Safety Supervision Practices and Data Analysis of Nitration Enterprises in Jiangsu Province

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Abstract: With the rapid development of domestic chemical technology, the safety problems of nitrification enterprises have become more and more prominent, posing a serious threat to public safety, and the community was once "afraid of nitrate". This paper takes the nitrification enterprises in Jiangsu Province, China as an example, and analyzes the data of the government's implementation of optimizing risk assessment, enhancing intrinsic safety, improving competence and quality, and perfecting emergency response and other safety regulatory measures, and the results show that the risk indicators of nitrification enterprises in 2023 have been significantly reduced compared to 2020, and the average risk value has decreased by 33%, and the overall risks of nitrification enterprises in Jiangsu Province have been effectively controlled. The four safety supervision measures are precise in direction, clear in standard, and remarkable in effect. After the implementation, there has not been a single fatal accident in the nitrification enterprises in Jiangsu Province so far, which can be a reference for the national nitrification enterprises as well as other high-risk sub-fields of safety remediation.

Keywords: Jiangsu Province; Nitration Enterprises; Safety Supervision; Data Analysis

1. Introduction

The *Investigation Report on the "3•21" Major Explosion Accident at Tianjiayi Chemical Co., Ltd. in Xiangshui, Jiangsu* published by the Ministry of Emergency Management in November 2019 highlighted the severe and recurring major accidents in Jiangsu Province, a region heavily populated with chemical industries. The report emphasized the profound lessons learned and underscored the need for heightened attention to mitigating chemical safety risks. Despite the urgency, the comprehensive safety management of hazardous chemicals and the targeted rectification of chemical enterprises in Jiangsu lacked specific standards and policy measures, failing to focus on critical risks and major hazards with tailored approaches [1]. In response, Jiangsu Province initiated a phased safety production improvement plan, consisting of a short-term "one-year quick fix" and a long-term "three-year overhaul". This paper analyzes the data derived from four key measures implemented during this period, with the findings reported below.

2. Advances in Safety Supervision and Information Technology Research

With the advent of the big data era, data has become the most crucial factor in safety supervision. In this digital age, the level of government data management has significantly improved, leading to substantial changes in governmental cognition and behavior [2]. Citizens are also increasingly required to connect to the internet frequently to search for and share new information [3]. Digitalization will further strengthen the bond between the government and the public, enhancing communication efficiency. Janowski explored the evolution of digital government development models, categorizing the "Digital Government Evolution Model" into four stages [4]; Scupola A and Zanfei A, through their research on the evolution of public governance, mentioned that public administration is shifting towards an internet-based model [5]; Paulin discussed the informatization of public governance, emphasizing the transformation of governance methods through technology [6]; Wang C and Medaglia R examined the application of big

data technology in governance, highlighting the growing need to integrate technology with the needs of society and citizens, fostering innovative applications and service models within the context of building a digital government [7]; ALHINAI proposed that big data has transformed the technical support, organizational systems, and behavioral models of traditional safety supervision [8]; IGLESIAS emphasized that emergency management information systems, capable of situational awareness, scenario simulation, and visual management, can aid decision-makers in making rapid and accurate emergency decisions [9].

3. Current Status of Nitration Enterprises in Jiangsu Province and Key Aspects of Safety Supervision

3.1 Overview of Nitration Enterprises in Jiangsu Province

As of 2020, there were 50 registered nitration enterprises in Jiangsu Province. In terms of regional distribution, Yancheng City accounted for 15 enterprises, Nantong City had 13, Lianyungang City hosted 9, Huaian City had 6, Yangzhou City had 3, Nanjing City had 2, while both Taizhou City and Suzhou City each had 1 enterprise. When categorized by industry, 19 enterprises produced pharmaceutical intermediates, 13 specialized in pesticides, and 18 focused on dye production. Regarding enterprise scale, there were 10 large enterprises with a production capacity exceeding 10,000 tons or employing more than 800 personnel, while the remaining 40 were classified as small to medium-sized enterprises. In terms of nitration reactor types, 46 enterprises utilized kettle-type reactors, while 4 employed microchannel or tubular reactors. Concerning production methods, 37 enterprises operated on a batch production basis, whereas 13 engaged in continuous production.

