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Harnessing Wastewater for Sustainable Paint Production: A Paradigm Shift in Industrial Practices

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ABSTRACT

Paint wastewater poses significant environmental challenges due to its high content of paint residues, which can contaminate water bodies and harm aquatic life. This study investigated a sustainable approach for the recovery of paint from paint wastewater through advanced treatment methods. The research focused on the development and optimization of a novel filtration system utilizing environmentally friendly materials for efficient paint residue removal. The systems employed in the paint recovery involved the use of both physical and chemical processes targeting a cost-effective paint recovery. Additionally, the study explored the potential reuse of recovered paint residues in industrial applications, thus minimizing waste generation and promoting circular economy principles. The proposed approach offers a promising solution to mitigate the environmental impact of paint wastewater while promoting resource conservation and sustainable practices in the paint manufacturing industry. The research findings demonstrated the feasibility and effectiveness of paint recovery from paint wastewater through chemical treatment methods. This included coagulation-flocculation techniques to treat the paint wastewater and also using affordable chemicals to recover the paint as well as using tools and equipment to test for the qualities according to the standards. Further optimization and scale-up of the above coagulation-flocculation method hold promise for broader industrial applications and a greater impact on reducing paint waste and its associated environmental footprint. In conclusion, the proposed paint recovery approach offered a promising avenue for reducing waste generation, conserving resources, and minimizing environmental pollution associated with paint manufacturing and usage. This research contributed to advancing sustainable practices in the paint industry and underscores the importance of adopting circular economy principles for a greener future. Coagulation-flocculation is the most effective chemical treatment method for paint recovery from wastewater. This involved adding chemicals like polyaluminium chloride or polyaluminium sulfate to the wastewater to form reasonable sludge that was then used to recover the paint

Keywords: Restoration; Wastewater; Paint sludge; Coagulation-flocculation; Namanve industrial area

INTRODUCTION

The utilization of wastewater as a resource in paint production represents a paradigm shift in industrial practices, where environmental sustainability and resource efficiency are paramount [1, 2]. This sets the stage for exploring the innovative approach of harnessing wastewater as a raw material in the paint manufacturing process. In recent years, industries have increasingly recognized the need to adopt more sustainable practices to mitigate the environmental impact of their operations. Among these practices, the conversion of wastewater from a waste product to a valuable resource holds significant promise. Paint production, known for its reliance on water-intensive processes and generation of wastewater containing various chemicals, stands to benefit greatly from this transformative approach [3–5]. The concept of producing paint from wastewater challenges traditional notions of waste management by reframing wastewater as a potential feedstock rather than a disposal concern [6–8]. By repurposing wastewater as a raw material, paint manufacturers can not only reduce their environmental footprint but also enhance resource efficiency and contribute to the circular economy principles. Through a holistic examination of the production of paint from wastewater, this introduction aims to provide insights into the transformative potential of harnessing wastewater as a sustainable resource in the paint. Paint production generates considerable amounts of wastewater containing various chemicals, including solvents, heavy metals, and organic compounds. Improper disposal of paint waste can lead to water pollution, soil contamination, and adverse effects on aquatic life [1, 2, 9]. Environmental regulations impose stringent guidelines for the treatment and disposal of industrial wastewater, including paint waste. Compliance with these regulations is crucial to minimize the ecological footprint and avoid legal consequences [9–11]. Advances in wastewater treatment technologies offer promising avenues for the efficient removal and treatment of paint waste. Techniques such as chemical precipitation, membrane filtration, and biological treatment can effectively reduce the concentration of pollutants in wastewater. Paint waste contains valuable components that can be recovered and reused, promoting circular economy principles [12]. Recycling solvents, reclaiming metals, and repurposing pigments are viable strategies to minimize waste generation and conserve resources. The management of paint waste presents economic challenges for industries, including disposal costs, regulatory fines, and potential damage to brand reputation. Implementing sustainable practices not only mitigates these risks but also fosters long-term cost savings and operational efficiency [13, 14]. Despite the advancements in wastewater treatment technologies, there is still a need for tailored solutions to address the unique composition and challenges of paint waste. This project aims to fill this gap by exploring innovative approaches and optimizing existing methodologies for paint waste management [15]. By comprehensively addressing the background and significance of paint waste from wastewater, this project sets the stage for developing effective strategies to mitigate its environmental impact and promote sustainable industrial practices. Around 80% of paint industry effluents come from equipment rinsing, so after the treatment, effluent, which is now diluted paint, may be used in manufacturing processes as a component of low-cost paints, or as a coolant or dilatant [5, 16, 17]. Microbial infection is typical for water-based paints because they contain inorganic and organic materials. The microbial infection occurs during the manufacturing stages of paint production and storage. The changes in various kinds of physical and chemical properties, such as high temperatures and humidity, increase the possibility of microbial contamination in paint [17] Therefore, wastewater created during manufacturing can be highly contaminated with microorganisms. Wastewater generated during the cleaning of paint manufacturing equipment might be highly contaminated with not only organic compounds and pigments but also microorganisms [15]. Despite significant advancements in wastewater treatment technologies, the disposal of wastewater remains a pressing environmental challenge, particularly in industries with water-intensive processes such as paint manufacturing. The conventional approach of treating and discharging wastewater fails to address the underlying issue of resource depletion and environmental degradation. Moreover, the production of paint generates substantial quantities of wastewater containing various chemicals, posing significant risks to ecosystem and human health if not managed effectively. In light of these challenges, there is a critical need for innovative solutions that not only mitigate the environmental impact of paint but also leverage wastewater as a valuable resource.

