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Hydrosense: A Hair-Based Absorption System for Heavy Metal Removal from Wastewater

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ABSTRACT: This study explores the utilization of human hair as a biosorbent for the removal of heavy metals from wastewater, addressing critical ecological and health risks. We developed a filtration device named "Hydrosense," which employs both untreated and chemically treated human hair to evaluate its adsorption capacities in simulated wastewater environments. The primary objectives were to determine the efficacy of human hair in removing heavy metals and to compare its performance with conventional industrial methods. Experimental results indicated that chemically treated hair significantly enhances the adsorption of heavy metals, achieving removal efficiencies comparable to existing treatments. This research underscores the potential of human hair as an efficient, cost-effective, and sustainable material for wastewater treatment applications.

KEYWORDS: wastewater treatment, heavy metal removal, biosorbent, human hair, adsorption

1. INTRODUCTION

The global community contends with the profound repercussions of wastewater contamination. Heavy metal presence constitutes a significant hazard to ecosystems and the health of human populations [1]. These toxic substances infiltrate the body through diverse pathways, instigating a range of health complications. Acute exposure may induce symptoms such as headaches and nausea, whereas chronic accumulation heightens the risk of severe disorders like cerebral palsy and potentially results in mortality. Furthermore, wastewater pollution is linked to millions of annual deaths worldwide and adversely affects the health of approximately one billion individuals [2].

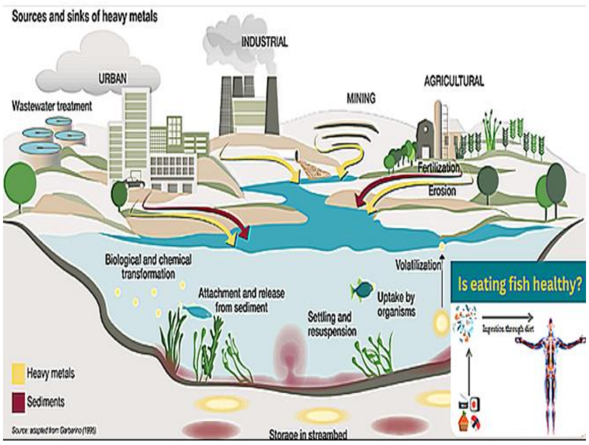


Figure 1. The sources of heavy metal pollution and the impact on the environment and humans

Inadequate wastewater treatment in Thailand systems from a vast number of factories operating outside regulated industrial zones. According to the Department of Industrial Works, 94% of the country's 77,400 factories [3-4] fall into this category, with 92% being small-scale facilities lacking centralized treatment systems. Prohibitive costs and limited effectiveness in heavy metal removal create major obstacles for smaller businesses, leaving them ill-equipped to address this pollution concern. Compounding the problem is the lack of awareness and sustainable practices at the local level. In Bangkok, a researcher's observations highlighted the widespread issue of hair being discarded by barber shops, representing a missed opportunity for potential reuse or proper disposal.

Consequently, the investigation focused on identifying solutions addressing both heavy metal and hair discarding problem. The structural properties of hair revealed a potential for heavy metal sequestration from wastewater, specifically due to its constituent protein, keratin [5]. As a fibrous protein, keratin possesses an abundance of cysteine, an amino acid bearing a thiol (-SH) group. This thiol functionality acts as the primary binding site for heavy metals within the keratin structure. Additionally, amino (-NH2) and carboxyl (-COOH) groups contribute to metal adsorption, albeit to a lesser degree [6].

