Indian Journal of Ecology (2022) 49(4): 1503-1509
DOI: https://doi.org/10.55362/IJE/2022/3690

Manuscript Number: 3690
NAAS Rating: 5.79

Adsorption Iron Ions from Aqueous Solution onto Duck Feathers Modification using $Na_2S_2O_5$

U.B.L. Utami, H. Susanto[1], B. Cahyono[2] and D. Ariyani

Chemistry Departement, Faculty of Mathematics and Sains,Lambung Mangkurat University Banjarmasin, Indonesia
[1]ChemicalmDepartement, Faculty of Engenering, Diponegoro University, Semarang, Indonesia
[2]Chemistry Department, Faculty of Mathematics and Sains, Diponegoro University, Semarang, Indonesia
E-mail: umi.baroroh@ulm.ac.id

***Abstract*:** Adsorption Iron Ions from Aqueous Solution onto Duck Feathers Modification using $Na_2S_2O_5$ has been done. The objectives were to study modification reactions, to determine adsorption capacity. Modification duck feather adsorbents done by 2 g of duck powder was dissolved in 25 mL $Na_2S_2O_5$ with a concentration of 0.025, 0.100, 0.175, 0.250, 0.325, 0.400 and 0.475M, then placed on hotplate stirrer at 50° C and stirred for 24 hours. The reaction mechanism was studied through functional group analysis using Fourier Transform Infrared (FTIR) spectroscopy**.** The results showed that adsorption capacity of Fe (III) by adsorbent of duck feather optimum with 3.25M and adsorption capacity before and after modification were 83.333 mg/g and 129.870 mg/g.

Keywords: Adsorption capacity, Iron, Duck feather, $Na_2S_2O_5$

The increase of duck breeding efforts can lead to increase produce duck feather waste. Based on data from the Livestock Service Office of South Kalimantan Province in 2019, the number of ducks is 4,786,370 population, are generated can be estimated that a total of 239 tons of duck feather waste. These duck feather to be used as adsorbents for absorbing metals in industrial wastewater. Related studiess on chicken feather modified with 6% CH_3OH and 2% HCl, adsorption capacity As(III) of 90,6 mg/g (Khosa, Wu and Ullah, 2013) and duck feathers on Fe(III) modified with 25% CH_3OH and 4% HCl adsorption capacity of 125 mg/g (Utami, Cahyono and Susanto, 2020). Duck feathers modified with NaOH have a relatively high concentration of Cu^{2+} and Cr^{6+} adsorption capacity (Xiangyu Jin, Lu Lu, Haibo Wu, Qinfei Ke, 2013). The adsorption capacity of Pb by chicken feathers is 1.9 g/L and by duck feathers 2.3 g/L (Kumari and U. Kiran Babu 2011). Copper adsorption with Dromaius novaehollandiae feathers and chitosan composite maximum adsorption was found to be 93.91% (Kumari and Sobha 2015). Sodium sulfide is used as a less expensive chemical substitute for keratin extraction. Research on modification of keratin with Na_2S and immersion in isopropyl alcohol or weak acid (13 to 50% increase) or by crosslinking of formaldehyde or glutaraldehyde (24 to 40% increase) (Poole and Church 2015). Pb^{2+} ion adsorption using $Na_2S_2O_5$ modified chicken feathers resulted in an adsorption capacity of 11.16 mg/g (Kong et al 2014). Cu adsorption on electroplating waste using modified $NaOH/Na_2SO_3$ chicken feathers resulted in an adsorption capacity of 38.43 mg/g (Sunarto 2014). Modification of keratin with sodium meta-bisulfite showed that the optimum level was 0.2 M with a yield of 87.6% (Ji et al 2014).

Previous research on the reaction mechanism of keratin using sodium sulfide includes the extraction of keratin from wool through sulfitolysis, with the formation of cysteine (R-S-H) (Aluigi et al 2014). The results of studies of keratin from rabbit hair showing typical absorption at 3420, 1650, 1543, 1240, and 685 cm^{-1}, showing NH(II), amide III (CN) and amide IV, respectively (Wang et al 2018). The results of another study showed the presence of disulfide bonds in keratin and formed SH (Zhang et al 2013) and disulfide bonds (S-S) from being completely broken down in hydrolysis (Hamouche et al 2018). For this reason, it is necessary to conduct research on the modification of keratin from duck feathers using $Na_2S_2O_5$ and study the reaction mechanism and study its adsorption.

MATRIAL AND METHODS

Preparation duck feather powder: One kg of duck feather is washed with detergent and water, then dried in the sun and the smell is gone, then heated with oven for 24 hours at 50°C to remove the remaining water content. The duck feather is milled using grinder and sieved using a 40 mesh sieve. 20 g of duck powder was soaked with 300 ml of 0.1 M HCl and 300 mL petroleum ether for 24 h, then washed with distilled water, then filtered using a Buchner filter. The obtained residue is dried with oven at 60°C. The results obtained were analyzed by FTIR.

