

## Utilization of keratin composed hen feather as an adsorbent for the removal of heavy metal divalent copper from the aqueous solution

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### Abstract

As the consumption of chicken increased in the past years, the discarded chicken feather wastes from the poultry farm and commercial market are the major wastes in Chennai. Even though chicken feathers are utilized in seat filler, shuttlecock, and animal feed, their production requires high quality feather so not all waste feathers are used. They are simply dumped into lands and rivers without treatment. This pollutes soil. The dumped areas may also provide suitable breeding places for flies which is potentially transmitting many diseases. So, recycling of these feathers may decrease solid waste. The hen feathers are rich in fibrillar protein keratin. Keratin is a crystalline protein of small molecular weight ~10kDa. The keratin is made of amino acid cystine, lysine, proline, serine etc., with reactive functional side chains arranged in twisted  $\beta$  sheets. This particular property can be utilized in environmental decontamination of heavy metals. so, the current study aims at removing heavy metal which is very toxic and also use of chicken feather as adsorbent thereby recycling it.

**Keywords:** Chicken feather, Keratin, Heavy metals, toxic, adsorbent

### Introduction

Water is undoubtedly a most essential element to life on earth. Without water life would not exist which is why polluted water is the biggest concern. There are different pollutants that contaminate water. They are inorganic contaminants (metals, heavy metals, and metalloids), organic contaminants, radiological contaminants, microbial contaminants, and others. Pollution of water decreases its purity, make it unsuitable and unsafe. It is a serious threat to aquatic habitat, plants, and human beings. The pollutants of concern include, mercury, cadmium, gold, silver, chromium, lead, copper, uranium, nickel, arsenic, selenium and zinc. Almost all heavy metals are serious toxicants such as carcinogens. Therefore, the contamination of water by

heavy metals actually affects all organisms. Humans an example of organisms feeding at the highest level are more prone to health problems because the concentration of heavy metals increase the food chain. Due to non-degradable in nature of heavy metal, it exists in environment for prolong time (Srividya and mohanty,2009)<sup>[47]</sup>. So, it is the need of the hour to reduce heavy metal contamination.

### Materials and Methods

#### Hen feather procurement (Adsorbent)

Hen feather is collected from Madhavaram poultry farm and other local poultry farms. All the procured feathers were country breed chicken feathers (Fig.1). The procured feathers are about the size of 10cm.



Fig 1: Procurement of Hen Feather

### Adsorbent Preparation

Hen feathers collected were first washed several times with ordinary water to clean and rinsed with distilled water. Then the washed feathers were dried for 3 days. Chicken feathers usually contain the soft barb part and the hard rachis. The hard rachis was removed and the barbs were cut into small

pieces each about 0.1mm in length using scissors. The barbs were then treated with acetone solution for 15minutes in order to remove adhering organic material. The adsorbent was then filtered through Whatman filter paper No:1 and rinsed with distilled water and again filtered and dried prior activation.

## Chemical modification of the chicken feather (Adsorbent)

### Activation of the adsorbent:

The chicken feather was modified chemically using tannic acid.



Fig 2: Tannic acid solution

### Activation Using Tannic Acid

10grams of chicken feather was soaked in 1 litre of 5% tannic acid (Fig.2). Then it was stirred in magnetic stirrer for 20 minutes (Fig.3). The adsorbent then filtered and rinsed in distilled water and again filtered and kept at 48degree Celsius for 48 hours (Awaluddin *et al.*,2014)<sup>[12]</sup>



Fig 3: Chicken feather activation

### Adsorbent Characterization

#### Fourier Transform Infra-red (FTIR) spectrophotometry analysis

The adsorbents were pressed into pellets and then FTIR analysis is done for feathers those which are unmodified and modified using tannic acid to evaluate the vibrational frequency changes in the functional groups of the adsorbents after activation and how it influences the additional removal.

#### Ash Content Analysis

A silica crucible is taken and are weighed in a weighing balance and the weight is noted. Two grams of chicken feather modified with tannic acid is taken in a crucible which were preweighed. It is then burnt by keeping it at 500degree Celsius for 10 minutes. Then, the crucible is reduced to the room temperature and weighed

The ash content is expressed in percentage.

