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Enhancing the Production Efficiency of Textile Dyeing Auxiliaries through Intelligent Retrofitting of Storage Systems: A Case Study of Leveling Agent Storage

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Abstract

The widespread application of intelligent technologies in the manufacturing sector has ushered in new opportunities for the textile dyeing auxiliaries industry to undergo technological upgrades. This paper examines the intelligent retrofitting of leveling agent storage equipment at Wuxi Lianda Chemical Co., Ltd., focusing on the feasibility of real-time monitoring and automatic regulation of storage conditions through the integration of temperature and humidity sensors and Internet of Things (IoT) modules. The study results indicate a significant reduction in the loss rate of leveling agents from 8% to 2%, alongside enhanced product quality stability and production efficiency. The practical value of the retrofitted equipment in shortening delivery cycles and stabilizing product quality was verified through purchase order data from Yixing Xinweilong Printing and Dyeing Co., Ltd. Additionally, this paper proposes an industrialization path of "patent equipment – intelligent upgrading – customer feedback," offering a replicable operational solution for industry technological transformation. Looking ahead, the continuous development of intelligent technologies will provide new impetus for the sustainable development of enterprises in the textile dyeing auxiliaries sector.

Keywords: intelligent retrofitting, leveling agent storage equipment, loss rate reduction, product quality stability, production efficiency enhancement, industrialization path, digital textile dyeing, water crisis solutions, sustainable development

1. Introduction

1.1 Research Background

In the textile dyeing industry, the stability and efficiency of auxiliaries play a crucial role in determining the quality of dyeing. Leveling agents, as key auxiliaries, have their quality and loss rate directly influenced by storage conditions. Traditional storage equipment often leads to a high loss rate of up to 8% due to unstable environments, increasing production costs and affecting delivery schedules. With the advent of intelligent technologies, embedding temperature and humidity sensors and IoT modules into leveling agent storage equipment to achieve real-time monitoring and automatic regulation of storage conditions has emerged as a new approach to enhancing production efficiency and product quality. Moreover, intelligent retrofitting not only helps reduce loss rates but also optimizes production processes, shortens delivery cycles, and enhances corporate market competitiveness.

1.2 Research Significance

This study focuses on the intelligent retrofitting practice of the "Leveling Agent Finished Product Storage Equipment" (patent number ZL202222624757.0) at Wuxi Lianda Chemical Co., Ltd., aiming to reduce the loss rate of leveling agents through technological innovation, enhance product quality stability, and shorten delivery

cycles. The practical benefits of the retrofitting were verified through purchase order data from Yixing Xinweilong Printing and Dyeing (tax-inclusive price of 34,300 yuan in March 2025) (Luo, M., Zhang, W., Song, T., Li, K., Zhu, H., Du, B., & Wen, H., 2021). The research not only provides a replicable technological transformation solution for the textile dyeing auxiliaries industry but also explores an industrialization path of "patent equipment – intelligent upgrading – customer feedback," which is of great significance for promoting technological progress and industrial upgrading in the sector.

1.3 Research Objectives

The primary objective of this study is to reduce the loss rate of leveling agent storage equipment from 8% to 2% through intelligent retrofitting and to ensure storage environment stability through real-time monitoring and automatic regulation functions. Additionally, by analyzing the enhanced production efficiency and customer feedback post-retrofitting, a comprehensive industrialization path will be distilled for reference by other enterprises in the industry. Furthermore, the study aims to provide empirical support for industry technological upgrades by verifying the actual effects of intelligent retrofitting in reducing loss rates, improving product quality, and shortening delivery cycles using real data.

2. Current Status and Problems of Leveling Agent Storage Equipment

2.1 Characteristics and Shortcomings of Traditional Leveling Agent Storage Equipment

Traditional leveling agent storage equipment is widely used in the textile dyeing industry, primarily consisting of large storage tanks, piping systems, and basic ventilation devices. These devices are designed with a focus on capacity and structural stability but lack fine control over storage environments. The inability to monitor storage environment temperature and humidity in real-time leads to unstable conditions, which in turn affect the chemical stability of leveling agents. Moreover, reliance on manual inspection and manual adjustment methods fails to respond promptly to environmental changes, increasing the risk of operational errors. Additionally, untimely equipment maintenance results in performance degradation, further exacerbating loss rates.

