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Analysing the Composition and Behaviour of Manufacturing Industry Effluents

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Abstract: This study aims to find a suitable adsorbent for reducing the chemical content, specifically heavy metals like cadmium, in industrial effluent post-treatment. The project involves the identification and preparation of adsorbents, testing their efficacy through trial-and-error methods, and comparing results with and without the adsorbent. Orange peel and *Delonix regia* seeds were chosen as potential adsorbents. After preparation and activation, the adsorbents were tested with cadmium nitrate solutions, and their effectiveness was evaluated using UV spectrophotometer. The results indicate promising potential for both non-activated and activated adsorbents in reducing cadmium concentrations, laying the groundwork for further research into industrial wastewater treatment methods.

This study offers a significant resource for policymakers, industry professionals, and environmentalists by offering a comprehensive view of the effluents of the manufacturing industry. It serves as a catalyst for sustainable industrial practices and the preservation of natural ecosystems.

Key words: Manufacturing sector, industrial effluents, environmental sustainability, pollution control, effluent analysis, environmental impact, water pollution, environmental regulations, sustainability in industry.

Introduction

The identification and quantification of hazardous metals in environmental samples present considerable challenges due to their low concentrations and the presence of numerous interfering substances. Trace amounts of these metals are frequently difficult to detect using conventional testing techniques. To get over these restrictions and improve the accuracy of metal measurement in environmental samples, solid phase extraction (SPE) appears to be a viable method.

SPE works by simultaneously cleansing the sample of interfering substances and selectively isolating target metals from complicated sample matrices. A number of variables, such as the particular metals being targeted and the materials selected, affect how effective SPE is. Adsorption, ion exchange, and complexation are some of the mechanisms that underpin SPE's operation.

In the analysis of the effluent treatment data reveals a notable increase in cadmium ion concentration following the treatment process. Before treatment, the cadmium concentration stood at 0.015 mg/L, while post-treatment, it exhibited an increase to 0.034 mg/L. This unexpected rise in cadmium levels prompts a closer examination of the treatment methodology and its impact on heavy metal removal. Phase 1 findings have been established, and now in Phase 2, methods for reducing cadmium concentration are under discussion.

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Literature Survey

Effluent treatment in the manufacturing sector is crucial for environmental sustainability, with extensive literature offering insights into various technological approaches. Studies by Borea et al. (2017) and Groves (1983) explore methods like ultrasound-assisted membrane ultrafiltration and dynamic membrane technologies, aimed at enhancing treatment efficiency and promoting water reuse to reduce environmental impact. Research by Kamali et al. (2019a and 2019b) underscores the importance of sustainability in adopting membrane-based technologies and forward osmosis (FO) for effluent treatment, highlighting the technical, economic, and environmental dimensions of optimising membrane performance.

In the pulp and paper industry, significant advancements have been made towards sustainability and efficiency. Helble (1999) highlights the efficacy of combining ozonation with fixed-bed biofilm reactors. Studies by Kamali and Khodaparast (2015) emphasise integrated approaches using sequencing batch reactor (SBR) pre-treatment and Fenton oxidation for effective pollutant removal. The petrochemical, textile, and mining industries face unique challenges requiring tailored wastewater management approaches. Advanced membrane technologies like reverse osmosis (RO) have shown efficacy in addressing complex wastewater compositions, as noted by Rautenbach et al. (2000).

Additionally, Ahmad et al. (2019) advocate for sustainable solutions in dairy waste management, reviews heavy metal pollution mitigation through membrane ultrafiltration enhanced with ultrasound. Studies addressing various aspects of wastewater treatment include microplastic characterisation, biological treatment optimisation (Dadrasnia, 2017), and advancements in heavy metal removal (Barakat, 2010).

The Ramifications of Industrial Growth

Increasing industrial growth frequently results in higher effluent levels, which raises the risk of soil, air, and water pollution. Natural resources, animals, and ecosystems may suffer as a result. Workers and the surrounding communities may be at risk for health problems from effluents containing dangerous materials. To reduce health risks, it is essential to comprehend their makeup. Compliance with environmental laws and standards is necessary for industrial growth. Maintaining compliance and averting legal problems require effluent analysis. All things considered, examining the effluents of the manufacturing sector is essential to tackling the health, environmental, and regulatory issues raised by industrial expansion and advancing more sustainable and conscientious methods.