The ash content is evaluated with the formula given below.

$$\text{Ash content (\%)} = (z-x/y-x) \times 100$$

Where,

Weight of empty crucible= x gram.

Weight of the crucible + sample = y gram.

After completing ashing, weight of the crucible+ash = z gram.

#### Moisture Content Analysis

Crucible was taken and weighed its weight in weighing balance. Then weigh 0.5 gram of feather modified using tannic acid and put it into crucible. Then weigh them again. Now keep the crucibles at 105 degrees Celsius for 15 minutes. After 15 minutes using tongs take out the crucibles and weigh it and note the values (repeat this step to get concordant value).

The moisture content is expressed in percentage.

$$\text{Moisture content (\%)} = (w-d/w) \times 100.$$

Where w=weight of the sample before drying.

d=weight of the sample after drying.

### Metal solution preparation (synthetic waste water)

The divalent copper stock solution of 100 ppm was prepared from cupric sulphate pentahydrate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ). 0.392 grams of cupric sulphate pentahydrate is dissolved in 1000ml of distilled water.

### Batch adsorption test

The experiments were carried out in the batch mode for the measurement adsorption capabilities.

### Effect of amount of adsorbent

100ml of divalent copper solution is taken in a 4 different beakers and various amounts of adsorbent (0.25,0.50,0.75, and 1 gram) was added. The beakers were stirred using magnetic stirrer at 150rpm for 15mins. Then the solution is filtered to remove the used adsorbents using Whatman filter paper No:42. Then samples were acid digested and atomic adsorption spectroscopy (AAS) is done using (ELICO SL 243 double beam AAS) to determine the remaining concentration after removal.

### Effect of time

100ml of divalent copper solution is taken in a beaker and the optimum value of adsorbent obtained from doing previous amount is chosen and put into beaker and stirred at various timings (15,30,45, and 60 minutes). It was filtered using Whatman filter paper No:42. Then samples were acid digested and atomic adsorption spectroscopy (AAS) is done using (ELICO SL 243 double beam AAS) to determine the remaining concentration after removal.

### Acid digestion of the samples

20ml of water sample was taken in a suitable beaker. 5ml of conc. nitric acid was added to it. It is then heated slowly and concentrated to 15-20ml. to this 5ml conc. nitric acid followed by 10ml conc. sulphuric acid was added and evaporated until white fumes appeared. An additional 1ml of concentrated nitric acid was added and evaporated. It was then cooled and made up to 100ml and estimated by AAS.

## Metal Analysis

### Preparation of metal standard solutions for the calibration curve principle

A series of samples containing known concentration of the compound of interest are analyzed and the corresponding absorbance is recorded. The calibration curve must be made at least 3 points plus a zero calibration. If the concentration of the sample exceeds the limit of calibration curve either the samples must be diluted to the appropriate concentration or the calibration curve must be extended with a higher concentration standard. If on the contrary, the concentration of the samples is lower than the lowest calibration curve's point, a new calibration curve could be prepared (Table.1).

**Table 1:** Preparation of metal standards

SL.NO	Metal	Salt	6 PPM	4 PPM	2 PPM
1.	COPPER ( $Cu^{2+}$ )	$CuSO_{4.5}H_{2}O$	0.02352	0.01568	0.00784

### Direct aspiration atomic adsorption

In direct aspiration atomic adsorption or flame atomic adsorption spectrophotometry (FAAS), a sample is aspirated and atomized in flame. A light beam from a hollow cathode lamp (HCL) or an electrodeless discharge lamp (EDL) is directed through the flame into a monochromator and onto a detector that measures the adsorbed light. Absorption depends on the presence free excited ground state atoms in the flame. Because the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample.

The digested sample were analyzed using (ELICO SL 243 double beam AAS) to check the remaining concentration of copper to find out the percentage removal. The instrument was fitted with specific lamp of particular metal. Acetylene gas was used as fuel and air as the support. The current flow was adjusted such that the mean of the energy profile was between 2.5 and 3. The instrument setting and operational conditions were done in accordance with the manufacturer's specifications (Modified CIBA,2004).

