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Solvent Recovery from Industrial Paint Waste using Batch Distillation: The Effect of Temperature

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ABSTRACT

Recovering materials from waste is a viable solution for managing paint-related organic solvent waste. This study focuses on the extraction of organic solvents from paint residues, which contain resins and pigments, to produce a renewed solvent. The method selected for recovery was distillation, which was used for optimizing the separation conditions for the solvents from their waste impurities. Using a batch distillation apparatus with a 30-L capacity, experiments were conducted at varying operating temperatures (120, 130, 140, 150, and 160°C) under a consistent vacuum pressure of 0.9 bar. The optimal results indicated that at 160°C and a vacuum pressure of 0.9 bar, a naphtha solvent with a 66.37% recovery rate was achieved at 19.91 L and an initial feed volume. This method of solvent recovery not only holds promise for waste reduction but also contributes significantly to environmental protection by minimizing pollutants.

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1. INTRODUCTION

Indonesia's industrial development poses significant risks to environmental quality, which is largely attributable to inadequate processing standards that lead to environmental pollution. This has further resulted in the deterioration of water, air, and soil resources (Sandoval-Martínez & Muñoz-Navarro, 2019). According to the Government Regulation of the Republic of Indonesia [PP RI] Number 101 of 2014, many pollutants originate from residues of activities rich in hazardous toxic materials (Mova Al'Afghani & Paramita, 2018). These pollutants are prominently produced in multiple processing industries, including petrochemicals, petroleum refining, metal plating, textiles, fertilizers, pesticides, and the paint industry. Notably, the paint industry's environmental footprint is substantial because of the production of liquid toxic wastes, primarily solvents employed for tasks such as washing, rinsing, tank cleaning, and maintenance of production equipment (Albasthomi *et al*., 2019).

Within the paint industry, two primary categories of paints are predominantly manufactured: water- and solvent-based. These classifications stem from the distinct methods employed to manage the liquid waste originating from their respective production processes. Despite its hazardous nature, liquid waste from the production of water-based paint can be directly channeled to wastewater treatment facilities for appropriate processing. Conversely, owing to its toxic properties, liquid waste from solvent-based paint cannot be directly disposed of in water systems. Instead, it necessitates initial containment, followed by a specialized treatment procedure administered by the paint industry (Zhang *et al*., 2018). Given the potential threats that such waste presents to both human health and the environment, various governmental and industrial bodies have promulgated policies targeting waste reduction. Strategies to curtail or eliminate waste from its origin encompass a myriad of techniques. These include the modification or complete redesign of processes, product reformulation, recycling or recovery of products, and substitution of conventional raw materials with their eco-friendly counterparts (Jaime *et al*., 2018).

Hence, an important consideration is determining an efficacious recovery methodology for solvent waste. Such a method should be contingent upon both the specific type of solvent used and the industry responsible for generating solvent waste. Methods for solvent recovery include decantation, membrane separation, and distillation. Decantation is a process used to separate the simplest mixture of solutions and solids by slowly flowing liquid such that the sludge is left at the bottom of the vessel. This method can be used if the precipitate has a large particle size and density, allowing it to separate well from the liquid. The advantage of decantation is that the process can be fast, the tools used are simple, and it can be done anywhere, but the disadvantage is that if the precipitate has not formed completely, then each filtrate is likely to be mixed with the sediment (Jorge *et al*., 2022).

Membrane technology is a method of separating two or more phases of substances using a semipermeable membrane. In general, mechanical separation processes separate the gas and liquid streams using membrane technology. Membrane technology has several advantages over other processes, such as that separation can be performed continuously or in bulk (batch), and the energy consumption is generally lower. Membrane processes can easily be combined with other separation processes. However, the drawback is the clogging of the membrane pores; at high pressure, it requires a lot of energy, and the membrane has a lifetime, where membrane replacement is carried out every 3–5 years (Ezugbe & Rathilal, 2020). Distillation is a method for separating chemicals based on differences in speed or ease of volatilization. The advantages of distillation are that it can separate substances with high boiling-point differences and produce high-purity products. However, the disadvantage is

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that the distillation method applies only to substances in liquid and gas phases (Zhao *et al*., 2022). In this study, distillation was used to achieve solvent recovery with high purity and is expected to be an effective method.