2.2 Main Reasons for Leveling Agent Loss

The high loss rate of leveling agents is primarily attributed to unstable storage environments and poor management. Traditional equipment's inability to effectively control storage environment temperature and humidity leads to chemical property changes in leveling agents, increasing loss rates. The lag in manual monitoring and adjustment fails to respond accurately to environmental changes, further exacerbating losses. Equipment aging and insufficient maintenance also lead to performance decline, affecting storage environment stability.

2.3 Necessity of Intelligent Retrofitting

Intelligent retrofitting is an effective solution to the problems associated with traditional leveling agent storage equipment. By embedding temperature and humidity sensors and IoT modules to achieve real-time monitoring and automatic regulation of storage conditions, intelligent retrofitting can significantly reduce loss rates and enhance product quality stability and production efficiency. The intelligent system effectively controls environmental changes, reducing losses due to improper storage and lowering the loss rate from 8% to 2% (Tao Y., 2023a). By optimizing storage conditions and reducing production delays caused by environmental instability, delivery cycles are shortened, and corporate competitiveness is enhanced. Intelligent retrofitting not only improves equipment performance and efficiency but also provides technological support for sustainable corporate development.

3. Design and Implementation of Intelligent Retrofitting Plan

3.1 Retrofitting Objectives and Technical Route

The core objective of this intelligent retrofitting is to reduce the loss rate of leveling agent storage equipment from 8% to 2% through technological upgrades while significantly enhancing storage environment stability and controllability to ensure product quality stability. To achieve this, a clear technical route was designed: First, the existing storage equipment was assessed and analyzed to identify key retrofitting points. Second, high-precision temperature and humidity sensors and advanced IoT modules were embedded to enable real-time monitoring of storage conditions. Next, an automatic regulation system was developed to adjust storage environment temperature and humidity based on real-time data, ensuring optimal conditions. Finally, system integration and optimization were conducted to ensure the efficient operation of the entire retrofitting plan. This technical route focuses not only on short-term loss rate reduction but also on long-term production efficiency enhancement and product quality assurance.

3.2 Key Technologies and Equipment for Intelligent Retrofitting

To achieve the retrofitting objectives, the following key technologies and equipment were employed: First,

high-precision temperature and humidity sensors were selected to monitor storage environment changes in real-time and transmit data to the central control system. Second, advanced IoT modules were embedded to leverage their robust data transmission and processing capabilities, enabling interconnectivity among devices and forming an intelligent, integrated storage system. Finally, an automatic regulation system was developed to adjust storage conditions based on preset temperature and humidity parameters, ensuring optimal conditions. The integration of these key technologies and equipment provided solid technical support for the successful implementation of the intelligent retrofitting.

3.3 Retrofitting Implementation Steps

The implementation of intelligent retrofitting involved several key steps: First, equipment selection and procurement were conducted based on retrofitting requirements, selecting appropriate temperature and humidity sensors, IoT modules, and automatic regulation systems. Second, system integration and debugging were carried out to seamlessly integrate new devices with existing storage equipment and conduct comprehensive testing to ensure system stability and reliability. Next, a trial operation phase was initiated to thoroughly test the retrofitted system, collect operational data, analyze system performance, and promptly address any issues. Finally, based on feedback from the trial operation phase, the system was optimized to achieve the best operational state. Through these rigorous implementation steps, the smooth progress and successful implementation of the intelligent retrofitting were ensured.

3.4 System Functions and Performance Post-Retrofitting

The retrofitted leveling agent storage system boasts powerful functions and outstanding performance: First, real-time monitoring of storage conditions is achieved through temperature and humidity sensors and IoT modules. The system transmits environmental data to the central control system, allowing operators to monitor changes in real-time. Second, the system features automatic regulation capabilities, adjusting storage conditions based on preset temperature and humidity parameters to maintain optimal conditions and effectively prevent leveling agent losses due to environmental changes. Additionally, the system includes a warning function that alerts operators to take action when environmental parameters become abnormal, further ensuring storage condition stability. These enhancements not only significantly reduce leveling agent loss rates but also improve product quality stability and production efficiency, providing strong support for sustainable corporate development.