Modification of duck feather adsorbents: 2 g of duck powder was dissolved in 25 mL $Na_2S_2O_5$ with a concentration of 0.025; 0.100; 0.175; 0.250; 0.325; 0.4000; and 0.475M, then placed on hotplate stirrer at 50°C and stirred for 24 hours. The mixture is filtered using a Buchner filter and washed with distilled water to neutral. A total of 0.25 g of duck powder was done by adsorption test on Fe 100 ppm solution. The mixture is homogeneous using a magnetic stirrer for 100 minutes, and then filtered using a Buchner filter. The results obtained were analyzed by Atomic Absorption Spectrophotometer (AAS-GBC Avanta Ω) in Industry Research and Standardization Center Banjarbaru, South Kalimantan and analyzed by Fourir Fourier Transform Infrared (FTIR 8201PC Shimadzu, Japan) spectra of samples were recorded in a wide range of wave number from 400 to 4000 cm^{-1} in Laboratory of Organic Chemistry and Biochemistry Department of Chemistry, Gadjah Mada University.

Determination of adsorption capacity of Fe by adsorbent duck feather: Fe solution of concentration 100, 150, 200, 250, and 300 ppm with pH 6. 50 mL Fe solution was pipetted into 5 provided erlenmeyer. A total of 0.25 g duck adsorbent is inserted into each erlenmeyer. The mixture was stirred using a magnetic stirrer for 100 minutes of contact time filtered using a Buchner filter. The results obtained were analyzed by Atomic Absorption Spectrophotometer (AAS-GBC Avanta Ω) in Industry Research and Standardization Center Banjarbaru, South Kalimantan the same procedure is performed on the adsorbent of duck that has not been activated. Furthermore, the adsorption capacity was calculated using the Langmuir and Freundlich Isotherm.

Data analysis: The data obtained based on the parameters studied and made the graph to know the amount of adsorbed metal (M), obtained from the difference of concentration M before and after adsorption by duck modified adsorbent from the measurement of Atomic Absorption Spectrophotometer. The data is then incorporated into the equation:

Ishoterm Langmuir

$$\frac{C_e}{q_e} = \frac{1}{b.K_L} + \frac{C_e}{b} \quad (1)$$

where, qe = the amount adsorbed per unit weight of adsorbent ($mg.g^{-1}$) Ce = the equilibrium concentration ($mg.L^{-1}$) K_L = the Langmuir adsorption constant, indicating the binding energy between adsorbent and adsorbate ($L.mg^{-1}$)

b = Maximum adsorption capacity ($mg.g^{-1}$)

Ishoterm Freundlich

Log qe = log KF + 1/n log Ce (2)

where, qe = Number of adsorbat adsorbed ($mg.g^{-1}$) Ce = Concentration of solution at equilibrium ($mg.L^{-1}$) KF and 1 / n = Freundlich constants of the adsorbent adsorption capacity and intensity.

RESULTS AND DISCUSSION

Adsorption of metal ions by fibrous materials such as keratin can be increased by treating it with a certain chemical, such as by adding $Na_2S_2O_5$. Activation is carried out using a 0.025; 0.100; 0.175; 0.250; 0.325; 0.400; and 0.475M. The activation of duck feather adsorbents aims to increase the number of ligands and form complexes with ferrous metal ions. The relationship between $Na_2S_2O_5$ and adsorption of duck feather adsorbent is shown in Figure 1.

From the picture, it can be seen that at the $Na_2S_2O_5$ concentration after 0.175M the condition of the adsorption capacity is stable until the concentration is 0.325M. At a concentration of .400, this begins to decrease, indicating that the $Na_2S_2O_5$ concentration is excessive, so it is no longer able to bind to keratin. The reaction that occurs between keratin and $Na_2S_2O_5$ is estimated to be seen in Figure 2, where cysteine thiol and S-sulfonation residues will occur. Sodium sulfite (SO_3-2), bisulfite (HSO_3-), and sulfite ($S_2O_5$2-) are the main sulfite compounds present in aqueous solutions and can be used for sulfitolysis. First, hydrosulfite and hydroxyl ions are formed from the reaction of sodium sulfite with water in Figure 4. In the next step, hydroxyl ions break disulfite bonds and form dehydroalanin and perthiocysteine as a propos (Poole and Church 2015).

