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Integrated Process Simulation and Feasibility Assessment of a Butyl Acrylate Manufacturing Plant from Acrylic Acid and n-Butanol in the Philippines

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The rising global demand for Acrylates driven by applications in paints, adhesives, textiles, and plastics has heightened the need for sustainable and economically viable production methods. Butyl acrylate, a key acrylate ester, is typically synthesized through the esterification of acrylic acid and n-butanol using homogeneous acid catalysts. However, these catalysts pose challenges related to corrosiveness, product separation, and environmental impact. This study presents the integrated process simulation and techno-economic assessment of a full scale butyl acrylate manufacturing plant in the Philippines utilizing heterogeneous catalysis. The process was modelled using Aspen HYSYS V11 software and included plantwide control strategies. Catalyst and site selection were supported through multi-criteria decision-making via Visual PROMETHEE. The proposed facility is designed to produce 31,328 metric tons per year of high-purity (99.99 %) butyl acrylate, with export targets including India, Vietnam, and Thailand, alongside domestic distribution. Economic analysis yields a projected return on investment (ROI) of 60.84 % and a payback period of 5.11 years, confirming the technical and financial viability of establishing local production and supporting the Philippines' entry into the regional butyl acrylate market.

1. Introduction

n-Butyl acrylate is one of the main components in the production of acrylic polymers (Moraru and Bildea, 2017). Its main applications are in the production of paints and coatings, adhesives and sealants, plastic additives, and textile. In 2023, 54.4 % of the global production of butyl acrylate went to the paints and coatings industry while 16.3 % went to the production of adhesives and sealants, 11 % plastic additives, 10 % chemical precursor, 5 % textiles, and other uses 3 % (Butyl Acrylate Market Size, Growth | Global Report, 2032, 2024.). Commercial production involves the esterification of acrylic acid with n-butanol in the presence of an acid catalyst, followed by distillation to achieve yields of 94–97 % (Riondel et al., 2002). It is the highest-volume acrylate ester and serves as a "soft monomer" that enhances low-temperature flexibility and toughness in various polymers (Ohara et al., 2011). Demand has been rising due to its durability, low cost, and its share of approximately 60 % of the global acrylic ester monomer market, representing over 2000 kt of annual consumption (Constantino et al., 2019). With no current domestic manufacturing, the Philippines relies entirely on imports, creating an opportunity to develop local production capacity. This study proposes the design of a pilot plant using Aspen HYSYS V11 for process simulation and PROMETHEE for multi-criteria decision-making, supporting SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production) through sustainable and resource-efficient manufacturing for local and export markets.

2. Market Study

In 2023, the global butyl acrylate market was dominated by the Asia-Pacific (APAC) region, followed by Europe and America. The steadily rising demand is mainly attributed to its wide use in paints, coatings, adhesives, textiles and other applications that support large-scale infrastructure development (Market.US, 2024). The

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demand for butyl acrylate is largely driven by construction and manufacturing activity. Because it is compatible with both solvent-based and aqueous technological applications, demand has remained stable despite the industry's shift toward alternatives. Comparative analysis shows that Asia-Pacific nations are experiencing much faster growth and market expansion than develop regions such as North America, Europe, and the Middle East (Prismane Consulting, 2024). In the Philippines, demand has grown steadily due to urban development, construction projects, and automotive coatings (6Wresearch, 2025). Import data from the Philippines, Vietnam, and India were used for forecasting, as sourced from the United Nations (UN) Comtrade database (UNComtrade, 2024). Five projection models were applied to establish a reliable correlation with the market trends: linear, logarithmic, exponential, 2nd order polynomial and power method. Among these, the logarithmic model demonstrated the highest R^2 value, making it the most suitable method for forecasting import trends, as illustrated in Figure 1. The Philippines exhibits a consistent upward trajectory in butyl acrylate import demand. Projections from 2024 to 2030 indicate a steady increase over this period, mirroring the growth in market needs.

