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Exploring Effective Ways of Green Printing to Reduce Harmful Volatile Organic Compounds Emissions

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Abstract: This paper delves into the transformative shift in the printing industry from traditional petroleum-based inks to sustainable alternatives, focusing on soy ink. Initially, it examines the environmental and health hazards associated with conventional printing, highlighting the detrimental impact of volatile organic compounds (VOCs) and toxic substances in inks. The emergence of soy ink as an eco-friendly solution is then explored. Derived from soybeans, soy ink significantly reduces the release of harmful VOCs and enhances the recyclability of printed materials. The paper discusses not only the environmental benefits of soy ink but also its operational and economic advantages, such as improved deinking capabilities and waste reduction. A notable development in soy ink technology is the use of soy methyl ester, which addresses the challenges of slow drying and penetration associated with traditional inks. The paper concludes by emphasizing the need for continued innovation in sustainable practices within the printing industry, positioning soy ink as a key player in aligning economic goals with environmental responsibility. The shift to soy-based inks exemplifies a broader trend towards sustainability, pivotal for the future health of the planet.

Keywords: Soy ink; Sustainable printing; Environmental impact; Soy methyl ester; Green innovation

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1. Introduction

Since the 1980s, many developed countries have proposed an innovative model of development, different from the traditional economic growth patterns, based on the reality of environmental damage caused by industrial development within their nations. The essence of this theory is the need for sustainable development of humanity and the economy, which requires emphasis on the carrying capacity of the ecological environment and resource constraints. Environmental protection is considered a crucial pillar for achieving sustainable development. With the continuous evolution of the green development concept, countries and industries worldwide have increasingly focused on research related to green development and production in their respective fields. Accompanying China's rapid economic growth, environmental degradation has become a common concern in developing countries. Issues such as increasing haze days, severe water pollution, and widespread solid waste have emerged. Particularly, the severe pollution caused by the printing industry has added significant pressure on local environmental protection departments. Balancing economic development with environmental protection presents an inevitable contradiction. To fundamentally resolve this conflict, it's essential to swiftly transition from a traditional economy to a circular economy. By the late 1980s, developed countries like Japan, the United States, and Germany first introduced the concept of "green printing." After more than three decades of development, the concept of green printing has become deeply ingrained and is now a common consensus in the printing industry of various countries [1].

2. The hazards of non-green printing

Traditional printing, from raw materials to post-printing processes, generates wastewater and toxic gases that pose significant hazards to human health and the environment. Particularly, printing inks, one of the five essential elements of printing, are a major source of pollution in the printing industry. For instance, solvent-based inks consist of pigments, binders, solvents, fillers, and additives, with solvents primarily being toxic organic volatiles such as aromatic hydrocarbons, lipids, and ketones. Annually, the global emission of volatile organic compounds (VOCs) caused by inks reaches several hundred thousand tons [2]. These volatiles contribute to a more severe greenhouse effect than carbon dioxide and can form oxides and photochemical smog under sunlight, leading to serious environmental pollution. Toluene and xylene found in inks are classified as second-class carcinogens by the state, severely damaging the nervous and respiratory systems of printing operators. In the case of food and pharmaceutical packaging, incomplete volatilization during the printing process can lead to contamination or even spoilage of the contents. Additionally, the inks contain inorganic pollutants, mainly heavy metals like lead, chromium, silver, and mercury. Lead, for example, hinders the formation of blood cells in the human body, and accumulation to a certain level can lead to poisoning, or in worse cases, induce cellular cancer.

3. Soy ink

Soy ink refers to an environmentally friendly ink made by replacing some of the petroleum-based mineral oils in traditional ink with soybean oil. Its pigments and resins are the same as those in conventional inks. The significant replacement of volatile petroleum-based solvents with green, natural vegetable oil, namely soybean oil, reduces the release of VOCs that cause air pollution. Additionally, its chemical inducers are non-toxic and greatly facilitate natural degradation, benefiting both the printing industry's environment and health safety [3].

3.1. Overview of soy ink

As a crucial consumable in the printing process, ink directly impacts a printing enterprise's ability to achieve green printing and energy conservation. Soybeans, primarily used in food, such as soy milk for breakfast or cooking oil, have applications beyond just culinary use. After technological processing, soybeans find use in various other areas, like in soy ink for printing. In the United States, about one-third of over 10,000 newspapers use soy ink, and over 90% of more than 1,500 magazines do the same. In 1991, Japan started selling high-safety, low-aromatic hydrocarbon solvents, with carcinogenic aromatic compounds constituting less than 0.5% of the content. The emergence of these non-aromatic hydrocarbon solvents, such as soy ink, has made the printing ink industry more eco-friendly. Osaka Printing Ink Co. Ltd. in Japan introduced a new eco-friendly ink "Opis100," a sheet-fed offset ink with a base of 100% vegetable oil, primarily soybean oil, meeting environmental standards. Soy ink is highly utilized in Japan and the United States, with 100% of Japan's offset inks and 17% of the U.S.'s offset inks being soy-based [4].

3.2. Advantages of soy ink

Firstly, soy ink is environmentally friendly. The degradation rate of pigment carriers in soy ink is over four times that of standard petroleum-based inks. Soy ink also exhibits better deinking properties in the paper recycling process, resulting in high-quality recycled paper, less waste, and lower recycling costs. Unlike traditional inks reliant on non-renewable petroleum, soy ink comes from a renewable plant source, soybeans, which are naturally regenerative and biodegradable. From both resource utilization and environmental perspectives, soy ink offers incomparable advantages over traditional inks. The color range of soy ink is broad, and it provides better results than traditional ink in the same quantity. It's easier to de-ink and process waste printed materials using soy ink, causing less damage to the paper and easier degradation of waste residues.