### Data Analysis

Percentage removal of divalent copper ions from initial solution concentration was calculated from the following formula

$$R = (- /) \times 100$$

Where is the initial metal ion concentration (mg/l) and is the metal ion concentration at the time t(mg/l)

## Results

### Adsorbent Characterization

FTIR analysis were carried out to identify the functional group present in the adsorbent (Fig.4). From the results, we can conclude that the inactivated chicken feather consists of alkene and aromatic groups (Table.2). Similarly, FTIR analysis was carried out to the activated adsorbent (Fig.5). From the results, it was confirmed that the chicken feather activated with tannic acid consists of phenol, alkene, alkane, aromatic and ether groups.

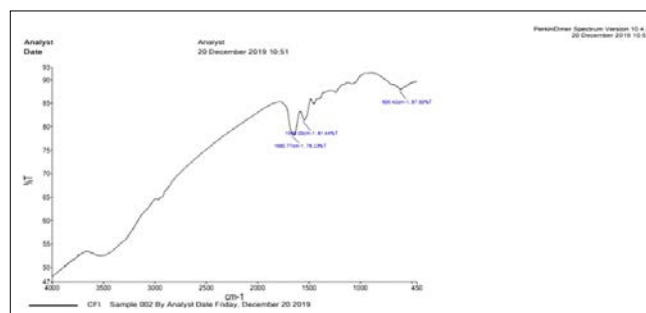
The change in functional group of adsorbent becomes an advantage, it gives ability to bind and sequester metal ions selectively. In this study, metal uptake and sorption capacity

being enhanced by modifying with tannic acid. Amino acid as a part of keratin in the chicken feather could be modified to form chelates with many metals as activated by tannic acid. (Ratna kumara *et.al.* 2011). To confirm functional group change in activation process FTIR analysis is conducted.

Figure 4 and 5 shows clear difference between the chicken feather spectrum before and after activated. Some new functional groups were found like alkane, ether in tannic acid. There was a peak shift in vernacular functional group. In general, chemical activation with tannic acid was successful.

**Table 2:** FTIR results of chicken feather inactivated

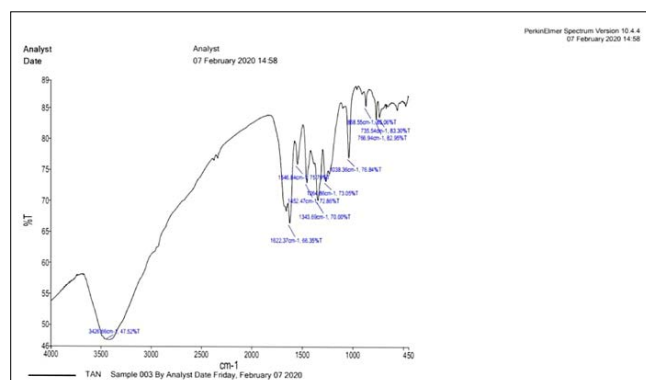
Compound	Intensity
Alkene	1650.77
Aromatic	1546.00



**Fig 4:** FTIR analysis of chicken feather inactivated

**Table 3:** FTIR results of chicken feather activated with tannic acid

Compound	Intensity
Phenol	3426.66
Alkene	1622.37
Alkane	1343.69
Aromatic	1546.84
Ether	1264.86



**Fig 5:** FTIR analysis of chicken feather activated with tannic acid

### Ash Test

The activated chicken feathers were burnt to calculate the ash content (Fig.6)

The ash content is expressed in percentage.

The ash content can be calculated using the below formula.

$$\text{Ash content (\%)} = (y-z/y-x) \times 100$$

Where,

Weight of empty crucible= x gram =34.00gram

Weight of the crucible + sample = y gram =36.00 gram

After completing ashing, weight of the crucible+ash = z gram=35.60 gram

Ash content =  $(36.00-35.60/36.00-34.00) \times 100$

Ash content of chicken feather activated with tannic acid is= 20%.



Fig 6: Ashing of modified chicken feather

**Moisture Content**

The moisture content of activated chicken feather was also calculated.

The moisture content is expressed in percentage.

The moisture content can be calculated from the following,

Moisture content (%) =  $(w-d/w) \times 100$ .

Where w=sample weight before drying

d=sample weight after drying.

Weight of the sample before drying (w) = 0.50 gram.

Weight of the sample after drying (d) = 0.45 gram.

