Hong Kong Student Science Project Competition 2023

Template of Extended Abstract (Investigation Design Proposal)
(Word Limit: 1,600 words, Pages: 3 pages only)

Team Number: JBBC131

Project Title: Biosorption of heavy metal ions from wastewater using keratinous biomaterials

Project Type: Investigation

***To our best knowledge, there are similar works in the field*; (if there are,) related research links are as below:**

https://www.hindawi.com/journals/ast/2022/7384924/
https://www.tdx.cat/bitstream/handle/10803/284239/hz1de1.pdf
https://dr.ntu.edu.sg/bitstream/10356/142466/2/Human%20hair%20keratin%20and%20its%20interaction%20with%20metal%20ions%20.pdf

The enhancement our project proposed / the difference with related research are:

Separation of chicken feathers into the vane and calamus for more specific data relating to biosorption factors, use of human nails as a potential biosorbent

Please delete if not applicable. The competition values the originality of works. Students must do enough literature research to ensure that their works are unique and list relevant reference materials before starting research or invention.

I. Background

- Provide background information of project and/or state the problem to tackle
- Provide highlights of the **literature review** with the support of pertinent and reliable references
- Provide an overview of work and mention the **research gap that the project is trying to fill**

Heavy metal ions are defined as the metals with the highest atomic masses, greater than 6g per cm^3, such as mercury, zinc, or cadmium. Heavy metal contamination are serious contributors to water pollution, due to their toxicity, tendency to bioaccumulate, and non-degradability. The effects of heavy metal ion exposure to humans encompass reduced growth and development, cancer, organ and cell damage, and death. The cumulation of heavy metals can be attributed directly to human industrial activities as a byproduct of industrial waste.

Biosorption stands out as a sustainable and inexpensive method of reducing metal contamination. Biosorption, a subcategory of adsorption, is the binding of ions from aqueous solutions to the surface of a biomass[1]. Keratinous biomaterials, i.e. nails, hair, feathers, etc., are particularly abundant, produced naturally by humans and livestock in daily life, accounting for over 4 million tons of waste annually worldwide[19]. They also show high capacities for adsorption due to their high contents of hydroxyl, carboxyl, and sulfhydryl groups, and are thus the main topic of interest in this report.

II. Objective(s)

- State the **aim(s)** of project

The aim of this project is as follows:

- To investigate the adsorption capacities of keratinous materials
- To investigate relationship between adsorption capacities and cysteine content

- To discover the best commonly available keratinous biomaterial to be used for biosorption of aqueous heavy metal ions

III. Hypothesis

□ Propose an explanation for a phenomenon and stating how the **hypothesis** can be **tested** by experiment

Keratinous biomaterials contain high amounts of the amino acid cysteine, a semi-essential amino acid that is mainly responsible for the binding of metal ions through chelation in the body. Cysteine thiolates are primary binding site for heavy metal ions such as $Fe^{2+/3+}$, Zn^{2+}, or Cu^{+}.[8] Moreover, the sulfhydryl group shows a high affinity for heavy metals such as cadmium, and has proved to be effective in mobilizing cadmium in treatment for cadmium toxicity[17].

Biosorption capacity relies on 2 main elements under our conditions.

1. Factors that affect adsorption, i.e. surface area/nature of adsorbent
2. Cysteine content of biomaterial

With our understanding of these 2 elements, our hypothesis goes as follows:

The best biosorbent will most likely be the chicken feather vane. While feather vane exhibits the lowest cysteine content in comparison to other keratinous biomaterials, representing about 5% of all amino acids in the feather[15], it has the advantage of being a nano-porous and intrinsic keratinous fiber[14], as well as having a large surface area in comparison to other biomaterials, all of which greatly increase its adsorption capacity.

Following the feather vane, sheep wool will likely take 2nd place. Although having lower cysteine content than human nails, being composed of 95% pure keratin, 11-17% of which is cysteine[17], it has a far superior adsorption surface and has been proved to be an effective biosorbent. Protein fibers on wool surface have polar and ionisable groups on the side chain of cysteine residues, which can strongly bind metal ions[16].

After sheep wool, human hair is expected to be the next best adsorbent. The composition of human hair is extremely similar to sheep wool, sharing a 95% keratin composition and cysteine quantities of around 10-18%[20]. While having a lower cysteine content than nails, we speculate human hair will display a better adsorption capacity due to its porous cortex.

Nails are built mainly of keratins, having the highest cysteine composition at up to 22%. This alone pushes it ahead of feather calamus, which shares its cysteine ratio with the feather vane, as neither have outstanding characteristics that would affect adsorption.