Furthermore, the adoption of a technologically advanced distillation unit or steam stripping could amplify the recovery rate. In a more recent investigation, Ordouei and Elkamel (2017) proposed a design aimed at the recovery of a thinner (a chemical solvent) from paint industry sludge. Their approach leverages the CSI (Composite Sustainability Index) methodology. This technique was implemented in a case study involving a conventional painting unit in an automobile manufacturing facility, and an innovative hybrid process. The primary objective was to efficiently recover thinner waste. Impressively, the hybrid process not only proved to be economically viable, but also exhibited marked reductions in waste, attenuated environmental impact, and diminished safety risks. Research in this area presents a potentially innovative approach for managing and reducing waste in the paint industry, while simultaneously recovering valuable solvents. The significance and novelty of this research topic became evident when the effects of temperature on the batch distillation process were examined. By exploring these effects, this study offers insights into the optimal conditions for maximizing solvent recovery. In contrast to continuous distillation, batch processes are more adaptable in terms of scalability. This may be particularly suitable for smaller operations or those dealing with fluctuating waste quantities (Ordouei & Elkamel, 2017).

2. METHODS

2.1. Tools and Materials

The tools used in this research were batch distillation and gas chromatography (Thermo Scientific 1310), and the material used in this research was organic solvent liquid waste from the paint industry. Naphtha is the solvent used in the paint industry. The waste is collected in a closed container and stored in a place protected from fire sources because of its flammable nature. The tools and materials used were located in the paint industry in Tangerang City, Banten, Indonesia.

2.2. Experimental Procedure

Samples for the distillation experiment, in the form of 30 liters of solvent waste, were obtained from a temporary waste collection unit in one of the paint industries. Before entering the distillation unit, the waste solvent was filtered to remove the solids contained. This is necessary for the proper operation of the distillation process. The sample was placed in a sealed drum before being placed in the distillation column. Typical paint industry waste is usually given a color that reflects the type of paint produced. This coloring is caused by pigments and dyes in the paint. Paint industry waste often contains organic compounds from raw materials such as resin, solvents, and other additives. **Figure 1** shows the waste before recovery with the distillation process.

The separation process starts with the principle of split by phase difference whereas a solvent distillation unit chemically separates solvents from wastewater through their application at high temperatures this process is described in **Figure 2**. Gas chromatography (GC) analysis was carried out in an industrial internal laboratory to determine the composition of the distillate.

Figure 1. The paint waste before distillation.

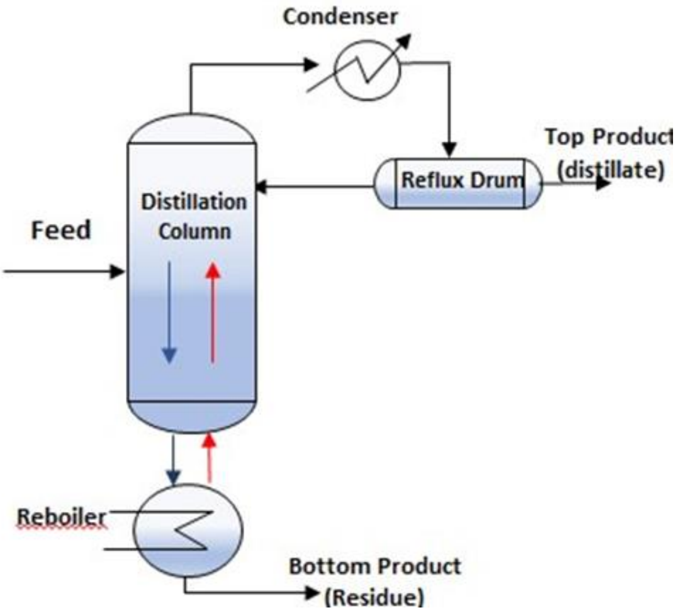

Figure 2. Batch distillation.

