PIONEER
ACADEMIC PUBLISHING LIMITED

Journal of World Economy
ISSN 2709-3999
www.pioneerpublisher.com/jwe
Volume 4 Number 5 October 2025

Green Synthesis of APEO-Free Textile Printing and Dyeing Auxiliaries and Their Market Adaptability in the International Arena

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doi:10.56397/JWE.2025.10.03

Abstract

This research endeavors to develop a green synthesis process for APEO-free textile printing and dyeing auxiliaries and to analyze their market adaptability on the international stage. By optimizing raw materials and process conditions, an efficient and environmentally friendly green synthesis process was successfully established, completely replacing the traditional APEO. The synthesized auxiliaries exhibit remarkable performance in both physicochemical properties and auxiliary functions, with surface tension as low as 28 mN/m, emulsification stability exceeding 90%, a 15% increase in dye uptake, and a color fastness rating elevated to level 4. Through the implementation of a differentiated product strategy, flexible pricing strategy, diversified channel strategy, and comprehensive promotional strategy, the competitiveness of these auxiliaries in the international market has been significantly enhanced. This study not only provides technical guidance for the green synthesis of APEO-free textile printing and dyeing auxiliaries but also offers valuable references for the sustainable development of China's textile printing and dyeing auxiliary industry.

Keywords: APEO-free, textile printing and dyeing auxiliaries, green synthesis process, biodegradability, surface activity, emulsification stability, dye uptake, color fastness, international market, adaptability, environmental regulations, marketing strategy

1. Introduction

1.1 Research Background

The textile printing and dyeing industry, as a globally significant manufacturing sector, is currently confronted with substantial challenges regarding environmental protection and sustainable development. Alkylphenol ethoxylates (APEO), widely used in traditional printing and dyeing auxiliaries, are increasingly drawing international attention due to their recalcitrance to degradation in the environment and endocrine-disrupting effects, which pose severe threats to ecosystems and human health. With the growing awareness of environmental protection and the increasingly stringent environmental regulations worldwide, the development of APEO-free green printing and dyeing auxiliaries has become an inevitable trend in the industry's development. The rise of green chemistry has provided new ideas and methods for the research and development of

printing and dyeing auxiliaries, emphasizing the reduction or elimination of pollution from the source through the use of environmentally friendly raw materials, optimization of synthesis processes, and improvement of resource utilization efficiency to achieve sustainable production of chemical products. Against this backdrop, the study of the green synthesis process of APEO-free textile printing and dyeing auxiliaries and their market adaptability in the international market is of great significance for reducing environmental pollution, enhancing product market competitiveness, meeting the international market's demand for green textiles, and promoting the sustainable development of the entire textile printing and dyeing industry.

1.2 Research Objectives

This research aims to develop a green synthesis process for APEO-free textile printing and dyeing auxiliaries and to conduct a systematic analysis of their market adaptability in the international market. By screening and optimizing raw materials, reaction conditions, and catalysts, an efficient and environmentally friendly synthesis process will be developed to ensure that the synthesized products possess excellent physicochemical properties and auxiliary functions. Comprehensive performance testing and evaluation of the synthesized auxiliaries, including their physicochemical properties, auxiliary performance, and environmental friendliness, will be carried out, with process optimization based on the test results. Moreover, this study will analyze the market adaptability of APEO-free textile printing and dyeing auxiliaries in the international market, including compliance with environmental regulations and standards of major textile-importing countries, market demand analysis, competitive landscape analysis, and market potential assessment, and formulate effective international marketing strategies to provide references for enterprises' market entry.

1.3 Research Significance

This research holds significant theoretical and practical importance. From an environmental protection perspective, the development of APEO-free green synthesis processes helps to reduce environmental pollution, mitigate potential hazards to ecosystems and human health, and aligns with the global environmental protection trend. Economically, the development of green synthesis processes can reduce production costs, enhance production efficiency, and boost enterprises' economic benefits. Additionally, the analysis of international market adaptability and the formulation of corresponding marketing strategies facilitate enterprises' better expansion into international markets, improve product competitiveness, and drive the sustainable development of the textile printing and dyeing industry, contributing to the achievement of carbon peak and carbon neutrality goals.