Crucial Effects on the Environment

Enhanced environmental stewardship in the manufacturing sector and targeted mitigation strategies are made possible by the identification of particular pollutants and their concentrations through effluent analysis.

Water bodies may become contaminated by chemicals, heavy metals, and other pollutants found in industrial effluents. Water sources are impacted, ecosystems are upset, and aquatic life is harmed by this pollution. Air pollution is caused by the release of gases and particulates into the atmosphere by certain manufacturing processes. Human health and air quality may suffer as a result of this and soil contamination can result from the seepage of wastewaters into the soil.

Sources of Industrial Effluents in Abundance

Petrochemical Industries

An important source of industrial effluents is the petrochemical sector. Several processes used in the manufacturing of petrochemical products, including plastics, chemicals, and fuels, result in the generation of effluents. Among the main sources of industrial effluents in the petrochemical sector are: Refineries, Chemical Synthesis, Cooling Water, Spills and Leaks. Because of the possible presence of hazardous chemicals, the possibility of contaminating soil and groundwater, and the significance of adhering to environmental regulations and standards, wastewater analysis is essential in the petrochemical industries. To reduce environmental damage, this analysis aids in the identification of pollutants, evaluation of their effects on the environment, and implementation of efficient treatment and mitigation strategies. Table 1 depicts the inference from literature survey.

Banana peels-The removal capacity depends on various factors such as the concentration of heavy metals, pH of the solution, contact time, and the surface area of the banana peel. It can remove approximately 60-90% of lead ions from water under optimal conditions. And up to 96% of cadmium ions.

Mango leaves-Mango leaves removal efficiencies range from 70% to 99% for different heavy metals.

Table 1: Inference from literature survey

S.No	*Author & Year*	*Adsorbent*	*Heavy metal*	*pH*	*Contact time*	*Dosage*	*Concentration*	*% removal (mg/g)*
1	Magdi Abdel Azzem, 2017	Mango leaves	Cd(II)	6	120min	0.5g	10mg/l	53.8%,
2	Fa Yuan Wang, 2010	Delonix regia biomass		2	60min	2.4	30ppm	4.4307 (mg/g)
3	Atefeh Abdolali, 2016	Bamboo charcoal	Cd(II)	7.15	480m	0.5g	20mg/l	40%
4	Prashant D Deshmukh, 2017	Combination of tea wastes, maple leaves and mandarin peels	Cd(II)	5.5	180min	5 g/L	50mg/l	31.73 (mg/g)
5	N. Azouaou, 2010	Banana peels	Cd(II)	7 & 8	120 min	0.5 g/100 ml	10ppm	5.91 (mg/g)
6	Muhammad Aqeel Ashraf 2012	Coffee grounds	Cd(II)	7	120 min.	9 g.	100mg/l	15.65 (mg/g)
7	Ponnusamy Senthil Kumar, 2012	Raphanus sativus peels biomass	Cd(II)	7	120 min.	0.1 g/30mL	100ppm	19.82 (mg/g)
8	Ch. Suresh, 2014	Sulfuric acid treated cashew nut shell	Cd(II)	5	30 min	1g/l	100ppm	436.7 (mg/g)
9	Asma Saeed, 2005	Wood apple shell	Cd(II)	5	5 to 70min	200mg.	10–1000mg /L	32.07 (mg/g)
20	Muhammad Aqeel Ashraf 2012	Papayawood	Cd(II)	5	60 min	0.97 mg/g	10 mg	94.90%
10	Alireza Saraeian, 2018	Raphanus sativus peels biomass	Cd(II)	7	120 min	0.1 g	10.0 mg/L	19.82 (mg/g)
11	Jasmin Shah, 2014	Sorghum x drummondii	Cd(II)	7.5	3 h	10 g /L	100±2 mg/ L	1.52 (mg/g)
12	A. Papandreou, 2007	Mulberry wood	Cd(II)	6	30min	0.1 g	5mg/L	403.73 (mg/g)
13	Janani R, 2022	Fired coal fly ash	Cd(II)	10	72 h		150 mg/L	18.98 (mg/g)

The Journal of Hazardous Materials Letters investigated the use of mango leaf-derived biochar for the removal of chromium (Cr) from water and reported a removal efficiency of over 90%.

