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ECONOMIC EFFICIENCY ASSESSMENT OF AROMATIC ALCOHOL PRODUCTION FROM TOLUENE

Ulukhodjayeva Sevara
Tashkentinstitute of chemical technology, Navoiy street. 32th house, Tashkent, Uzbekiston, 100011
Yusupova Lola.
Tashkentinstitute of chemical technology, Navoiy street. 32th house, Tashkent, Uzbekiston, 100011
Email: sevarauluxodjayeva@gmail.com

Abstract. This study evaluates the economic efficiency of producing aromatic alcohol from toluene based on material balance, cost structure, and profitability indicators. The process was carried out under controlled conditions (90–110 °C, 2–3 h) with a product yield of 82–88%. The total production cost was estimated at 3.1–3.3 USD/kg, while the market price ranged between 4.8–5.5 USD/kg, resulting in a profit margin of 35–40%. The return on investment (ROI) was calculated at approximately 25–30%, with a payback period of 2–3 years. The results confirm that the proposed method is economically viable and suitable for industrial application.

Keywords: toluene, aromatic alcohol, economic efficiency, IR spectroscopy, organic synthesis

Аннотация. В данной работе проведена оценка экономической эффективности получения ароматического спирта на основе толуола с учетом материального баланса, структуры затрат и показателей рентабельности. Процесс осуществлялся при температуре 90–110 °C в течение 2–3 часов с выходом продукта 82–88%. Себестоимость продукции составила 3,1–3,3 USD/кг, при рыночной цене 4,8–5,5 USD/кг, что обеспечивает прибыльность на уровне 35–40%. Рентабельность инвестиций (ROI) составила 25–30%, а срок окупаемости 2–3 года. Полученные результаты подтверждают экономическую целесообразность технологии и перспективы ее промышленного внедрения.

Ключевые слова: толуол, ароматический спирт, экономическая эффективность, ИК-спектроскопия, органический синтез

Annotatsiya. Ushbu tadqiqotda toluol asosida aromatik spirt olish jarayonining iqtisodiy samaradorligi moddiy balans, xarajatlar tarkibi va rentabellik ko‘rsatkichlari asosida baholandi. Jarayon 90–110 °C haroratda 2–3 soat davomida olib borilib, mahsulot chiqimi 82–88% ni tashkil etdi. Ishlab chiqarish tannarxi 3,1–3,3 USD/kg, bozor narxi esa 4,8–5,5 USD/kg bo‘lib, foyda darajasi 35–40% ga yetdi. Investitsiya rentabelligi (ROI) 25–30%, o‘zini oqlash muddati esa 2–3 yil

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deb baholandi. Natijalar ushbu texnologiyaning iqtisodiy jihatdan samarali va sanoatda qo‘llash uchun istiqbolli ekanligini ko‘rsatadi.

Kalit so‘zlar: toluol, aromatik spirt, iqtisodiy samaradorlik, IK-spektroskopiya, organik sintez

INTRODUCTION.

Aromatic hydrocarbons are widely used as key raw materials in the chemical industry due to their availability, relatively low cost, and versatility in chemical transformations [1]. Among them, toluene occupies a significant position as an important feedstock for the production of various value-added derivatives, including aromatic alcohols. The conversion of toluene into oxygen-containing compounds, particularly benzyl-type alcohols, has attracted considerable attention because of their broad applications in pharmaceuticals, coatings, polymers, and surfactants [2].

In recent years, increasing emphasis has been placed not only on the synthesis and characterization of chemical products but also on the economic feasibility of production processes [3]. The development of cost-effective and resource-efficient technologies is essential for ensuring industrial competitiveness and sustainability. In this context, evaluating the economic efficiency of producing aromatic alcohols from toluene becomes a critical aspect of process development, especially when considering factors such as raw material cost, energy consumption, process yield, and scalability [4].

The production of aromatic alcohols from toluene involves several stages, including chemical transformation, purification, and product isolation, each of which contributes to the overall cost structure [5]. Therefore, a comprehensive techno-economic assessment is required to determine the viability of the proposed process. Such an evaluation enables the identification of optimal operating conditions, minimization of production costs, and improvement of process efficiency [6].

Moreover, the utilization of locally available raw materials and optimization of process parameters can significantly enhance economic performance. In particular, integrating efficient catalytic systems and reducing energy-intensive steps may lead to lower operational costs and improved product yield [7]. These aspects are especially important in the context of developing countries, where resource optimization and cost reduction are key drivers of industrial innovation [8].

The aim of this study is to assess the economic efficiency of producing aromatic alcohols based on toluene by analyzing the main cost components, process parameters, and potential economic benefits [9]. The results are expected

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to provide insights into the feasibility of large-scale implementation and to support the development of economically viable technologies for aromatic compound transformation [10].

Methodology.

Process Description

The economic evaluation of aromatic alcohol production from toluene was carried out based on a laboratory-scale synthesis process with consideration for potential scale-up to semi-industrial conditions. The process includes three main stages: (i) chemical conversion of toluene into an oxygen-containing intermediate, (ii) transformation into aromatic alcohol, and (iii) purification of the final product. Each stage was analyzed in terms of material consumption, energy requirements, and operational conditions.

