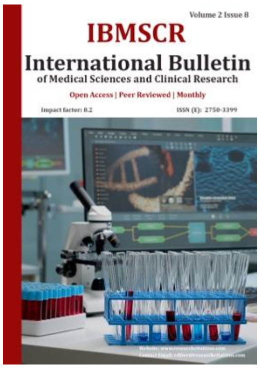

PRODUCTION AND TECHNOLOGY OF ACID NITRILES FROM MIXED DISTILLED FATTY ACIDS (DFA)

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https://doi.org/10.5281/zenodo.18844921

Abstract. This scientific article analyzes the theoretical foundations and technological aspects of producing fatty acid nitriles from mixed distilled fatty acids. The chemical composition of distilled fatty acids, which are considered by-products of the vegetable oil and fat industry, and their conversion into nitriles through ammonolysis, amidation, and dehydration processes are discussed based on reliable scientific sources. The influence of catalysts, reaction temperature, and pressure on nitrile yield and product quality is critically evaluated. Furthermore, the results of studies conducted by both local and international researchers are reviewed, highlighting the economic and environmental advantages of producing fatty acid nitriles from renewable raw materials. The findings of this study demonstrate the practical significance of utilizing distilled fatty acids for deep processing, obtaining high value-added chemical products, and developing environmentally sustainable technologies in the chemical industry.

Keywords. Mixed distilled fatty acids, fatty acid nitriles, ammonolysis, amidation, dehydration, catalysts.

Аннотация. В данной научной статье проанализированы теоретические основы и технологические аспекты получения нитрилов жирных кислот из смеси дистиллированных жирных кислот. На основе достоверных научных источников рассмотрены химический состав дистиллированных жирных кислот, являющихся побочными продуктами масложировой промышленности, а также их превращение в нитрилы посредством процессов аммонолиза, амидирования и дегидратации. Проведена критическая оценка влияния катализаторов, температуры и давления реакции на выход нитрилов и качество получаемого продукта. Кроме того, рассмотрены результаты исследований отечественных и зарубежных ученых, подчеркивающие экономические и экологические преимущества получения нитрилов жирных кислот из возобновляемого сырья. Результаты исследования демонстрируют практическую значимость глубокой переработки дистиллированных жирных кислот для получения высокоценных химических продуктов и развития экологически устойчивых технологий в химической промышленности.

Ключевые слова: смесь дистиллированных жирных кислот, нитрилы жирных кислот, аммонолиз, амидирование, дегидратация, катализаторы.

Introduction

IBMSCR | Volume 6, Issue 02, February

In modern chemical industry, the efficient utilization of renewable and secondary raw materials is considered one of the most pressing issues. The limited availability of petrochemical resources, their rising cost, and the increasing severity of environmental problems are driving industry toward the search for alternative feedstock sources. From this perspective, products derived from vegetable and animal fats, particularly distilled fatty acids (DFA), have gained significant importance as valuable raw materials for the chemical industry. Distilled fatty acids are products obtained as a result of technological processes in the oil and fat industry, mainly during saponification followed by vacuum distillation. Structurally, they consist of a mixture of aliphatic fatty acids with C_{16}–C_{18} carbon chains, predominantly palmitic, stearic, and oleic acids. These acids exhibit high reactivity and serve as convenient starting materials for the synthesis of various functional derivatives such as amides, nitriles, amines, and esters. In recent years, the deep processing of distilled fatty acids to obtain high value-added products has been extensively studied from both scientific and practical perspectives. One of the most promising products in this field is acid nitriles, which are widely used as important intermediate compounds in various branches of the chemical industry. Acid nitriles serve as key raw materials in the production of synthetic amines, polymers, surfactants, pharmaceutical preparations, and agrochemicals.