Moisture content (%) =  $(0.50-0.45/0.50) \times 100$ .

Moisture content (%) of chicken feather activated with tannic acid = 10%

**Removal of metal by adsorbent**

**Effect of adsorbent dosage**

The effect of initial adsorbent dosage was investigated, since it can determine the biosorption capacity under given operating condition. The adsorption at various dosages is given in the data below. As expected, the rate of divalent copper removal increased along with the increasing of sorbent dosages. This can be explained since more active sites of sorbent were exposed when the sorbent dose increased. After sometime the percentage removal declined. The highest of copper removal was obtained by tannic acid activated adsorbent with corresponding dosage 0.50 is 49%. So, the optimum dosage is fixed to be 0.50. The optimum dosage is very important in accordance to economical reason if will be applied in real scale wastewater treatment process (Table.4)

Table 4: Concentration data 1

Sample	Absorbance	Concentration (mg/l)
0.25 grams adsorbent at 15 minutes	0.0373	0.89
0.50 grams adsorbent at 15 minutes	0.0339	0.81
0.75grams adsorbent at 15 minutes	0.0472	1.1

**Percentage Removal**

**Effect of amount of adsorbent**

The absorption of heavy metals by the absorbent depends on various factors. The amount of absorbent was studied using the following method (Fig.7)

Initial concentration of divalent copper = 1.61mg/L.

Percentage removal was calculated by,

$$R = ((C_o - C_t) / C_o) \times 100$$

Percentage removal by 0.25gram of adsorbent =  $((1.61-0.89)/1.61) * 100$   
 $=0.4472*100$   
 $= 44.72\%$

Percentage removal by 0.50gram of adsorbent=  $((1.61-0.81)/1.61) * 100$   
 $=0.4968*100$   
 $=49.68\%$

Percentage removal by 0.75 gram of adsorbent=  $((1.61-1.1)/1.61) * 100$   
 $=0.3167*100$   
 $=31.67\%$

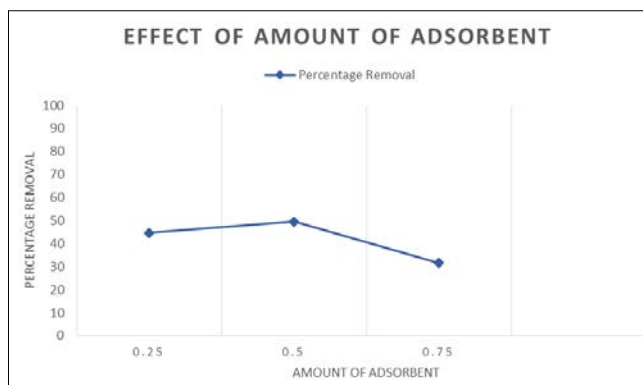


Fig 7: Effect of amount of adsorbent

**Effect of contact time**

Effect of contact time on divalent copper removal by the adsorbent is determined. The optimum time could not be obtained as the removal is alternatively increasing and decreasing as time increases. But the maximum removal was at 15 minutes (Table.5)

Table 5: Concentration data 1

Sample	Absorbance	Concentration (mg/l)
0.50gram of adsorbent at 15 minutes	0.0339	0.81mg/L
0.50grams of adsorbent at 30 minutes	0.0631	1.52mg/L
0.50grams of adsorbent at 45 minutes	0.0414	0.99mg/L
0.50grams of adsorbent at 60 minutes	0.0513	1.23mg/L

**Percentage Removal**

**Effect of time**

Initial concentration of divalent copper = 1.61mg/L.

Percentage removal was calculated using the formula below,

$$R = ((C_o - C_t) / C_o) \times 100$$

**Effect of contact time:**

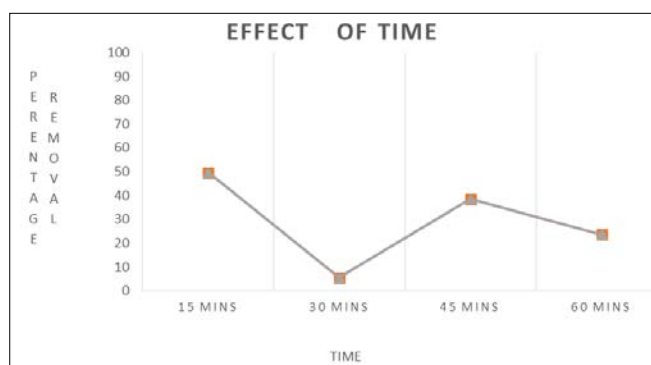
Initial concentration of divalent copper= 1.61 mg/L.