The dehydroalanin formed from this reaction is very reactive and forms lanthionin and lysinoalanine through a cross linking with cysteine and lysine (Fig. 6). This cross-linking reaction can improve the mechanical properties of the final regeneration product, however, sodium sulfite treatment can damage the backbone of proteins, and therefore, optimizing the extraction conditions is an important step to maintain the structure of keratin (Shavandi *et al.*, 2008). Thiol

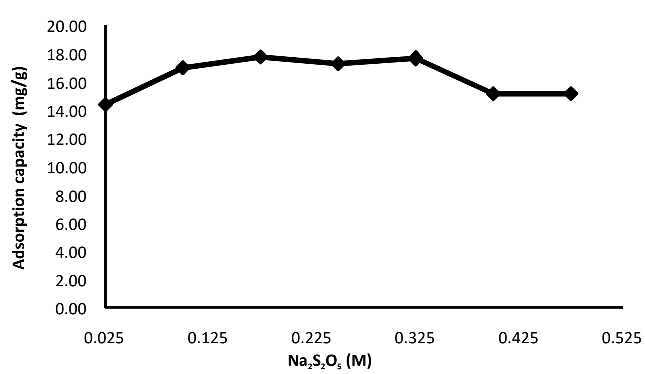

Fig. 1. Relationship between $Na_2S_2O_5$ concentration and Fe adsorption capacity

R-S-S-R + $Na^{2+}S_2O_5^{2-}$ ↔ R – S^- + R – S – $S_2O_5^-$

Keratin Sodium disulfite Cystein thiol Cystein S –Sulphonate

Fig. 2. Sulfitolysis cystin reaction by sulfite

groups (-SH) play a definite role during the grafting of the Monomer methyl Acrylate (MMA) onto the wool by providing sites for grafting. Thiol groups present on the cysteine aminoacids have been reported as the preferred sites for grafting monomers by some researchers. (Shavandi and Ali 2019). Fourier Transform Infrared Spectrophotometer is used to identify functional groups keratin from duck feather before and after modification with $Na_2S_2O_5$, and duck feather adsorbents after contact with Fe^{3+}. FTIR spectra results can be seen in Figure 7. Identify functional groups in FTIR spectra of adsorbent duck feathers before modification, after modification with $Na_2S_2O_5$, and after the adsorption process with Fe, showed in Table 1**.**

Based on Table 1, the infrared spectrum of the duck feather before modification shows an absorption of 3266 cm^{-1} indicating a symmetrical OH stretching vibration range of NH, strengthened by the presence of buckling N_2H which absorbs near 1531 cm^{-1}, SH stretching vibrations appear at 2276 cm^{-1}, 1629 cm^{-1} which marks the absorption of C=O carboxylic acid, Absorption 1235 cm^{-1} marks the stretching vibration of CO carboxylic acid and 1072 which marks CN, Based on the results of FTIR spectra it can be concluded that in duck feathers there are keratin groups, similar to research on chicken feathers and rabbit fur (Sa'adah N, R. Hastuti 2013), (Wang et al 2018).

Infrared spectrum of duck feather after modification shows 1618.80 cm^{-1} absorption which indicates the presence of C=O carboxylic acid absorption. This is reinforced by the O-H vibration in the wave number 3266.17 cm^{-1}. The FTIR spectra of the $N_{a2}S_2O_5$ modified duck feathers are in agreement with the results of keratin studies from rabbit hair

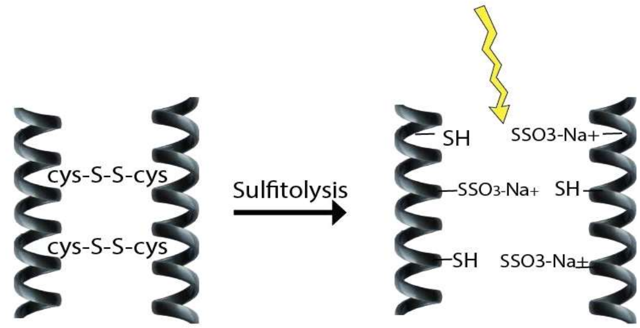

Fig. 3. Schematic diagram of the sulfitolysis reaction which breaks the strong disulfide bonds of keratin fibers

$$NaS_2O_5 + H_2O \longrightarrow 2Na^+ + HS_2O_5^- + OH^-$$

Fig. 4. Reaction of the formation of hydroxyl and hydroxyl ions from the reaction of sodium disulfite with water