Methodology

Traditionally, nitriles have mainly been synthesized from petroleum-derived hydrocarbons. However, such methods are characterized by high energy consumption, complex technological schemes, and environmental risks. Therefore, the development and improvement of technologies for producing nitriles from biologically derived fatty acids have become one of the priority areas of modern chemical science. In particular, the production of acid nitriles from mixed distilled fatty acids is economically advantageous and allows the creation of waste-free or low-waste technologies. Mixed distilled fatty acids (DFA) are important secondary products of the oil and fat industry, obtained through the hydrolysis of vegetable or animal fats followed by vacuum distillation. From a chemical composition standpoint, DFA mainly consist of a mixture of saturated and unsaturated higher fatty acids, predominantly containing C_{16}–C_{18} carbon chains. Specifically, palmitic acid ($C_{15}H_{31}COOH$), stearic acid ($C_{17}H_{35}COOH$), and oleic acid ($C_{17}H_{33}COOH$) form the major components of DFA. In recent years, scientific research on the production of nitriles from fatty acids has been conducted in several main directions:

Development of low-temperature catalysts. Chinese scientist Li Zhang and his colleagues have succeeded in reducing the nitrilation temperature to 190–200 °C using an In_2O_3–ZnO-based catalyst, which contributes to lowering energy consumption.

Single-step technologies. Researchers in the United States are studying the possibility of obtaining nitriles by directly reacting triglycerides with ammonia. This approach reduces the need for hydrolysis and distillation stages.

Catalyst-free or low-catalyst processes. Some studies are investigating nitrilation in supercritical ammonia environments, which may contribute to the development of more environmentally friendly technologies.

According to scientific literature, the composition of distilled fatty acids (DFA) varies depending on the type of raw material (cottonseed, soybean, sunflower oil, etc.) and the distillation conditions. For example, in DFA obtained from cottonseed oil, the content of oleic acid may reach 40–45%, which significantly influences the physicochemical properties of the

IBMSCR | Volume 6, Issue 02, February

final product during the subsequent nitrilation process. Therefore, preliminary analysis of DFA composition and determination of its fractional composition are of crucial technological importance in nitrile synthesis. Acid nitriles (R–C≡N) are among the most important derivatives obtained from fatty acids. They are typically synthesized through a sequential three-step chemical process: ammoniation, amidation, and dehydration (water elimination). These reactions are carried out under elevated temperatures and catalytic conditions.

Results

Scientific studies indicate that the formation of ammonium salts of fatty acids is the initial and essential stage of the process. The reaction proceeds as follows:

$R–COOH + NH_3 \rightarrow R–COONH_4$

Upon heating, the formed ammonium salt converts into an amide:

$R–COONH_4 \rightarrow R–CONH_2 + H_2O$

In the next stage, the amide molecule undergoes dehydration to form a nitrile:

$R–CONH_2 \rightarrow R–C\equiv N + H_2O$

Research conducted by the German scientist H. R. H. Fischer and his collaborators in the mid-20th century demonstrated that the amidation and dehydration stages are the rate-determining steps of the overall reaction in the production of nitriles from fatty acids. According to their findings, the acid–base properties of the catalyst significantly increase nitrile yield [1].

The first stage in the technology for producing nitriles from DFA is the ammoniation process. At this stage, fatty acids react with ammonia in either liquid or vapor phase. Studies show that supplying ammonia in excess promotes complete formation of the ammonium salt and reduces the likelihood of side reactions. Experiments conducted by Russian scientists A. V. Lapshin and N. S. Karpov demonstrated that optimal results were achieved when ammoniation was carried out at 150–180 °C. According to their conclusions, excessive temperature increases may lead to thermal decomposition of fatty acids before amide formation [2].

The amidation and nitrilation stages are often performed continuously within a single apparatus. During this process, the temperature is raised to 200–260 °C. Catalysts are used to accelerate the dehydration stage. According to studies by the French scientist J. P. Arnaud, catalysts based on aluminum oxide (Al_2O_3) and zinc oxide (ZnO) show high efficiency in converting fatty acid amides into nitriles. Experimental results demonstrated nitrile yields reaching 85–92% [3].

Similar results have been reported in local studies. Research conducted by Uzbek scientists shows that nitrilation of DFA obtained from cottonseed oil in the presence of an Al_2O_3 catalyst produces high-purity aliphatic nitriles, which are suitable raw materials for subsequent amine synthesis. The choice of catalyst plays a crucial role in the production of acid nitriles. Catalysts not only increase reaction rates but also reduce the formation of by-products. Scientific literature reports the widespread use of metal oxide catalysts such as Al_2O_3, TiO_2, ZnO, and In_2O_3. American scientist R. A. Sheldon, in his research based on green chemistry principles, emphasizes that the use of heterogeneous catalysts in the production of nitriles from fatty acids is environmentally safer and economically more efficient. According to him, catalyst recyclability and long-term stability are significant advantages at the industrial scale [4].