$$\begin{aligned} \text{Percentage removal at 15minutes} &= ((1.61-0.81)/1.61) * 100 \\ &= 0.4968 * 100 \\ &= 49.68\% \end{aligned}$$

$$\begin{aligned} \text{Percentage removal at 30 minutes} &= ((1.61-1.52)/1.61) * 100 \\ &= 0.0559 * 100 \\ &= 5.59\% \end{aligned}$$

$$\begin{aligned} \text{Percentage removal at 45 minutes} &= ((1.61-0.99)/1.61) * 100 \\ &= 0.3850 * 100 \\ &= 38.50\% \end{aligned}$$

$$\begin{aligned} \text{Percentage removal at 60 minutes} &= ((1.61-1.23)/1.61) * 100 \\ &= 0.2360 * 100 \\ &= 23.60\% \end{aligned}$$



**Fig 8:** Effect of Time

## Discussion

Pin *et al.*, (2014) extracted keratin from hen feather and developed it as adsorbent for the dye methylene blue removal. Muhammed A. Bharosa *et al.*, (2014) studied the effect of chemical modification of chicken feather in arsenic removal. They modified feathers with for dopants like, N-isopropylacrylamide, allyl alcohol, trisino cyclohexylpos and reported that allyl alcohol, and poses biosorbents executed high removal. Ita *et al.*, (2011) reported the usage of chicken feathers for chromium removal from aqueous solutions. Alok *et al.*, (2007) used hen feather for the removal of indigo carmine dye. Sameer *et al.*, (2003)<sup>[14]</sup> used chemically treated chicken feather for zinc removal. They concluded alkaline solutions 0.2N NaOH can be used in absorption process and 0.6wt% solution of dodecyl sulfate, as anionic surfactant followed by untreated chicken feather. Guadalupe *et al.*, (2008) used chicken feathers to remove lead from aqueous solutions and reported equilibrium studies at different temperature, pH and metal concentrations. Wei *et al.*, (2016) treated chicken feather by two step pyrolysis and used it as an adsorbent to remove calcium, manganese from the synthetic waste water. Kong *et al.*, (2016) prepared chicken feather protein-based semi impenetrating polymer networks adsorbent resin for the uptake the of heavy metal ions from aqueous solutions. Sayeed *et al.*, (2005) used chicken feathers treated with 0.95N NaOH and 0.6 NaOCl solutions as regenerable sorbents to remove calcium, manganese, iron and magnesium and successfully treated waste waters from industries in Egyptian industrial areas.

In our current study, Hen feathers from Madhavaram poultry farm were modified using tannic acid. Synthetic metal solution containing copper ions is made from copper

sulphate pentahydrate. Then modified hen feather is characterized using FTIR, and moisture test and ash test is done. Batch adsorption test was done. Effect of amount of adsorbent and effect of time was studied. The removal was maximum at 15minutes. The optimum amount of adsorbent was found to be 0.50gram at which removal is maximum. Thus, modified hen feather is very useful for heavy metal removal and waste water management.

## Conclusion

The above study demonstrated the usage of modified hen feathers as adsorbent significantly removed copper ions from aqueous solution. The maximum amount of copper removal by tannic acid activated hen feather is 49.68%. The optimum amount of adsorbent is 0.50gram. The attempt to find optimum time couldn't be achieved. It could be verified from earlier studies that unmodified hen feather has lesser removal capacity compared to tannic acid activated hen feather. Tannic acid activation has enhanced the removal capacity of chicken feather. Thus, modified feather is proved to be a good adsorbent in future for largescale waste water treatment.