MATERIALS AND METHODS

Equipment and Chemicals

The equipment used includes beakers, a nephelometric turbidity meter, aeration pumps, water pumps, a viscometer, a density cup, a paint dryer machine, and pH meter. Chemicals used include polyaluminium chloride, aluminum sulphate, sodium carbonate, potassium dichromate, and ferrous ammonium sulphate.

Preliminary Tests

The experiment carried out was adopted from GUO et al., [18, 19] with minor modifications.

In this procedure, different wastewater samples were used to get different results using different chemicals. Common chemicals used in the study included polyaluminium chloride brown, polyaluminium chloride yellow, and aluminium sulphate.

Experiment One

Sample One

In 500ml of beaker spatula end full of polyaluminium chloride brown was added to the sample forming 120ml of sludge in 1 hr. and 5 mins with clear water and no particles present

Sample Two

In 500ml of beaker, 3 spatula endful of polyaluminium chloride brown was added giving 130ml of sludge in 1hr and 15mins forming clear water with some particles.

Sample Three

In 500 ml of the beaker, 2.5 spatula endful of polyaluminium chloride yellow were added giving 200 ml of sludge in 1hr and 35 mins with dull or unclear water with some particles.

Sample Four

In 500ml of a beaker, 3 spatula end full of aluminium sulphate and 1.5 spatula endful of sodium carbonate produce 140ml of sludge in 2 hours with unclear water [18, 19]

Experiment Two

Sample one

In 500 ml of sample in the beaker, 3 spatula endful of polyaluminium chloride brown was added to give 170 ml of precipitate in 1hr and 15 mins with relatively clear water.

Sample two

In 500ml of sample, 4.5 spatula endful of polyaluminium chloride brown was added to give 145ml of precipitate in 47 mins with clear water

Sample Three

In 500ml of beaker, 2.5 spatula endfuls of polyaluminium chloride brown were added followed by 2 spatula endful of polyaluminium chloride yellow giving 150 ml of precipitate in 41 mins with clear water.

Dosing the Waste Water Tank

During the wastewater dosing using the coagulating chemicals, I used manual dosing because it was easy to monitor the amount of chemicals added. I added the chemicals (polyaluminium chloride, brown) in small proportions as I monitored the nature of the coagulation and flocculation.

