INVESTIGATING THE POSSIBILITIES OF USING FLY ASH FOR "SURFACTANT REMEDIATION" IN WASTEWATER TREATMENT

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Abstract

The potential of fly ash is examined in this research, a byproduct of coal combustion, as an effecient adsorbent for removing anionic surfactants from wastewater. Given the critical role of wastewater treatment in public health and environmental sustainability, the study focuses on advanced methods to address surfactant pollution. Traditional treatment methods often fail to remove surfactants, leading to environmental hazards. Fly ash, rich in silica, alumina, and iron oxides, offers a cost-effective and sustainable solution. This research investigates the modification of fly ash using acidic solutions to improve its adsorption properties. The modified fly ash demonstrated a significant improvement in removing Sodium Lauryl Sulfate (SLS), reaching up to 98% adsorption efficiency from aqueous solutions. The study highlights the affect of pH, particle size, and retention time on the adsorption process. According to the findings, modified fly ash is a viable substitute for large-scale water treatment applications, contributing to a circular economy by repurposing industrial byproducts.

Keywords: Adsorption, Anionic, Surfactant, Fly Ash, Wastewater-Treatment.

1. Introduction

The treatment of wastewater is crucial to preserving public health and environmental sustainability, requiring intricate procedures to rid household, commercial, and agricultural water flows of pollutants [1]. This treatment typically comprises primary, secondary, and tertiary stages, each targeting different types of pollutants. Among the myriad challenges in wastewater treatment, the removal of surfactants—key components in household detergents, industrial cleaners, and personal hygiene products—stands out because to their widespread presence and environmental impact. Surfactants, particularly anionic surfactants such as linear alkylbenzene sulphonates (LAS) which reduce surface and interfacial tensions, can be toxic to aquatic organisms, disrupt oxygen transfer, and create foaming problems in treatment facilities [2].Their amphiphilic nature, characterized by both hydrophilic and hydrophobic properties, allows them to persist at interfaces and complicate biodegradation processes. The environmental implications of surfactants are profound, as even low concentrations can disrupt cellular functions in aquatic life and lead to persistent foams that hinder water aeration [3]. These compounds also contribute to the solubility of persistent organic pollutants, exacerbating water pollution. Consequently, understanding the fate, distribution, and persistence of surfactants—shaped by sorption and degradation processes influenced by environmental conditions—is crucial [4].

Innovative approaches to treating surfactant pollution are being investigated. Membrane filtration technologies, including ultrafiltration, reverse osmosis, microfiltration, and nanofiltration, have shown promise, particularly nanofiltration, although challenges like membrane fouling remain. Coagulationflocculation processes using chemicals like alum or ferric chloride have demonstrated high surfactant removal rates but come with operational complexities and sludge management issues. Emerging materials, such as fly ash—a byproduct of coal combustion—offer a cost-effective and sustainable solution for surfactant removal. Rich in silica, alumina, and iron oxides, fly ash is a powerful adsorbent for a variety of contaminants, such as heavy metals, dyes, and organic compounds, due to its large surface area and adsorption capability [5, 6]. Utilizing fly ash not only improves wastewater treatment but also promotes recycling industrial byproducts, contributing to a circular economy and reducing environmental pollution. This research paper explores these advanced methodologies and materials, particularly focusing on the potential of using fly ash, to improve surfactant removal in wastewater treatment and mitigate their environmental impact.

2. Literature

It has been demonstrated that traditional wastewater treatment techniques are inefficient at eliminating hazardous substances and surfactants from wastewater streams [7]. Surfactants, frequently used in household and industrial products, pose significant environmental concerns due to their recalcitrant nature and resistance to biodegradation. Consequently, they frequently flow through municipal wastewater treatment facilities before being released into open water. This discharge can result in foaming, interfere with oxygen transfer, and harm aquatic life [8] Additionally, certain transformation products, like sulphonyl carboxylic acids, nonylphenol ethoxylates, octyl phenol ethoxylates, and nonylphenol carboxylic acids, exhibit higher toxicity compared to their precursor compounds [9]

High concentrations of surfactants can disrupt aquatic ecosystems by altering the surface tension of water and affecting the behaviour of aquatic organisms. Certain surfactants pose health concerns to both humans and wildlife due to their toxicity to marine life and ability to bioaccumulate in the food chain [10, 11]. Furthermore, certain surfactants have endocrine-disrupting properties, which can impact the hormonal balance of aquatic organisms and potentially human health [8].Given these challenges, there is an urgent need for alternative, cost-effective, and environmentally friendly approaches to surfactant removal from wastewater. Compared to other functional categories of adsorbents, fly ash has a number of advantages, making it a superior choice for certain water treatment applications. Among the primary benefits is its abundance and cost-effectiveness, as it is a readily available byproduct of coal combustion, which reduces dependency on costly raw materials [12].