## References

1. Aguayo-Villarreal IA, Bonilla-Petriciolet A, Hernández-Montoya V, Montes-Morán MA, Reynel-Avila HE. Batch and column studies of Zn<sup>2+</sup> removal from aqueous solution using chicken feathers as sorbents. *Chemical Engineering Journal*,2011;167(1):67–76. doi: 10.1016/j.cej.2010.11.107
2. Ajmal M, Khan AH, Ahmad S, Ahmad A. Role of sawdust in the removal of copper (II) from industrial wastes. *Water Research*,1998;32(10):3085-3091.
3. Al-Asheh S, Banat F, Al-Rousan D. Beneficial reuse of chicken feathers in removal of heavy metals from wastewater. *Journal of Cleaner Production*,2003;11(3):321–326. doi:10.1016/s0959-6526(02)00045-8
4. Anantha RK, Kota S. Removal of lead by adsorption with the renewable biopolymer composite of feather (*Dromaius novaehollandiae*) and chitosan (*Agaricus bisporus*). *Environmental Technology & Innovation*,2016;6:11-26.
5. Banat F, Al-Asheh S, Al-Rousan D. Comparison between Different Keratin-composed Biosorbents for the Removal of Heavy Metal Ions from Aqueous Solutions. *Adsorption Science & Technology*,2002;20(4):393–416. doi:10.1260/02636170260295579
6. Bilal M, Shah JA, Ashfaq T, Gardazi SMH, Tahir AA, Pervez A, *et al.* Waste biomass adsorbents for copper removal from industrial wastewater—a review. *Journal of hazardous materials*,2013;263:322-333.
7. Chiramba R, Charis G, Fungura N, Danha G, Mamvura T. Production of activated carbon from poultry feathers for waste water treatment. *Water Science and Technology*, 2019.
8. Daraei H, Yazdan bakhsh AR, Manshour M, Noorisepehr M. Study of equilibrium and kinetic models for removal of chromium (VI) and lead (II) by modified feather by H<sub>2</sub>O<sub>2</sub>. *International Journal of Environment and Waste Management*,2013;12(4):453-465.