3. RESULTS AND DISCUSSION

Based on the research that has been conducted, the results of the research have obtained some data that show that the temperature in the distillation process affects several factors, including distillate flow rate, distillate volume, and percent recovery from the distillation process of solvent waste.

3.1. The Effect of Temperature on Flow Rate, Volume of Disstillate, and Percent of Recovery

Several tests were carried out to obtain test results or experiments with several variations, and the experimental results are shown in **Figure 3**, which shows the effect of temperature on distillation flow rates.

The higher the incoming temperature value, the higher the temperature distribution value, which results in a high heat transfer capacity value and produces a faster flow rate that flows better. This was observed in the highest temperature data of 160 °C, causing the flow rate to be 0.766 L/min. In addition to affecting the flow rate, temperature changes that increase the flow rate can affect the volume of distillate that comes out of the distillation process, as shown in **Figure 3** This explains the effect of temperature on the volume of distillate produced.

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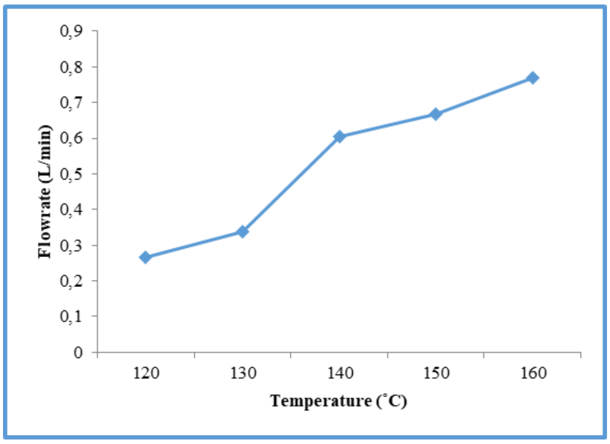

Figure 3. The effect of temperature on flow rate.

Figure 4 shows the effect of temperature on increasing the volume of distillate, it can be observed that in this study the largest temperature of 160°C can increase the volume of distillate by 19.91 liters from 30 liters of solvent waste. The effect of temperature on the distillate volume is highly dependent on the specific conditions of the distillation process. It can influence the rate of vaporization, separation of components, and overall efficiency of distillation. To optimize the distillation process, it is essential to carefully control and monitor the temperature while considering other factors, such as pressure and the properties of the substances being distilled. Temperature also influences solvent recovery. This is shown in **Figure 5**, which indicates that the percentage of solvent recovered for both solvents ranged from 65.57% to 66.37%, with an average recovery of 66.01%.

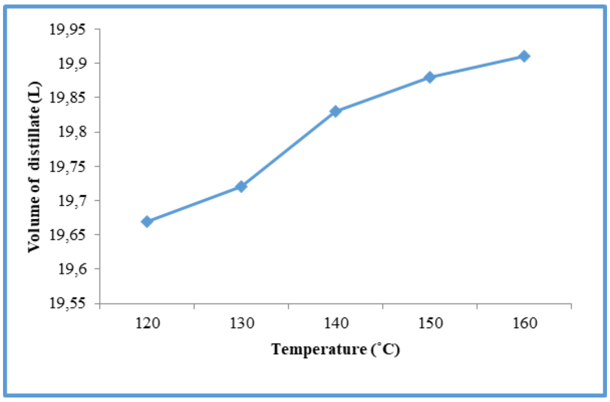

Figure 4. The effect of temperature on the volume of distillate.

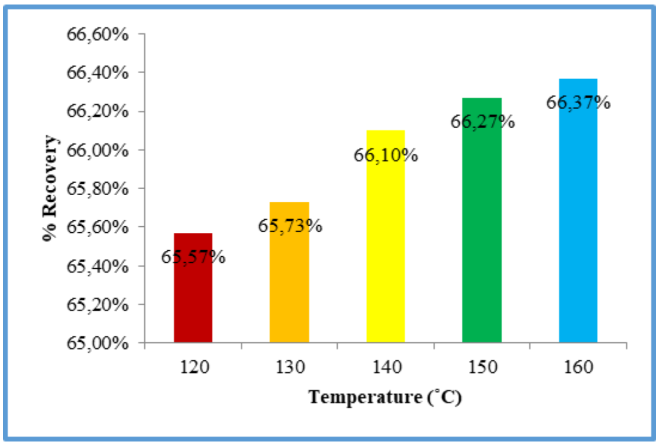

Figure 5. The effect of temperature on solvent recovery.