Bamboo charcoal- A study published in the Journal of Hazardous Materials reported that bamboo charcoal exhibited high adsorption capacity for heavy metals like Pb, Cd, and Cu, with removal efficiencies ranging from 80% to 99% under optimal conditions.

Coffee grounds- A study published in the Journal of Hazardous Materials reported that Coffee grounds exhibited high adsorption capacity for heavy metals like Pb, Cd, and Cu, with removal efficiencies ranging from 20% to 50% under optimal conditions.

***Raphanus sativus* peels biomass-**The removal capacity depends on various factors such as the concentration of heavy metals, pH of the solution, contact time, and the surface area of the *Raphanus sativus* peels. It can remove approximately 60-80% of lead ions from water under optimal conditions.

Wood apple shell-Studies have reported varying percentages of cadmium removal ranging from 50% to over 90% using wood apple shell as an adsorbent.

Methods

In this study, the selection of orange peel and *Delonix regia* seeds as adsorbents was based on several key factors, including their natural abundance, cost-effectiveness, and reported adsorption potential for heavy metal removal. Orange peel is a byproduct of the fruit industry, making it an easily accessible and low-cost material, while *Delonix regia* seeds are abundant in tropical regions, further reducing the economic burden of procurement. Both materials have been identified as effective biosorbents due to their high surface area and the presence of functional groups that facilitate metal ion binding. In comparison to established solutions such as activated carbon, which is widely used but often costly, these biosorbents offer a more sustainable and affordable alternative. Although activated carbon has higher adsorption capacity and is commercially available in various forms, the environmental benefits and scalability of using these biodegradable, waste-derived adsorbents make them promising solutions for cadmium removal in industrial effluents. This comparative analysis underscores the potential of orange peel and *Delonix regia* seeds as viable alternatives for metal adsorption, particularly in resource-limited settings.

For chemical activation, specific reagents were employed, and the materials were subjected to controlled conditions to optimise their adsorption capabilities. Thermal activation involves heating the adsorbents at designated temperatures for a predetermined duration to enhance their porosity and surface area. These comprehensive descriptions of the preparation and activation processes provide clarity on the methods used and facilitate reproducibility in future studies.

Chemical Pretreatment on Adsorbents

Orange peel, a common agricultural waste product, has been extensively studied for its adsorption capabilities. It contains various functional groups such as hydroxyl, carboxyl, and carbonyl, which can effectively adsorb heavy metals like cadmium from wastewater. The porous structure of orange peel provides a large surface area for adsorption, enhancing its efficiency. Additionally, being biodegradable, it offers an eco-friendly solution for wastewater treatment. The preparation process outlined, including sun-drying, grinding, washing, and sieving, ensures that the orange peel is properly treated and optimised for adsorption.

Delonix regia seeds, commonly known as flamboyant or flame tree seeds, also exhibit promising adsorption properties. These seeds contain compounds like tannins and lignin, which contribute to their adsorption capacity. Tannins are polyphenolic compounds known for their affinity towards heavy metals, making *Delonix regia* seeds effective adsorbents. Similar to orange peel, the preparation process involves sun-drying, grinding, washing, and sieving to enhance its adsorption efficiency. Moreover, *Delonix regia* seeds are readily available and cost-effective, making them a viable option for industrial wastewater treatment.

The adsorbent chosen for this study is a combination of Orange Peel and *Delonix regia* seeds. These materials were selected based on their potential to effectively adsorb heavy metals and other pollutants present in industrial wastewater.

The selected materials are subjected to a sun-drying process for seven days. This step aims to remove moisture content from the adsorbent, enhancing its adsorption capabilities and ensuring stability during subsequent processing. The dried materials are finely ground to produce a powder with increased surface area, promoting better adsorption efficiency.