Fly ash has a high surface area and porous structure, which are important for effective adsorption, leading to the effective removal of a wide range of contaminants including dyes, heavy metals, and organic pollutants. Additionally, various functional groups present on its surface enhances its chemical reactivity, enabling it to form strong bonds with contaminants and improve removal efficiency [13]. Unlike some synthetic adsorbents that require complex manufacturing processes, fly ash can be used in its raw form or with minimal processing, further lowering operational costs. Its thermal and chemical stability ensures consistent performance under diverse environmental conditions, making it suitable for long-term use [14]. Moreover, utilizing fly ash for water treatment helps in waste management by repurposing industrial byproducts, contributing to environmental sustainability. These factors collectively make fly ash a versatile and economical alternative to traditional adsorbents in water purification processes.

3. Materials

The fly ash used in this study was sourced as a byproduct from a coal combustion power plant. Initial characterization of the fly ash included analysis of its physical properties including surface area, particle size distribution, and porosity [14]. Chemically, the fly ash composition was dominated by silica, alumina, and iron oxides, containing trace amounts of other elements [13].

The chemicals utilized for the modification of fly ash included sulfuric acid (H_2SO_4) and hydrochloric acid (HCl). Other reagents utilized in the study were Sodium Lauryl Sulfate (SLS) for the preparation of stock solutions, potassium chloride (KCl) and hydrochloric acid (HCl) for buffer preparation, sodium hydroxide (NaOH), chloroform, and Methylene Blue reagent. The equipment employed in the study included a magnetic stirrer for continuous stirring during adsorption experiments, a pH meter for monitoring and adjusting the pH of the solutions, a muffle furnace for drying modified fly ash, a vortex mixer for vigorous mixing during sample preparation, a colorimeter for measuring the concentration of surfactants, and a vacuum filtration setup for separating solid and liquid phases.

4. Methodology

Distilled water was used to dilute the stock solution to prepare surfactant solutions at various concentrations, using precise measurements to ensure accuracy. A calibration chart was developed using the Methylene Blue Active Substances (MBAS) method, involving standard solutions of known surfactant concentrations. A spectrophotometer was used to measure their absorbance, forming a calibration curve to determine unknown concentrations. For enhancing adsorption properties, fly ash was improved with H_2SO_4 and HCl to remove impurities and activate the surface.

The modified fly ash was then washed and dried. To test adsorption ability, different quantities of modified fly ash were mixed with surfactant solutions of known quantity. Using a magnetic stirrer, these mixtures were stirred for homogeneity and optimal contact. After stirring, to separate the solid fly ash from the mixture, a Buchner funnel was used to filter the mixtures, ensuring a clear filtrate. The absorbance of the filtrate was measured using the MBAS method, and surfactant concentrations were determined using the calibration chart. Finally, the data were analyzed to assess the effects of fly ash modification on adsorption. Trends and correlations between surfactant concentration, absorbance, and fly ash dosage were found, giving valuable information about the effictiveness of modified fly ash as an adsorbent for surfactant removal. The methodology is depicted in the Fig 4.1.

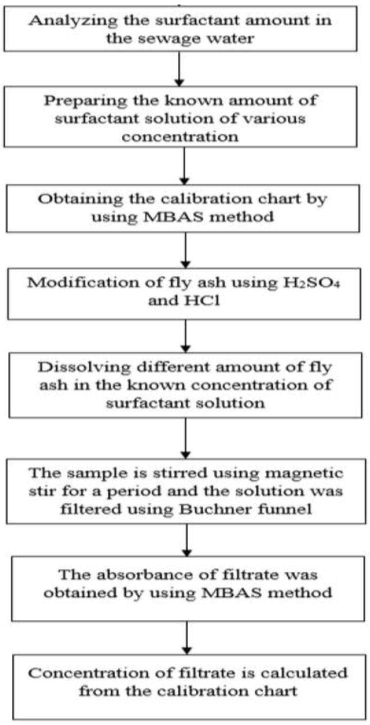

Fig 4.1: Flowchart of methodology

4.1 Modification of Fly ash

Modified Fly Ash: To modify the fly ash, a solution was prepared by mixing equal volumes of 1 mol/L H_2SO_4 and 1 mol/L HCl. 20 grams of fly ash was added to 200 ml of this solution, the mixture was then stirred for 2 hours to ensure thorough contact between the fly ash and the acids as shown in fig 4.2. This process aimed to increase the surface area and introduce functional groups that enhance the adsorption capacity. After stirring, using vacuum filtration the mixture was filtered to remove excess liquid as shown in figure 4.3, and the modified fly ash was dried in a muffle furnace at 230°C for 2 hours as shown in fig 4.4. The dried fly ash was then segregated to achieve a particle size range of 40 to 45 microns as shown in fig 4.5.