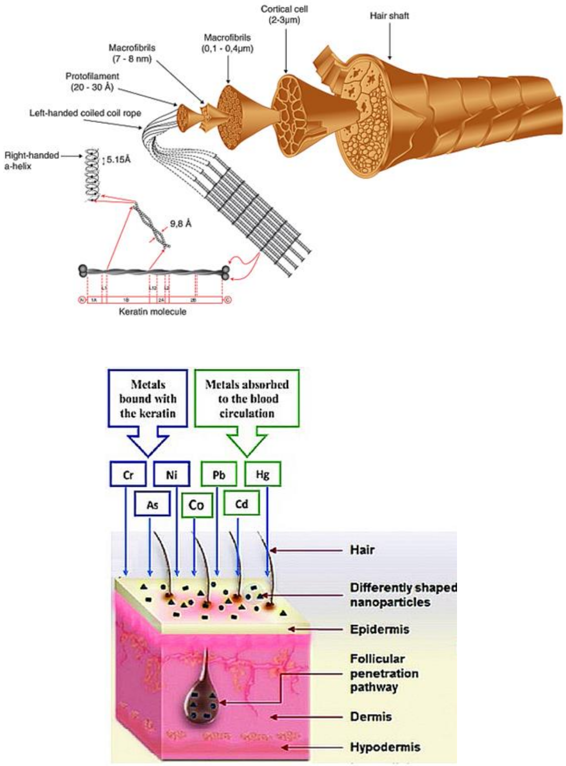


Figure 2. Mechanism of heavy metal absorption within hair structure [9]

Additional research explored the biosorptive capacity of both untreated and chemically treated human hair within a multi-metal system [7]. Experiments were conducted with a 0.1 mmol/L initial metal ion concentration, 24-hour contact time, pH of 4.0, and a 0.1 g biosorbent to 10 ml solution ratio. To enhance adsorption, a subset of hair samples was treated with hydrogen peroxide in an acidic medium, targeting the disulfide bonds in keratin. Results demonstrated significant uptake of cadmium (Cd), copper (Cu), and lead (Pb) – heavy metals frequently encountered in industrial wastewater [8]. Fourier-transform infrared spectroscopy (FT-IR) was employed to measure these capacities, substantiating keratin's potential as a heavy metal adsorbent. So, this information suggests that hair has the potential to capture heavy metals.

In our device, human hair was strategically selected as the filter material for intercepting heavy metals within wastewater. A specialized coating was applied to boost the device's adsorption capacity. The focus on user-friendliness is evident in the device's streamlined design for installation and upkeep. The integrated filter cartridge and cover system safeguards against hair loss while maximizing heavy metal removal. Findings substantiate the hair-based filter's efficiency, matching that of prevalent industry methods, and establish the framework for future expansion of this technology into the industrial sector.

2. OBJECTIVE (PURPOSE)

1.To develop a heavy metal adsorbent in wastewater using hair:

While sedimentation tanks are common for heavy metal removal in wastewater, their cost and limited efficiency highlight a need for alternative solutions. Despite research demonstrating the potential of hair as a biosorbent [7], no devices currently utilize this approach. This research proposes the development of a cost-effective, hair-based device tailored for integration into industrial wastewater systems.

2. To study the efficiency of heavy metal adsorption in wastewater using the device:

The device investigates the potential of treated hair, a readily available biomaterial, as a sustainable filtration medium for heavy metal adsorption in wastewater. The aim of this research is to determine the effectiveness of hair in binding specific heavy metals.

Hypothesis

Human hair can be developed into an effective heavy metal adsorbent for wastewater, and its absorption capacity can be further enhanced through specific chemical treatments or modifications.

3. METHODS AND MATERIALS

3.1 Hair Treatment and SEM Characterization

3.1.1 Gathering and Preparing Hair Samples

Hair samples were gathered from local barbershops in Bangkok's Bang Khae District. These samples, which came from a variety of individuals, were then prepared for the experiment. This preparation involved washing the hair with a standard laboratory detergent, rinsing it multiple times with deionized water to remove any contaminants, and allowing it to dry at room temperature (22 ±1 °C). Once dried, the hair samples were cut into small pieces of about 1-2 mm in length using scissors.