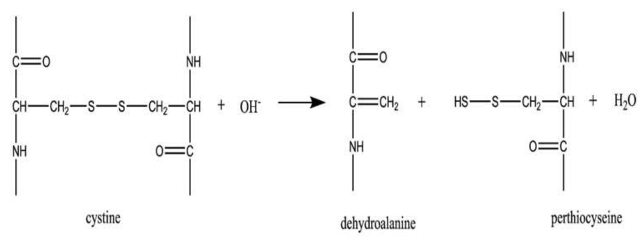

Fig. 5. Hydroxyl ion reaction breaks dehydroalanine sulfite bonds

Table 1. Analysis of functional groups in FTIR spectra of adsorbent duck feathers before modification, after modification with $Na_2S_2O_5$, and after the adsorption process with Fe

Adsorbent before modification (cm^{-1})	Adsorbent after modification (cm^{-1})	Adsorbent after the adsorption process with Fe (cm^{-1})	Reference wave numbers (cm^{-1})	Cluster function prediction
3266.42	3265.17	3273.98	3000 - 3700	O-H
2276.00	2276.00	2337.72	2300-2700	S-H
		2108.64		
1629.27	1618.80	1630.65	1500 - 1900	C=O
1531.56	1536.03	1522.60	1500 - 1650	N-H
1450.01	1448.21	1448.03	1340-1470	C-H
1396.09				
1341.74	1229.26			
1235.79	1201.46	1229.81	1000 - 1300	C-O
	1159.60			
	1077.52			
1072.32	1023.44	1023.32	900 - 1300	C-N

showing typical absorption at 3420, 1650, 1543, 1240, and 685 cm^{-1}, showing NH(II), amide III (CN) and amide IV (Wang et al 2018). The results of keratin studies from rabbit hair showing characteristic absorption at 3420, 1650, 1543, 1240, and 685 cm^{-1}, respectively showing NH(II), amide III (C-N) and amide IV. Keratin modified with a deep eutectic solvent (DES) mixture of choline chloride and oxalic acid shows the absorption of amide I, which may be associated with lower amounts of α-helical crystallites. In addition, new weak absorption bonds appear in 1317, 1170, and 1124 cm^{-1} absorption of hydrogen-bound NH groups (amide A, stretch NH), amide I (C = O stretch), amide II (flexible NH), amide III (CN stretching), and IV amide. Absorption bands appear at 1317, 1170, and 1124 cm^{-1}, which are associated with disulfide bonds in keratin and form SH (Zhang et al 2013) Disulfide bonds (S-S) from are broken down thoroughly in the hydrolysis. Keratin modified by Na_2S, the FTIR results showed that the carboxylic acid group in the sample was at wave numbers 1261 and 1262 cm^{-1}. Amides at 3369 and 3376 cm^{-1}, and at wave numbers 2361 cm-1 indicate the presence of amines (Yilmaz et al 2019). Keratin extraction with NaOH shows that the main structures of amide I, amide II and amide III are maintained, meaning that the peptide bond (−CONH) is not greatly affected in the process of base hydrolysis (Hamouche et al 2018). At wave numbers 3265 cm^{-1}, there are OH and NH (amide A) stretches, and at 2916 cm^{-1} is associated with symmetrical stretch CH_3 vibrations, while amide I is connected mainly to C=O stretch vibrations and occurs in the range (1700-1600 cm^{-1}). Modification of keratin from chicken feathers using methanol in an atmosphere acid showed that there was a change in peak sharpness at 1653 cm-1 and a significant change at 1738 cm^{-1} where esterification occurred in O of the carbonyl group, in the range of characteristic absorption (1750-1717 cm^{-1}) (Khosa, Wu and Ullah, 2013).

In duck feather adsorbents that have been contacted with Fe solution, the O-H vibration occurs at a wave number of 3425.58 cm^{-1}. The S-H stretching vibration appeared at 2276.00 cm^{-1}. The bending N-H velocity of NH_2 appeared at 1531.56 cm^{-1}. In the duck feather adsorbent that has been contacted with Fe solution, the bending N-H vibration appears at the wave number 1522.60 cm^{-1}. The C-O stretching of the ester appeared at 1159.60cm^{-1} and shifted to 1235.79 cm^{-1}. The C-N vibration gave the absorption at wave number 1023.32 cm^{-1} and shifted to 1072.32 cm^{-1}. Alteration of the functional summits of the functional groups is suspected to have proved the interaction at the time of the amodification process and when contacted with Fe^{3+}. This ligand will donate the free electron pairs and occupy the empty orbitals in the sub duster of the ferrous metal (central metal ion). Donation of ligand pairs of electrons to iron metal ions results in covalent coordination bonding. The possible scheme of Fe metal bond with keratin is shown in Figure 5. Like structure (an intrachain complex in wool keratin) could be formed if two carboxyl groups of two neighboring protein chains matched. Taking into account the expected value of such fragments frequency (50 per g of wool), Cu(II) uptake associated with the carboxylic residues can reach 150–300 μmoles/g of wool (Nikiforova, Kozlov and Islyaikin 2019).