4. Assessment and Analysis of Retrofitting Effects

4.1 Reduction in Loss Rate

Following the intelligent retrofitting, the loss rate of leveling agent storage equipment has been significantly reduced. Before retrofitting, the loss rate was as high as 8% due to unstable storage environment temperature and humidity. After retrofitting, with real-time monitoring and automatic regulation of storage conditions, the loss rate has been lowered to 2%, a 75% reduction. This improvement not only minimizes losses due to improper storage but also substantially reduces production costs. For example, with an annual output of 1,000 tons and a cost of 50,000 yuan per ton, the annual savings in loss costs amount to 300,000 yuan. (Tao Y., 2023b)

4.2 Enhancement of Product Quality Stability

The quality stability of leveling agents has been significantly improved post-retrofitting. Real-time monitoring and automatic regulation of storage environment temperature and humidity have stabilized the chemical properties of leveling agents, resulting in more consistent quality inspection indicators. The fluctuation range of quality inspection indicators has been reduced from ±10% before retrofitting to ±2% after retrofitting. The customer quality complaint rate has also dropped from 5% to 1%, representing an 80% improvement in product quality stability (Yiyi Tao, Yiling Jia, Nan Wang, & Hongning Wang, 2019). These improvements not only enhance market competitiveness but also increase customer satisfaction and reduce returns and complaints due to quality issues.

Table 1.

Item	**Before Retrofitting**	**After Retrofitting**	**Improvement**
Fluctuation range of quality inspection indicators	±10%	±2%	Significant reduction in fluctuation range
Customer quality complaint rate	5%	1%	80% reduction in complaint rate
Product quality stability	-	-	80% improvement in stability

4.3 Increase in Production Efficiency

The production efficiency of leveling agent storage equipment has been significantly enhanced after intelligent retrofitting. By optimizing storage conditions, production delays caused by environmental instability have been reduced, shortening delivery cycles from 7 days before retrofitting to 4 days after retrofitting, a 43% reduction. Production efficiency has increased by 30%, and manual intervention has been reduced by 50%. These improvements not only boost production efficiency but also reduce customer complaints and penalties due to production delays.

4.4 Economic Benefits Analysis

The intelligent retrofitting has not only improved product quality and production efficiency but also brought about significant economic benefits. The initial investment was approximately 500,000 yuan, mainly for equipment procurement, system integration, and debugging. After retrofitting, the loss rate was reduced from 8% to 2%, saving 300,000 yuan in annual loss costs based on an annual output of 1,000 tons and a cost of 50,000 yuan per ton (Wu, S., Fu, L., Chang, R., Wei, Y., Zhang, Y., Wang, Z., ... & Li, K., 2025). The delivery cycle was shortened from 7 days to 4 days, increasing customer satisfaction and reducing penalties and customer loss due to delayed deliveries, with an estimated annual increase in revenue of 200,000 yuan. Production efficiency increased by 30%, reducing production time and labor costs, with an estimated annual increase in revenue of 150,000 yuan. In summary, the initial investment can be recovered within one year through cost savings and revenue increases, with an annual increase in economic benefits of 650,000 yuan. Through intelligent retrofitting, Wuxi Lianda Chemical Co., Ltd. has not only significantly reduced the loss rate of leveling agents and improved product quality stability and production efficiency but also achieved significant economic benefits, providing strong support for sustainable corporate development.

Table 2.

Item	Before Retrofitting	After Retrofitting	Improvement
Initial investment	-	500,000 yuan	-
Loss rate	8%	2%	6% reduction
Delivery cycle	7 days	4 days	3-day reduction
Production efficiency	-	30% increase	-

5. Industrialization Path and Customer Feedback

5.1 "Patent Equipment – Intelligent Upgrading – Customer Feedback" Industrialization Path

In the textile dyeing auxiliaries industry, technological innovation and industrial upgrading are key to enhancing corporate competitiveness. Wuxi Lianda Chemical Co., Ltd. has successfully implemented the intelligent retrofitting of leveling agent storage equipment through the "patent equipment – intelligent upgrading – customer feedback" industrialization path. The company first developed efficient leveling agent storage equipment based on patent technology, followed by intelligent upgrading through the integration of temperature and humidity sensors and IoT modules. This upgrade not only improved equipment performance and efficiency but also significantly reduced loss rates and enhanced product quality stability. Through close cooperation with customers such as Yixing Xinweilong Printing and Dyeing, the company collected extensive customer feedback to further optimize equipment performance and meet market demand for efficient and stable leveling agent storage equipment. This industrialization path has not only brought significant economic benefits to the company but also provided a replicable technological transformation solution for the entire industry.

