UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 6(3), March (2026), 1850-1859
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

# Design and Local Fabrication of Modular Alkyd Resin Production Plant using Soybean Oil Feedstock

Raphael Stone Odera[1], Martin Emeka Ibenta[2*], Chukwuebuka Golden Iloh[2], Henry Chukwuka Oyeoka[2]
[1]Department of Chemical Engineering, Nnamdi Azikiwe University
[2]Department of Polymer Engineering, Nnamdi Azikiwe University
[*]Corresponding Author's E-mail: me.ibenta@unizik.edu.ng

**Abstract**
This study presents the novel modular design and local fabrication of an alkyd resin production plant built entirely from locally available materials, addressing Nigeria's dependence on imported equipment. The production process employs a two-step synthesis: alcoholysis of soybean oil with glycerol to form monoglyceride, followed by esterification with phthalic anhydride. The plant design integrates a jacketed semi-batch stirred tank reactor, shell-and-tube condenser, and liquid-phase decanter, all fabricated from mild steel. Material and energy balances established optimal operating conditions for a 5 kg/batch capacity, with reactor temperature range of 200 to 240 °C, a batch time of 3 hours, reaction rate of $36 \times 10^{-6}$ mol/hr, heat requirement of 1882.32 kJ, and cooling water demand of 9 liters. The plant incorporates temperature monitoring, mechanical agitation by a 600-Watt DC motor, and pressure relief for safe operation. Successful fabrication and testing confirm the technical feasibility of indigenous modular alkyd resin production, providing a scalable pathway to reduce import dependence and strengthen local manufacturing capability in Nigeria.

**Keywords:** Alkyd resin, local fabrication, soybean oil, modular plant design, alcoholysis, esterification

## 1. Introduction

Alkyd resins represent one of the most widely utilized synthetic polymer systems in the coatings and paint industry, valued for their excellent film-forming properties, durability, adhesion characteristics, and cost-effectiveness. These polyester-based resins are produced through the polycondensation reaction of polyhydric alcohols, polybasic acids or their anhydrides, and fatty acids or oils, resulting in materials that exhibit superior performance in protective and decorative coating applications (Chardon et al., 2021; Elba., et al., 2018; Chiplunkar and Pratap, 2016). The global demand for alkyd resins continues to grow steadily, driven by expanding construction activities, automotive manufacturing, and industrial coating requirements across developing and developed economies (Oragwu et al., 2024). Despite this increasing demand, many developing nations remain heavily dependent on imported alkyd resin production equipment and technology, leading to significant foreign exchange expenditure, limited local industrial capacity, and reduced competitiveness in the regional coatings market.

Alkyd resins are notable in the industry for being derived from sustainable raw materials, primarily vegetable oils, which serve as renewable alternatives amid rising petroleum prices and environmental concerns. This shift towards green resources has attracted attention in both academia and industry, focusing on polysaccharides, natural rubber, sugars, proteins, and especially plant oils due to their biodegradability, low toxicity, absence of volatile organic compounds, and affordability (Gandini et al., 2016). Alkyd resins are commonly synthesized via the fatty acid or monoglyceride processes. The monoglyceride process involves two steps: first, an alcoholysis reaction producing monoglycerides by reacting vegetable oil with a polyol, followed by a polycondensation step where these monoglycerides react with dibasic acids or anhydrides such as maleic, glutaric, succinic, and phthalic anhydrides (Jones et al., 2017). Phthalic anhydride is widely used owing to its cost-effectiveness, ease of production, and favorable resin properties. While the glyceride oil and polyol conversion to monoglyceride can occur without a catalyst at very high temperatures, such conditions pose industrial challenges including oil degradation risk and high energy consumption, making them less appealing commercially (Mustapha et al., 2023). The use of bio-based oils like soybean, linseed, or castor oils not only enhances sustainability by reducing carbon footprints but also supports renewable agricultural practices. Current research and industry practice emphasize developing eco-friendly materials, improving energy efficiency, and optimizing catalyst use to lower environmental impact while maintaining production quality. These sustainable approaches are essential as the industry moves towards greener chemical processes and enhanced performance of alkyd resins in coatings and other applications (Glenn et al., 2021; Glenn et al., 2023).