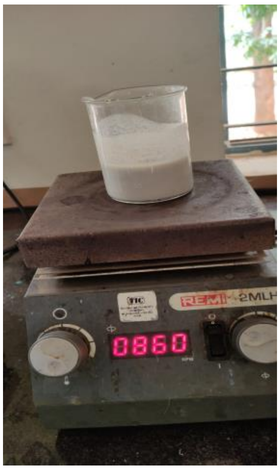

Fig 4.2: Agitation of fly ash with modifier solution

Fig 4.3: Vacuum filtration of modified fly ash

Fig 4.4: Drying in muffle furnace

Fig 4.5: screening of fly ash

4.2 Preparation of surfactant stock solution:

Stock SLS Solution: A stock solution of Sodium Lauryl Sulfate (SLS) was prepared by dissolving 50 mg of SLS in 500 ml of distilled water to create a 100-ppm solution. The stock solution was then diluted further for the preparation of solutions ranging from 10 to 100 ppm for calibration and testing.

Buffer Addition and Stirring: A buffer solution was prepared by dissolving 2 g of KCl in 1 ml of 35% HCl to maintain the pH around 4.

4.3 Adsorption studies

The set up included three conical flasks, each containing 50 ml of the stock SLS solution and 5 ml of the buffer solution. Different amounts of fly ash (0.5 g, 1 g, and 1.5 g) were added to the respective flasks. The flasks were stirred for 2 hours to ensure optimal interaction between the fly ash and the SLS solution as displayed in fig.4.6 After stirring, the mixtures were vacuum filtered, and the filtrate was collected for the purpose of analysis, as depicted in fig 4.8 and 4.9. The remaining SLS concentration was determined using a colorimeter and the MBAS method.

Fig 4.6: Flask containing stock solution and fly ash

Fig 4.7: Solution kept for stirring

Fig 4.8: Vacuum filtration

4.4 Procedure for Quantifying Anionic Surfactants (MBAS method)

5 cm³ sample solution was adjusted to an alkaline pH above 8.3 using NaOH, as showcased by the phenolphthalein endpoint turning pink. After neutralizing with H_2SO_4, 2 cm³ each of chloroform and Methylene Blue reagents were added, and the mixture was shaken vigorously by making use of a vortex mixer. The organic phase containing the surfactant complex was moved to a second test-tube, washed, and filtered through glass wool. The final volume was adjusted to 20 cm³ with chloroform and measured at 620 nm using a spectrophotometer. These detailed steps ensured the accurate preparation, modification, and analysis of fly ash for assessing its effectiveness in adsorbing surfactants from wastewater.

5. Results

A plot of a calibration curve was made for known concentrations of the stock SLS solution, ranging from 10 to 100 ppm, as shown in Fig 5.9. This curve was essential for determining the relationship between the SLS concentration and the absorbance measured using the MBAS method. The calibration curve served as a reference to identify the concentration of SLS in the samples after the adsorption experiments.

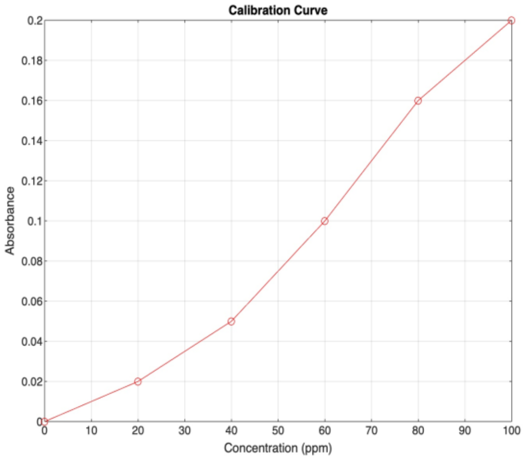

Fig 5.9: Calibration curve

5.1 Adsorption Efficiency of Unmodified Fly Ash

The initial experiments aimed to obtain the adsorption efficiency of unmodified fly ash in removing the anionic surfactant Sodium Lauryl Sulfate (SLS) from aqueous solutions. Test was carried for two different particle sizes: below 45 micron and 45-73 micron. The adsorption capacity was assessed by measuring the absorbance of the SLS solution with varying amounts of fly ash (0.5 g, 1.0 g, and 1.5 g). For the below 45 micron and 45-73-micron particle size, the absorbance values were recorded as shown in Fig 5.10.