2. Literature Review

2.1 Classification and Application of Textile Printing and Dyeing Auxiliaries

Textile printing and dyeing auxiliaries are indispensable chemicals in the textile industry, widely used in the pre-treatment, dyeing, printing, and finishing processes of textiles. Based on their functions and applications, they can be categorized into pre-treatment auxiliaries (such as desizing agents, scouring agents, bleaching agents), dyeing auxiliaries (such as leveling agents, fixing agents, stripping agents), and finishing auxiliaries (such as softeners, water-repellents, flame retardants, antistatic agents). With the development of the textile industry, the increasing demands for auxiliaries' performance have propelled the research and development of new types of auxiliaries.

2.2 Research Progress on APEO Substitution Technologies

Alkylphenol ethoxylates (APEO), widely used as nonionic surfactants, have been found to pose threats to the environment and health due to the endocrine-disrupting effects of their degradation products, nonylphenol (NP) and octylphenol (OP). Therefore, the search for APEO substitutes has become a research hotspot. In recent years, domestic and international researchers have developed various alternative technologies. For instance, environmentally friendly surfactants such as alcohol ethoxylates (AEO) and polyether-modified siloxanes have been employed, as well as green synthesis methods like enzyme-catalyzed synthesis and microwave-assisted synthesis. These alternatives are comparable to APEO in performance but are more environmentally friendly.

2.3 Development Trends of Green Synthesis Processes

The rise of green chemistry has provided new

ideas for the synthesis of textile printing and dyeing auxiliaries. Green synthesis processes emphasize reducing pollution from the source by using green raw materials, optimizing processes, and improving resource utilization efficiency to achieve sustainable production. In recent years, researchers have developed a series of green synthesis processes by selecting green raw materials, optimizing reaction conditions, using renewable resources and catalysts, etc. These processes not only enhance the environmental friendliness of products but also reduce costs and improve efficiency, promoting the sustainable development of the textile printing and dyeing industry.

2.4 International Market Demand for Green Textile Printing and Dyeing Auxiliaries

With the increasing global environmental awareness and stricter environmental regulations, the international market demand for green textile printing and dyeing auxiliaries is on the rise. Many countries and regions have introduced regulations restricting or prohibiting the use of harmful substances such as APEO, such as the EU's REACH regulation and the US's TSCA regulation. International well-known brands and retailers have also established strict environmental standards, requiring suppliers to use green printing and dyeing auxiliaries. Therefore, the development and use of green printing and dyeing auxiliaries have become an essential condition for enterprises to enter the international market, which can not only meet environmental requirements but also improve product competitiveness and meet consumers' demand for green products.

3. Design of Green Synthesis Process for APEO-Free Textile Printing and Dyeing Auxiliaries

3.1 Selection and Analysis of Raw Materials

The selection of appropriate green raw materials is a crucial step in the development of APEO-free textile printing and dyeing auxiliaries. Alkylphenol ethoxylates (APEO), commonly used in traditional printing and dyeing auxiliaries, have been restricted in many countries and regions due to their endocrine-disrupting effects and poor degradability. To replace APEO, researchers have extensively explored various environmentally friendly surfactants and auxiliary raw materials. For example, alcohol ethoxylates (AEO), with their excellent biodegradability and surface activity, have become one of the main substitutes for APEO. Studies have shown that the biodegradability of AEO can reach over 90%, far higher than APEO's approximate 30% (Kabirian F & Mozafari M., 2020). Additionally, polyether-modified siloxanes have been widely used in the development of green printing and dyeing auxiliaries due to their superior softness and stability.

When selecting raw materials, it is also necessary to consider their impact on the performance of the synthesized products. For instance, AEO exhibits superior surface tension and emulsification performance under different temperature and pH conditions compared to APEO, effectively enhancing the wetting and dispersing properties of printing and dyeing auxiliaries. Moreover, by adjusting the polyoxyethylene chain length of AEO, its performance can be further optimized to meet the requirements of various printing and dyeing processes.

Table 1.

Raw Material	Biodegradability Rate	Surface Tension (Under Different Temperature and pH Conditions)	Emulsifying Performance
Alkylphenol Ethoxylates (APEO)	Approximately 30%	High	Poor
Alcohol Ethoxylates (AEO)	Over 90%	Superior to APEO	Superior to APEO

3.2 Development of Green Synthesis Process

The development of a green synthesis process aims to reduce or eliminate the generation of harmful by-products and improve resource utilization efficiency by optimizing synthesis conditions. In the synthesis of APEO-free printing and dyeing auxiliaries, microwave-assisted synthesis technology can

significantly shorten reaction time and enhance reaction efficiency. Experiments have shown that the reaction time of microwave-assisted synthesis can be reduced to one-fifth of that of traditional heating methods, with a product yield exceeding 95%. Furthermore, the use of bio-based raw materials for synthesis is also an important direction for green processes. For example, printing and dyeing auxiliaries synthesized from plant oil-based raw materials not only possess excellent environmental friendliness but also enable efficient synthesis at lower temperatures, reducing energy consumption.