However, despite the extensive research on alkyd resin synthesis and formulation, relatively limited attention has been given to the design and fabrication of small-scale, locally adaptable alkyd resin production plants suitable for developing economies. Most existing studies focus primarily on resin chemistry, catalyst optimization, or product performance, while comprehensive engineering design frameworks that integrate material and energy balances, equipment sizing, and fabrication using locally available materials are rarely documented in open literature. Furthermore, commercially available alkyd production systems are typically designed for large-scale industrial operations and rely heavily on imported equipment, which can be costly and difficult to maintain in resource-constrained environments. This creates a technological gap that limits the ability of local manufacturers to establish cost-effective alkyd resin production facilities. Therefore, there is a need for a practical and scalable plant design approach that emphasizes local fabrication, affordability, and operational suitability for small- to medium-scale production

The establishment of locally fabricated alkyd resin production plants presents a strategic opportunity to address these challenges while fostering indigenous technological capability and industrial self-reliance. Local fabrication of chemical processing equipment offers numerous advantages including reduced capital investment costs, easier maintenance and repair through readily available spare parts and technical expertise, shorter lead times for equipment installation and commissioning, and the development of local engineering and manufacturing skills (JCT Machinery, 2025). Furthermore, locally designed and fabricated plants can be optimized for specific regional raw material characteristics, production scales appropriate for local market demands, and operational conditions that reflect the available utilities and infrastructure. The successful implementation of such projects contributes significantly to technology transfer, employment generation, and the broader goal of industrial diversification in developing economies (Jinzong Machinery, 2024).

This study focuses on the comprehensive design, engineering analysis, and fabrication of a modular alkyd resin production plant utilizing locally available materials and manufacturing capabilities. The research encompasses detailed material and energy balance calculations to establish optimal process parameters, rigorous equipment design specifications for the key unit operations including a jacketed semi-batch stirred tank reactor, shell-and-tube condenser, and liquid-phase decanter, and systematic fabrication procedures employing mild steel as the primary construction material. The production process is based on the two-phase synthesis route involving the initial alcoholysis of soybean oil with glycerol to produce monoglyceride, followed by esterification with phthalic anhydride to yield the final alkyd resin product. The plant is designed for batch operation with a standardized production capacity of five kilograms per batch, providing flexibility for small to medium-scale manufacturing operations while maintaining process efficiency and product quality standards. By demonstrating the feasibility of local fabrication of alkyd resin production equipment, this study aims to provide a practical framework and technical reference for industrial entrepreneurs, chemical engineers, and policymakers interested in establishing cost-effective, locally-owned alkyd resin manufacturing facilities. The successful completion of this project represents a significant step toward reducing import dependency, enhancing local manufacturing competence, and contributing to the sustainable development of the chemical process industries in developing regions.

## 2.0 Materials and methods

### 2.1. Materials and Apparatus

The materials utilized in the production of alkyd resin included soybean oil (a triglyceride oil), glycerol, phthalic anhydride, xylene, litharge, and nitrogen gas for maintaining an inert reaction atmosphere (Abbas & Ahmad, 2020; Dizman & Kaçakgil, 2023; Selim et al., 2024). For the fabrication of plant equipment, the study employed mild steel sheets owing to their favorable cost, corrosion resistance, and mechanical properties (Zhao et al., 2026). Ancillary materials and apparatus incorporated bolts, nuts, flanges, electrode, shaft, paint, anchor blade (for agitation), a 600-

watt DC motor (to drive the agitator), motor base, stands, inlet and outlet pipes, airtight lid, tap, thermocouple, thermometer, flowmeter, pipe tubers, and supporting clips.

### 2.2. Process and Plant Design

Material balance calculations established the foundation for batch sizing and quantitative process flow. Each production batch was standardized at 5 kg, with the composition consisting of 60% soybean oil, complemented by calculated proportions of the remaining reactants. Water generation during esterification was estimated at 1% of the total oil-alcohol mixture, based on established patent standards. Figureureure 1 depicts the block flow diagram for the production of alkyd resin plant. Detailed flow mapping of outputs, inputs, and accumulations was conducted for each process stage, ensuring accurate prediction of product yield and operational efficiency. The block flow diagram for the production of alkyd resin is shown in Figureureure 1.

