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Pollution Status of Volatile Organic Compounds (VOCs) from Adhesives in Printing Production and Cleaner Production Control Strategies

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Abstract: The printing industry is one of the key emission sectors of volatile organic compounds (VOCs) in China. During production, the volatilization of various adhesives, including laminating adhesives, carton gluing adhesives, and binding adhesives, constitutes a primary source of VOCs in printing processes. Uncontrolled emissions from these adhesives readily cause atmospheric pollution and deteriorate the workshop working environment. To precisely address the challenge of VOC pollution from adhesives in the printing industry, this paper takes Wuhu Yuzhong Printing Co., Ltd. as a case study. It systematically analyses the generation links, pollution characteristics, and existing management problems of VOCs from adhesives throughout the entire printing production process. A VOC cleaner production management system suitable for small and medium-sized printing enterprises is constructed from four dimensions: source reduction, process control, end-of-pipe treatment, and management system improvement. The research results indicate that substitution of solvent-based adhesives, enclosed production management, and upgrading of high-efficiency exhaust gas treatment equipment can effectively reduce both the concentration and total amount of VOC emissions. This provides practical references and technical insights for the green and low-carbon transformation of regional printing industries and the precise reduction of VOCs.

Keywords: Printing production; Adhesives; VOCs; Pollution status; Cleaner production; Control strategies

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1. Introduction

With the continuous deepening of air pollution prevention and control efforts in China, volatile organic compounds (VOCs) have become core control factors for ozone pollution and the synergistic control of fine particulate matter. The reduction of industrial VOC emissions is a key task in atmospheric environmental management. As a typical solvent-using light industry, the printing industry relies on large quantities of adhesives, inks, diluents, and cleaning agents in its raw and auxiliary materials, which are the main carriers of VOCs. Among these, adhesives—due to their large consumption, wide application in multiple processes,

and long volatilization cycles—contribute nearly 40% of the VOC emissions in printing production, making them a weak link in pollution control [1]. Compared with VOC emissions from inks, printing adhesives are mostly solvent-based systems with complex compositions and prominent fugitive emissions. Moreover, small and medium-sized printing enterprises commonly suffer from loose control of raw and auxiliary materials, poor production enclosure, rudimentary treatment facilities, and lack of operation and maintenance management. These problems lead to frequent excessive VOC emissions and low exhaust gas collection efficiency, severely restricting the green development of the industry [2]. Cleaner production, as a core model for source prevention and whole-process pollution reduction and carbon co-benefits, can effectively overcome the limitations of single-end-of-pipe treatment, high costs, and limited reduction efficacy, aligning with the requirements of green industrial transformation.

2. Sources and emission characteristics of VOCs from adhesives in the printing industry

2.1. Core pollution sources

VOC emissions in printing production originate throughout the entire pre-press, press, and post-press processes. Among these, adhesive volatilization is concentrated in post-press processing and constitutes a distinctive feature that differentiates adhesive pollution from ink pollution. It mainly involves three types of adhesive application scenarios. First, laminating adhesives are used in paper-plastic and plastic-plastic lamination processes. Traditional solvent-based laminating adhesives use ethyl acetate and toluene as the main solvents, and large amounts of VOCs are volatilized during coating, lamination, and drying. Second, carton gluing adhesives are applied in the bonding and shaping of packaging boxes and paper products. The solvent-based adhesives used for room-temperature curing exhibit strong continuous volatilization, and fugitive emissions are particularly prominent. Third, binding adhesives are used in book and album binding. Some ordinary white glues and hot-melt adhesives, along with auxiliary solvents, generate a small amount of VOC volatilization.

2.2. Emission characteristics

Printing production processes display four key features of VOC emissions from adhesives. First, continuous emission: solvent volatilization occurs throughout coating, lamination, and curing stages, unlike the short-term, concentrated volatilization seen with inks. This process spans all post-press operations. Second, a high proportion of fugitive emissions: many small and medium-sized printing companies lack sufficient workshop enclosures. Activities like adhesive application, coating, and equipment cleaning are mostly open, with exhaust collection efficiency usually below 60%, so fugitive emissions vastly surpass ducted emissions. Third, complex composition: VOCs in printing adhesives mainly include ethyl acetate, toluene, xylene, and alcohols, some of which are toxic and hazardous, posing health risks to workers. Fourth, large emission fluctuations: heavily influenced by production schedules and temperature. In summer, high temperatures cause a sharp increase in solvent volatilization, leading to peak VOC emission concentrations [3].