In the 2020 ministerial-level supervision and inspection of nitration enterprises, the 50 nitration enterprises in Jiangsu Province had an average of 42.1 identified safety hazards per enterprise, with an average of 0.75 major hazards per enterprise. The inspection highlighted six key issues: 1. Inadequate understanding of the full-process risks associated with nitration processes, leading to ineffective safety risk management (26 enterprises, 52%). 2. Significant deficiencies in the establishment of emergency measures, resulting in an inability to respond effectively to abnormal conditions (25 enterprises, 50%). 3. Improper configuration or non-activation of interlock and alarm systems for the nitration process (24 enterprises, 48%). 4. Overall low levels of safety management, with safety requirements not being effectively enforced (23 enterprises, 46%). 5. Failure to effectively implement basic safety control requirements and critical monitoring parameter schemes for the nitration process (18 enterprises, 36%). 6. Ineffective implementation of inherently safe design principles aimed at eliminating or reducing hazards by understanding the nature of materials or processes (14 enterprises, 28%). These six issues broadly reflect the state of safety management in Jiangsu's nitration enterprises prior to safety rectification efforts.

3.2 Safety Supervision Measures for Nitration Enterprises in Jiangsu Province

In the development of process industries, four main strategies have emerged for preventing major accidents and losses: standard-based, compliance-based, continuous improvement-based, and risk-based approaches [10]. Enterprises may implement multiple strategies simultaneously to achieve unified risk control and management. Given that China's chemical industry is currently undergoing a period of transition and transformation, Jiangsu Province has adopted risk-based safety supervision measures, which align with current public safety needs. These measures are effectively integrated into Jiangsu's "Five-in-One" safety production information platform [11].

3.2.1 Optimizing risk assessment

In 2020, the Ministry of Emergency Management issued the *Guidelines for Safety Risk and Hazard Investigation in Nitration Enterprises*, which established methods and standards for risk grading. While these guidelines provide a way to measure an enterprise's safety management level, they do not fully reflect the overall risk profile of the enterprise. In practice, Jiangsu Province has adopted nine key indicators for risk assessment, including process hazard risk, material hazard risk, production equipment risk, employee qualification risk, operational

risk, key nitration process risk, major hazard risk, hazard rectification rate, and quantified safety management assessment scores (as detailed in Table 1). These indicators comprehensively account for process risks, equipment risks, as well as operational and management risks, providing a true reflection of the risk landscape in nitration enterprises across the province. Coupled with the requirements of the *Regulations on the Safety Production Risk Report of Industrial Enterprises in Jiangsu Province* (Provincial Government Decree No. 140) issued on November 21, 2020, Jiangsu's approach closely monitors significant risks and major hazards within nitration enterprises.

Table 1. Content of the Nine Risk Assessment Indicators for Nitration Enterprises

No.	Indicator Name	Scoring Criteria
1	Process Hazard Risk	Normal temperature and pressure: 1 point; Normal temperature and pressure with a Level 3 major hazard source: 2 points; Low temperature or negative pressure with a Level 3 major hazard source: 3 points; Normal temperature and pressure or above with a Level 2 major hazard source: 4 points; High temperature and pressure with a Level 1 major hazard source: 5 points.
2	Material Hazard Risk	Presence of Class A fire hazard, explosive substances, highly toxic chemicals, flammable toxic gases, or material thermal evaluation of Level 3 or above: 1 point for each.
3	Production Equipment Risk	Microchannel: 1 point; Tubular continuous: 2 points; Kettle-type continuous: 3 points; Semi-continuous or semi-batch: 4 points; Batch: 2 points.
4	Employee Qualification Risk	All with college degrees or above: 1 point; All with high school degrees or above: 2 points; Some with middle school degrees: 3 points; More than 50% with middle school degrees: 4 points; Some employees with no formal education: 5 points.
5	Operational Risk	Fully mastered: 1 point; Fully familiar: 2 points; Somewhat familiar: 3 points; Basic understanding: 4 points; 50% or more unfamiliar: 5 points.
6	Key Nitration Process Risk	1–3 issues: 1 point; 4–6 issues: 2 points; 7–10 issues: 3 points; 10–15 issues: 4 points; More than 15 issues: 5 points.
7	Major Hazard Risk	No major hazards: 1 point; 1–3 major hazards: 2 points; 4–6 major hazards: 3 points; 7–10 major hazards: 4 points; More than 10 major hazards: 5 points.
8	Hazard Rectification Rate	100%: 1 point; Above 95%: 2 points; Above 90%: 3 points; Above 85%: 4 points; Below 85%: 5 points.
9	Quantitative Safety Management Assessment Score	Above 80 points: 1 point; Above 70 points: 2 points; Above 60 points: 3 points; Above 50 points: 4 points; Below 50 points: 5 points.