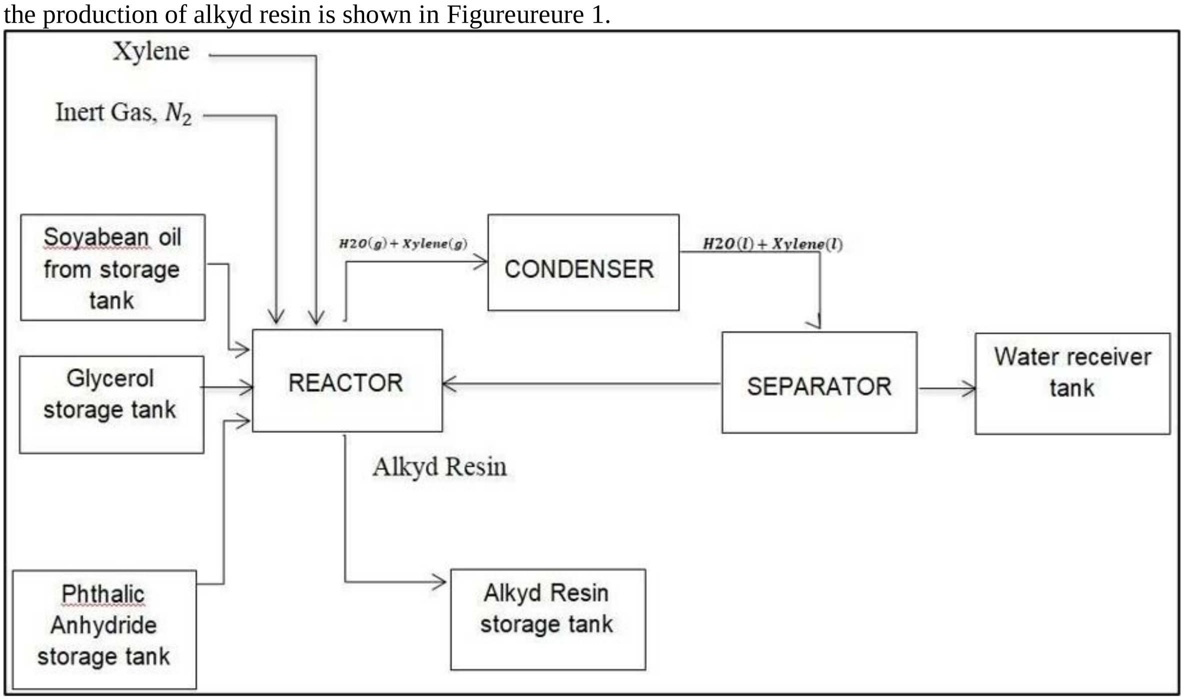


**Figure 1: Block Flow Diagram for the production of Alkyd Resin**

### 2.3. Reactor Design and Fabrication

The core equipment designed was a jacketed semi-batch stirred tank reactor (STR), selected for its adaptability to batch and continuous processing. The reactor operated within a temperature range of 200°C to 240°C, with design features enabling precise control over both heat and agitation. The temperature range is in accordance with the work of Aigbodion and Okieimen (2001). The vessel was dimensioned with a volume of 8.33 liters, a diameter of 220 mm, a height of 220 mm, and a wall thickness of 6 mm. Fabrication involved the sequential cutting and shaping of mild steel sheets, welding of the body, base, flanges, and entry ports, followed by the installation of an anchor blade agitator driven by the DC motor. External heating was accomplished using jackets or coils, and temperature and pressure regulation was achieved via integrated sensors and safety controllers.

### 2.4. Condenser Design and Fabrication

Vapor generated during the reaction was managed using a shell-and-tube heat exchanger type condenser (Kasumu et al., 2017). The heat exchanger contained a tube bundle composed of 17 tubes, each with an outer diameter of 21 mm, an inner diameter of 19 mm, and a length of 1000 mm. The shell diameter measured 205.13 mm, while the bundle diameter was 152.13 mm and the tube pitch was 26.55 mm. Fabrication procedures involved the cutting and assembly of the shell and tube components, welding of tube plates and supports, and the installation of inlet and outlet connections for cooling fluids. Removable tube bundles were incorporated in the design to facilitate periodic maintenance and minimize fouling.

### 2.5. Decanter Design and Fabrication

The decanter, a cylindrical vessel designed for liquid phase separation, was fabricated to ensure sufficient residence time and effective density-based stratification of product and by-product layers (Sorsamäki & Nappa, 2015). The vessel included distinct zones allowing for heavy and light liquid stratification, dispersion, and clear phase accumulation. Mild steel sheets were cut and welded into the specified dimensions; inlet and outlet ports as well as sampling taps and a secure cover were systematically installed to ensure operational efficiency and safety.

### 2.6. Process Control and Instrumentation

Both temperature and agitation were closely managed throughout production. The integration of thermocouples and thermometers into the reactor and condenser facilitated real-time monitoring and control, while the DC motor's speed regulator provided optimal mixing conditions tailored to viscosity changes during the reaction. Flowmeters measured feed rates, and pressure relief valves were installed to ensure safe operation under both pressurized and vacuum conditions as recommended by Hellemans (2009) and (Johnson & Niemeier, 2020).