A Brief Description of Paint Waste Water Treatment Process

Paint wastewater was first collected in a designated tank or pit to avoid spills and ensure easy handling. During the wastewater sampling and testing, a sample of wastewater was taken and tested with various chemicals to see which one coagulates better or undergoes flocculation faster and better. In the flocculation and coagulation was where a confirmed coagulating chemical polyaluminium chloride was added to the wastewater to form. Agglomerates. These agglomerated the fine particles and suspended solids forming larger flocs. In the sedimentation, the wastewater was allowed to settle in a sedimentation, tank, where the large flocs and particles settled to the bottom due to gravity, forming a sludge layer. [20]. The Oxidation process was carried out, for wastewater with persistent organic pollutants that were not easily biodegradable an aerator machine was used to blow in air into the waste water. The partially treated wastewater was passed through various filtration systems such as the press filter to remove the remaining suspended solids and smaller particles that escaped sedimentation. The sludge collected from sedimentation was dewatered and the resulting sludge cake was stored for paint recovery. Throughout the entire treatment process, regular monitoring is essential [21].

Testing For Parameters in Sludge and Restored Paint

This is done to meet the standards of waste treatment. I tested for parameters such as turbidity, COD, BOD, pH, total dissolved solids, and other parameters to ensure that both the recovered water and sludge meet the required standards.

Testing for BOD in wastewater

Procedure

Testing for BOD was adapted from [19] with minor modifications for efficient results.

Testing BOD (Biochemical Oxygen Demand) levels in paint wastewater involves several steps:

A representative sample of the paint wastewater was collected using appropriate sampling techniques to ensure accuracy. The collected sample was transferred to BOD in a container and sealed to prevent the entry of atmospheric oxygen. Microorganisms, typically bacteria from a seed culture, are added to the sample. These microorganisms consume the organic matter present in the wastewater, thereby reducing the dissolved oxygen concentration in the sample. Before incubation began the initial dissolved oxygen concentration in the sample was measured using a dissolved oxygen meter [22]. The sealed containers are placed in a temperature-controlled environment (usually around 20°C) for a specified incubation period, typically 5 days. At the end of the incubation period, the dissolved oxygen concentration in the sample is measured again using the dissolved oxygen meter.

Calculation: The BOD level is calculated using the formula:

BOD (mg/L) = (Initial DO - Final DO) * Dilution Factor / Sample Volume. (Massonnet & Muehlethaler, 2022).

Testing for COD

The procedure used for testing for COD was one suggested by Xu et al., [23]. With minor modifications. Briefly, clean, sterile containers were used to collect representative samples of the paint wastewater. The containers were properly labeled with sample identification details such as numbers. Necessary reagents for the COD analysis were prepared. This typically involved preparing a potassium dichromate solution and a silver sulfate catalyst solution. A known volume of the paint wastewater sample was transferred into a COD digestion flask. A prepared potassium dichromate solution and silver sulfate catalyst were added to the flask. The flask in a digestion apparatus was heated at 150°C for 2 hours. This step oxidized the organic matter in the sample, converting it into inorganic compounds. After digestion, the flask was allowed to cool to room temperature. Once cooled, the remaining dichromate in the solution was titrated with a standardized ferrous ammonium sulfate (FAS) solution.[23]. An appropriate indicator (commonly ferroin or diphenylamine sulfonic acid) was added to facilitate endpoint detection. Continuous titration was done until a color change occurred, indicating the endpoint of the reaction. The COD concentration in the paint wastewater sample was calculated using the volume and concentration of the FAS solution used in the titration. The volume of FAS solution used was converted to COD concentration using a standard formula.