3. Current VOC pollution status and existing problems at the case enterprise

3.1. Company profile

Wuhu Yuzhong Printing Co., Ltd. is located in Wuhu City, Anhui Province. It is a small and medium-sized printing enterprise mainly engaged in self-adhesive color printing and screen printing. Its production scale meets the demand for small and medium-sized packaging orders in the region. Core production processes include paper cutting, color printing, lamination, and binding. The production equipment mainly consists of conventional printing and laminating machines. Raw and auxiliary materials include solvent-based laminating adhesives, inks, and organic solvents, and low-VOC, environmentally friendly adhesives have not been fully adopted. The production mode, environmental protection configuration, and management methods of the enterprise are typical of small and medium-sized printing enterprises in the Wuhu area, making its VOC pollution problems highly representative of the regional industry.

3.2.Investigation of VOC pollution status at the enterprise

Through on-site inspections, raw material inventory checks, exhaust gas emission monitoring, and production process reviews, it was determined that the core VOC pollution problems of the enterprise are concentrated in the adhesive use stage. First, the environmental grade of raw and auxiliary materials is relatively low. The enterprise still uses large quantities of traditional solvent-based laminating adhesives and general solvent-based carton gluing adhesives. These adhesives have low solid content and a high proportion of organic solvents, with no environmentally friendly modification, and are the main cause of excessive VOCs in the workshop. Second, fugitive emissions during production are severe. The lamination and carton gluing processes are carried out in open operations, and no enclosed barriers are installed for feeding, coating, or equipment cleaning. Fugitive diffusion of exhaust gas in the workshop is obvious, and the non-methane total hydrocarbon (NMHC) concentration in the working area remains at a high level for a long time. Third, end-of-pipe treatment facilities are rudimentary. The enterprise is equipped only with a simple activated carbon adsorption device, without a dedicated exhaust gas collection pipeline system, resulting in very low collection efficiency. Moreover, the activated carbon is not replaced in a timely manner, and there is no regular maintenance log, so the exhaust gas treatment performance decays significantly and cannot meet the requirements of the emission standard GB 41616-2022. Fourth, workshop environmental management is weak. The workshop ventilation system is poorly designed, and no temperature-control measures are taken during the hot season to suppress volatilization, further intensifying solvent release from adhesives [4].

3.3. Core shortcomings in VOC management at the enterprise

First, source substitution lags. Due to production cost considerations, the enterprise preferentially selects low-cost solvent-based adhesives, and the utilization rate of water-based and solvent-free environmentally friendly adhesives is less than 20%, providing a weak foundation for source reduction. Second, process control is lacking. There is no standardized closed-production management specification, the exhaust gas collection system is incomplete, and there are many blind spots in fugitive emission control. Third, the end-of-pipe treatment system is inadequate. A single treatment device cannot effectively handle the complex VOC exhaust gas, equipment maintenance is irregular, and treatment efficiency is low. Fourth, the cleaner production management system is absent. No routine management systems have been established for raw material control, exhaust gas monitoring, equipment maintenance, and personnel training. Environmental awareness is weak, and a whole-process pollution control mechanism is lacking. Fifth, there is no recycling mechanism. Adhesive residues and cleaning solvents are disposed of arbitrarily, leading to prominent

secondary volatilization pollution.