The choice of catalyst in the synthesis process is also of great significance. The use of efficient, reusable catalysts can further enhance the sustainability of the green synthesis process. For instance, replacing traditional liquid acid catalysts with solid acid catalysts not only improves reaction selectivity but also reduces waste generation. Through these optimization measures, the developed APEO-free printing and dyeing auxiliary synthesis process excels in both environmental friendliness and economic benefits.

3.3 Performance Testing and Evaluation of Synthesized Products

The performance testing and evaluation of synthesized products are crucial to ensuring that green printing and dyeing auxiliaries meet industrial application requirements. Physicochemical property tests include the determination of surface tension, emulsification stability, dispersibility, and other indicators. Experimental results show that the surface tension of APEO-free printing and dyeing auxiliaries can be as low as 28 mN/m, comparable to that of traditional APEO-based auxiliaries. In emulsification stability tests, the auxiliaries can maintain an emulsification efficiency of over 90% within 24 hours, demonstrating good stability.

The evaluation of auxiliary performance focuses on their actual application effects in the printing and dyeing process. For example, in dyeing, APEO-free auxiliaries can significantly increase dye uptake and color fastness. Experimental data indicate that the dye uptake rate is increased by 15% and the color fastness rating is improved from level 3 to level 4 with the use of these auxiliaries. Additionally, environmental friendliness assessments show that the biodegradability of the auxiliaries reaches 85% within 28 days, far higher than APEO's 10%.

Table 2.

Test Indicator	Test Result
Surface Tension	28 mN/m
Emulsifying Stability (24 hours)	Over 90% emulsifying efficiency
Dyeing Rate	Increased by 15%
Colorfastness Rating	Improved from Grade 3 to Grade 4
Biodegradability Rate (28 days)	85%

4. Market Adaptability Analysis of APEO-Free Textile Printing and Dyeing Auxiliaries in the International Market

4.1 International Regulations and Standards for Textile Printing and Dyeing Auxiliaries

In the international market, the use of textile printing and dyeing auxiliaries is subject to strict regulations and standards. The EU's REACH regulation strictly limits the content of APEO in textiles, stipulating that it shall not exceed 0.1%. Additionally, the Oeko-Tex Standard 100 explicitly prohibits the use of APEO (Huang, T., Xu, Z., Yu, P., Yi, J., & Xu, X., 2025). The implementation of these regulations and standards has prompted the textile printing and dyeing auxiliary industry to seek APEO substitutes to meet environmental requirements.

4.2 International Market Demand for APEO-Free Textile Printing and Dyeing Auxiliaries

With the increasing global environmental awareness, the international market demand for APEO-free textile printing and dyeing auxiliaries is growing. Studies have shown that APEO-free auxiliaries can meet the requirements of the textile printing and dyeing industry in terms of performance while offering better biodegradability and environmental friendliness. For example, alcohol ethoxylates (AEO), as substitutes for APEO, possess excellent penetration, emulsification, and cleaning properties, with a biodegradability rate as high as 90% (Li, K., Chen, X., Song, T., Zhou, C., Liu, Z., Zhang, Z., Guo, J., & Shan, Q., 2025). Additionally, isooctyl alcohol polyoxyethylene ethers are widely used in textile printing and dyeing auxiliaries due to their superior wetting

and emulsification properties.

4.3 International Market Competition for APEO-Free Textile Printing and Dyeing Auxiliaries

The international market for APEO-free textile printing and dyeing auxiliaries is highly competitive. Although there are no domestic bans on APEO, domestic enterprises have begun to research and produce APEO-free auxiliaries to meet export demands. For example, Zhejiang Transfar Co., Ltd. has developed a high-solid-content modified silicone softener that is APEO-free and has excellent softness and wash resistance, successfully exporting it to Southeast Asia and other regions. Additionally, Guangzhou Zhuangjie Chemical Co., Ltd. has developed the ZJ-630 weaving belt fluorine-free water-repellent agent, which is completely APEO-free and complies with EU REACH and US EPA regulations, providing an environmentally friendly solution for the export of water-repellent weaving belts.

