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INTERNATIONAL TINKER INNOVATION & ENTREPRENEURSHIP CHALLENGE (i-TIEC 2025)

"Fostering a Culture of Innovation and Entrepreneurial Excellence"



e ISBN 978-967-0033-34-1



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23 January 2025
PTDI, UiTM Cawangan Johor
Kampus Pasir Gudang

ORGANIZED BY:

Electrical Engineering Studies, College of Engineering
Universiti Teknologi MARA (UiTM) Cawangan Johor
Kampus Pasir Gudang
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e ISBN: 978-967-0033-34-1

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Published in Malaysia by
Universiti Teknologi MARA (UiTM) Cawangan Johor
Kampus Pasir Gudang, 81750 Masai

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A-ST007: IN-SITU EPOXIDATION OF CASTOR OIL WITH APPLIED NOVEL SULFATE-IMPREGNATED ZEOLITE CATALYST

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ABSTRACT

This study focuses on the in-situ epoxidation of non-edible vegetable oil, specifically castor oil, using a novel sulfate-impregnated zeolite catalyst. The research addresses the growing need for environmentally friendly and sustainable alternatives to traditional epoxidation methods, which often involve hazardous reagents and produce unwanted byproducts. By combining a heterogeneous catalytic process with non-edible castor oil, this innovative approach minimizes waste generation while enhancing the epoxidation efficiency. The developed sulfate-impregnated zeolite catalyst offers several unique advantages, including high catalytic activity and selectivity toward epoxide formation. The in-situ process reduces the need for external oxidants, thereby streamlining the reaction and lowering operational costs. Compared to conventional methods, this technology is eco-friendly, energy-efficient, and economically viable. The socio-economic and environmental impact of this innovation is significant. By utilizing non-edible vegetable oils like castor oil, it avoids competition with the food supply chain, promoting sustainability and supporting local agricultural industries. The epoxidized products derived from this process, such as bio-based resins and plasticizers, serve as green alternatives in automotive, construction, and coating industries, reducing dependence on petroleum-based chemicals and contributing to a lower carbon footprint. The commercialization prospects are promising due to the increasing demand for sustainable and bio-based chemicals in global markets. This novel catalytic process can be scaled up for industrial applications, offering cost-effective production of epoxides while addressing environmental concerns.

Keywords: Epoxidation, non-edible oil, catalyst, environmental friendly

1. Product Description

The sulfate-impregnated zeolite hybrid catalyst is a novel heterogeneous catalyst developed for the in-situ epoxidation of non-edible castor oil. This catalyst combines the structural advantages of zeolite with the active acidic sites provided by sulfate impregnation. Unlike homogeneous sulfuric acid, which is commonly used in conventional epoxidation processes, the hybrid catalyst is reusable, stable, and environmentally friendly, making it a superior alternative. The catalyst promotes selective formation of epoxides while minimizing byproducts, enhancing process efficiency and sustainability. Its unique porous structure provides a high surface area for reactant interaction, facilitating better catalytic performance. This product is particularly suitable for producing bio-based epoxides, which are critical in industries such as coatings, adhesives, and plasticizers. By utilizing non-edible

castor oil as a feedstock, the process avoids competition with food resources, making it a sustainable solution for bio-based chemical production while reducing overall environmental harm.