3.1.2 Chemical Treatment of Hair Samples

A portion of the hair samples underwent a chemical treatment process to enhance their adsorption capacity for heavy metals. This process involved weighing 20.0 g of untreated hair and soaking it in 400 mL of a pretreatment reagent (10% H2O2) with an adjusted pH of 9. After a specific duration (5 hours), the solution was filtered to separate the hair. The hair samples were then washed multiple times with deionized water to remove any remaining reagents. To reduce the loss of treated hair during this process, the hair was separated from the washing water using centrifugation, and the liquid was then decanted. Finally, the treated and cleaned hair samples were allowed to dry at room temperature.

3.1.3 Preparation of a Heavy Metal Solution

A multi-metal solution was prepared for the adsorption experiment. This solution contained several heavy metal ions, such as Cr (III), Mn (II), Ni (II), Co (II), Cu (II), Zn (II), Cd (II), and Pb (II). These ions were created by dissolving the nitric salts of each metal in deionized water. A 1000 ppm stock solution was first prepared and diluted to achieve the desired initial heavy metal concentration for each experiment. The pH of the solution was adjusted as needed by adding sodium hydroxide and nitric acid.

3.1.4 Adsorption Experiment

The adsorption experiment was conducted by adding 0.1 g of biosorbent (either untreated or chemically treated hair) to 10 ml of the heavy metal solution. The mixture was gently stirred and left in contact for 24 hours at a pH of 4.0. This provided enough time for the heavy metals to bind to the hair samples.

3.1.5 SEM Analysis of Hair Samples

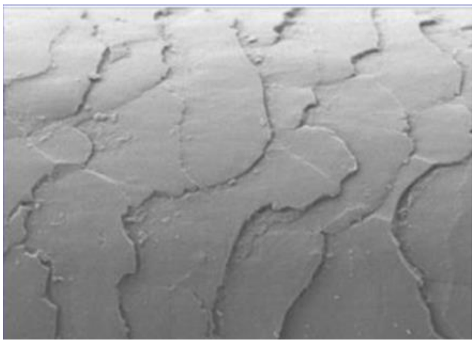


Figure 3. High-resolution SEM micrograph of hair surface (10 µm magnification) [7]

Scanning electron microscopy (SEM) was used to examine the morphological changes in hair samples before and after adsorption. This involved preparing the hair samples for SEM analysis, which may have included drying and mounting them on an appropriate holder. The SEM images provided valuable information about the surface characteristics of the hair samples and how they changed as a result of heavy metal adsorption. Comparing SEM images of untreated and treated hair samples helped visually confirm the adsorption of heavy metals on the hair.

3.2 Device Development and Design

3.2.1 Components and Specifications

The Arduino Uno R3 (microcontroller) : functions as the central controller in this system, interfacing with the TDS sensor and transmitting data to a computer for monitoring purposes which show the quality water.

Figure 4. Arduino Uno R3 [10]

A TDS sensor (Total Dissolved Solids sensor): measures the concentration of dissolved solids in water, expressed in parts per million (ppm). Since heavy metals contribute to the total dissolved solids in water, a TDS sensor can provide an indirect indication of potential heavy metal contamination.