9. de la Rosa G, Reynel-Avila HE, Bonilla-Petriciolet A, Cano-Rodriguez I, Velasco-Santos C, Martínez-Hernández AL. Recycling poultry feathers for Pb removal from wastewater: kinetic and equilibrium studies. *International Journal of Chemical and Biomolecular Engineering*,2008;1(4):185-193.
10. Enkhzaya S, Shiomori K, Oyuntsetseg B. Removal of Heavy Metals from Aqueous Solution by Adsorption using Livestock Biomass of Mongolia. *Journal of Environmental Science and Technology*,2017;10(3):107-119.
11. Fadillah G, Putri ENK, Febrianastuti S, Maylinda EV, Purnawan C. Adsorption of Fe Ions from Aqueous Solution Using  $\alpha$ -Keratin-Coated Alginate Biosorbent. *International Journal of Environmental Science and Development*,2018;9(3):82-85.
12. Gao P, Liu Z, Wu X, Cao Z, Zhuang Y, Sun W, *et al.* Biosorption of chromium (VI) ions by deposits produced from chicken feathers after soluble keratin extraction. *CLEAN–Soil, Air, Water*,2014;42(11):1558-1566.
13. Gupta S, Pal A, Ghosh PK, Bandyopadhyay M. Performance of waste activated carbon as a low-cost adsorbent for the removal of anionic surfactant from aquatic environment. *Journal of Environmental Science and Health, Part A*,2003;38(2):381-397.
14. Ho YS. Removal of copper ions from aqueous solution by tree fern. *Water research*,2003;37(10):2323-2330.
15. Kar P, Misra M. Use of keratin fiber for separation of heavy metals from water. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology*,2004;79(11):1313-1319.
16. Kayalvizhi K, Alhaji NMI. Removal of copper using activated carbon adsorbent and its antibacterial antifungal activity. *European Journal of Medicinal Plants*, 2020, 24-33.
17. Khosa MA, Wu J, Ullah A. Chemical modification, characterization, and application of chicken feathers as novel biosorbents. *RSC advances*,2013;3(43):20800-20810.
18. Kumaraguru K, Vinoth D, Kumar RS, Lal SR, Rengasamy M. Mercury (II) Ions Removal by Adsorption. *Elixir Renewable Energy*,2017;102:44236-44238.
19. Kumari AR, Babu UK, Sobha K. Optimization of lead adsorption using animal biopolymers by factorial design. *Int J Sci Innov Discover*,2011;1:303-319.
20. Lee SH, Yang JW. Removal of copper in aqueous solution by apple wastes. *Separation Science and Technology*,1997;32(8):1371-1387.
21. Lopez M, Cuapio O, Cardenas P, Balcazar M, Jauregui V, Bonilla P. Determination of Cr and Cd concentration adsorbed by chicken feathers.
22. Martinez-Hernandez AL, Velasco-Santos C, De Icaza M, Castano VM. Microstructural characterization of keratin fibres from chicken feathers. *International journal of environment and pollution*,2005;23(2):162-178.
23. Mendoza RC, Grande JO, Acda MN. Effect of Keratin Fibers on Setting and Hydration Characteristics of Portland Cement. *Journal of Natural Fibers*, 2019, 1-8.
24. Mittal A. Adsorption kinetics of removal of a toxic dye, Malachite Green, from wastewater by using hen feathers. *Journal of hazardous materials*,2006;133(1-3):196-202.
25. Mondal NK, Basu S, Das B. Decontamination and optimization study of hexavalent chromium on modified chicken feather using response surface methodology. *Applied Water Science*,2019;9(3):50.
26. Moon WC, Palaniandy P, Yusoff MS, Dahlan I. Adsorption studies on heavy metal removal from synthetic wastewater by pyrolyzed chicken feather fiber. *Desalination and Water treatment*,2017;62:307-315.
27. Morris JC, Weber jr WJ. Removal of biologically-resistant pollutants from waste waters by adsorption. In *Advances in water pollution research*. Pergamon, 1964, 231-266.
28. Noll KE. Adsorption technology for air and water pollution control. CRC Press, 1991.
29. Nurmiyanto A, Adyandana J, Satrania M, Lady EA, Artha YA, Yulianto A. chicken feather waste as biosorbent for chromium (vi) removal from aqueous solution. In *International Conference on Sustainable Built Environment, Department of Environmental Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia*, 2014.
30. Olawale SA, Funke AW, Dede AH, Hajara Y. Biosorption of Pb (II) and Cu (II) from Aqueous Solution Using Chicken Feathers: Thermodynamics and Mass Balance Studies. *Asian Journal of Applied Chemistry Research*, 2018, 1-9.
31. Paul ED, Nwokem NC, Anumonye FU. Biosorption of Nickel (II) from aqueous solution onto activated carbon prepared from chicken feather. *Journal of Applied Sciences and Environmental Management*,2019;23(6):1057-1060.
32. Periasamy K, Namasivayam C. Process development for removal and recovery of cadmium from wastewater by a low-cost adsorbent: adsorption rates and equilibrium studies. *Industrial & engineering chemistry research*,1994;33(2):317-320.
33. Qadeer R, Akhtar S. Kinetics study of lead ion adsorption on active carbon. *Turkish journal of chemistry*,2005;29(1):95-100.
34. Rakesh KE, Antony R. Bio sorption Studies of Chromium Ions with Modified Chicken Feathers. *Biomedical Journal of Scientific & Technical Research*,2017;1(7):1819-1822.
35. Reynel-Avila HE, Bonilla-Petriciolet A, de la Rosa G. Competitive sorption of Pb, Cd, and Ni on chicken feathers from binary aqueous solutions. *International Journal of Chemical Reactor Engineering*,2012;10(1):1-25.
36. Reynel-Avila HE, Bonilla-Petriciolet A, de la Rosa G. Analysis and modeling of multicomponent sorption of heavy metals on chicken feathers using Taguchi's experimental designs and artificial neural networks. *Desalination and Water Treatment*,2015;55(7):1885-1899.
37. Rohaizar NAB, Hadi NBA, Sien WC. Removal of Cu (II) from water by adsorption on chicken eggshell, 2013.
38. Ruthven DM. Principles of adsorption and adsorption processes. John Wiley & Sons, 1984.
39. Sabela MI, Kunene K, Kanchi S, Xhakaza NM, Bathinapatla A, Mdluli P, *et al.* Removal of copper (II)