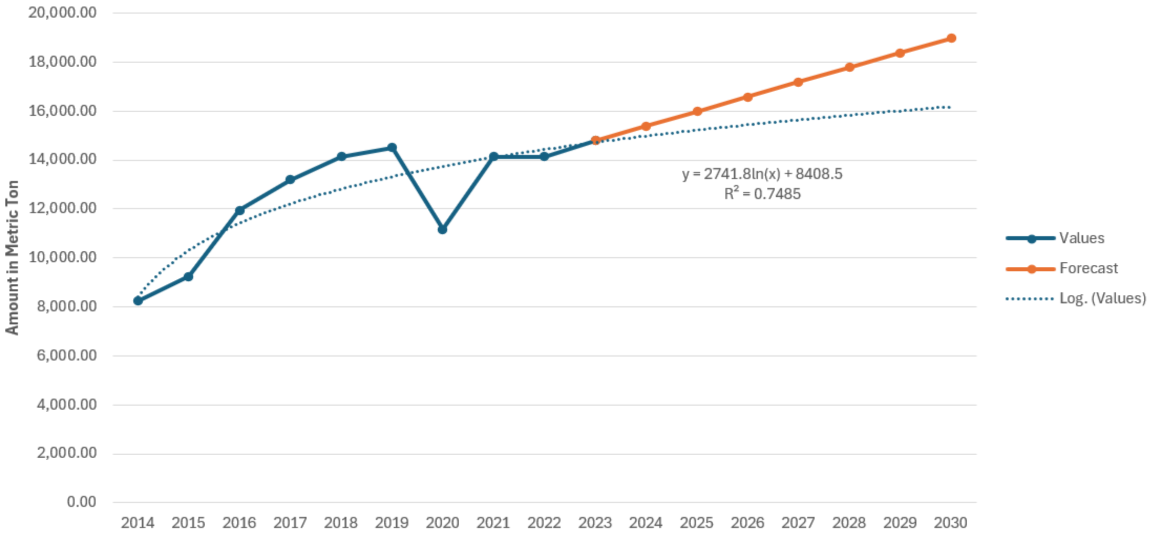

Figure 1: Accepted Forecast of the Importation Trend of Butyl Acrylate

Table 1 presents the target capacity of the proposed plant for butyl acrylate based on its imports, with the second column detailing the targeted market share percentages and the third column reflecting the associated volume requirements. Based on aggregated import data from the Philippines, India, Vietnam, and Thailand, the projected annual plant capacity for butyl acrylate production is calculated to be 31,328 t.

Table 1: Plant Capacity of Butyl Acrylate based on import forecast of Philippines, India, Vietnam and Thailand

Country	Market Share Percentage	Demand (t)	Market Share (t)	Total Plant Capacity (t)
Philippines	50 %	18,108	9,054	31,328
India	5 %	356,874	17,843.70	
Vietnam	5 %	45,604	2,280.20	
Thailand	5 %	43,000	2,150	

3. Technical Study

Commercially, butyl acrylate is produced through the esterification of acrylic acid and n-butanol using strong homogeneous acid catalysts such as sulfuric acid, para-toluene sulfonic acid, and hydrofluoric acid. While effective, these catalysts are highly corrosive, toxic, and difficult to separate from the final product (Altıokka and Ödeş, 2009). Recent studies have highlighted the advantages of heterogeneous catalysts, which offer comparable conversion rates, can be reused multiple times, and are easier to recover from the reaction mixture. They also exhibit lower toxicity and reduced corrosiveness. Accordingly, this study adopts a heterogeneous catalyst for the proposed process.

3.1 Process Selection

In this study, Visual PROMETHEE is used to help address the challenge of evaluating and comparing multiple assessment criteria. Visual PROMETHEE is a multicriteria decision-making tool that uses varying functions to determine the optimum scenario between multiple assessments. In this case, three different catalysts which are called amberlyst 15, amberlyst 131, and dowex 50WX8-400 are compared to one another in order to ascertain the most efficient, most superior, and overall the best resin to use for the production of butyl acrylate. The criteria and its respective weights are as follows: Price (20 %), Product Yield (30 %), Exchange Capacity (20 %), Availability (30 %). The percentages prioritize product yield and availability because they most strongly affect lifecycle economics, higher yield improves revenue per run, and assured availability prevents costly delays, while exchange capacity and price are weighted to reflect their secondary but still material impacts on operating cost and replacement frequency. Figure 2a shows the complete ranking of the catalyst selection in PROMETHEE which favors amberlyst 131 as the most suitable catalyst for the production of butyl acrylate.