This step ensures the stability of the adsorbent and removes any remaining moisture, preventing potential interference with the adsorption process. Finally, the prepared adsorbent is sieved to obtain a uniform particle size. This step ensures consistency in the application and allows for better control over the adsorption process during the experimental phase.

The basic parameters such as pH, contact time, Dosage and concentration are chosen based on the literature references. The average values for all the papers are taken and used as parameters for the experimental part.

Chemical Activation

Distilled Water Wash

The process of distilling the wash serves the purpose of eliminating any remaining base and acid particles that might be lingering within the adsorbent. Following this, the adsorbent undergoes a thorough washing to ensure complete removal of any traces. Figure 1 depicts Dry orange peel, Figure 2 depicts the Delonix regia seeds and Figure 3 depicts the Oven dried adsorbent samples.

Base Wash

Following the completion of the wash with distilled water, introduce a 0.5M solution of sodium hydroxide into the vessel. Combine this base solution with the adsorbents for a duration of 10 minutes, after which allow the mixture to settle undisturbed for a period of 2 hours.

Figure 1: Dry orange peel.

Figure 2: *Delonix regia* seeds.

Acid Wash

In a beaker, place 1kg of adsorbent material. Dilute 20 ml of concentrated sulphuric acid (H_2SO_4) in 2 L of distilled water to prepare the acid solution. Exercise caution to prevent any contamination of the adsorbent with ash particles. Gently stir the adsorbent mixture for 10 minutes while wearing protective gloves. Allow the beaker to sit undisturbed for a period of 24 hours.

Preparation of Synthetic Solution

Following the activation of the adsorbents, a synthetic solution of cadmium nitrate was meticulously prepared in distilled water to help prepare a synthetic solution of cadmium with a concentration of 0.034 mg/L. Transfer the weight into a dry, clean 1-liter volumetric flask after weighing it using an analytical balance. Add enough distilled water to completely dissolve the cadmium nitrate, agitating or swirling until no solid is left behind. Then, make sure that the distilled water is thoroughly mixed by filling the volumetric flask to the indicated 1-L mark. Grab a tiny aliquot, weigh it, and figure out the concentration to confirm the produced solution's strength. If necessary, dilute or concentrate the solution to change the concentration

Experimental Result

General

Water samples were collected from the [Petrochemical Company] site both before and after the treatment process. To guarantee representative samples, strict sampling procedures were used. The concentrations of the designated chemical parameters were then

Figure 3: Oven dried adsorbent samples.

determined by subjecting the collected samples to laboratory analysis. The focus was on assessing key chemical parameters, including pH, oil and grease, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), as well as the presence of heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As).

Heavy Metals Analysis (Pb, Cd, Hg, As)

Method: Various (e.g., Atomic Absorption Spectroscopy - AAS, Inductively Coupled Plasma Mass Spectrometry - ICP-MS)

Procedure: Use specialised equipment to detect and quantify the concentrations of heavy metals in the water sample. The choice of method depends on the specific heavy metal being analysed.

Experimental Comparison

The effluent treatment has demonstrated significant improvements in various chemical characteristics. The reduction in oil and grease, biological oxygen demand, chemical oxygen demand, and total suspended solids indicates an effective treatment process. The heavy metals, though initially within acceptable limits, have either been maintained or further reduced after treatment, ensuring compliance with environmental standards. Monitoring of pH levels post-treatment is recommended for a comprehensive assessment of the effluent quality. Figure 4 depicts comparison of un-treated vs treated effluent characteristics.

Also, the analysis of the effluent treatment data reveals a notable increase in cadmium ion concentration