### 2.7. Material and Energy Balance Calculations

In the study on the fabrication of alkyd resin, the material balance methodology is based on understanding the relationship between input materials and output products under batch process conditions in accordance with the principle of conservation of mass and material balance analysis (Himmelblau & Riggs, 2012).. The methodology uses a mass balance equation framed as shown in equation 1 around the reactor and condenser units.

$$Input + Generation = Output + Accumulation \tag{1}$$

For the reactor, since it operates under batch conditions, the Generation term equals Accumulation, leading to the simplification that the sum of input reactants (monoglyceride, phthalic anhydride, xylene) and any additional inputs equals the alkyd resin produced. The material balance is performed on a 5 kg per batch basis with assumptions about composition percentages and negligible intermediate reactions, which is consistent with standard material balance practices involving basis selection and simplifying assumptions in batch process analysis (Felder et al., 2020).. For the condenser, the material balance assumes steady state with no chemical reactions, so Generation and Accumulation are zero, making Input equal Output, ensuring the mass of condensed vapors equals the mass of vapors entering the condenser. Also, rigorous energy balance calculations were performed to determine the heat required for initiating and maintaining the esterification reaction, alongside the latent heat demands of vaporizing xylene and water (Felder et al., 2020). Design methods integrated the log mean temperature difference (LMTD) and overall heat transfer coefficient to appropriately size the reactor heating and condenser cooling systems, thereby enhancing product stability and minimizing energy wastage.

### 2.8. Equipment Assembly and Testing

Following fabrication, all plant equipment components were assembled in sequence. Integration of sensors, agitators, drive systems, and piping preceded initial leak and pressure testing to certify vessel integrity. Process simulation subsequently involved heating, mixing, and phase separation cycles, with calibration routines applied to all temperature and flow instrumentation. Verification of system output was achieved by cross-referencing actual product yield and material balance calculations against theoretical predictions.

### 2.9. Safety and Maintenance

Throughout equipment design and fabrication, priority was given to safety and ease of maintenance. The reactor and other vessels were fitted with pressure relief devices and robust temperature controls. Surfaces were coated with protective paint to minimize corrosion, and removable sections, such as condenser tube bundles and decanter covers, were included for routine cleaning and inspection. Maintenance protocols emphasized regular checks on moving parts, sensor calibration, and inspection of weld joints and pressure seals to ensure sustained, safe operation of the plant.

## 3.0 Result and Discussion

### 3.1. Material Balance on the Reactor

The process of producing alkyd resin was analyzed through detailed material balance calculations. On the reactor, the input materials included soybean oil, glycerol, phthalic anhydride, and xylene. The output consisted mainly of the alkyd resin product and by-products such as water. For each stage of the reaction, the mass and mole quantities of raw materials and products were determined. In Phase 1 (Table 1), 3.00 kg of soybean oil and 0.60 kg of glycerol were transformed into 3.60 kg of monoglyceride. In Phase 2 (Table 2), 3.60 kg of monoglyceride, 1.448 kg of phthalic anhydride, and 0.064 kg of xylene combined to generate 5.00 kg of alkyd resin, with water and residual solvents as additional outputs. The total mass balance across the stages confirmed consistency in input and output quantities.

**Table 1: Material Balance on the reactor (Phase 1)**

| INPUT | | | | OUTPUT | | | |
|---|---|---|---|---|---|---|---|
| Compound | Molecular weight (kg/kmol) | No. of moles | Mass (kg) | Compound | Molecular weight (kg/kmol) | No of moles | Mass (kg) |
| Soyabean oil | 920 | 0.0032 | 3.00 | Monoglyceride | 119 | 0.019 | 3.60 |
| Glycerol | 92 | 0.0130 | 0.60 | | | | |
| Total | | | 3.60 | Total | | | 3.60 |

Table 2: Material balance on the reactor (Phase 2)

| INPUT | | | | OUTPUT | | | |
|---|---|---|---|---|---|---|---|
| Compound | Molecular weight (kg/kmol) | No. of moles | Mass (kg) | Compound | Molecular weight (kg/kmol) | No of moles | Mass (kg) |
| Monoglyceride | 119 | 0.0019 | 3.60 | Alkyd Resin | - | - | 5.00 |
| Phthalic anhydride | 148 | 0.0097 | 1.448 | Xylene-Water(g) | 56 | 0.002 | 0.112 |
| Xylene | 106 | 0.0006 | 0.064 | | | | |
| Total | | | 5.112 | Total | | | 5.112 |

### 3.2. Material Balance on the Condenser

The condenser was designed to handle the vapor phase output from the reactor, primarily consisting of xylene and water. The material balance on the condenser demonstrated that the total input mass of the vapor phase, comprising 0.112 kg xylene-water mixture, matched the total output after condensation, further split into 0.064 kg xylene and 0.048 kg water (Table 3). This confirmed the efficiency of the condenser in separating and collecting the by-products without loss, achieving a complete phase change as required. The material balance across the condenser showed that the total vapor input (0.112 kg) was equal to the total liquid output, confirming steady-state operation with no accumulation. This agrees with classical mass balance principles for process equipment as outlined in Perry's Chemical Engineers' Handbook (Perry, 1950).