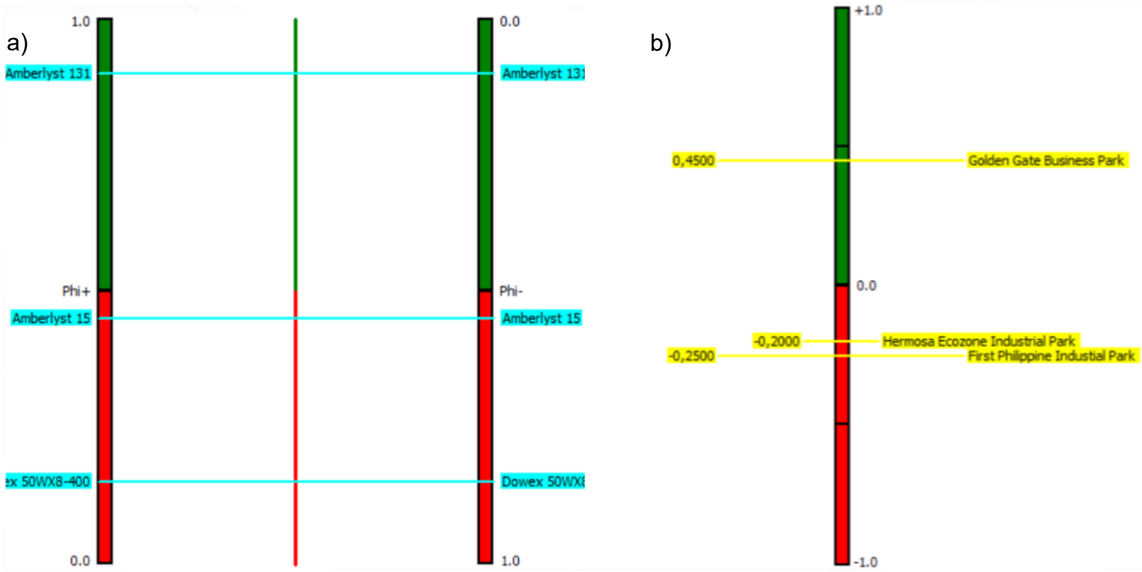

Figure 2: Visual PROMETHEE Complete Ranking for (a) Process Selection and (b) Plant Location Selection

3.2 Plant Location Selection

Based on Towler and Sinnott (2021) the location of the plant has a significant effect on the feasibility of the project and the scope for future possible expansions of the production plant. The reference plant for the land area requirement for the proposed manufacturing facility is the butyl acrylate production plant in China, Wanhua Petrochemical (Yantai) Co., Ltd. The production capacity of Wanhua Petrochemical (Yantai) Co., Ltd is 120,000 t/y, with a total land area of 6.16 ha. Utilizing Eq(1), given that the production capacity of butyl acrylate is about 31,328 t/y, the proposed plant size is approximately 1.61 ha.

$$\frac{Plant\ Capacity_{\ Basis}}{Land\ Area_{\ Basis}} = \frac{Plant\ Capacity_{\ Actual}}{Land\ Area_{\ Actual}} \tag{1}$$

Three industrial parks with an available land, all of which are affiliated with Philippines Economic Zone Authority (PEZA) are chosen for determining the ideal land for the butyl acrylate plant: First Philippine Industrial Park (FPIP) in Santo Tomas. Batangas, Hermosa Ecozone Industrial Park (HEIP) in Hermosa, Bataan, and Golden Gate Business Park in General Trias, Cavite. There are several aspects to consider when selecting a suitable plant location. The criteria are the following with its respective weight percentages: Distance from target market (25 %), Distance from the ports (30 %), Land cost (25 %), Electricity Cost (10 %) and Water cost (10 %). The criteria mentioned favors the lowest possible cost for each of the plant locations stated and its percentages that are based from its total cost. Visual PROMETHEE was used to evaluate the three industrial parks for the plant site location selection. Based on the evaluation results, Golden Gate Business Park in Cavite emerged as the most suitable site for establishing the proposed butyl acrylate manufacturing facility as depicted in Figure 2b.

3.3 Process Specifics

The production of butyl acrylate involves an equilibrium limited esterification reaction between acrylic acid and n-butanol, having water as a byproduct (Ostaniewicz-Cydzik et al., 2014). This continuous process operates 340 days annually and presents challenges such as multiple azeotrope systems and the backward reaction, which limits conversion since reactants are never fully consumed. The latter can be mitigated by removing water from the system to drive the equilibrium forward in accordance with Le Chatelier’s principle. After the reaction in the packed bed reactor (PBR), the mixture is separated and purified through multiple distillation columns, each equipped with a recycle stream to return unreacted n-butanol and acrylic acid to the mixer, while high-purity butyl acrylate is obtained and cooled to atmospheric conditions.