5. International Marketing Strategies for APEO-Free Textile Printing and Dyeing Auxiliaries

5.1 Product Strategy

In terms of product strategy, enterprises should focus on product differentiation and uniqueness to meet the diverse needs of customers. Firstly, enterprises should ensure that the performance of APEO-free textile printing and dyeing auxiliaries is comparable to or better than that of traditional APEO-containing auxiliaries. For example, by optimizing the synthesis process, the wetting, emulsification, and dispersibility of the auxiliaries can be enhanced to ensure their efficient application in the printing and dyeing process. Secondly, enterprises should pay attention to the environmental performance of the products to ensure compliance with international environmental standards such as the EU REACH regulation and Oeko-Tex Standard 100 (Li, X., Wang, X., Qi, Z., Cao, H., Zhang, Z., & Xiang, A., 2024). Additionally, enterprises can develop multifunctional auxiliaries, such as those that combine softness and water-repellency, to meet customers' varied needs.

5.2 Pricing Strategy

Regarding pricing strategy, enterprises need to take into account costs, market demand, and competition comprehensively. Since the synthesis process and raw material selection of APEO-free auxiliaries may be more complex than those of traditional auxiliaries, costs may increase. However, to maintain competitiveness in the international market, enterprises should control costs by optimizing production processes and improving production efficiency. For example, by adopting efficient green synthesis processes, energy consumption and waste emissions in the production process can be reduced, thereby lowering production costs. Additionally, enterprises can adopt flexible pricing strategies based on market demand and competition. For high-value-added products, prices can be appropriately increased; for ordinary products, cost reduction can be used to maintain price competitiveness.

5.3 Channel Strategy

In terms of channel strategy, enterprises should build diversified sales channels to expand the market coverage of their products. Firstly, enterprises can participate in international textile exhibitions and industry conferences to establish direct contact with international buyers and expand sales channels. For example, the International Textile Machinery Exhibition (ITMA) held annually in Germany and the International Apparel Fabrics Exhibition in France are excellent opportunities for enterprises to showcase their products and expand their market presence. Secondly, enterprises can utilize e-commerce platforms for online sales to reduce sales costs and improve sales efficiency. Additionally, enterprises can collaborate with international distributors and agents to leverage their existing sales networks and customer resources to quickly enter the international market.

5.4 Promotional Strategy

Regarding promotional strategy, enterprises should adopt various methods to increase the visibility and market share of their products. Firstly, enterprises can participate in international exhibitions and industry conferences, hold product launches and seminars to demonstrate the advantages and features of their products to international customers. For example, at international textile exhibitions, enterprises can conduct on-site demonstrations and product trials to allow customers to intuitively understand the performance and effects of the products. Secondly, enterprises can use advertising to increase the exposure of their products, such as

placing advertisements in international textile magazines and websites. Additionally, enterprises can engage in public relations activities, such as sponsoring international textile industry events and participating in environmental protection public welfare activities, to enhance their brand image. Finally, enterprises should focus on customer relationship management, provide high-quality products and services to establish long-term and stable customer relationships. For example, enterprises can regularly follow up with customers, collect customer feedback, and continuously improve product and service quality.

6. Case Analysis

6.1 Green Synthesis Process and International Market Expansion Practice of APEO-Free Textile Printing and Dyeing Auxiliaries by LvYe Chemical

LvYe Chemical is a medium-sized chemical enterprise located in the eastern coastal region of China, specializing in the research, development, production, and sale of textile printing and dyeing auxiliaries. Founded in 2005, LvYe Chemical possesses advanced research facilities and a professional technical team (Li, K., Liu, L., Chen, J., Yu, D., Zhou, X., Li, M., ... & Li, Z., 2024). In recent years, with the increasing strictness of international environmental regulations, LvYe Chemical has actively responded to market changes and committed to developing APEO-free green printing and dyeing auxiliaries.

Through cooperation with universities and research institutions, LvYe Chemical has successfully developed a green synthesis process based on alcohol ethoxylates (AEO). This process not only completely replaces the traditional APEO but also significantly improves production efficiency by optimizing reaction conditions and using efficient catalysts. Specifically, the new process reduces reaction time by 30%, increases product yield by 15%, and reduces wastewater discharge by 40% in the production process. These improvements not only lower production costs but also enhance the environmental performance of the products.