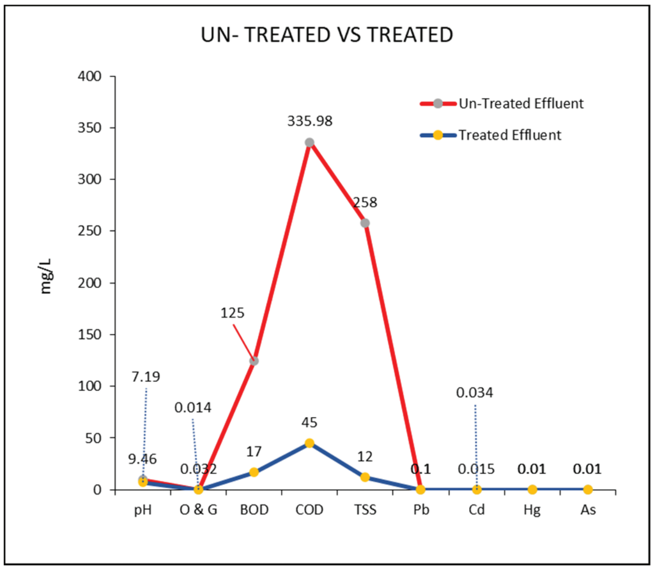

Figure 4: Comparison of un-treated vs treated effluent characteristics.

following the treatment process. Before treatment, the cadmium concentration stood at 0.015 mg/L, while post-treatment, it exhibited an increase to 0.034 mg/L.

In response to this increase, a thorough evaluation of the treatment methods, such as assessing the efficiency of precipitation or adsorption techniques employed for cadmium removal, is imperative. Additionally, measures to prevent potential sources of cadmium contamination within the treatment system should be implemented.

Analysis and Discussion

UV spectrophotometry was employed to measure the transmittance values of the stock solution samples, establishing a correlation between cadmium concentration and transmittance. Calibration curves derived from these measurements served as essential tools for quantifying cadmium concentrations in experimental samples based on their transmittance values.

Raw Adsorbent

In batch experiments, untreated synthetic solution samples were compared with treated samples containing non-activated DR and OP adsorbents. Analysis revealed that both adsorbents exhibited some degree of cadmium removal, albeit with varying efficiencies. The transmittance values obtained from the UV spectrophotometer indicated a reduction in cadmium concentrations in treated samples compared to untreated samples. However, the efficacy of non-activated DR was relatively lower compared to non-activated OP, as evidenced by the higher transmittance values observed in OP-treated samples. Figure 5 depicts standardisation of cadmium stock solution.

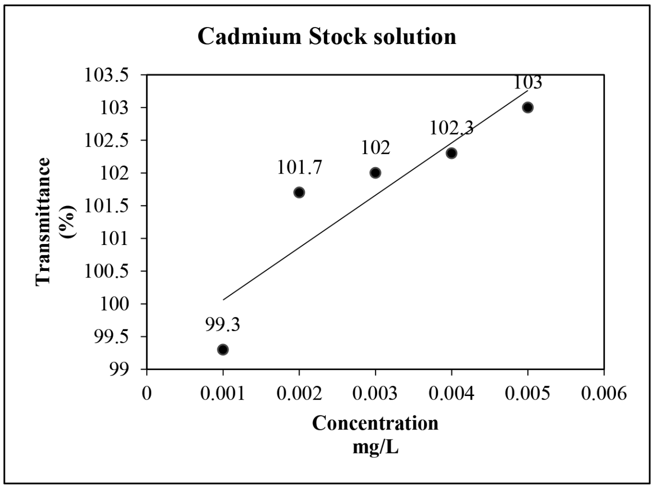

Figure 5: Standardisation of cadmium stock solution.

Chemically Activated Adsorbent

Activated forms of Delonix Regia Powder (DRP) and Orange Peel Powder (OPP) were meticulously prepared and evaluated for their effectiveness in reducing cadmium concentrations in industrial wastewater. Activation processes, including acid and base washes followed by oven drying, were employed to enhance the adsorption capabilities of both adsorbents. Figure 6 depicts percentage removal of cadmium concentration.

Batch experiments were conducted, comparing untreated industrial wastewater samples with treated samples containing activated DRP and OPP adsorbents. The analysis revealed significant improvements in cadmium removal efficiency compared to non-activated counterparts.

The observed superior performance of activated DRP and OPP underscores the significance of activation in enhancing the adsorption capabilities of natural adsorbents. Further optimisation and refinement of activation processes could potentially enhance adsorption efficiency even further.