3.4 Reaction Kinetics

This study focuses solely on the esterification of acrylic acid with n-butanol to produce n-butyl acrylate and water. This type of reaction can be achieved in liquid phase using catalysts to enhance the reaction rate. According to the laboratory experiments done by Sert et al. (2013) using amberlyst 131 as a solid catalyst, the Langmuir-Hinshelwood-Hougen-Watson (LHHW) model describes the reaction mechanism accurately. As a result, this model is adapted in this study. The Aspen HYSYS software only accepts base units expressed as molar concentration per unit volume per unit time, whereas the LHHW model is formulated in molar concentration per unit mass per unit time. Therefore, the LHHW equation is converted to conform to the unit requirements of Aspen HYSYS. Another limitation of using the LHHW model in Aspen HYSYS is its assumption that all active sites are equivalent and uniform, and that all reactions occur under steady-state conditions. The rate constants used for the reaction mechanism inputted inside Aspen HYSYS V11, describing the formation of butyl acrylate through the esterification reaction between acrylic acid and n-butanol, is as follows:

$$K_f = 4.55 \times 10^6 expexp\left(-\frac{57{,}421}{RT}\right) \tag{2}$$

$$K_b = 2.75 \times 10^7\, exp\left(-\frac{75{,}163}{RT}\right) \tag{3}$$

Where both units of the forward rate constant (K_f) and backward rate constant (K_b) are in kmol/kg-s and R is the ideal gas constant with T as the relative temperature in Kelvin.

3.5 Process Simulation

Figure 3 shows the overall manufacturing process which is divided into four sections in the plan. Section 1 is the feed preparation stage, section 2 is mainly focused on the esterification reaction inside the packed bed reactor, section 3 is the removal of water from the system along with 1-butanol and water binary recycle, section 4 is the purification of the product along with the recycling of acrylic acid.

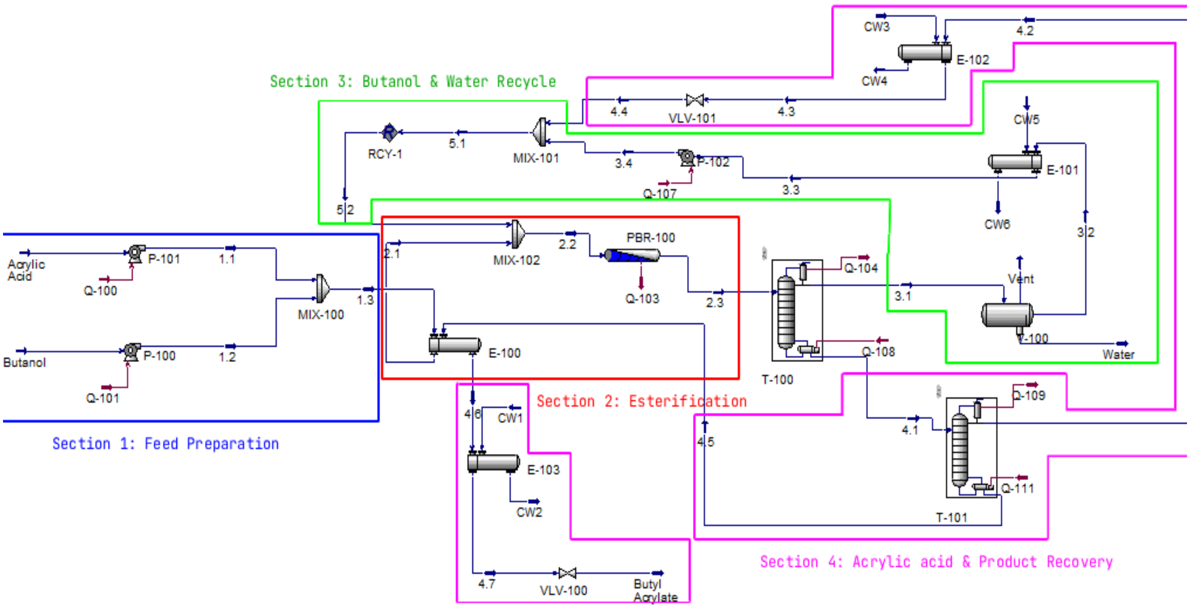

Figure 3: Overview of Aspen HYSYS V11 process simulation of the production of butyl acrylate

The raw feed materials are pumped and mixed before entering a heat exchanger to be heated up to 85 °C at pressures of 1.5 bar. According to Moraru and Bildea (2017) this is the optimal conditions for the esterification reaction to happen inside the packed bed reactor. The reactor contains 2,411 kg of amberlsyt 131 as the solid catalyst tightly packed inside its multi-tubular design. The resulting mixture is then passed through a pressure swing distillation system to separate the azeotropic components and recycle the unreacted raw materials. The process employs two recycle systems to reuse unreacted raw materials in order to increase the efficiency of the design and reduce the waste material. The obtained product stream's excess heat is recovered and used to heat the mixed feed stream to the optimal temperature. It is then cooled off to atmospheric conditions and ready to be stored.