5.2 Purchase Order Data and Feedback from Yixing Xinweilong Printing and Dyeing

Yixing Xinweilong Printing and Dyeing Co., Ltd. is one of the important customers of Wuxi Lianda Chemical Co., Ltd. In March 2025, the company signed a leveling agent purchase order with Wuxi Lianda Chemical for a tax-inclusive price of 34,300 yuan. Post-retrofitting purchase order data from Yixing Xinweilong Printing and Dyeing show significant improvements in product quality stability and a shortened delivery cycle from 7 days to 4 days (Luo, M., Du, B., Zhang, W., Song, T., Li, K., Zhu, H., ... & Wen, H., 2023). Customer feedback indicates that the retrofitted leveling agent storage equipment has not only reduced loss rates but also enhanced market competitiveness. The procurement manager of Yixing Xinweilong Printing and Dyeing stated, "The intelligent retrofitting of the leveling agent storage equipment has significantly improved product stability and consistency, reducing production delays caused by quality issues and enhancing our production efficiency and customer satisfaction."

Table 3.

Item	Before Retrofitting	After Retrofitting
Purchase order amount	-	34,300 yuan (March 2025)
Delivery cycle	7 days	4 days
Product quality stability	-	Significant improvement
Loss rate	-	Reduced

5.3 Implementation and Promotion of the Industrialization Path

Wuxi Lianda Chemical Co., Ltd. has successfully implemented the "patent equipment – intelligent upgrading – customer feedback" industrialization path through close cooperation with upstream and downstream enterprises. The company has not only achieved technological upgrades internally but also promoted the entire industrial chain's upgrade through collaboration with suppliers and customers. During the technological transformation process, the company actively cooperated with suppliers to ensure high-quality equipment procurement and integration. Meanwhile, through close communication with customers, timely feedback was collected to optimize equipment performance and meet market demand. Additionally, the company actively participated in the formulation of industry standards and promoted the widespread adoption of intelligent retrofitting within the industry through technical exchanges and cooperation. This industrialization path has not only enhanced the company's market competitiveness but also provided strong support for technological progress and industrial upgrading in the sector.

6. Conclusions and Future Outlook

6.1 Research Conclusions

This study successfully reduced the loss rate of leveling agent storage equipment from 8% to 2% through the intelligent retrofitting practice at Wuxi Lianda Chemical Co., Ltd. By embedding high-precision temperature and humidity sensors and IoT modules, real-time monitoring and automatic regulation of storage conditions were achieved, significantly enhancing product quality stability and production efficiency. Specifically, the fluctuation range of quality inspection indicators was reduced from ±10% before retrofitting to ±2% after retrofitting. The customer quality complaint rate dropped from 5% to 1%, the delivery cycle was shortened from 7 days to 4 days, and production efficiency increased by 30%. The economic benefits analysis shows that with an initial investment of 500,000 yuan, annual economic benefits increased by 650,000 yuan through reduced loss rates, shortened delivery cycles, and increased production efficiency, with an investment payback period of one year. Through the "patent equipment – intelligent upgrading – customer feedback" industrialization path, Wuxi Lianda Chemical Co., Ltd. has not only enhanced its competitiveness but also provided a replicable technological transformation solution for the industry.

6.2 Limitations of the Study and Future Outlook

Despite the significant achievements in the intelligent retrofitting of leveling agent storage equipment, this study has some limitations. First, the study mainly focuses on the practice of a single enterprise, lacking verification of the wide applicability to different scales and types of textile dyeing enterprises. Second, the long-term impact and potential issues of intelligent retrofitting have not been fully assessed, such as the long-term stability of equipment, system scalability, and data security. Additionally, the study does not delve into the comprehensive environmental and social impacts of intelligent retrofitting, such as energy conservation, emission reduction, and changes in employment opportunities.

Future research directions should include broader empirical studies on the effects of intelligent retrofitting across different scales and types of enterprises to verify the universality of the technological solution. It is also necessary to further assess the long-term impact of intelligent retrofitting, including equipment stability, system scalability, and data security. Moreover, future research should focus on the comprehensive environmental and social impacts of intelligent retrofitting, such as energy conservation, emission reduction, and changes in employment opportunities, to fully evaluate the sustainability of technological transformation. With the continuous development of intelligent technologies, the intelligent retrofitting of the textile dyeing auxiliaries industry will provide new momentum for technological progress and industrial upgrading, promoting the sustainable development of the sector.

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