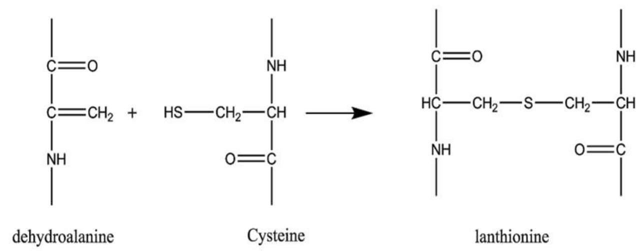

Fig. 6. Arrangement of lanthioalanin by the addition of cysteine to dehydroalanin

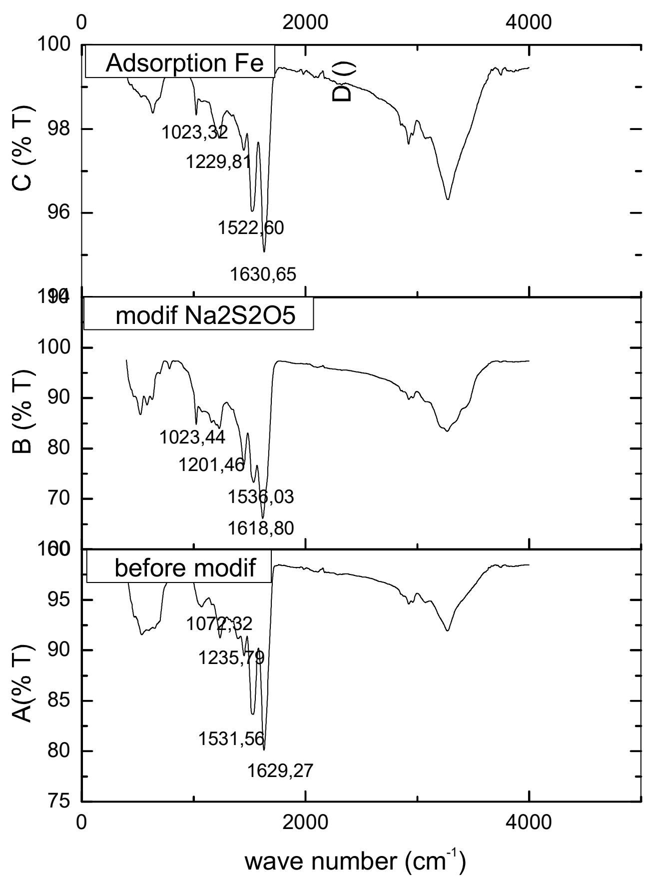

Fig. 7. FTIR spectra of duck finger adsorbent (A) before modification, (B) after modification with $Na_2S_2O_5$ and (C) after Fe^{3+} adsorption

Determination of adsorption isotherm model is done to know the process of adsorption of the iron metal ion by duck adsorbent modification with $N_{a2}S_2O_5$. The adsorption isotherm model used to describe the adsorption process on the solid surface, Langmuir and Freundlich isotherms. The adsorption capacity of Fe metal ions by duck adsorbent before and after modification is shown in Figure 9 and 10.