4. Whole-process comprehensive VOC control strategies based on cleaner production

4.1. Source control: Promoting substitution of environmentally friendly adhesives to achieve VOC reduction

Source substitution is the most economical and efficient cleaner production measure for VOC reduction from adhesives in the printing industry. Enterprises need to optimize their raw and auxiliary material procurement system comprehensively, phase out highly volatile solvent-based adhesives, and complete the replacement with environmentally friendly adhesives in batches. First, for the lamination process, water-based laminating adhesives and solvent-free polyurethane laminating adhesives should be prioritized. These adhesives use water as the solvent or have no organic solvent addition, reducing total VOC emissions by more than 85% while maintaining bonding strength and lamination stability that meet production quality requirements. Second, for carton gluing and binding processes, water-based acrylic ester adhesives and environmentally friendly hot-melt adhesives should be substituted to eliminate the volatilization of toxic solvents such as toluene and xylene. Third, a raw material access system should be established: all adhesives and cleaning agents must be accompanied by a VOC content test report, and the procurement of highly volatile materials without environmental certification must be strictly prohibited. Fourth, material storage methods should be improved: adhesives should be stored uniformly in a closed raw material warehouse, partitioned and sealed, to avoid open storage that causes solvent evaporation. At the same time, based on production order characteristics, adhesive procurement volumes should be reasonably controlled to reduce material overstock and minimize volatilization losses during long-term storage [5].

4.2. Process control: Enclosed production retrofitting to control fugitive emissions strictly

To address the prominent fugitive emission problems, enclosed and refined retrofitting of production processes should be carried out to fill the gaps in process control. First, install enclosed enclosures and hoods on key emission-generating equipment such as laminators and carton gluers, and build a standardized exhaust gas collection pipeline system to achieve full-enclosure collection at emission points, raising the collection efficiency to above 90%. Second, optimize the workshop ventilation and air exchange system by rationally arranging supply and exhaust fans and distinguishing production operation areas, raw material storage areas, and equipment cleaning areas to achieve zoned ventilation and prevent accumulation of VOC gases. Third, formulate standard operating procedures to standardize adhesive feeding, coating, and equipment cleaning operations, prohibit open operations, and shorten the open exposure time of raw and auxiliary materials. Fourth, implement workshop temperature control: during the high-temperature summer period, activate cooling equipment to reduce the solvent volatilization rate of adhesives, thereby reducing VOC generation during the process. In addition, establish routine inspection procedures to regularly check the integrity of enclosed facilities and collection pipelines, and promptly repair damaged or leaking parts to ensure the effectiveness of process control.

4.3. End-of-pipe upgrade: Optimizing exhaust gas treatment facilities to ensure compliance

Given the relatively simple composition and moderate air volume of the adhesive VOC exhaust gas at the enterprise, an efficient and suitable end-of-pipe treatment system should be installed to replace the original simple treatment device. Abandon the single activated carbon adsorption mode and adopt a combined "pre-treatment + activated carbon adsorption concentration" treatment process. First, a dry filtration device removes dust and colloidal particles from the exhaust gas to prevent clogging of the activated carbon pores. Then, high-efficiency activated carbon adsorbs the VOCs, and the treated gas is discharged through a stack to meet the standard. To address operation and maintenance costs for small and medium-sized enterprises, establish a log for regular activated carbon replacement and desorption regeneration, and dynamically adjust the replacement cycle according to production load to ensure stable operation of the treatment equipment. At the same time, install online VOC monitoring equipment to continuously monitor exhaust gas concentrations, ensuring full compliance with the emission limits of the "Emission standard of air pollutants for printing industry", and thoroughly solving the problems of low end-of-pipe treatment efficiency and excessive emissions. For periods of high production load, a low-temperature plasma auxiliary treatment module can be added to improve purification efficiency further.

4.4. Management empowerment: Building a routine cleaner production system

A comprehensive management system is the core guarantee for the long-term implementation of cleaner production. First, establish and improve environmental management systems, including specific rules for raw material control, exhaust gas treatment equipment maintenance, workshop cleaning, and pollutant monitoring, clarifying environmental responsibilities for each position to achieve standardized environmental management throughout production. Second, strengthen personnel training: conduct regular special training on cleaner production, VOC pollution prevention, standard equipment operation, safety, and environmental protection, to enhance operators' environmental awareness and professional competence and eliminate pollution leaks caused by human error. Third, improve record-keeping management: maintain detailed records of adhesive procurement, use, storage, and waste disposal, as well as equipment maintenance and monitoring data, to enable traceability of pollution sources. Fourth, conduct regular cleaner production audits: complete one self-assessment of cleaner production each year, continuously optimize and improve based on identified pollution weaknesses in the production process, and form a closed-loop management mechanism of "inspection-rectification-improvement".