Table 3: Material balance data on the condenser

| INPUT | | | | OUTPUT | | | |
|---|---|---|---|---|---|---|---|
| Compound | Molecular weight (kg/kmol) | No. of moles | Mass (kg) | Compound | Molecular weight (kg/kmol) | No of moles | Mass (kg) |
| Xylene-water | 56 | 0.002 | 0.112 | Xylene | 116 | 0.006 | 0.064 |
| | | | | Water | 18 | 0.003 | 0.048 |
| Total | | | 0.112 | Total | | | 0.112 |

### 3.3. Energy Balance on the Reactor

The study assessed the energy requirements for heating, reaction, and thermal management. Inputs included the heat content of monoglyceride, phthalic anhydride, and the xylene-water mixture at defined operating conditions. The output measured the heat content of the alkyd resin and other products after reaction. The total heat input for the process across all reactants was calculated and compared with the output heat contained in the product and by-products as seen in Table 4. The excess energy in the reactor amounted to 1882.32 KJ, and the mass of cooling water required for temperature maintenance was found to be 9 liters, ensuring efficient temperature control through the batch period.

| **INPUT** | | | | | **OUTPUT** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Compound** | **Mass (kg)** | **Cp (KJ/mol K)** | **T (K)** | **H (KJ)** | **Comp** | **Mass (kg)** | **Cp (KJ/mol K)** | **T (K)** | **H (KJ)** |
| Monoglyceride | 3.6 | 2.215 | 175 | 159.5 | Alkyd resin | 5.00 | 1.83 | 175 | 1601.25 |
| Phthalic anhydride | 1.48 | 1.08 | 175 | 31.27 | Xylene-water | 0.112 | 3.67 | 175 | 64.225 |
| Xylene | 0.064 | 1.72 | 75 | 2.20 | | | | | |
| Total | | | | 192.9 | | | | | 1665.47 |

**Table 4: Energy balance data on the reactor**

### 3.4. Energy Balance on the Condenser

The condenser was analyzed for its energy consumption and heat transfer capacity. It was shown that the energy content of the xylene-water vapor entering the condenser matched the energy content after condensation, ensuring conservation of energy across the unit (Himmelblau & Riggs, 2012). Input heat to the system was 64.225 KJ, and output heat after condensation and cooling was 103.01 KJ (Table 5). This demonstrates the condenser's capability to achieve the necessary phase transition while controlling the temperature rise from 25°C to 50°C in the coolant.

**Table 5: Energy balance data on the condenser**

| **INPUT** | | | | | **OUTPUT** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Comp | Mass (kg) | Cp (KJ/mol K) | T (K) | H (KJ) | Comp | Mass (kg) | Cp (KJ/mol K) | T (K) | H (KJ) |
| Xylene-water | 0.112 | 3.67 | 175 | 64.225 | Xylene-water | 0.112 | 3.67 | 25 | 103.01 |
| Total | | | | 192.97 | | | | | 103.01 |

### 3.5. Reactor Design

The reactor selected was a mild steel, jacketed semi-batch stirred tank reactor. Its key specifications included a volumetric capacity of 8.33 liters, diameter of 220 mm, and wall thickness of 6 mm. The reactor design allowed for efficient mixing, controlled heating, and safe operation under batch conditions. The reaction rate was $36 \times 10^6$ mol/hr with a batch time of 3 hours as seen in Table 6. Temperature and pressure control systems, including relief valves and integrated distillation setups for by-product removal, were incorporated for optimal reaction progress and safety.