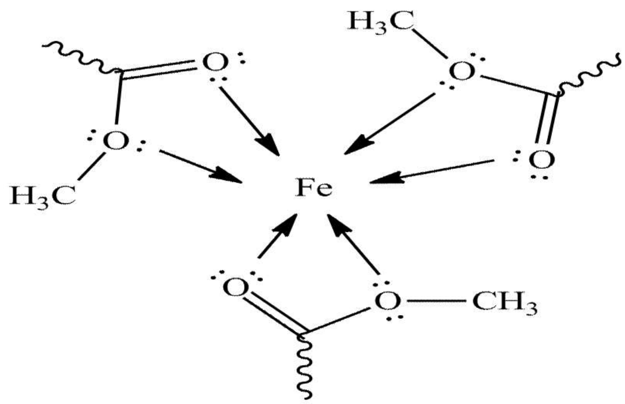

Fig. 8. Schematic possibilities of Fe metal bond with keratin

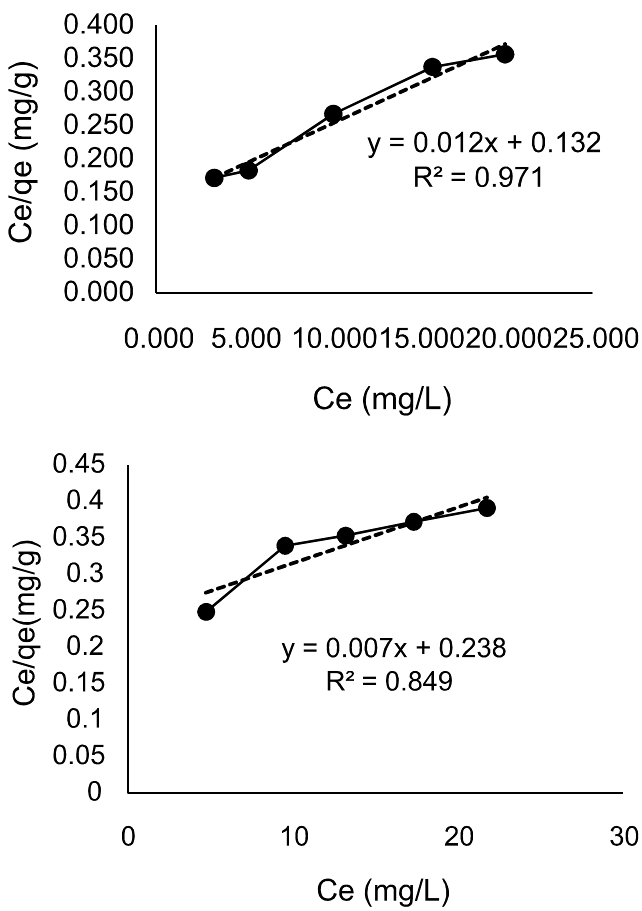

Fig. 9. Langmuir isotherm adsorption of Fe duck feather adsorbent before and after modification $Na_2S_2O_5$

Figures 9 and 10 shows that the adsorption of Fe on duck feather follows Langmuir and Freundlich isotherms. The adsorption ion of iron metal by adsorbent of duck feather follows the equation having the value of R^2 close to number 1. The result of the comparison of R^2 value indicates that the Langmuir and Freundlich isotherms equation have R^2 value close to 1. This suggests that the duck's adsorbent surface is homogeneous and adsorb only one adsorbate molecule for each of its adsorbent molecules, as well as the Langmuir isotherm, in general, would be preferable to apply to chemical adsorption. The adsorption of Fe by chitosan (Radnia, Ghoreyshi and Younesi, 2011), Rice Hush ash (RHA) (Zhang et al 2014) iron by fly ash from coal (Irawan and Rumhayati 2014), and kaolin based nanocomposite (Shaban, Hassouna and Nasief, 2017) also follows Langmuir and Freundlich isotherms. Isotherm Langmuir > Temkin >Freundlich biosorption iron using oil palm biomasses (Khosravihaftkhany and Morad 2013). The research of adsorption dye textile by father according isotherm Langmuir and Freundlich are tantrasine and malachite green, azo dye amido black 10B, and azo dye brilliant yellow and textile dyes by hen feathers performed by (Mittal, Thakur and Gajbe 2012) (Mittal, Thakur and Gajbe 2013). Methylene

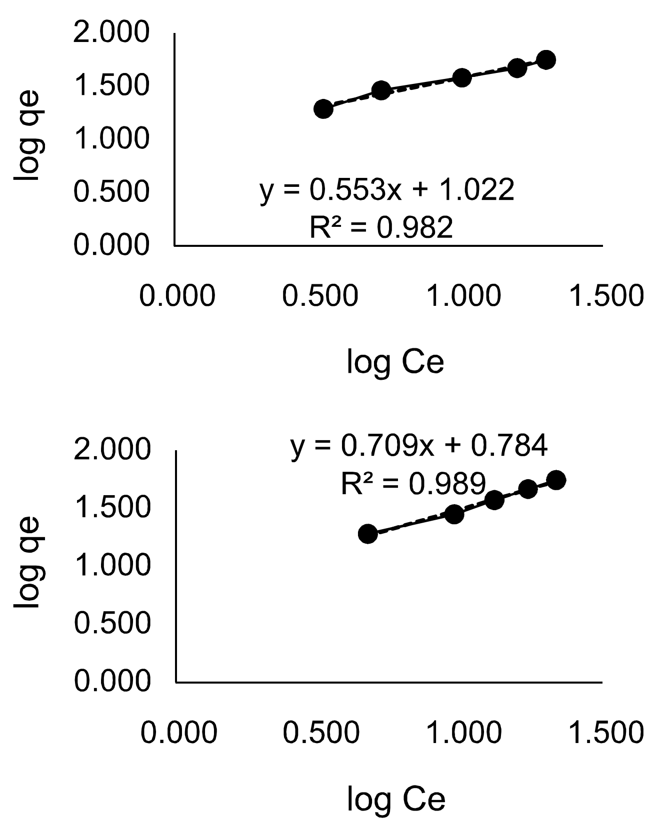

Fig. 10. Freundlich isotherm adsorption of Fe duck feather adsorbent before and after modification $Na_2S_2O_5$

