand and economic conditions are favorable.

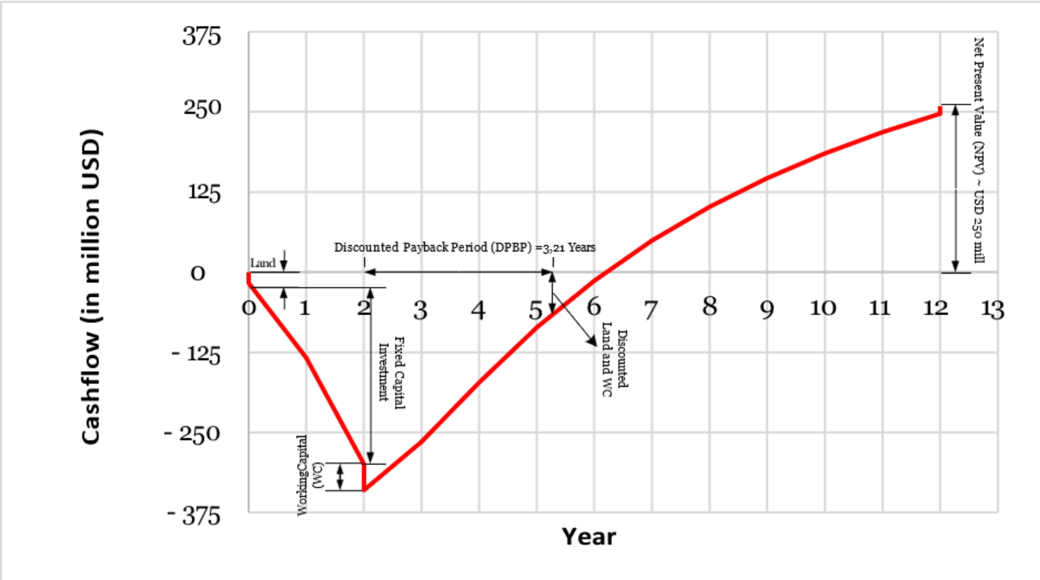


Figure 3. Cashflow diagram.

4. Conclusions

Based on the comprehensive heat integration design and economic feasibility analysis, it can be concluded that the proposed LLDPE plant employing the Sclairtech process is both technically and economically viable. The implementation of a Heat Exchanger Network significantly enhances energy efficiency, reducing high-pressure steam and cooling water demands and resulting in utility cost savings of approximately USD 2,243 per hour.

Furthermore, key economic indicators obtain a payback period of 3.21 years, a net present value of USD 250.48 million, and an internal rate of return of 16%. These results demonstrate the project's strong financial potential. The sensitivity analysis confirms the plant’s resilience under unfavorable market conditions, reinforcing its long-term investment attractiveness. Overall, the integration of advanced process technology with optimized thermal management supports the feasibility and sustainability of establishing an LLDPE production facility in Indonesia.

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Conflicts of Interest: The authors declare no conflicts of interest.

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