Figure 5. Analog TDS sensor module water solubility conductivity SEN0244

3.2.2. Device Structure and Material

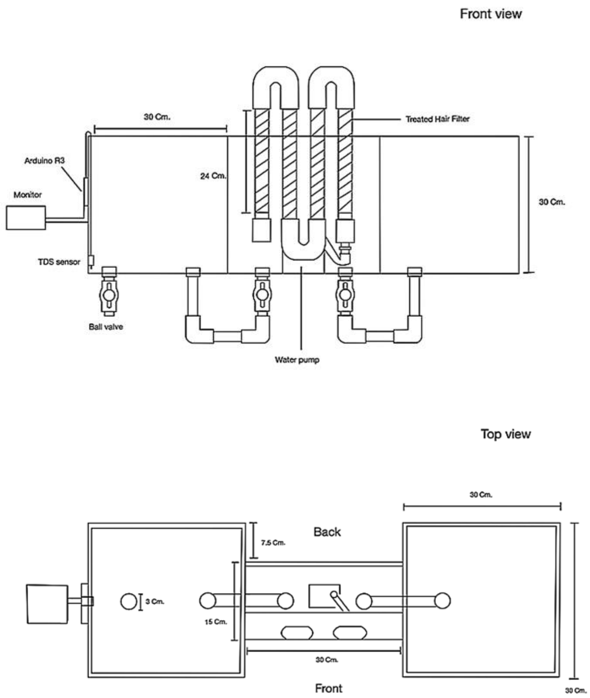


Figure 6. The device drawing in front view and top view

The device utilizes a tripartite acrylic chamber system for heavy metal filtration simulation. Wastewater contaminated with heavy metals is held in the initial compartment (30x30x30 cm). The central chamber (30x15x30 cm) functions as the filtration unit, containing an acrylic tube packed with 120 grams of treated hair. This tube interfaces with a U-shaped PETG pipe. A modified cap, containing cotton wool, prevents treated hair from exiting the filter and provides an inlet port for a water pump. Filtered water accumulates in the final compartment (30x30x30 cm). This final compartment is equipped with a ball valve for controlled release and a TDS sensor for quantifying the efficacy of heavy metal removal. This could illustrate the filtration of waste water system in factory.

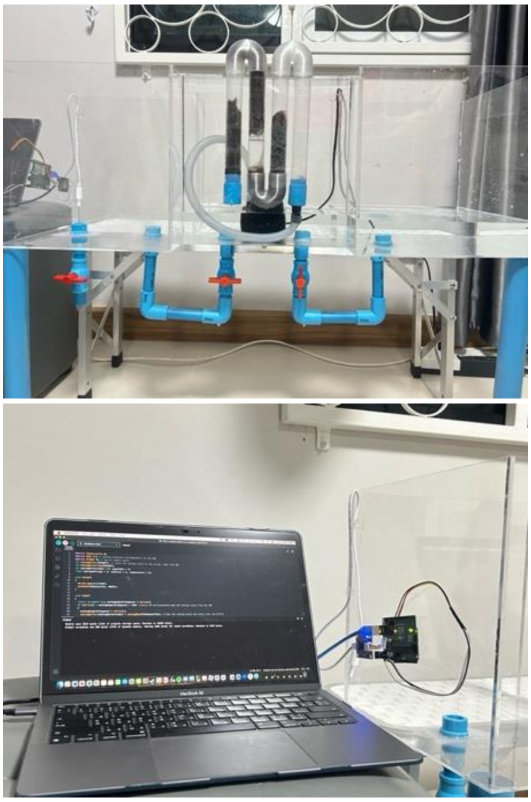


Figure 7. The picture of chamber part and monitoring part

Figure 8. Overview picture of the device

3.3 Device Operating System

3.3.1 Wastewater treatment system

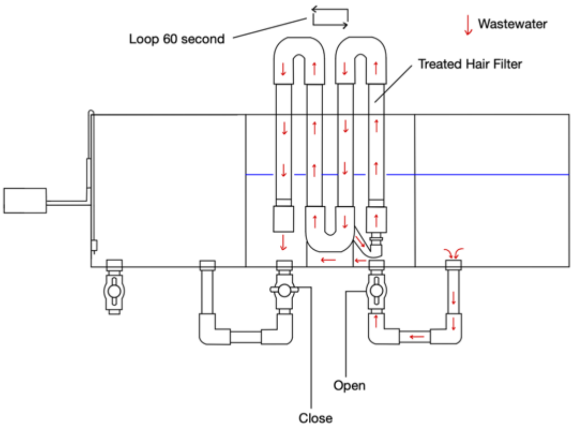


Figure 9. Diagram illustrating wastewater filtration cycle in the treated hair device.