Secondly, soy ink offers superior printing quality. Soy ink is resistant to smudging, preventing readers from getting their hands dirty while reading newspapers or magazines. It also does not emit unpleasant odors, unlike traditional petroleum-based inks, which can easily stain readers' hands and have a strong, unpleasant smell.

Thirdly, soy ink is more economical. Printing the same quantity of paper requires less soy ink than conventional ink, thus reducing ink usage and printer cleaning costs. It's estimated that green printing companies can reduce their annual energy and material costs by approximately 600 million yuan by implementing various environmental measures. In a survey conducted by the China Printing Technology Association and China Printing Magazine among 150 enterprises, 81 companies noted that using green printing materials helps increase corporate profits [5].

3.3. The role of soy methyl ester in soy ink

Soy ink involves replacing some or all of the petroleum-based mineral oil solvents in traditional ink with soy oil. Soy oil itself has a higher relative molecular mass and viscosity compared to mineral oil, resulting in significantly reduced penetration speed into paper after printing with soy ink, thereby greatly decreasing both the fixing speed on paper and the oxidation drying speed, which can greatly affect printing speed and efficiency.

The latest technology in soy ink utilizes a derivative of soy oil, soy methyl ester [6], produced by reacting soy oil with methanol. This reaction typically requires a catalyst, such as an alkaline substance (e.g., sodium hydroxide or potassium hydroxide). The chemical equation can be simplified as follows:

$$C_3H_5(OOCR)_3 + 3CH_3OH \rightarrow C_3H_5(OH)_3 + 3RCOOCH_3$$

Here, $C_3H_5(OOCR)_3$ represents triglyceride (soy oil), CH_3OH is methanol, $C_3H_5(OH)_3$ is glycerol, and $RCOOCH_3$ represents fatty acid methyl ester (soy methyl ester), where R is the alkyl group from the fatty acid.

Soy methyl ester's molecular structure resembles mineral oil, especially in the length of the hydrocarbon part and the overall size of the molecule, with similar properties and a viscosity of 3–15 mPa/s. Thus, the soy methyl ester solvent is rapidly absorbed by coated paper, addressing the slow drying issue of soy ink. Its better solvency with resins also provides more flexibility in ink formulation.

Tests of soy methyl ester have shown that:

(1) The viscosity of soy methyl ester binders is lower than that of mineral oil binders, and their yield value is higher, indicating a better structure that can withstand more shear force generated between ink rollers on printing machines than mineral oil binders. The lower viscosity of soy methyl ester binders is advantageous for offset inks, facilitating better ink transfer between rollers, ensuring consistent ink film thickness in printed images, and reducing ink consumption.

(2) Using soy methyl ester helps avoid problems during ink transfer, resulting in better printing images, and also aids in the accurate reproduction of dots, producing brighter and clearer images.

(3) Soy methyl ester ink is superior to mineral oil ink in terms of a lower rate of viscosity increase per minute. A significant rise in viscosity can cause issues like paper fuzzing during printing. The print stability of soy methyl ester ink is also notably better than that of mineral oil ink. The drying time and skinning time of soy methyl ester ink are longer than mineral oil ink, indicating that soy methyl ester ink maintains a longer open time and is less prone to skinning in the ink can.
(4) The viscosity of soy methyl ester ink changes less with temperature compared to mineral oil ink, giving it an advantage in high-temperature applications.

4. Conclusion

This paper has extensively explored the significant shift from traditional petroleum-based inks to more sustainable alternatives like soy ink in the printing industry, a change that reflects a broader movement towards environmental responsibility and sustainability.

The initial sections of the paper highlighted the environmental and health hazards posed by conventional printing processes, especially concerning the release of VOCs and the presence of toxic substances like heavy metals in inks. This backdrop set the stage for the introduction of soy ink as an innovative solution.

Soy ink, primarily derived from soybeans, emerges as a compelling alternative due to its lower environmental impact and renewable nature. It significantly reduces the release of harmful VOCs and improves the recyclability of printed materials. The advantages of soy ink are not limited to environmental benefits; they extend to operational efficiency and economic viability. Soy ink's superior deinking capability enhances the quality of recycled paper and reduces waste, while its widespread adoption in countries like the United States and Japan showcases its practical applicability and growing acceptance in the global market.

A critical innovation in the domain of soy ink is the development and utilization of soy methyl ester. This derivative addresses some of the key limitations of soy ink, such as slower drying times and reduced penetration rates compared to traditional inks. Soy methyl ester enhances the performance of soy ink by improving its drying speed and stability, thereby ensuring high-quality printing without compromising environmental standards.

The findings of this study underscore the necessity for continued innovation and adoption of sustainable practices in the printing industry. Soy ink represents a significant step forward in reducing the environmental footprint of printing while maintaining, and in some cases, enhancing the quality and efficiency of printing processes. This shift towards eco-friendly alternatives like soy ink is not just a matter of environmental responsibility but also a strategic move towards sustainability in the printing industry.

In conclusion, the transition to soy-based inks is a clear demonstration of how industry can align economic objectives with environmental stewardship. The future of printing lies in embracing such sustainable practices, which are crucial for the long-term health of our planet and its inhabitants. As this paper illustrates, soy ink is not just an alternative; it is a testament to the potential of green innovation in transforming industries toward a more sustainable future.

Author contributions

Both authors contributed equally to this paper.

Disclosure statement

The authors declare no conflict of interest.

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