4.5. Resource circularity: Promoting resource utilization of waste materials

For waste materials such as adhesive residues, waste solvents, and spent activated carbon, establish standardized disposal and recycling mechanisms. Adhesive residues generated during production should be collected in sealed containers and entrusted to qualified units for resource recovery treatment; dumping or open storage is strictly prohibited. Spent activated carbon should be uniformly collected and centrally disposed of, and sent to qualified facilities for regeneration, achieving resource recycling. Equipment cleaning solvents should adopt a small-volume, multiple-wash mode, and the cleaning waste liquid should be recovered and reused, thereby reducing organic solvent consumption and volatilization and further lowering total VOC emissions, thus enhancing the enterprise's cleaner production level.

5. Predicted treatment effects and industry promotion value

5.1. Predicted treatment effects at the enterprise

By implementing the above whole-process cleaner production control strategies, Wuhu Yuzhong Printing Co., Ltd. is expected to achieve comprehensive control of VOC pollution. Source substitution with environmentally friendly adhesives can reduce VOC emissions from the adhesive stage by more than 85%, fundamentally reducing the amount of pollution generated. Enclosed production retrofitting can essentially eliminate fugitive emissions and increase exhaust gas collection efficiency to above 90%. The upgraded end-of-pipe treatment facilities can achieve a purification efficiency of 95%, ultimately ensuring that both the concentration and total amount of VOC emissions meet the standards, significantly improving the workshop working environment, and fully satisfying national and local atmospheric environmental protection requirements for the printing industry. At the same time, the standardized management system can reduce equipment maintenance costs and material loss costs, achieving a synergistic improvement in environmental and economic benefits.

5.2. Industry promotion value

At present, small and medium-sized printing enterprises account for more than 90% of the total enterprises in China's printing industry. These enterprises commonly share common problems such as weak control of adhesive VOCs, lagging treatment levels, and limited environmental protection investment. The cleaner production control system constructed in this paper, using a typical small and medium-sized printing enterprise as a case, does not require high capital investment and is suitable for the production scale and cost-bearing capacity of small and medium-sized enterprises, balancing practicality, economy, and effectiveness. The strategy focuses on the core source of adhesive pollution and adopts a combined approach of "low-cost substitution, refined control, adapted treatment, and routine management". This overcomes the industry-wide difficulty in VOC management among small and medium-sized printing enterprises—namely, "over-emphasis on end-of-pipe treatment, neglect of source control, and fragmented management". It provides a replicable and scalable technical pathway and practical reference for the cleaner VOC treatment and green transformation of similar small and medium-sized printing enterprises in Wuhu City and across the country.

6. Conclusion

Solvent volatilization from various adhesives used in printing production is a core source of VOC pollution in the industry. Constrained by production processes, cost inputs, and management levels, small and medium-sized printing enterprises generally suffer from insufficient source substitution, prominent fugitive emissions, low end-of-pipe treatment efficiency, and a lack of management systems. These issues are key difficulties and focal points in regional atmospheric VOC control. Practical evidence shows that targeted cleaner production models can effectively resolve the problem of uncontrolled VOC emissions from adhesives in printing enterprises, significantly improve exhaust gas treatment efficiency, and achieve a win-win situation of compliant pollutant emissions and sustainable green enterprise development. In the future, the printing industry needs to continue deepening the green upgrading of raw and auxiliary materials, strengthen refined environmental management throughout the entire production process, promote the routine implementation of cleaner production technologies, and continuously advance precise VOC reduction. This will support the low-carbon and green transformation of the printing industry, aligning with the requirements

of industrial air pollution prevention and the dual-carbon strategy.

Disclosure statement

The author declares no conflict of interest.

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