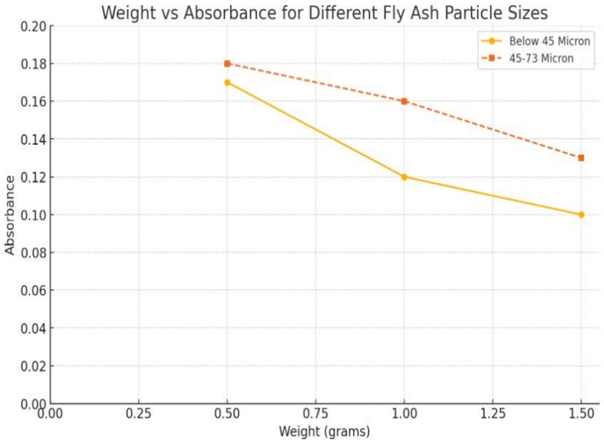

Fig 5.10: Absorbance of unmodified fly ash

These results show that unmodified fly ash had limited adsorption capacity for SLS, with the smaller particle size (below 45 micron) showing a marginally better adsorption performance compared to the larger particle size (45-73 micron). Despite this slight improvement, the overall efficiency was insufficient, necessitating further modification to enhance the fly ash's adsorption properties.

Modified Fly Ash:

To increase the adsorption efficiency, the fly ash was chemically modified using a mixture of Sulfuric Acid (H_2SO_4) and Hydrochloric Acid (HCl). In the trial 1 the capacity of adsorption was assessed by measuring the absorbance of the SLS solution after treating with fly ash of varying amounts (0.5 g, 1.0 g, and 1.5 g). The result is shown in Fig 5.11.

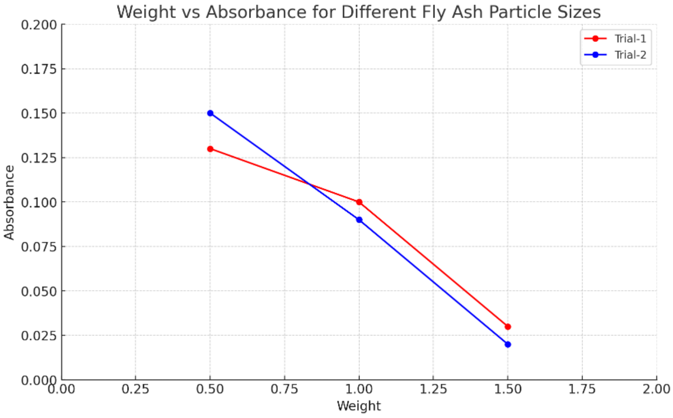

Fig 5.11: Absorbance of modified fly ash

Results showed a significant reduction in SLS concentration, with the modified fly ash removing 98% of the surfactant. The initial SLS concentration of 100 ppm was decreased to 2 ppm, indicating high adsorption efficiency. The same procedure and quantity of modified fly ash were used to validate the results in trial 2. The result is shown in Fig 4.11. Consistent with Trial 1, the final SLS concentration was again reduced to 2-4 ppm, confirming the reliability and effectiveness of the modified fly ash in adsorbing the surfactant. The absorbance values in both trials were significantly lesser than those observed with unmodified fly ash, demonstrating the enhanced adsorption capacity of the modified material.

5.2 Comparison of Unmodified and Modified Fly Ash

A comparison of the overall findings from the experiments revealed the differences between the adsorption capacities of unmodified and modified fly ash: Unmodified fly ash has limited adsorption capacity with marginally improved results for the smaller particle size (below 45 micron) compared to the larger particle size (45-73 micron). Modified fly ash has substantial improvement in adsorption properties, with 1.5 g of modified fly ash effectively removing 98% of the SLS from the solution. The modification process significantly enhanced the surface properties, enabling better interaction and adsorption of the surfactant molecules.

6. Conclusion:

The high adsorption rate of modified fly ash, reaching up to 98%, indicates its practical applicability in water treatment systems. This effectiveness shows that fly ash is a useful technique for combating water pollution since it can remove a variety of toxins from water effectively. Considering its quantity, affordability and enhanced performance when modified, fly ash is a highly promising adsorbent for large-scale water treatment applications. This study confirms that modified fly ash can significantly improve water quality, presenting a viable and economical solution for mitigating environmental pollution.

In conclusion, the study demonstrated that unmodified fly ash exhibits limited effectiveness in adsorbing anionic surfactants from water, with marginally better performance for smaller particles. The adsorption capacity of unmodified fly ash was insufficient, prompting the need for modification to enhance its performance. The modification of fly ash using sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) significantly improved its adsorption capacity. The most effective adsorption was achieved with 1.5 g of modified fly ash, successfully removing 98% of SLS from the solution. These findings underscore the potential of modified fly ash as a highly efficient and cost-effective adsorbent for water treatment applications. The achieved 98% surfactant adsorption rate suggests the efficacy of the proposed process for surfactant removal in water treatment. This high adsorption level suggests that fly ash can efficiently capture surfactants from water solutions. Thus, the process shows promise for practical application in water treatment systems aimed at mitigating surfactant contamination.

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