The process initiates with the introduction of heavy metal-contaminated wastewater into the rightmost chamber. Opening the first ball valve allows wastewater to flow via underlying piping into the central filtration chamber. The water pump then circulates the wastewater through the treated hair filter tubes. Filtered effluent exits via the final tube. Once water levels equalize between the two chambers, the system maintains this cycle for 60 seconds to optimize heavy metal capture by the hair filter (all of this process will open only the first ball valve on the right).

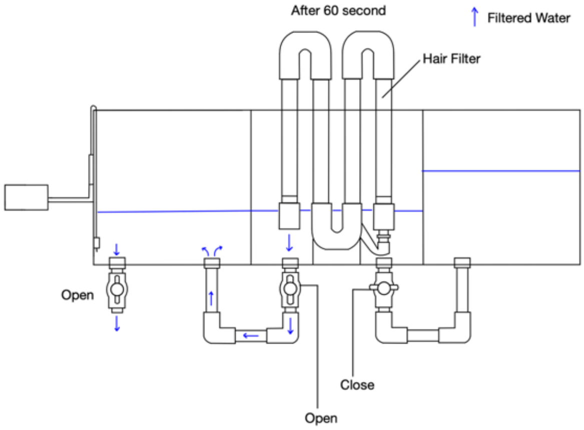


Figure 10. Diagram illustrating the filtered water quality assessment and release process.

After the 60-second filtration cycle, the first ball valve is closed, and the second ball valve is opened. This redirects filtered water to the final chamber. In this chamber, a TDS sensor monitors the remaining heavy metal concentration (in ppm) prior to release. The final ball valve controls the release of treated water from the system .

4. RESULTS

4.1 Adsorption Capacity

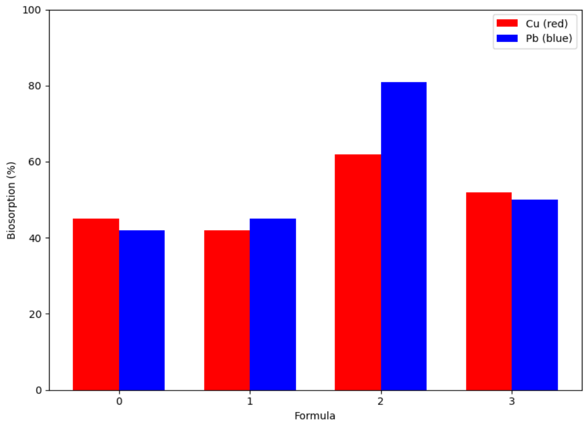
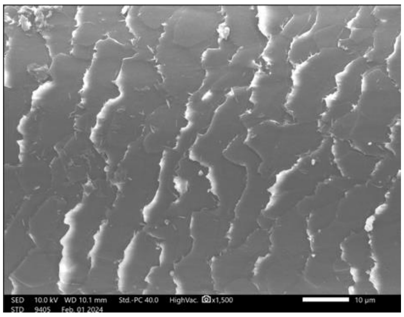


Figure 11. Compares hair absorption between treated hair (various formulas) and untreated hair (formula 0). Experimental conditions: 0.1 mmol/L metal ions, 24 h contact time, pH 4.0, 0.1 g biosorbent in 10 mL solution by using UV-Vis spectroscopy.

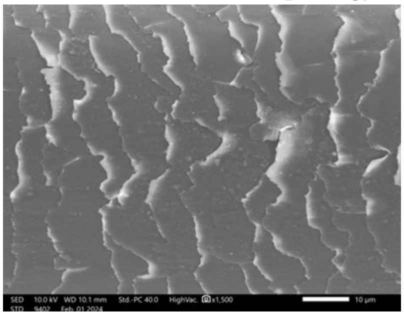
The adsorption experiment indicated that both untreated and chemically treated hair absorb significant amounts of heavy metals. Untreated hair absorbed 42% copper (Cu), and 40% lead (Pb). Notably, chemically treated hair had superior adsorption, removing 63% of Cu and 81% of Pb in formula 2. These findings support keratin's efficacy as a heavy metal adsorbent in formula 2 which each formula contain different concentration of EDTA.