Acid nitriles obtained from DFA possess high molecular weight, good thermal stability, and notable chemical reactivity. They can be hydrogenated to produce primary amines, which are widely used in the manufacture of surfactants, emulsifiers, and polymer stabilizers. Scientific studies indicate that nitriles derived from fatty acids are more biodegradable than petroleum-based nitriles, making them environmentally preferable. Consequently, in European Union countries, the share of nitriles produced from bio-based raw materials is increasing annually. The industrial implementation of acid nitrile production from mixed distilled fatty acids is closely related to technological continuity, energy efficiency, and product quality. In practice, the process is mainly carried out using continuous reactors. Such reactors enable stable operation at high temperature and pressure, ensuring uniform processing of raw materials.

According to scientific sources, the nitrilation process in industry is often conducted in tubular reactors or fluidized-bed reactors. The temperature is maintained at 220–260 °C, while pressure ranges from 0.3 to 1.0 MPa. Under these conditions, the conversion of amides to nitriles proceeds at high rates, and the reaction equilibrium shifts toward nitrile formation. Research by Japanese scientist K. Nakamura demonstrated that conducting the process in a continuous reactor system can increase nitrile yield by 10–15% [5]. He emphasized that continuous operation allows precise control of heat exchange and reaction time, thereby reducing the formation of by-products. An important aspect of nitrile production technology from fatty acids is its energy consumption and environmental impact. Compared to traditional petrochemical processes, DFA-based nitrile synthesis requires relatively less energy because the raw material already consists of molecules containing functional groups. Swedish scientist M. Larsson reported that carbon dioxide emissions during the synthesis of fatty acid-based nitriles are 25–30% lower than those of petroleum-based analogues. This finding further confirms the environmental advantages of using bio-based raw materials. Moreover, the main by-product formed during the process is water. If the technological regime is properly optimized, harmful gases or toxic wastes are virtually not generated. Therefore, the production of nitriles from fatty acids complies with the principles of green chemistry [6].

Discussion

When working with mixed distilled fatty acids (DFA), certain technological challenges arise. The primary issue is the non-uniformity of their component composition. Fatty acids with different chain lengths exhibit different reactivities under identical conditions. According to studies by the German scientist W. Franke, unsaturated oleic acid enters the amidation and nitrilation processes more rapidly than stearic acid [7]. This may reduce the uniformity of the resulting mixed nitrile composition. Therefore, in industrial practice, preliminary fractionation or adjustment of process parameters is often applied. Another significant issue is coke formation on the active surface of the catalyst. During prolonged operation, a carbonaceous layer may form on the catalyst surface, reducing its activity. To overcome this problem, periodic catalyst regeneration or the use of modified catalysts is recommended. The economic efficiency of producing acid nitriles from DFA is explained by the low cost of raw materials and compatibility with existing industrial infrastructure. Deep processing of oil and fat industry by-products allows the production of value-added products. According to economic assessments, the production cost of nitriles derived from fatty acids may be 15–20% lower than that of petroleum-based nitriles. This is particularly important for developing countries, as it enables the efficient use of locally available raw materials.

Conclusion

IBMSCR | Volume 6, Issue 02, February

This scientific article systematically analyzed the theoretical foundations, technological processes, and scientific research conducted by local and foreign scholars in the field of producing acid nitriles from mixed distilled fatty acids.

The study demonstrated that distilled fatty acids represent an economically advantageous and renewable raw material of the oil and fat industry. Their deep processing enables the production of high value-added products. The results indicate that the production of acid nitriles mainly consists of ammoniation, amidation, and dehydration stages. The efficiency of these stages directly depends on reaction temperature, pressure, catalyst type, and raw material composition. In particular, nitrilation processes carried out in the presence of Al_2O_3-, ZnO-, and In_2O_3-based catalysts are characterized by high yields and product quality. Overall, scientific sources confirm that the chemical composition of mixed distilled fatty acids significantly affects the nitrilation process. Although the higher reactivity of unsaturated fatty acids increases the rate of nitrile formation, precise control of technological parameters is required to ensure stable industrial-scale operation.

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