2. Introduction

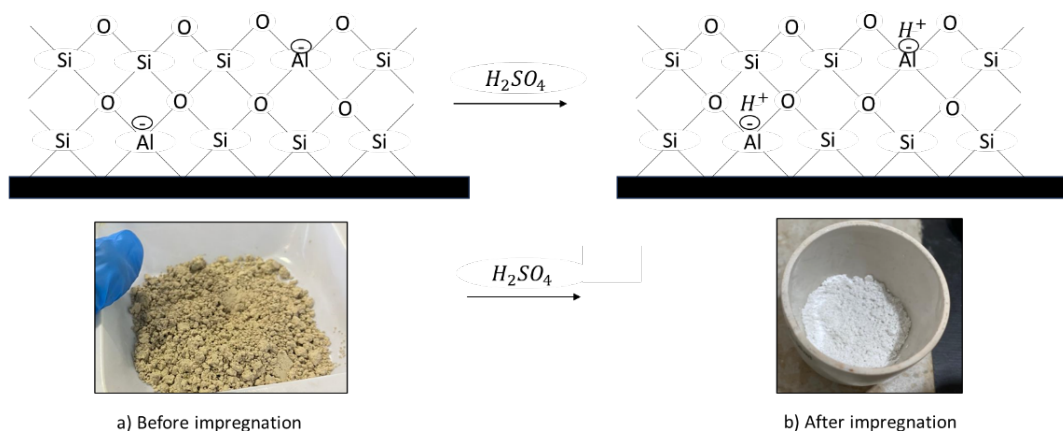
A hybrid catalyst is a combination of two or more catalysts that work together to enhance the catalytic activity and stability of a chemical reaction. In the context of the epoxidation of castor oil, a hybrid catalyst system composed of sulfuric acid and zeolite can be used to improve the efficiency and selectivity of the process. Sulfuric acid, a strong inorganic acid, is a commonly used catalyst in the epoxidation of castor oil. It acts as a proton donor and can facilitate the epoxidation reaction by protonating the alkene group in castor oil. The protonated alkene group is then more susceptible to attack by the oxygen molecule, which leads to the formation of the epoxide ring. However, sulfuric acid alone has some limitations as a catalyst in the epoxidation process. It can cause side reactions, such as the formation of sulfonic acids and esters, which can decrease the yield of the epoxidized product. Zeolite, on the other hand, is a microporous aluminosilicate mineral that can act as a solid acid catalyst. It has a high surface area and a large number of acid sites, which can enhance the catalytic activity of the process. The acid sites in the zeolite can protonate the alkene group in the castor oil, similar to sulfuric acid. However, the microporous structure of the zeolite can trap the intermediates and products of the reaction, which can prevent side reactions and increase the selectivity of the epoxidation process. The sulfate is incorporated into the zeolite crystal structure, which can improve the catalytic activity of the material in certain reactions. When sulfuric acid and zeolite are used together as a hybrid catalyst system, they can work synergistically to enhance the catalytic activity and stability of the epoxidation process. The sulfuric acid can protonate the alkene group in the castor oil, while the zeolite can trap the intermediates and products of the reaction. This can prevent side reactions and increase the selectivity of the process, resulting in a higher yield of the epoxidized product.

The use of a hybrid catalyst system composed of sulfuric acid and zeolite can also have environmental benefits. The use of sulfuric acid as the catalyst in the epoxidation process can generate sulfuric acid waste, which can be difficult and costly to dispose of [8]. However, the use of zeolite as a catalyst can reduce the amount of sulfuric acid waste generated, as it can be easily separated from the reaction mixture and reused. One example of such reaction is the production of gasoline from methanol, which is a key step in the methanol-to-gasoline process. Zeolite, ZSM-5 has been used as a catalyst in this process due to its unique crystal structure, which allows it to selectively adsorb and activate methanol molecules. The impregnation increases the catalytic activity of ZSM-5 in this reaction, as it enhances the acidity of the zeolite. Based on a study, the impregnation of sulfuric acid on zeolite had increased conversion of methanol to gasoline. Thus, in this case, the catalyst would also help in increasing the yield of epoxy during the experiment. **Table 1** below compares the different catalyst used in the epoxidation process of castor oil.

Table 1: Comparison of different catalyst used for epoxidation of castor oil

<i>Catalyst</i>	<i>Oxirane Conversion (%)</i>	<i>Reaction time (h)</i>	<i>References</i>
<i>Amberlite</i>	48	24	[10]
<i>Formic Acid</i>	6	24	[10], [11]
	85.3	4	[11]
<i>Phosphoric Acid</i>	74.58	3	[12]

Strong acid sulfuric acid has a tendency to protonate the zeolite's active sites, changing the zeolite's acidity. During the impregnation process, the sulfuric acid would replace some of the initial presence in the zeolite structure by adding protons (H^+) to the zeolite framework. The zeolite's acidic characteristics may change because of the protons replacing the cations and increasing the number of acidic sites. The general balance between acidic and basic sites within the zeolite structure may be impacted by the increase in acidic characteristics brought about by the addition of protons through sulfuric acid treatment. The mechanism of introduction of protons to zeolite are presented as per **Figure 1**.