IV. Methodology

- List out the materials to be used
- Describe the **experimental protocol** including the set-up of **control experiment** (if any), **repeated experiment** (if any), and its scientific theory
- Indicate with the support of reasons, the **analysis** to be used in the investigation

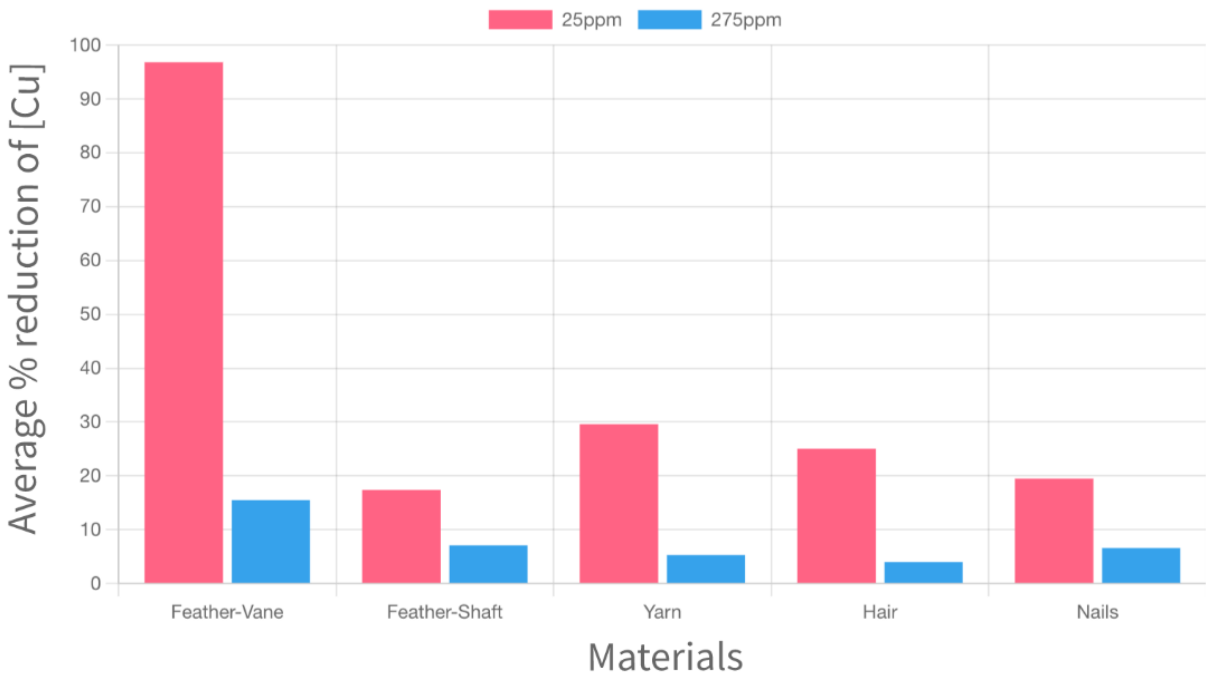
Materials used:

- Keratinous biomaterial samples (4.5g);
  - Chicken feather vane
  - Chicken feather calamus
  - Human hair
  - Sheep wool
  - Human nails
- Cu (II) Heavy metal ion solution (720ml)
  - Copper (II) sulphate solution **($CuSO_4$)**
  - Copper (II) chloride solution **($CuCl_2$)**

1. Prepare 40ml Cu (II) solution samples of varying concentrations by adding distilled water to copper sulphate solution using a measuring cylinder and burette
2. Prepare 4.5 grams of each biomaterial sample by maximizing surface area by processing into small pieces and use of scale
3. Separate biomaterial samples into 9 0.5g samples using a scale
4. Add 3 of each biomaterial sample into 40mg/L concentration copper solution (repeats for reliability), as well as one without (control), in boiling tubes
5. Place boiling tubes into orbital shaker for 1 hour
6. Take out from orbital shaker
7. Separate solution from keratinous biomaterials with use of syringe-driven filter unit (0.22 um) into separate labeled boiling tubes
8. Place boiling tubes in ICP-OES for processing
9. Remove boiling tubes and receive results for processing
10. Repeat with other concentrations

- Describe the **expected results** with the selected approach
- Discuss **limitation** and compare with existing related works (if any)
- Discuss the importance or impact of the research and how it is applicable to real problems

	Replicate						Averages of % reduction of Cu (only 25ppm & 275ppm, 1dp)
	1		2		3		
	FINAL [Cu] (mg/L)	% reduction of [Cu]	FINAL [Cu] (mg/L)	% reduction of [Cu]	FINAL [Cu] (mg/L)	% reduction of [Cu]	
25 ppm control=34.975 mg/L							
25 ppm feather vane	0.134	99.6	31.440	10.1	2.084	94.0	96.8%
25 ppm feather shaft	30.117	13.9	29.502	15.6	27.025	22.7	17.4%
25 ppm yarn	24.127	31.0	25.116	28.2	24.614	29.6	29.6%
25 ppm hair	26.249	24.9	26.154	25.2	33.706	3.6	25.05%
25 ppm nail	28.161	19.5	-	-	-	-	19.5%
150 ppm control=147.000 mg/L							
150 ppm feather vane	130.099	11.5	130.538	11.2	144.794	1.5	N/A
150 ppm feather shaft	147.824	-0.6	148.419	-1.0	146.117	0.6	N/A
150 ppm yarn	139.782	4.9	135.593	7.8	139.634	5.0	N/A
150 ppm hair	157.875	-7.4	156.362	-6.4	155.526	-5.8	N/A
150 ppm nail	137.194	6.7	-	-	-	-	N/A
275 ppm control=257.400 mg/L							
275 ppm feather vane	219.222	14.7	214.496	16.5	217.943	15.2	15.5%
275 ppm feather shaft	239.990	6.6	235.744	8.3	240.748	6.3	7.1%
275 ppm yarn	244.782	4.8	242.648	5.6	242.845	5.5	5.3%
275 ppm hair	242.572	5.6	247.418	3.7	249.798	2.8	4.0%
275 ppm nail	240.1177	6.6	-	-	-	-	6.6%