COD (mg/L) = (A-B) ×F×8000/V×W

Where;

A = Initial volume of potassium dichromate solution (in mL)

B = Volume of potassium dichromate solution used in blank (in mL)

F = Factor for the volume of dichromate solution used (typically 0.25)

V = Volume of sample (in mL)

W = Weight of sample (in grams) (Rice & Baird, 2017)

Testing for Turbidity

The procedure adopted was according to Kiyemba Et al [24] with minor modifications. A representative sample of the paint wastewater was obtained from the treatment process, ensuring that the sample was well mixed to reflect the overall turbidity of the wastewater. A turbidity meter was used which was nephelometric turbidity meter (NTU meter). This instrument measured the scattering of light by particles in the water. A turbidity meter typically has a light source and a detector. The nephelometric turbidity meter (NTU meter) was calibrated according to the National water standards. This step ensured accurate readings. The sample chamber of the turbidity meter was filled with the wastewater sample. Make sure there are no air bubbles, as they could affect the accuracy of the readings. The turbidity reading was taken from the instrument. The unit of turbidity measurement was typically NTU (Nephelometric Turbidity Units). The turbidity reading was compared with regulatory standards or internal guidelines for wastewater treatment[24].

Sludge Storage

In this procedure, the sludge was removed from the treatment tank and then put in a porous bag to drain out the remaining water till the required level for reuse.

Paint Production Process

In this process, the paint components were analyzed that could be missing in the paint sludge according to the desired paint type. According to my interest, my emphasis was to make paint that has weatherguard components. 200g of the paint sludge was taken and put into a tin to start paint-making by adding specified amounts of the paint components. By doing this the lost paint components were restored and the sludge finally became paint [25]. The paint was made by the continuous stirring of the sludge with the added chemicals until all the chemicals were mixed. This mixing can be done manually or by using a mixer machine. Testing was carried out to ensure that the paint was ready for use. This included both chemical and physical testing.

Quality Control Tests for the Restored Paint

Drying Time

Drying time was tested according to the ISO 2811-1:2011 with minor modifications. A sample of paint was taken and applied onto a wall or a sheet of paper and left to be at room temperature or atmospheric temperature and left to stand while monitoring the time taken for the paint to dry efficiently.

pH

A pH pen was inserted into the paint sample and the readings were recorded.

Density

The paint density was measured according to the (ISO 2811-1:2011) standards with minor modifications. A sample of paint was taken and put into a density cup and sealed properly. The density cup was put on a weighing machine to record the mass of the paint. A formula was used to calculate the density of the paint

Density= mass÷volume (ISO 2811-1:2011).

Viscosity

The paint viscosity was tested according to ASTM D2196-20 with minor modifications. A wet sample of the paint was put in a sample cup. The sample cup containing paint was then placed below the rotating paddle of the viscometer. (ASTM D2196-20). The rotating paddle was then inserted into the paint, the read button was pressed and the reading displayed on the screen. This reading displayed the viscosity of the paint. The reading gave values in Krebs units.

Testing for Gloss

The gloss for the restored paint was tested with reference from van der root et al 2018 with minor modifications. A tri-Gloss meter was used to measure the gloss or sheen of the paint. Gloss is an important attribute of surface appearance and is defined as the luster or shininess of the paint. When a defined light source illuminated a surface, it was partly scattered and partly reflected at an equal but opposite angle. This specular reflection determined the surface gloss level. The intensity of the specula reflection, which depended on the material and the illumination angle, was measured under specified conditions. Results expressed in Gloss Units (GU) [26].

RESULTS

Testing parameters for treated wastewater as adopted by APHA (American Public Health Association) with minor modifications

Table 1: Shows the parameters obtained from wastewater.

pH	7.372 (National standards for wastewater is 6.0-8.0
BOD	33.45 mg/L (National standard for wastewater is 50 mg/L)
COD	95mg/L National standard for wastewater is 100mg/L)
Color (true)	35 TCU (National standard for wastewater is 300 TCU)
Turbidity	1.79 NTU (National standard for wastewater is 30 NTU)

Table 2 Chemical components added during paint making as adopted by (Rajan et al., 2019) with minor adjustments