**Table 6: Equipment specification data for reactor**

| S/N | PARAMETER | VALUES |
|---|---|---|
| 1. | Reaction rate, r | $36\ x\ 10^{-6} mol/lit$ |
| 2. | Reactor Volume, V | $0.00833 m^3$ |
| 3. | Batch rector time | 3hrs |
| 4. | Volumetric flow rate | $0.2785 m^3/hr$ |
| 5. | Space velocity | 33.443/hr |
| 6. | Qexcess in the reactor | 1882.315346KJ |
| 7. | Mass of cooling water | 9 litres ( $2.50 cm^3/sec$) |

### 3.6. Condenser Design

The condenser chosen was a shell-and-tube heat exchanger made of mild steel, featuring 17 tubes with an outer diameter of 21 mm, an inner diameter of 19 mm, and a length of 1 meter per tube. The total heat transfer area was 1.1549 m², and the log-mean temperature difference was established at 104.97°C as seen in Table 7. The design provided for adequate heat exchange, effective condensation of xylene and water vapors, and minimal pressure drop. The tube pitch, bundle diameter, shell diameter, baffle spacing, and pressure drop values were optimized for the process requirements, enabling robust and efficient operation.

**Table 7: Equipment specification data for condenser**

| S/N | PARAMETER | VALUES |
|---|---|---|
| 1. | Heat transfer are for the condenser, A | $1.1549 m^2$ |
| 2. | Log mean temperature difference, $\Theta m$ | 104.97°C |
| 3. | Overall Coefficient required, µ | $1000 W/m^{2\circ}C$ |
| 4. | Wall temperature | 87.5°C |
| 5. | Area of one tube | $0.066 m^2$ |
| 6. | Number of tubes, $Nt$ | 17tubes |
| 7. | Outer diameter of tube, $do$ | 21mm |
| 8. | Inter diameter of tube, $di$ | 19mm |
| 9. | Length of tube | 1000mm |
| 10. | Tube pitch, $Pt$ | 26.55mm |
| 11. | Inside coefficient for water, $hi$ | $1566.385 W/m^{2\circ}C$ |
| 12. | Tube Pressure drop, $\Delta Pt$ | $138.0174 N/m^2$ |
| 13. | Mean water temperature | 37.5°C |
| 13. | Mean water temperature | 37.5°C |
| 14. | Bundle diameter, $Db$ | 152.13mm |
| 15. | Shell diameter, $Ds$ | 205.13mm |
| 16. | Baffle Spacing, $Lb$ | 41.026mm |
| 17. | Shell pressure drop, $\Delta Ps$ | $406.1029 N/m^2$ |
| 18. | Cross flow Area, $As$ | $1.6831\ x\ 10^{-3} m^2$ |
| 19. | Mean Shell side temperature | 125°C |

The results confirmed that the material and energy balances in both the reactor and condenser were consistent, ensuring efficient conversion of reactants to products, effective separation and removal of by-products, and optimum use of energy as recommended by Himmelblau and Riggs (2012). The equipment specifications derived from these balances informed the final reactor and condenser designs, supporting safe, reliable, and effective alkyd resin production in the study. Figures 2 and 3 show the 3D view of the alkyd resin modular plant, and the fabricated alkyd resin modular plant.