- from wastewater using green vegetable waste derived activated carbon: An approach to equilibrium and kinetic study. *Arabian Journal of Chemistry*,2019;12(8):4331-4339.
40. Sabela MI, Kunene K, Kanchi S, Xhakaza NM, Bathinapatla A, Mdluli P, *et al.* Removal of copper (II) from wastewater using green vegetable waste derived activated carbon: An approach to equilibrium and kinetic study. *Arabian Journal of Chemistry*,2019;12(8):4331-4339.
  41. Saha S, Zubair M, Khosa MA, Song S, Ullah A. Keratin and chitosan biosorbents for wastewater treatment: a review. *Journal of Polymers and the Environment*, 2019, 1-15.
  42. Salmani MH, Ehrampoush MH, Rafati L, Farzi M, Barzegar K. Study of Co (II) adsorption from aqueous solution using protein granules produced from chicken feather. *Environmental Health Engineering and Management Journal*,2015;2(4):193-197.
  43. Sayed SA, Saleh SM, Hasan EE. Removal of some polluting metals from industrial water using chicken feathers. *Desalination*,2005;181(1-3):243-255.
  44. Schmidt WF, Codling EF, Thomas CG, Line MJ, Gassner G, Stuczynski T. Binding of heavy metal ions to fibers and filters from poultry feathers. In *NONWOVENS CONFERENCE*. TAPPI PRESS, 1997, 105-110.
  45. Sharma S, Gupta A, Chik SMST, Kee CYG, Podder PK, Subramaniam M, *et al.* Study of different treatment methods on chicken feather biomass. *IJUM Engineering Journal*,2017;18(2):47-55.
  46. Slejko FL, editor. *Adsorption technology: a step-by-step approach to process evaluation and application*. M. Dekker, 1985, 1-6.
  47. Srividya K, Mohanty K. Biosorption of hexavalent chromium from aqueous solutions by *Catla catla* scales: equilibrium and kinetics studies. *Chemical Engineering Journal*,2009;155(3):666-673.
  48. Suffet IH, McGuire MJ. Activated carbon adsorption of organics from aqueous phase. In *abstracts of papers of the american chemical society*. amer chemical soc,1978;176(sep):1-1.
  49. Sun P, Liu ZT, Liu ZW. Chemically modified chicken feather as sorbent for removing toxic chromium (VI) ions. *Industrial & engineering chemistry research*,2009;48(14):6882-6889.
  50. Suyama K, Fukazawa Y, Suzumura H. Biosorption of precious metal ions by chicken feather. *Applied biochemistry and biotechnology*,1996;57(1):67.
  51. Suzuki M, editor. *Fundamentals of adsorption*. Elsevier, 1993.
  52. Theophanides T, Anastassopoulou J. Copper and carcinogenesis. *Critical reviews in oncology/hematology*,2002;42(1):57-64.
  53. Tumane RG, Nath N, Khan A. Risk assessment in mining-based industrial workers by immunological parameters as copper toxicity markers. *Indian journal of occupational and environmental medicine*,2019;23(1):21.
  54. Ulmanu M, Maranon E, Fernandez Y, Castrillon L, Anger I, Dumitriu D. Removal of copper and cadmium ions from diluted aqueous solutions by low cost and waste material adsorbents. *Water, air, and soil pollution*,2003;142(1-4):357-373.
  55. Umedum NL, Anarado CJO, Eboatu AN. Chicken feather as sequestrant for lead ions in aqueous solution. *Int. J. Modern Anal. Sep. Sci*,2014;3(1):51-66.
  56. Villaescusa I, Fiol N, Martínez M, Miralles N, Poch J, Serarols J. Removal of copper and nickel ions from aqueous solutions by grape stalks wastes. *Water research*,2004;38(4):992-1002.
  57. Yadav AK, Abbassi R, Gupta A, Dadashzadeh M. Removal of fluoride from aqueous solution and groundwater by wheat straw, sawdust and activated bagasse carbon of sugarcane. *Ecological engineering*,2013;52:211-218.
  58. Zhang H, Carrillo F, Lopez-Mesas M, Palet C. Valorization of keratin biofibers for removing heavy metals from aqueous solutions. *Textile research journal*,2019;89(7):1153-1165.
  59. Zhuang Y, Zhao XX, Zhou MH. Cr (VI) adsorption on a thermoplastic feather keratin film. *Desalination and Water Treatment*,2014;52(13-15):2786-2791.