Table 2. Data of equations and ditermination coefficients (R^2) for adsorption of Langmuir isotherms and Freundlich isotherms

Adsorbent	Isotherm Langmuir Equation	q_{max} (mg/ g)	R^2
Before modification	y = 0.012x + 0.1323	83.333	0.972
Modification $Na_2S_2O_5$	y = 0.0077x + 0.2383	129.870	0.849

blue by feather keratin (Chowdhury and Saha 2012a), amoxicillin by chicken feather carbon (Li et al 2017). To calculate the adsorbent adsorption capacity of modified $Na_2S_2O_5$ duck further obtained from Langmuir and Freundlich isotherm equation obtained from the relationship between Ce log and log qe. The results of the equation and the ditermination coefficient (R^2) and the adsorption capacity (qmax) for the adsorption can be seen in Table 2.

Table 2 shows the graph of the relationship between Ce/me to the concentration of the iron solution. so that the value of adsorption capacity for Fe^{3+} ions by $Na_2S_2O_5$ modified duck further that 129.870 mg/g. Compared with previous studies conducted. Where the adapted capacity of the chicken feather is 6% CH_3OH and 2% HCl in As (III) only 96.00 mg/g (Khosa, Wu and Ullah, 2013). The other research results adsorption of copper with Dromaius novaehollandiae feathers and chitosan composite. was adsorption capacity of 18.78 mg/l (Kumari and Sobha, 2015). The adsorption of lead using biopolymer feather chicken on lead (Pb) of adsorption capacity was 1.9 g/l. and lead (Pb) adsorption by duck feather adsorption capacity was 2.3 g/l (Kumari and Babu 2011). Adsorption of Methylene Blue by chicken feather with the adsorption capacity of 134.76 mg /g (Chowdhury and Saha, 2012b). Maximum sorption capacity (q_{max}) by chicken feather and magnetized activated carbon were 76.3, 56.5, 113.3, 32.6, and 45.5 respectively for Cd^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+} and Zn^{2+}, showing the suitability of the new sorbent for water and waste-water treatment usages (Rahmani-sani et al 2020). The maximum adsorption capacities were ACF powder-hydrolyzed feathers (PHF) bio-modifier and *Trapa natans husks* (TH) are 50.2 mg/g for Cd(II) and 46.7 mg/g for Ni(II)) were higher than those of AC (33.8 mg/g for Cd(II) and 31.15 mg/g for Ni (II) (Yin et al 2019).

CONCLUSIONS

Analysis of keratin from duck feathers using $Na_2S_2O_5$ showed that keratin had formed which was indicated by a shift in wavenumber in the FTIR spectrum. Adsorption capacity of Fe(III) by adsorbent of duck feather modified with $Na_2S_2O_5$ optimum with 3.25M and adsorption capacity before & after modification were 83.333 mg/g and 129.870 mg/g. Adsorption of Fe on duck feather modified with $Na_2S_2O_5$ follows Langmuir and Freundlich isotherms. Duck feathers that have been modified with $Na_2S_2O_5$ can be used as adsorbents in wastewater containing heavy metals

ACKNOWLEDGEMENTS

We would like to express our deep thanks to Ministry of Research Technology and Higher Education of the Republic of Indonesia for funding part of this research through Incentive Program for Dissertation Doctor Research Grant.

REFERENCES

Chowdhury S and Saha P Das 2012. Biosorption of methylene blue from aqueous solutions by a waste biomaterial: Hen feathers. *Applied Water Science* **2**(3): 209-219.

Hamouche H, Hamouche H, Makhlouf S, Chaouchi A and Laghrouche M 2018. Humidity Sensor Based on Keratin bio Polymer Film. *Sensors and Actuators, A: Physical*. Elsevier B.V; **282**: 132-141.

Irawan C and Rumhayati B 2014. Adsorption of Iron (II) By Fly Ash Adsorbent from Coal. *Journal of Pure and Applied Chemistry Research* **3**: 88-99.

Ji Y, Chen J, Lu J, Li Z, Xing L and Ding S 2014. Extraction of keratin with ionic liquids from poultry feather. *Separation and Purification Technology*. Elsevier B.V; **132**: 577-583.

Khosa MA, Wu J and Ullah A 2013. Chemical modification, characterization, and application of chicken feathers as novel biosorbents. *RSC Advances* **3**(43): 20800.

Khosravihaftkhany S and Morad N 2013. Biosorption of Pb (II) and Fe (III) from aqueous solutions using oil palm biomasses as adsorbents. *Water Air Soil Pollut* **224**: 1455.

Kong J, Yue Q, Sun S, Gao B, Kan Y, Li Q and Wang Y 2014. Adsorption of Pb(II) from aqueous solution using keratin waste - hide waste: Equilibrium, kinetic and thermodynamic modeling studies. *Chemical Engineering Journal*. Elsevier B.V; **241**: 393-400.