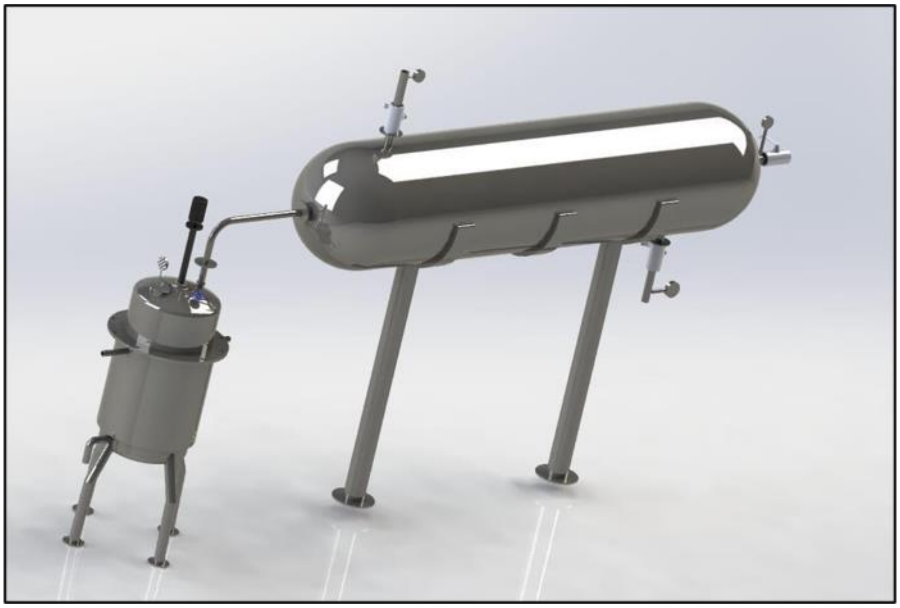

**Figure 2: 3D view of the alkyd resin modular plant**

**Figure 3: The fabricated alkyd resin modular plant**

## 4.0. Conclusion

This study successfully demonstrates the feasibility and practical viability of designing, and fabricating a modular alkyd resin production plant using locally available materials and manufacturing capabilities. The comprehensive approach encompassing detailed material and energy balance calculations, rigorous equipment design specifications, and systematic fabrication procedures has resulted in a functional production system capable of producing 5 kg batches of alkyd resin through a two-phase synthesis process involving alcoholysis and esterification reactions. The material balance calculations confirmed the consistency and efficiency of the production process, with precise quantification of inputs and outputs across both reactor and condenser units. Phase 1 successfully converted 3.00 kg of soybean oil and 0.60 kg of glycerol into 3.60 kg of monoglyceride, while Phase 2 transformed 3.60 kg of monoglyceride, 1.448

kg of phthalic anhydride, and 0.064 kg of xylene into 5.00 kg of alkyd resin product. The condenser efficiently managed vapor separation, recovering 0.064 kg of xylene and 0.048 kg of water from the 0.112 kg xylene-water mixture. Energy balance analysis established that the reactor required 1882.32 KJ of excess energy with 9 liters of cooling water for optimal temperature control, while the condenser demonstrated effective heat transfer capability with a log mean temperature difference of 104.97°C and heat transfer area of 1.1549 m².
The fabricated equipment—comprising a jacketed semi-batch stirred tank reactor (8.33 liters, 220 mm diameter, 6 mm wall thickness), shell-and-tube condenser (17 tubes, 1000 mm length), and liquid-phase decanter—successfully met all design specifications and operational requirements. The use of mild steel as the primary construction material proved appropriate for the operating conditions while ensuring cost-effectiveness and ease of fabrication. Integration of process control instrumentation, including thermocouples, thermometers, flowmeters, and a 600-watt DC motor-driven agitation system, enabled precise monitoring and control of critical process parameters throughout the batch production cycle. This work represents a significant step toward industrial self-reliance and sustainable development in the coatings and paint industry. Future research directions could explore optimization of reaction conditions to enhance product yield and quality, investigation of alternative renewable feedstocks for improved sustainability, development of automated control systems for consistent batch-to-batch performance, scale-up studies to increase production capacity while maintaining efficiency, and comprehensive techno-economic analysis to evaluate commercial viability at various production scales. The successful implementation of locally fabricated alkyd resin production plants has the potential to stimulate economic growth, create employment opportunities, foster indigenous technological capabilities, and contribute meaningfully to the broader objectives of industrial diversification and sustainable manufacturing in developing economies.

### 4.1 Economic Viability and Scale-Up Considerations

The alkyd resin production system is economically viable at laboratory and small-scale levels due to its use of locally available raw materials, low-cost mild steel construction, and simple unit operations. Operating costs are mainly driven by raw material procurement and moderate energy requirements, with the calculated heat demand (1882.32 kJ per batch) suggesting manageable thermal energy consumption under proper insulation or heat recovery.

While the current design is suitable for small-scale and pilot production, industrial-scale viability will require process optimization, improved heat and mass transfer design, and a full techno-economic analysis to evaluate cost competitiveness and investment feasibility.

### 4.2 Safety and Operability Discussion

The current small-scale alkyd resin production system involves elevated temperatures, flammable solvents (xylene), and reactive chemicals, requiring strict safety measures. Adequate ventilation is essential to prevent vapor accumulation, while proper sealing of the reactor and condenser minimizes leaks. Temperature and pressure must be continuously monitored using installed instrumentation to avoid overheating or overpressure conditions. The use of mild steel necessitates regular inspection to prevent corrosion-related failures.

Operability is supported by the modular design and basic control instruments; however, consistent monitoring of agitation, temperature, and cooling water flow is required to maintain stable reaction conditions. Safe handling and storage of raw materials, use of personal protective equipment (PPE), and provision of emergency shutdown procedures further enhance safe and reliable operation of the system.

## 5.0 Recommendation

Future studies should optimize key process parameters, including reaction temperature, reaction time, agitation speed, and reactant ratios, and evaluate the performance of the system at pilot and industrial scales to improve product quality, process efficiency, and production capacity.