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Each component of the mixture had a specific boiling point. By controlling the temperature, the desired solvent could be selectively evaporated from the mixture. **Figure 5** also shows that a higher temperature range (120oC – 160°C) was required. This is because the waste solvent is first filtered to remove most of the semisolids, which affects the distillation temperature. In addition, naphtha solvents have a high boiling point. Therefore, it is expected to be distilled at higher temperatures for extended periods. At temperatures below the boiling point, the solvent does not evaporate, and no recovery occurs. At temperatures significantly above the boiling point, other components may start evaporating, leading to reduced selectivity and potential contamination of the recovered solvent.

Figure 6(a) shows the top product of the distillation process. This refers to the vapor being converted back into a liquid after being separated from the original solvent. On the other hand, in **Figure 6(b)**, the residue in the distillation column usually consists of the heaviest component which has the highest boiling point.

In a comprehensive study by Indarti and Soeswanto (2012), solvent recovery methodologies specifically tailored to the paint industry were explored. They focused on the separation of organic solvents from impurities by using an evaporation technique. The process involved a rotary evaporator with a feed capacity of 1,000 ml. The experimental conditions were controlled by varying the operating temperature and pressure. Laboratory findings indicated that at an operating temperature of 130°C and a pressure setting of 700 mbar, the solvent produced had a mass composition of 50.51% ethylbenzene, 8.79% butyl acetate, and 7.81% o-xylene. This produced 178 ml of solvent, accounting for a recovery rate of 71.2% relative to the total feed volume. In contrast, process simulation deduced the ideal temperature for evaporation to fall between 135°C and 143°C, with an optimal pressure of 1 absolute bar. Dursun and Sengul (2006) contributed to this body of research by investigating waste minimization techniques for solvent-based paint factories. Their key proposition for waste reduction is pivotal for technological advancement within the factory. The integration of a distillation unit can yield solvent recoveries of up to 70% from wastewater (Retno Indarti, 2012).

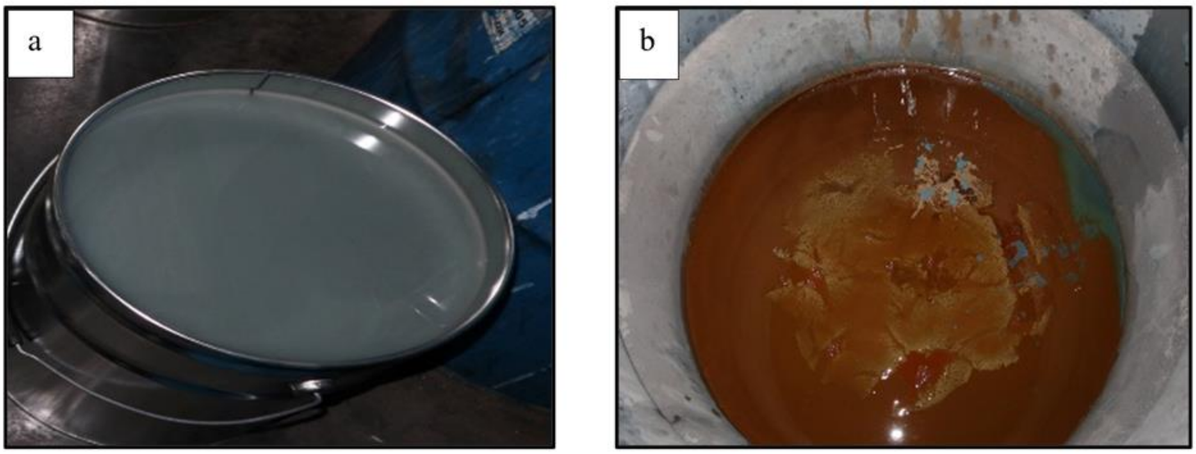

Figure 6. (a) Solvent after recovery (b) residue.