4. Financial Feasibility

The cost of land was determined using Eq(1), while the remaining facility expenses were estimated following the methods of Towler and Sinnott (2021), which apply historical data and cost indices to adjust for current labor, material, and energy prices. The Chemical Engineering Plant Cost Index (CEPCI), a composite index for the U.S. process plant industry published monthly in *Chemical Engineering* magazine, was used for cost updates. All values were first calculated in U.S. Dollars (USD) and then converted to Philippine Pesos (PHP). A summary of the calculated costs is presented in Table 2.

Table 2: Summary of Overall Plant Costs

Cost	Parameter / Specifics	Value (PHP)	Total (PHP)
Total Fixed Capital Investment	Inside Battery Limit	206,813,674	592,668,422
	Outside Battery Limit	166,326,677	
	Design and Engineering Cost	37,314,035	
	Contingency Charges	37,314,035	
	Land Cost	144,900,000	
Variable Costs of Production	Raw Materials Expenses	2,298,488,00	2,359,275,126
	Electricity Expenses	19,245,956	
	Water Cost	8,232,320	
	Shipping and Transportation Costs	33,308,842	
Total Fixed Cost of Production	Operating Labor Cost	28,923,751	101,963,582
	Maintenance Cost	6,204,410	
	Real Property Tax	1,685,564	
	Insurance Cost	37,314,035	
	Utilities (Electricity and Water Costs)	27,478,276	
	Running License Fees and Permits	135,665	
	Telecommunication Expenses	221,880	

Table 3: Income Statement of the proposed manufacturing facility (in millions of PHP)

Year	Plant Capacity	Revenue	Total Cost of Production	Depreciation	Taxable Income	Income Tax	Net Profit	Cumulative Income
0	-	-	-	-	-	-	-1,941	-1,941
1	-	-	-	-	-	-	-1,941	-1,941
2	-	-	-	-	-	-	-1,941	-1,941
3	50 %	1,998	1,192	37.31	675	0.00	675	-1,266
4	75 %	2,997	1,769	33.58	1,100	0.00	1,100	-165
5	100 %	3,996	2,350	30.22	1,520	0.00	1,520	1,354
6	100 %	3,996	2,350	27.20	1,525	0.00	1,525	2,880
7	100 %	3,996	2,350	24.48	1,527	0.00	1,527	4,408
8	100 %	3,996	2,350	22.03	1,530	0.00	1,530	5,938
9	100 %	3,996	2,350	19.83	1,532	0.00	1,532	7,471
10	100 %	3,996	2,350	17.85	1,533	0.00	1,073	8,544

When cash inflows are not balanced, there is a need to calculate the cumulative net cash flow for every period and then utilize Eq(4) to get the payback period:

$$Payback\ Period = A + \frac{B}{C} \tag{4}$$

where A represents the final period where the cumulative income remains negative. B is the absolute value of the cumulative net cash flow at the end of that period, and C is the total cash inflow in the period immediately after A. The cumulative net cash flow is determined by subtracting the initial outflow from the total inflows up to that point. As shown in Table 3, year 4 is the last year with a negative cumulative income, making it the value for A in Eq(4). Based on the same table, B is Php 165 million, and C is Php 1,520 million for year 5, resulting in a payback period of 5.11 years. Towler and Sinnott (2021) also note that return on investment (ROI), calculated using Eq(5), is a basic indicator of economic performance. In this case, the ROI at year 5 is 60.84 %.

$$ROI\ (at\ year\ 5) = \frac{Net\ annual\ profit}{Total\ investment} \times 100\ \% \qquad (5)$$

5. Conclusion

This study successfully demonstrated how a full-scale butyl acrylate production facility could be planned and developed in the Philippines in a manner that is both technically sound and financially viable. Aspen HYSYS V11 was used for process simulation, while Visual PROMETHEE supported multi-criteria decision-making for catalyst and site selection. The results confirm the Philippines' potential to establish domestic manufacturing capacity in this sector, enabling the country to participate more competitively in the Asia-Pacific butyl acrylate market. The proposed facility is designed to produce approximately 31,328 metric tons of high-purity (99.99 %) butyl acrylate annually. After evaluation of multiple industrial zones, Golden Gate Business Park in Cavite was identified as the optimal location based on logistical and economic factors. Financial projections indicate strong economic viability, with a return on investment of 60.84 % and a payback period of 5.11 years, supporting long-term profitability. This study demonstrates the technical and economic feasibility of establishing a domestic production facility while emphasizing the potential to reduce import dependency, create industrial opportunities, and position the Philippines as a contributor to the growing global demand for this essential acrylate.

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