3.2.2 Enhancing inherent safety

Nitrated compounds possess significant decomposition energy, and nitration reactions are highly exothermic. To enhance the inherent safety of these processes—by minimizing energy scale, reducing risk levels, and enabling automatic control—continuous nitration via microreactors and tubular reactors is essential. On August 13, 2020, the Jiangsu Provincial Emergency Management

Department issued the *Guiding Opinions on Further Enhancing the Inherent Safety Level of Nitration Enterprises*, which, for the first time, stipulated that "newly built, modified, or expanded nitration units should, in principle, adopt microchannel and other continuous nitration production processes to improve inherent safety and control risks at the source". This directive has garnered widespread attention across the country. Jiangsu Province, guided by risk management priorities, has outlined three specific scenarios for selecting nitration processes: 1. For the nitration of active aromatic hydrocarbons with a single substituent—such as benzene, toluene, and chlorobenzene—where the reaction occurs rapidly in a liquid-phase system, continuous production is best achieved using microchannel and tubular reactors. 2. For nitration reactions in non-homogeneous systems that involve the precipitation of small amounts of solids and require high mixing efficiency due to slower reaction rates, a kettle-type continuous process can be selectively applied. 3. For more complex processes characterized by stringent reaction conditions, prolonged reaction times, and non-homogeneous systems or solid reactants/products, achieving continuous production in a single reactor is challenging. In such cases, a combination of reactors—such as microchannel with tubular, microchannel with kettle-type, or tubular with kettle-type—can be employed to facilitate continuous production. According to the latest elimination catalog [12], the use of batch or semi-batch kettle-type nitration processes is prohibited for 27 nitration-related chemicals, including nitrobenzene. Enterprises must complete the required modifications within two years, after which continued use will be prohibited. Jiangsu Province maintains a stringent oversight model, involving enterprise self-inspections, park-level inspections, county and city verifications, and provincial-level supervision. By leveraging major hazard cross-checks, high-level segmented field inspections, license renewal verifications, and law enforcement inspections, the province ensures timely updates, attention to renovation efforts, and the elimination of nitration enterprises that fail to meet safety production standards.

Additionally, to optimize nitration process control systems, enhance automation across the entire process, reduce personnel in hazardous areas, and rigorously manage significant safety risks, Jiangsu Province has strictly implemented the *Guidelines for Full-Process Automation Transformation of Nitration Processes in Chemical Enterprises (Trial)*. These guidelines establish the standards for achieving full-process automation for nitration units and their related upstream and downstream production processes. The province has organized industry experts to conduct on-site reviews of the self-assessment reports submitted by nitration enterprises, ensuring compliance with basic requirements for full-process automation, process control systems, emergency shutdown systems, combustible and toxic gas alarm systems, and on-site audible and visual alarms. This verification process includes the automatic (emergency) shutdown capability of the process control systems for entire nitration processes and workshops, monitoring and alarm functions for critical nitration parameters, interlock systems, emergency power, feed and heating cut-off, emergency cooling systems, automatic isolation and spraying systems, as well as the establishment of an independent safety instrumented system (SIS) for nitration processes, with a mandated Safety Integrity Level (SIL) classification for the SIS.

3.2.3 Improving competency and quality

For personnel involved in nitration processes, Jiangsu Province has established a three-tier qualification system based on educational background and professional titles. First, key figures in nitration enterprises—such as primary leaders, those responsible for production, equipment, technology, safety, and safety management—must hold a relevant college degree or higher, or possess an intermediate or higher professional title in chemistry or related fields. Second, operators of production units and storage facilities associated with nitration processes are required to have a high school diploma or above, or a vocational education level in chemistry or a related discipline. Third, operators handling explosive nitrated substances must have at least a college degree in chemistry or a related field.