Titanium dioxide	5g
Waterproof	10ml
Thickener (cellulosic derivatives)	3-4 drops
Binder (cellulosic polymer)	15 ml
Defoamer	7 ml
Acticide	20 ml
Water	50 ml
Pigments (various colors)	Few drops

Table 3 Results of tests on the restored paint ASTM D2196-20 with minor modifications

Drying time	15 minutes
Gloss	15 gloss units (10-35 gloss units, medium gloss)
Viscosity	0.5 KU(Krebs unit)
Density	1.5 (1.5-2.5 range according to company standards)
pH	7.372 (National standards for wastewater is 6.0-8.0)

DISCUSSION

The overall study indicated the possibility of restoring lost paint components in paint sludge and reformulating new paint. The wastewater treatment provided the need to test for the parameters in the water. As the pH was tested using the pH meter, the value was 7.372 indicating compliance according to the national wastewater standards (6.0-8.0). However, the test was also compliant with the WHO standards (6-9) [25]. In the process of carrying out the BOD test using the bacillus culture, the result showed a result of 33.45 mg/L as recommended by the National wastewater standards of 50 mg/L indicating that the results are within the acceptable range. However, the WHO standard is 60mg/L hence the test results still fall in the acceptable range [27]. The COD tested using a titration of potassium dichromate with ferroin indicator provided 95 mg/L of COD while the National wastewater standard is 100mg/L, the value of COD in the water indicated that a lot of chemicals were dissolved in the paint wastewater but did not exceed the required limits of discharge The tests carried out on the turbidity of the waste water indicated that 1.79 NTU (Nephelometric units) were obtained as the National waste water standards was is 30 NTU, showing that the treated water was pure in terms of color hence safe for discharge or reuse [9]. In the paint-making process, the chemicals added were to restore the lost paint components that enhance the weather guard paint type. The titanium dioxide that was added enhanced the paint coverage and hiding power by scattering and reflecting light, which would result in a more vibrant and durable finish. Additionally, titanium dioxide would help improve the paint's resistance to weathering and UV radiation [28]. The addition of waterproof (silicone) was to enhance the paint's resistance to water damage such as moisture penetration, swelling, and degradation over time [29]. At a later stage, a thickener (cellulosic derivative) was added to control the viscosity of the paint, help in preventing dripping of the paint during application as well as improving its flow properties and enhancing the overall performance of the coating. The thickener achieves this by increasing the viscosity of the paint. However careful adding was required (drops only) as much of it would destroy the paint quality [29]. For the paint's durability, an acticide was added in a reasonable quantity of 20ml to prevent the growth of microorganisms such as bacteria and fungi. These microorganisms can degrade paint causing odor, discoloration, and deterioration of the coating. The density of emulsion-based exterior paint typically ranges from 1.3 to 1.6 grams per cubic centimeter (g/cm^3), depending on the formulation and specific ingredients used. When the density of the paint was tested, it produced a density of 1.5 which is compliant with the global company standards. Pigments enhance the paint's desired color, they are mostly composed of inorganic substances such as iron, chromium, copper, nickel, and many others. During the paint making, the pigments were added dropwise as color matching was carried out to see if it was the desired color. These pigments cannot be added in excess quantities since they might disorganize the desired paint color hence careful addition was required [30].

CONCLUSION

The research findings demonstrated the feasibility and effectiveness of restoring lost paint components in paint wastewater and reformulating new paint through the chemical treatment method (coagulation-flocculation process). By implementing the chemical treatment method significant quantities of usable paint components can be recovered, contributing to environmental sustainability, resource conservation, and potential cost savings for paint manufacturers. Further optimization and scale-up of the above method hold promise for broader industrial applications and a greater impact on reducing paint waste and its associated environmental footprint. This study underscores the importance of further exploration and adoption of paint recovery technologies to mitigate environmental pollution and promote circular economy practices within the paint industry

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