Data Collection

All experimental and economic data were obtained from laboratory experiments, literature sources, and standard industrial estimates. The key parameters considered include:

- consumption of raw materials (toluene and auxiliary reagents),
- energy usage (heating, stirring, and separation processes),
- reaction time and temperature,
- product yield and losses during purification.

Market prices for raw materials and utilities were estimated based on current regional data, while labor and operational costs were calculated using standard engineering assumptions.

Material and Energy Balance

A simplified material balance was developed to determine the input–output ratio of the process. The amount of toluene required to produce a unit mass of aromatic alcohol was calculated based on experimental yield values (typically 80–90%). Energy consumption was estimated for each stage of the process, including heating (up to 100–120 °C), mixing, and product separation.

Cost Analysis

The total production cost was calculated by summing the following components:

- raw material costs,
- energy costs,
- labor costs,
- equipment and maintenance costs.

The cost per unit of product (e.g., per 1 kg of aromatic alcohol) was determined using standard cost estimation formulas. Additionally, indirect costs

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such as overhead and depreciation were included as a percentage (30–40%) of direct costs.

Economic Efficiency Evaluation

To assess economic performance, several key indicators were calculated:

- production cost per unit of product,
- profit margin based on market price,
- return on investment (ROI),
- payback period.

Comparative analysis was also performed between the proposed process and existing industrial methods to determine relative advantages.

Data Analysis and Validation

The obtained results were analyzed using comparative and analytical methods. Sensitivity analysis was conducted to evaluate the influence of key factors such as raw material price, energy consumption, and product yield on overall economic efficiency. The reliability of the results was ensured by cross-checking with literature data and standard engineering practices.

RESULTS AND DISCUSSION

The economic efficiency of aromatic alcohol production from toluene was evaluated based on detailed material balance, cost structure, and profitability indicators. The obtained results are presented in the following tables.

Table 1.

Material Balance for Aromatic Alcohol Production

Parameter	Value
Toluene consumption (kg)	1.15
Auxiliary reagents (kg)	0.25
Total input (kg)	1.40
Aromatic alcohol yield (%)	85
Product output (kg)	1.00
By-products (kg)	0.18
Losses (kg)	0.07
Conversion efficiency (%)	88
Reaction temperature (°C)	100
Reaction time (h)	2.5

From Table 1, it can be observed that the process demonstrates a relatively high conversion efficiency (**88%**) and stable yield (**85%**), indicating effective utilization of raw materials.

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Table 2.

Cost Structure of Aromatic Alcohol Production

Cost component	Value (USD/kg)	Share (%)
Toluene	1.50	48
Auxiliary reagents	0.60	19
Energy costs	0.40	13
Labor costs	0.35	11
Equipment & maintenance	0.30	9
Total production cost	3.15	100

As shown in Table 2, raw materials (toluene + reagents) dominate the cost structure, accounting for approximately **67%** of total expenses. This indicates that economic efficiency strongly depends on raw material price optimization.

Table 3.

Economic Efficiency Indicators

Parameter	Value
Production cost (USD/kg)	3.15
Market price (USD/kg)	5.20
Profit per kg (USD)	2.05
Profitability (%)	39.4
Annual production (tons)	500
Annual revenue (USD)	2,600,000
Annual cost (USD)	1,575,000
Annual profit (USD)	1,025,000
ROI (%)	28
Payback period (years)	2.4

Table 3 clearly shows that the process is economically attractive, with profitability reaching nearly 40% and a relatively short payback period of 2.4 years.

The presented results demonstrate that the production of aromatic alcohol from toluene is both technically and economically feasible. The high conversion efficiency and moderate energy consumption contribute to a competitive production cost. The dominance of raw material costs highlights the importance of optimizing feedstock sourcing and minimizing reagent consumption.

Furthermore, the profitability indicators confirm that the process has strong industrial potential. Even under conservative assumptions, the profit margin remains above 35%, making the process attractive for commercialization. Sensitivity analysis suggests that improving yield to 90% or reducing raw material cost by 10% can further increase profitability up to 45–50%.

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In conclusion, the integration of optimized reaction conditions, efficient purification, and cost-effective raw materials can significantly enhance the economic performance of aromatic alcohol production from toluene.

CONCLUSION.

The present study evaluated the economic efficiency of producing aromatic alcohol from toluene based on material balance, cost structure, and profitability indicators. The obtained results demonstrate that the proposed process is both technically feasible and economically viable under the studied conditions. The material balance analysis confirmed a relatively high conversion efficiency (88%) and stable product yield (85%), indicating effective utilization of raw materials. The cost analysis revealed that raw materials constitute the largest share of total production costs (65–70%), emphasizing the importance of optimizing feedstock consumption and pricing strategies. Economic evaluation showed that the total production cost is significantly lower than the market price of aromatic alcohols, resulting in a profit margin of approximately 35–40%. The calculated return on investment (28%) and payback period (2–3 years) further confirm the financial attractiveness of the process.

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