Meanwhile, in terms of education and training, Jiangsu Province has seriously carried out

safety education and training activities for the main persons in charge of production and operation units and practitioners, and centralized training and education for the main persons in charge by year. The province enforces strict safety training assessments for "three key personnel categories" within production and operation units, and rigorously manages special operations personnel, such as those involved in electrical and welding work. The construction of chemical safety skills training bases and safety training facilities for hazardous chemicals enterprises is actively promoted. Training institutions within the province are urged to optimize and refine the training content and assessment standards for nitration process operators, with a focus on evaluating their knowledge of process principles, practical operations, and emergency response. Regular reviews ensure that personnel are proficient in the "five understandings, five capabilities, and five competencies".

Improper alarm management—such as unreasonable alarm settings, untimely responses, incorrect response methods, or alarm overload—can prevent timely corrections when production conditions deviate, thereby reducing the safety of the process and potentially leading to accidents. To address this, Jiangsu Province guided Nanjing City in launching the *City-wide Chemical (Hazardous Chemicals) Enterprises Alarm Management Improvement Action Plan*. This plan directs enterprises to establish alarm management systems according to the *Guidelines for Chemical Enterprise Process Alarm Management*, covering the full lifecycle of process alarms, including strategy, identification, approval, setting, implementation, operation, maintenance, monitoring and evaluation, change management, and review. Alarms should be configured to accurately and promptly reflect equipment failures, process deviations, or abnormal conditions.

3.2.4 Perfecting emergency response

Jiangsu Province mandates that nitration enterprises determine the type of safety relief devices based on the properties of the discharge medium from the nitration reactor, the characteristics of overpressure conditions, and the performance of the safety relief system. Enterprises should install either downward or upward explosion venting systems, accompanied by facilities for the safe collection and treatment of released materials. The nitration reaction system must implement at least one of the following measures for continuous mitigation: emergency cooling, controlled depressurization, quenching suppression, sudden cooling and flooding, draining, or pressure relief and explosion venting. Valves associated with these mitigation measures (except for pressure relief and explosion venting) should be remotely controllable. If a draining system is employed, an emergency kettle or tank must be provided, equipped with appropriate measures based on material characteristics, such as an effective cooling and stirring system, or the addition of quenching agents or inhibitors to ensure that the materials remain safely controlled. In cases where the released materials pose a high risk of combustion or explosion, the emergency kettle or tank should be placed outside the nitration workshop. If the calculated pressure relief measures fail to meet the pressure relief requirements, these measures cannot be considered as independent protection layers within the SIL (Safety Integrity Level) classification.

To enhance emergency response capabilities in nitration enterprises, Jiangsu Province requires improvements in cooling, firefighting, isolation, emergency power supply, and audio-visual alarms. For example, in nitration unit areas involving flammable, explosive, or decomposition-explosive risks, it is recommended to install automatic sprinklers and other cooling systems. For equipment containing flammable or explosive media, automatic firefighting systems should be installed. Facilities such as nitration reactors, nitrated material storage tanks, and tanks connected to the nitration system that could be mutually affected during an accident should be equipped with emergency automatic shutoff valves for isolation. In cases where nitration reactor agitation (or circulation pumps) cannot meet safety shutdown requirements during a power outage, an independent backup power supply (EPS) should be provided. The nitration workshop, including areas with raw materials, intermediates, and finished products, as well as warehouses for hazardous waste, and post-treatment facilities involving nitrated substances, should be equipped with

audio-visual alarm systems and remote video monitoring to ensure that on-site personnel receive abnormal situation alerts and evacuate promptly. With the deepening of Jiangsu Province's "Five-in-One" safety production information platform, the role of personnel positioning systems in accident prevention and emergency response has become increasingly significant.