**Acknowledgements**
Not applicable.

## Nomenclature

3D= 3 Dimensional
LMTD = Log Mean Temperature Difference
DC=Direct Current

**Declaration of Generative AI and AI-assisted technologies in the writing process**

During the preparation of this work the author(s) used Microsoft word, BIOVIA Draw 2017 and Adobe photoshop 2020 in order to produce the manuscript, and graphical abstract. After using these tools, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

**References**

Abbas, S., & Ahmad, Z. (2020). Synthesis and Study of Thermo Physical Properties of Phthalic anhydride glycerol Resin (PAGR) from Soybean Oil. Journal of Materials Science Research, 9(1).

Aigbodion, A., & Okieimen, F. (2001). An investigation of the utilisation of African locustbean seed oil in the preparation of alkyd resins. Industrial Crops and Products, 13(1), 29-34.

Chardon, F., et al. (2021). "Hybrid alkyds, the glowing route to reach cutting-edge properties?" Progress in Organic Coatings 151: 106025.

Chiplunkar, P. P. and A. P. Pratap (2016). "Utilization of sunflower acid oil for synthesis of alkyd resin." Progress in Organic Coatings 93: 61-67.

Dizman, C., & Kaçakgil, E. C. (2023). Alkyd resins produced from bio-based resources for more sustainable and environmentally friendly coating applications. Turkish Journal of Chemistry, 47(1), 1-23.

Elba, M. E., et al. (2018). "Progress in organic coating: Synthesis and characterization alkyd resin based on soya bean oil and glycerin using zirconium octoate as catalyst." Chemical Technology Indian Journal 13(1): 118.

Felder, R. M., Rousseau, R. W., & Bullard, L. G. (2020). Elementary principles of chemical processes. John Wiley & Sons.

Gandini, A., et al. (2016). "Progress of polymers from renewable resources: furans, vegetable oils, and polysaccharides." Chemical reviews 116(3): 1637-1669.

Glenn, A. F., et al. (2023). "Exploiting the Use of Salvia Hispanica L.(chia) Oil as a Renewable Raw Material to Produce Air-Drying Alkyd Resins: A Comparative Study." Macromolecular Reaction Engineering 17(4): 2300014.

Glenn, A., et al. (2021). "Salvia hispanica L.(Chia) Oil as a potential renewable raw material for the production of Air-Dry Alkyd resins." ACS Applied Polymer Materials 3(12): 6186-6197.

Hellemans, M. (2009). The safety relief valve handbook: Design and use of process safety valves to ASME and International Codes and Standards. Elsevier.

Himmelblau, D. M., & Riggs, J. B. (2012). Basic principles and calculations in chemical engineering. FT press.

Johnson, M. D., & Niemeier, J. (2020). Safety guidelines for continuous processing. In Continuous pharmaceutical processing (pp. 441-476). Springer.

Jones, F. N., et al. (2017). Organic coatings: science and technology, John Wiley & Sons.

Kasumu, A. S., Nassar, N. N., & Mehrotra, A. K. (2017). A heat-transfer laboratory experiment with shell-and-tube condenser. Education for Chemical Engineers, 19, 38-47.

Machinery, J. (2024). "Setting Up an Alkyd Resin Plant: Essentials to Know." Retrieved 24 Nov, 2025, from https://www.jinzongmachinery.com/a-news-setting-up-an-alkyd-resin-plant-essentials-to-know.html.

Machinery, J. C. T. (2025). "Helping African Customers Build Alkyd Resin Production Line ". Retrieved 24 Nov, 2025, from https://www.jctmixingequipment.com/news/helping-african-customers-build-alkyd-resin-production-line.html.

Mustapha, A. O., et al. (2023). "New Alkyd Resins from Underutilized Indigenous Seed Oils: Synthesis and Characterization." Karbala International Journal of Modern Science 9(2): 7.

Oragwu, I. P., et al. (2024). "Comparative Studies on Alkyd Resins from Palm (Elaeis guineensis) Oil and Mango (Mangifera) Seed-Oil." Open Journal of Polymer Chemistry 14(4): 199-213.

Perry, J. H. (1950). Chemical engineers' handbook. In: ACS Publications.

Selim, M. S., El-Hoshoudy, A. N., Zaki, E. G., El-Saeed, A. M., & Farag, A. A. (2024). Durable graphene-based alkyd nanocomposites for surface coating applications. Environmental Science and Pollution Research, 31(31), 43476-43491.

Sorsamäki, L., & Nappa, M. (2015). Design and selection of separation processes. Finland: VTT Technical Research Centre of Finland Ltd.

Zhao, W., Ye, J., Li, L., & Zheng, G. (2026). Flow-Field Modeling and Mixing Mechanisms of the Twin-Shaft Mixers Based on LBM–LES Coupling. Machines, 14(1), 56.