4.2 SEM Analysis

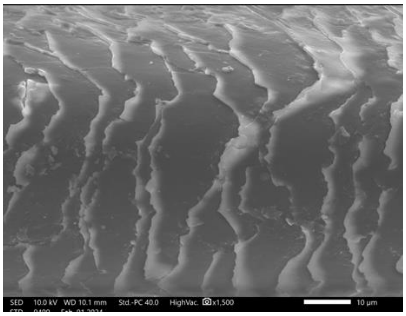
The SEM analysis revealed significant changes in the surface morphology of the hair samples following the adsorption process. The images revealed an increase in surface roughness, indicating that heavy metals were successfully adsorbing onto hair samples. A visual comparison of SEM images from untreated and treated hair samples confirmed heavy metal adsorption.



Control hair: SEM image of untreated hair showing the baseline surface morphology.



Hair after 50 cycles of absorption: SEM image displaying increased surface roughness and heavy metal adsorption after 50 absorption cycles.



Hair after 60 cycles of absorption: SEM image illustrating further increased surface roughness and continued heavy metal adsorption after 60 absorption cycles.

Figure 12. Scanning electron microscopy (SEM) images showing the surface morphology changes in hair samples due to heavy metal adsorption.

4.3 Device Efficiency

The device, which uses human hair as a filter material, was found to be effective at removing heavy metals from wastewater. The device's adsorption capacity was increased by applying a specialized coating to the hair. The integrated filter cartridge and cover system was effective in preventing hair loss and maximizing heavy metal removal. The efficiency of the hair-based filter was comparable to that of commonly used industry methods, laying the groundwork for the technology's future industrial applications.

5. Discussion

The results of this study indicate that human hair, both untreated and chemically treated, has significant potential as a biosorbent for heavy metals in wastewater. The adsorption capacities observed for copper (Cu), and lead (Pb) were particularly noteworthy, with chemically treated hair exhibiting superior adsorption compared to untreated hair. This supports the hypothesis that the structural properties of hair, specifically the presence of keratin and its constituent amino acid cysteine, can facilitate heavy metal sequestration.

These findings align with existing theories and published data on the use of biosorbents for heavy metal removal. The use of biosorbents has been widely studied due to their cost-effectiveness, availability, and environmental friendliness. The results of this study contribute to the growing body of evidence supporting the use of biosorbents, and specifically human hair, in addressing the global issue of heavy metal contamination in wastewater.

However, like any experimental study, there were potential sources of error and unexpected issues. Variability in the data could have arisen from differences in the hair samples, such as variations in hair type, age, and chemical treatment. Additionally, uncontrolled events such as changes in ambient temperature or pH could have affected the results. Future studies should aim to control for these variables to ensure more consistent and reliable results.

In terms of future research directions, this study opens up several avenues. Further research could explore the use of different types of hair (e.g., animal hair) or different chemical treatments to enhance adsorption capacity. Additionally, scaling up the experiment to test the effectiveness of hair as a biosorbent in real-world wastewater treatment scenarios would be a valuable next step. The development of user-friendly devices like Hydrosense, which integrate hair-based filters for heavy metal removal, also presents exciting opportunities for practical application of this research.

In conclusion, this study provides a promising starting point for the use of human hair as a biosorbent in wastewater treatment. With further research and development, this could become a viable solution to the pressing issue of heavy metal contamination, benefiting communities worldwide.

6. CONCLUSION

This study demonstrates that human hair is an effective material for removing heavy metals from wastewater. Chemically treated hair removed even more heavy metals than untreated hair. This research supports the idea that hair, particularly the protein keratin it contains, can bind with heavy metals. These findings suggest that hair, a plentiful and often discarded resource, could be used in cost-effective and environmentally friendly filters for wastewater treatment. This has led to the development of the "Hydrosense" device as a practical example of how hair-based filters can be used to address the problem of heavy metal contamination in researcher area.

7. ACKNOWLEDGMENT

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