4. Data Analysis of Implementation Outcomes

Since 2020, Jiangsu Province has implemented the aforementioned four safety supervision measures, achieving notable results. As shown in Table 2, by December 2023, there are 22 nitration enterprises in Jiangsu Province, while 28 nitration enterprises that did not meet safety production conditions have voluntarily exited the market, reducing the total number of enterprises by 56%. This reflects Jiangsu Province's commitment to safety production. Among the 22 remaining nitration enterprises, 13 have adopted microchannel or tubular reactors, with the percentage of advanced equipment usage rising from 8% in 2020 to 59%, significantly mitigating major risks and markedly reducing the volume of liquid retained on-site. Seventeen of these enterprises have adopted continuous production methods, increasing from 26% in 2020 to 77%, leading to a significant rise in automation levels and a substantial reduction in the number of on-site operators. In the 2023 special safety rectification for nitration enterprises, the average number of potential hazards per nitration enterprise in Jiangsu Province was 10.3, a reduction of 76% compared to 2020. The number of major hazards was 0.3 per enterprise, a decrease of 60% compared to 2020. Additionally, the proportion of problems related to critical items in nitration processes has become relatively low, indicating a significant improvement in the intrinsic safety and safety management levels of nitration enterprises in Jiangsu Province.

Table 2. Comparison of Basic Conditions of Nitration Enterprises in Jiangsu Province, 2020 vs. 2023

Year	Number of Nitration Enterprises	Microchannel or Tubular Reactors (units)	Continuous Production Units (units)	Average Number of Potential Hazards (items per enterprise)	Average Number of Major Hazards (items per enterprise)
2020	50	4	13	42.1	0.75
2023	22	13	17	10.3	0.30

The comparison chart of the nine risk assessments for nitration enterprises in Jiangsu Province in 2020 and 2023 (Figure 1) also reveals a significant reduction in all risk indicators. The average risk score has decreased from 28.2 in 2020 to 19.0 in 2023, a reduction of 33%, indicating that the overall risk of nitration enterprises in Jiangsu Province has been effectively controlled.

5. Conclusions

This paper has analyzed four risk-based safety supervision measures implemented by Jiangsu Province for nitration enterprises. These measures are directionally precise, have clear standards, and have shown significant results, as evidenced by the absence of fatal accidents in nitration enterprises in Jiangsu Province since 2020. Firstly, the establishment of nine risk assessments allows for a reasonable determination of an enterprise's safety risk value, facilitating the government and enterprises in formulating risk mitigation strategies. Secondly, by clearly defining the direction for intrinsic safety transformation, the application of new equipment and processes in high-risk subdivisions can be rapidly advanced. Thirdly, the enhancement of skills and competencies has significantly promoted the identification and management of hazards and the safe operation of job positions within enterprises. Fourthly, improving emergency response procedures is a critical measure in preventing production safety accidents.

In the era of big data, quantifiable safety management data presents an unprecedented opportunity for government safety supervision, significantly advancing the construction of a "comprehensive safety and emergency response" system. However, there are still some shortcomings, such as the need to verify the timeliness and authenticity of safety management data on the enterprise side, the lack of a comprehensive industry-wide safety management database, and the limited

specificity of data analysis on digital platforms.

Safety supervision faces a variety of unpredictable challenges. Moving forward, it is recommended to refine safety management business processes based on modern management theories and to conduct research and application of safety supervision data analysis. This approach will provide essential technical support for the continuous and stable development of the industry.

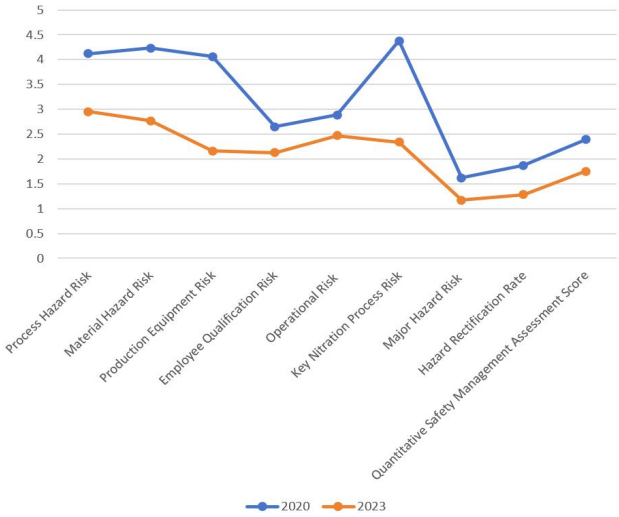

Figure 1. Comparison of the Nine Risk Assessments for Nitration Enterprises in Jiangsu Province, 2020 vs. 2023

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