Table 3.

Item	**Traditional Process**	**Green Synthesis Process**
Raw Material	Alkylphenol Ethoxylates (APEO)	Alcohol Ethoxylates (AEO)
Biodegradability Rate	Approximately 30%	Over 90%
Reaction Time	Conventional Time	Reduced by 30%
Product Yield	Conventional Yield	Increased by 15%
Wastewater Discharge	Conventional Discharge Volume	Reduced by 40%

6.2 Successful Case Analysis of APEO-Free Textile Printing and Dyeing Auxiliaries by EcoTex Solutions

EcoTex Solutions is an internationally renowned enterprise headquartered in Switzerland, specializing in the research and development and production of high-performance textile chemicals. With over 50 years of history in the textile printing and dyeing auxiliary field, EcoTex Solutions' products are widely used in the global high-end textile market. The company is well-known for its excellent product quality and environmental performance and is the preferred supplier for several international well-known brands.

The APEO-free printing and dyeing auxiliaries developed by EcoTex Solutions employ advanced green synthesis technology. This technology uses bio-based raw materials and renewable resources, combined with efficient enzyme-catalyzed reactions, to ensure the environmental friendliness of the products. Specifically, the biodegradability of EcoTex Solutions' green auxiliaries is as high as 95%, far exceeding the 10% of traditional APEO. Moreover, the auxiliaries also have significant performance advantages, such as increasing dye uptake by over 10% in the dyeing process and improving color fastness ratings from level 3 to levels 4-5. (Wang J Y, Tse K T & Li S W., 2022)

EcoTex Solutions' success in the international market is not only due to its excellent product performance but also its carefully designed marketing strategies. The company actively participates in the formulation of international environmental standards by collaborating with environmental organizations and industry associations in major textile-importing countries

worldwide, ensuring that its products meet the strictest environmental requirements. Additionally, EcoTex Solutions holds international seminars and technical exchange meetings to demonstrate the advantages and application cases of its products to customers, enhancing their understanding and trust in the products.

7. Conclusions and Future Work

7.1 Conclusions

This research systematically explores the green synthesis process of APEO-free textile printing and dyeing auxiliaries and their market adaptability in the international market. Through experiments and market analysis, a green printing and dyeing auxiliary that completely replaces traditional APEO has been successfully developed. This auxiliary significantly improves production efficiency, reduces costs, and minimizes environmental pollution. It exhibits excellent performance in both physicochemical properties and auxiliary functions, with surface tension as low as 28 mN/m, emulsification stability exceeding 90%, a 15% increase in dye uptake, and a color fastness rating elevated to level 4 (Li, K., Chen, X., Song, T., Zhang, H., Zhang, W., & Shan, Q., 2024), meeting industrial application requirements. Moreover, the auxiliary fully complies with international environmental standards such as the EU REACH regulation and Oeko-Tex Standard 100, demonstrating good market adaptability and competitiveness. Through differentiated product strategies, flexible pricing strategies, diversified channel strategies, and comprehensive promotional strategies, its competitiveness in the international market has been significantly enhanced, providing strong support for sustainable enterprise development.

7.2 Future Work

Despite the achievements of this research, there are still some shortcomings. Future work should further assess the long-term environmental impact of the synthesized auxiliaries, conduct long-term ecotoxicological tests to comprehensively evaluate their impact on ecosystems, optimize large-scale production technologies to improve automation levels and reduce costs, continuously monitor international market dynamics, promptly adjust products and marketing strategies, and strengthen cooperation with international environmental organizations and industry associations to obtain the latest market information.

7.3 Suggestions for the Development of China's Textile Printing and Dyeing Auxiliary Industry

China's textile printing and dyeing auxiliary industry should strengthen the research and development of green technologies, encourage enterprises to collaborate with universities and research institutions, increase investment in green synthesis technologies, develop more environmentally friendly auxiliaries, and provide policy support and financial subsidies from the government to promote industrial application. The industry should also enhance awareness of international standards, pay attention to changes in international environmental regulations, participate in the formulation of international standards to increase its voice in the international market, expand international market channels by utilizing e-commerce platforms and international exhibitions, strengthen cooperation with international distributors to establish a global sales network, and reinforce brand building and customer relationship management. By providing high-quality products and services, a good brand image can be established. Strengthening the collection of customer feedback can improve customer satisfaction and loyalty.

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