3.2. Identification of Sample Peaks by Gas Chromatography Analysis

Each solvent waste sample (samples 1, 2, 3, 4, 5, and pure naphtha blank) that passed the sample preparation stage was analyzed by Gas Chromatography (GC). The results of GC analysis showed that each sample contained naphtha.

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A blank sample of pure naphtha with a concentration of 90% was used for the GC analysis. The blank sample had a retention time (rt) of 3.730 min with an intensity of 367.337 in that time range, and the source of the contaminant could be determined through comparison and observation of rt and the peak area of 5.74 (%). Samples 1–5 exhibited retention times and naphtha compounds that matched the blank solution. One example of the clue is in samples 1 to 5 with retention times of 3.744, 3.735, 3.753, 3.744, and 3.743 minutes at intensities of 179.352, 929.125, 929.416, 138.407, and 166.78 with peak areas of Peak areas of 6.11%, 6.11%, 6.06%, 6.17%, 5.83% respectively, there are similarities with the naphtha blank solution (see **Figure 7**).

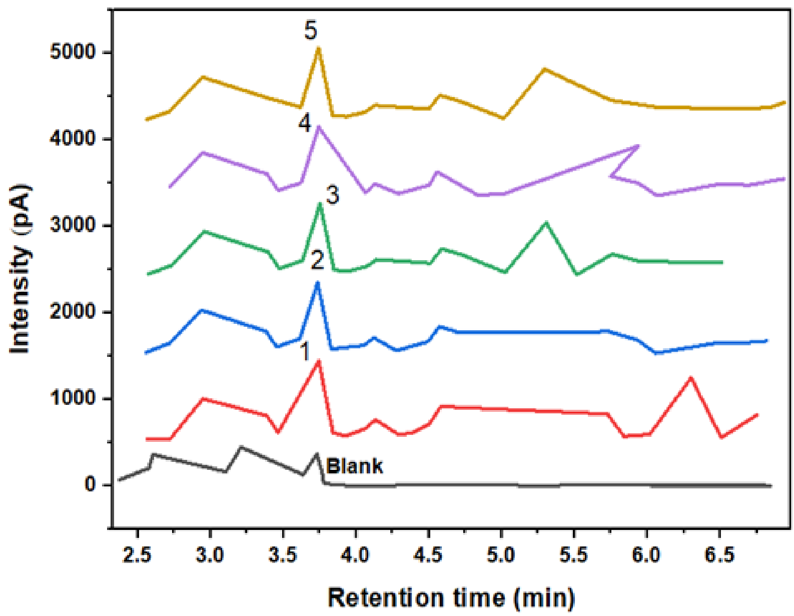

Figure 7. Chromatogram sample.

4. CONCLUSION

Solvent recovery from industrial paint waste using batch distillation is a crucial topic because it addresses both environmental and economic concerns. Solvents play a significant role in paint formulations, aiding the dispersion of pigments, promoting adhesion, and aiding in application. After use, particularly in industrial settings, significant volumes of waste paint-containing solvents are generated. Recovering these solvents is beneficial as it reduces the need to dispose of hazardous waste and also reduces the need to purchase new solvents. This research found that approximately 66.37 % of the solvent waste in the paint industry is recovered for use in manufacturing as a new material for the paint manufacturing process. The highest recovery is achieved at a temperature of 160oC which resulted in a percent recovery of 66.37%. Hazardous waste produced in the paint-manufacturing industry should be minimized for economic and environmental reasons. The modification of technologies in factories is one way to reduce the amount of waste. Based on this research we can resume the potential limitations and suggestions for the next research. The study might be limited to certain solvents found in industrial paint waste. Paint formulations can contain solvents, and the recovery efficiency can recover significantly from one solvent to another. The recovered solvent might still contain impurities or paint residues. While the study may have focused on recovery rates, it might not yet deeply explore the energy consumption and economic feasibility of the process. Further research on ensuring the quality of the recovered solvents, perhaps introducing additional purification steps post-distillation.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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