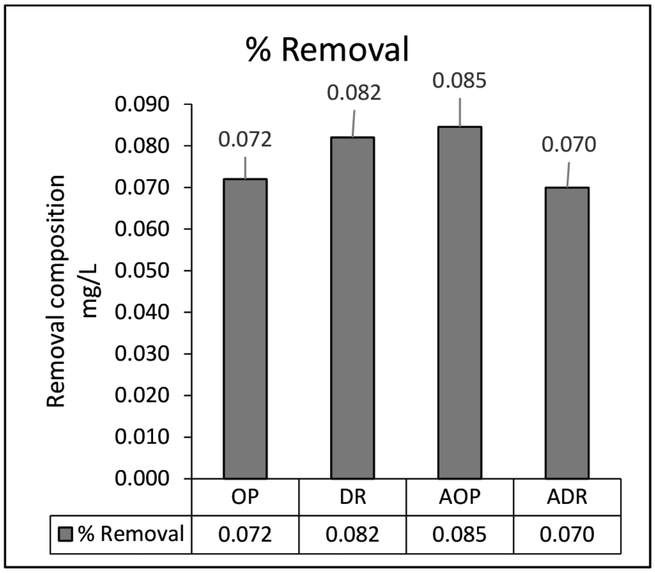

Figure 6: Percentage removal of cadmium concentration.

Result

The purpose of this experimental study was to identify an appropriate adsorbent for reducing the chemical content of industrial wastewater, with a specific focus on cadmium. The investigation yielded significant insights into the effectiveness of Orange Peel (OP) and *Delonix regia* (DR) seeds as prospective adsorbents through a systematic methodology that included adsorbent manufacturing, batch adsorption trials, and analytical analysis. A thorough examination of the experimental outcomes and their implications highlights the research's relevance in addressing environmental pollution issues and developing sustainable wastewater treatment methods.

Twelve samples were prepared using both activated and non-activated Orange Peel and *Delonix regia* seeds for the batch adsorption studies. Under controlled conditions, cadmium nitrate solutions were applied to these samples, and UV spectrophotometry was utilised to measure transmittance values, which served as indicators of cadmium concentrations in the treated samples. The observed cadmium removal efficiencies were minimal, with 7.2% removal for raw Orange Peel, 8.2% for raw *Delonix regia*, 8.5% for activated Orange Peel, and 7% for activated *Delonix regia*. These results underscore the importance of activation in enhancing adsorption efficiency, yet they also indicate the need for further investigation into alternative adsorbents.

The inclusion of environmental impact assessments and considerations for the long-term sustainability of the adsorbents used is crucial for enhancing the relevance of this research to policymakers and industry stakeholders. This study evaluates the ecological consequences of utilising organic adsorbents, such as Orange Peel and *Delonix regia* seeds, focusing on their lifecycle, including sourcing, preparation, and disposal, to ensure that their application does not adversely affect ecosystems. Additionally, discussions on the biodegradability, potential for regeneration, and overall ecological footprint of these adsorbents compared to conventional options like activated carbon are essential. Emphasising sustainable practices, such as sourcing these materials from agricultural waste, aligns with circular economy principles and highlights the potential for effective cadmium removal while minimising environmental harm. By addressing these aspects, this research demonstrates not only the efficacy of the proposed adsorbents but also positions itself as a valuable resource for advancing responsible wastewater treatment methodologies that meet the growing demand for sustainable solutions in industrial applications.

Conclusion

The results of the experiment show that different adsorbents have differing levels of cadmium removal effectiveness; activated Orange Peel (OP) showed the highest efficacy at 8.5%, followed by raw Delonix Regia (DR) at 8.2%. For activated DR, however, the efficiency dropped to 7%. More research into OP and DR activation techniques is advised in order to maximise the process and increase the materials' adsorption capabilities. Research comparing various activation methods for both adsorbents can shed light on which strategy works best. Finding ways to combine OP and DR to maximise their synergistic effects could result in even better eradication efficiencies. Furthermore, in order to evaluate the viability of industrial applications, scale-up studies are essential. Sustainability will be ensured by assessing the regenerability and reusability of activated adsorbents and by carrying out an environmental impact assessment. By putting these suggestions into practice, the initiative can help remove cadmium from industrial wastewater more successfully, advancing both environmental preservation and human well-being.

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