All biosorbents successfully reduced the concentration of copper, with chicken feather vane vastly outstripping the competition, at both high concentrations and low concentrations of copper. What was surprising was by how much feather vanes outperformed other biomaterials, performing 327.027% better than the runner-up, the sheep yarn. Also surprising was the performance of chicken feather calamus in 275ppm copper solution, as it was expected to perform poorly in comparison to others, instead being the runner-up to chicken feather vanes.

150ppm trial results were ignored due to an technical error that occurred with the orbital shaker, changing the time the materials spent in the solution.
Anomalies found in the 25ppm results were ignored. This is mostly likely because we initially centrifuged these 2 samples in an attempt to separate the biomaterials from the heavy metal solution.

Notably, our results differ heavily from similar studies. In a study done by Helen Zhang[16], chicken feather vanes only had a biosorption percentage of around 35% in copper solution, being outperformed by both human hair at 42% and sheep wool at approximately 96%[16]. Throughout the study, it is consistently outperformed by sheep wool and biosorption efficiency seems to heavily vary depending on the metal used, as well as factors such as temperature and pH. This is a limitation of our research, as we were unable to test the efficiency of biosorption on other metals or other factors that could affect the effectiveness of biosorption.

Although heavy metal poisoning is not especially prevalent in humans, it could pose a serious threat to populations in LEDCs with an abundance in natural resources, which mostly rely on industries like agriculture and mining to exist, such as Tanzania. Due to contamination from the mines in the northern areas of Tanzania, their tap water contains exceeding levels of lead. The maximum concentration of lead (found in Mbagala) was about 11 times greater than the WHO permissible limit[11]. Of the 59 million people in Tanzania, 16 million people lack access to safe water, and 44 million people lack access to safely managed household sanitation facilities[25]. In settlements downstream like Dar Es Salaam[21], where the mercury content in rivers could be the highest, drinking untreated water could result in saturnism, a form of lead poisoning with adverse effects like stomach cramps, constipation, and weakness and pains in the muscles[27].
Marine species, with fish in particular, were also found to have a similar reaction to heavy metal poisoning. Even at low concentrations, heavy metals were found to have an profound impact on major organs of the fish. Many predatory fishes consumed by humans were found to contain exceeding levels of mercury due to bioaccumulation from consuming other species, with larger fishes such as swordfish containing 0.995µg/g, which is approximately 22 times over the maximum recommended intake of mercury by the EPA. The bioaccumulation of mercury in marine species could cause minamata, a form of organic mercury poisoning[24]. The synergy of heavy metals with biochemical inducements in fish may also prevent the communication of the fish with their surroundings, making them less aware of potential dangers and traps[26].
By applying the methods used in our research to these areas, we could reduce the heavy metal concentration in those waters and provide safer, cleaner water to those impacted.

V. If your team will compete the Sustainable Development Award, please indicate the specific sustainable development goal the project is related to, and provide justification for competing for this award. ***(Word limit: 300 words)***

This project relates to SDG 6, “Clean Sanitation And Water For All”. The project’s goal is to fulfill the goal of eliminating the threat of heavy metal ions in water in a sustainable and affordable way using low-cost products, many of which are byproducts of agricultural practices.

The main goal of this project is wastewater treatment, which works to meet the drinking water sanitation and quality targets set by the SDG. It relates directly to SDG 6.3, Improving Water Quality and Wastewater Treatment. The target is officially to "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally". This project would focus on 'halving the proportion of untreated wastewater' as well as 'increasing recycling and safe reuse" to alleviate the harms of heavy metal ions in wastewater. The use of byproducts as a method for wastewater treatment would be a sustainable method that employs substances that are often discarded as waste, that even those in poverty and LDCs can access easily; thus, "Clean Sanitation And Water For All."

VI. Conclusion

- Make a conclusion of the design project and the way forward of the research

Biosorption was successfully carried by all biomaterials to an adequate degree, chicken feather vane being the most effective biosorbent, reducing the concentration of copper by an average of 96.6% in 25ppm solution, and an average of 15.5% for 275ppm solution. Chicken feather vane performed the best in both categories, followed by yarn in 25ppm solution, and chicken feather calamus in 275ppm solution. Thus, biomaterials with a high keratin content act as effective biosorbents, particularly biomaterials acquired from chickens. Everyday waste products could be used to reduce wastewater contamination as an alternative to directly discarding them.

Citations

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