Kumari AR, Kiran U and Babu KS 2011. Optimization of lead adsorption using animal biopolymers by factorial design **1**(3): 303-319.

Kumari AR and Sobha K 2015. Cost effective and eco-friendly method for copper removal by adsorption with Emu feather (Dromarus novaehollandiae) and Chitosan (Agaricus bisporus) Composite. *International Journal of ChemTech Research* **8**(4) : 1769-1782.

Li H, Hu J, Wang C and Wang X 2017. Removal of amoxicillin in aqueous solution by a novel chicken feather carbon : Kinetic and equilibrium studies. *Water, Air, & Soil Pollution* **228***:* 201.

Mittal A, Thakur V and Gajbe V 2012. Evaluation of adsorption characteristics of an anionic azo dye Brilliant Yellow onto hen feathers in aqueous solutions. *Environmental Science and Pollution Research* **19**(6): 2438-2447.

Mittal A, Thakur V and Gajbe V 2013. Adsorptive removal of toxic azo dye Amido Black 10B by hen feather. *Environmental Science and Pollution Research* **20**(1): 260-269.

Nikiforova T, Kozlov V and Islyaikin M 2019 Journal of Environmental Chemical Engineering Sorption of d-metal cations by keratin from aqueous solutions. *Journal of Environmental Chemical Engineering*. Elsevier **7**(5): 103417

Poole AJ and Church JS 2015. The effects of physical and chemical treatments on Na 2 S produced feather keratin films. *International Journal of Biological Macromolecules*. Elsevier B.V; **73** : 99-108.

Radnia H, Ghoreyshi AA and Younesi H 2011. Isotherm and Kinetics of Fe (II) Adsorption onto Chitosan in a Batch Process. *Iranica Journal of Energy & Environment* **2**(3): 250-25.

Rahmani-sani A, Pardeep S, Pankaj R, Eder CL, Ioannis A, Dimitrios AG, Selvaraju S, Tetiana AD and Ahmad HB 2020. Bioresource Technology Use of chicken feather and eggshell to synthesize a novel magnetized activated carbon for sorption of heavy metal ions. *Bioresource Technology*. Elsevier **297**(10): 122452.

Shaban M, Hassouna MEM and Nasief FM 2017. Adsorption properties of kaolinite-based nanocomposites for Fe and Mn pollutants from aqueous solutions and raw ground water : Kinetics and equilibrium studies. *Environmental Science and Pollution Research* **24**(3): 22954-22966.

Shavandi A, Silva TH and Bekhit AA 2008. Dissolution, Extraction and biomedical application of Keratin: Methods and factors affecting the extraction and physicochemical properties of keratin center for material science and technology, University of Otago, Dunedin, New Zealand Minho, Headqu.

Shavandi A and Ali MA 2019. Progress in organic coatings graft polymerization onto wool fibre for improved functionality. *Progress in Organic Coatings*. Elsevier **130**: 182-199.

Utami UBL, Cahyono B and Susanto H 2020. Isotherms and capacity adsorption of Fe(III) onto duck feather modification using CH_3OH and HCl solution'. *Rasayan Journal of Chemistry* **13**(4) : 2106-2113.

Received 22 March, 2022; Accepted 22 May, 2022

Wang D 2018. Extraction of keratin from rabbit hair by a deep eutectic solvent and its characterization. *Polymers* 1**0**(9): 993.

Xiangyu Jin, Lu Lu, Haibo Wu and Qinfei Ke, HW 2013. Duck feather/nonwoven composite fabrics for removing metals present in textile dyeing effluents. *Journal of Engineered Fibers and Fabrics* **8**(3): 89-96.

Yilmaz T, Amine Y, Yakup C, Sinan U, Adem Y and Deniz U 2019. Treatment of acidic mine drainage in up-flow sulfidogenic reactor: Metal recovery and the pH neutralization. *Journal of Water Process Engineering*. Elsevier **32**(8): 100916.

Yin W, Congcong Z, Jingtao X, Jian Z, Zizhang G and Yahui S 2019. Removal of Cd(II) and Ni(II) from aqueous solutions using activated carbon developed from powder-hydrolyzed-feathers and Trapa natans husks. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. Elsevier **560**(10): 426-433.

Zhang J 2013. Isolation and characterization of biofunctional keratin particles extracted from wool wastes. *Powder Technology* **246**: 356-362.

Zhang Y and Zhao J 2014. Biosorption of Fe(II) and Mn(II) Ions from aqueous solution by rice husk ash. *BioMed Research International*. https://doi.org/10.1155/2014/973095.