**Figure 1.** Hybrid catalyst before and after impregnation of sulfuric acid with zeolite

3. Novelty and uniqueness

The sulfate-impregnated zeolite hybrid catalyst introduces an innovative approach to the epoxidation of non-edible vegetable oils, specifically castor oil. Its novelty lies in its hybrid nature, which combines the benefits of both homogeneous and heterogeneous catalysts. Unlike conventional sulfuric acid (homogeneous catalyst), this hybrid catalyst is reusable, stable under harsh reaction conditions, and environmentally friendly. It eliminates the need for costly separation processes and minimizes corrosive waste streams. The sulfate

impregnation enhances the acidic properties of zeolite, improving its catalytic activity while maintaining the structural integrity of the zeolite framework. This ensures high selectivity and yield in epoxide production. Additionally, its heterogeneous nature allows for easy recovery and reusability, reducing operational costs and environmental impact. This technology is unique in its ability to combine sustainability with efficiency. By utilizing non-edible castor oil as the feedstock, it supports bio-based chemical production without interfering with food supply chains. The hybrid catalyst sets a benchmark for cleaner, greener, and economically viable industrial epoxidation processes.

4. Benefit to mankind

The sulfate-impregnated zeolite catalyst provides multiple benefits to mankind by offering a sustainable and eco-friendly solution for the production of bio-based chemicals. It reduces the dependency on petroleum-derived epoxides, which are harmful to the environment and contribute to carbon emissions. By utilizing non-edible castor oil, the process avoids competition with food resources, supporting food security and rural agriculture. Technology also minimizes hazardous chemical waste by replacing corrosive homogeneous sulfuric acid with a reusable heterogeneous catalyst, thereby reducing environmental pollution and improving safety in industrial applications. Furthermore, the bio-based epoxides produced are essential components in the manufacture of eco-friendly resins, adhesives, plasticizers, and coatings, contributing to the development of sustainable products.

5. Innovation and Entrepreneurial Impact

This project fosters innovation by introducing a novel hybrid catalyst technology that addresses critical industrial and environmental challenges. By replacing conventional sulfuric acid with a reusable heterogeneous catalyst, the project enhances process sustainability, reduces waste, and promotes resource efficiency. The use of non-edible castor oil as a feedstock aligns with global trends toward green chemistry and bio-based product innovation. The project also contributes to a culture of entrepreneurship within the community, institution, and industry by creating opportunities for small and medium enterprises (SMEs) to enter the sustainable chemical production market. Local farmers benefit from increased demand for non-edible castor oil, fostering agricultural entrepreneurship. At the institutional level, the project inspires students and researchers to explore sustainable technologies, encouraging innovation-driven learning and business ventures.

6. Potential commercialization

The sulfate-impregnated zeolite catalyst has strong commercialization potential due to its cost-effectiveness, reusability, and environmental benefits. Industries involved in the production of epoxides, bio-based resins, coatings, adhesives, and plasticizers can adopt this technology to replace conventional, less sustainable methods. The demand for bio-based chemicals is growing globally, driven by stricter environmental regulations and consumer preferences for greener products. This catalyst reduces operational costs by eliminating the need for costly separation processes and enabling catalyst reuse across multiple reaction

cycles. Additionally, its application in utilizing non-edible castor oil ensures a sustainable feedstock supply that does not interfere with food production. The technology can be scaled up for industrial applications, creating opportunities for collaboration with chemical manufacturers, startups, and agricultural industries. By offering a cleaner, greener alternative to traditional epoxidation methods, this innovation is well-positioned to meet market demands and drive the commercialization of sustainable chemical processes.

7. Acknowledgment

The author wanted to thank the supervisory team for their dedication and support.

8. Authors' Biography



Mohd Aathif, postgraduate currently in semester 3 in PhD of Chemical Engineering. Doing his research on novel sulfate-impregnated zeolite catalyst applied to in-situ epoxidation of castor oil and production of bio-based polyol using environmental friendly reagents.



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