COMBINED ELECTROCHEMICAL OXIDATION AND ADSORPTION METHODS FOR AMMONIA AND MOLYBDENUM(VI) REMOVAL FROM AQUEOUS SOLUTION

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Abstract - Water pollution is a global issue. In the currentstudy, electrochemical oxidation (EO) and adsorption methods were applied to remove ammonia and molybdenum(VI) from aqueous solution. In the first step (contaminantelimination with EO), response surface methodology was employed to do statistical analysis. Contact time (1–3 h), initial concentration of pollutants (10–50 mg/L), and pH (3–6) were the three independent factors in this experiment. Sodium sulfate (as electrolyte) and Ti/RuO_2–IrO_2 (as electrode) were applied during EO. At the optimum performance in the EO, the contact time, the initial concentration of contaminants and pH were 2.4 h, 27.4 mg/L, and 4.9. And the removaleffectiveness for ammonia and molybdenum were 79.4%, 48.0%, and 55.9%, respectively. On the basis of the preliminary experiments, the current and voltage were set at 50 mA and 7 V, respectively. After treating water at optimum EO performance, the aqueous solution was moved to a granular composite adsorbent (BAZLSC) column. BAZLSC improved the removaleffectiveness for ammonia and molybdenum(VI) to 99.9%..

Keywords - Ammonia, Electrochemical oxidation, Molybdenum, RSM

I. INTRODUCTION

Disposing of industrial, agricultural, and municipal waste into lakes and rivers can cause the deposition of contaminants in the environment [1]. Water pollutants can threaten people health. One of the main pollutants is ammonia.

Ammonia nitrogen contributes to the enhanced eutrophication of rivers and lakes, depletion of dissolved oxygen, and fish toxicity in gaining water [2]. The ammonia elimination techniques proposed in the literature include air stripping, use of biological reactors, electrochemical oxidation (EO), ozonation, and adsorption [3, 4]. Phenol is an organic pollutant which may threaten environment.

The contamination of water by heavy metals over the depletion of industrial wastewater is an international environmental issue. Quick industrialization has significantly contributed to the release of theoretically toxic heavy metals to water streams [7]. Molybdenum is a highly toxic metal. Vital techniques for eliminating metals from water are physical/chemical methods, such as adsorption and EO.

EO is a physical/chemical method for treating water and wastewater, and its application to various types of wastewater has been investigated extensively in recent years. The EO process is a promising wastewater treatment method chiefly due to its effectiveness and ease of operation [3]. Electrochemical technology, which is an advanced oxidation process, is the most promising method for treating organic contaminants and heavy metals; this technology includes electrodialysis, electrocoagulation, electroflotation, anodic oxidation, and electrochemical oxidation [8]. Several researchers have investigated the treatment of different wastewaters by EO using several types of compounds [9]. The process of electrochemical degradation of contaminants may be divided into direct and indirect oxidation procedure. In the direct oxidation procedure, contaminants are adsorbed by the surface of the anode at first, and then over the electron transfer reaction of hydroxyl radical formation (•OH); strong oxidative free radical damage of contaminant molecular structure, decomposition to CO_2. In the indirect electrochemical oxidation procedure, to produce strong oxidizing agents such as hypochlorous acid/chlorine, ozone, H_2O_2, etc., oxidant contaminants subsequent generation and electrochemical oxidation occurs in solution [10]. Chen et al. [8] investigated EO in the treatment of heavy metal wastewater. Cossu et al. [11] used Ti/PbO_2 and Ti/SnO_2 anodes to eliminate ammonia nitrogen and chemical oxygen demand from landfill leachate by EO. They reported that EO could remove a high amount of COD and ammonia. Beside it, researchers have recommended combined techniques because of the high contamination levels of industrial wastewater.

Adsorption is a prevalent wastewater treatment method and commonly combined with other techniques [12]. Several researchers have investigated the use of adsorption to treat different types of wastewater [13, 14]. Several studies [15, 16] have verified that the use of adsorbents can eliminate a considerable amount of contaminants, especially heavy metals. Numerous adsorbents, such as activated carbon, limestone, shell, cement, and zeolite, have been used in the literature [3, 4]. In this contemporary study, BAZLSC, a new composite adsorbent, was used which could do adsorption and ion-exchange in a same time since it includes

bentonite, zeolite, cockleshell, limestone, activated carbon and cement.

In current study, EO and adsorption techniques have been combined to achieve 100% removaleffectiveness. However, the current system design has not yet been reported in the literature. Therefore, this research aims to (1) evaluate the performance of combined systems that incorporate EO and adsorption in removing ammonia and molybdenum from aqueous solutions, (2) introduce a novel process, i.e., granular BAZLSC combined EO process, and (3) monitor adsorption isotherms during adsorption treatment.

II. DETAILS EXPERIMENTAL

This study was divided into two parts. In the first stage, a synthetic aqueous solution was treated by EO. Statistical analysis and optimization were performed using response surface methodology (RSM). In the second stage, water was moved to a fixed-bed adsorption column for further treatment after EO. Beside it, Adsorption isotherms were monitored.

2.1. Producing Synthetic Aqueous Solution

In this research, tap water was contaminated with two compounds, namely, ammonia (NH_3-N), and molybdenum(VI). The concentrations of these contaminants were produced by dissolving their chemical grades in water. Ammonia concentration was obtained by dissolving ammonium hydroxide in water [17]. The standard solutions of Mo(VI) were gained via dissolving Na_2MoO_4•$2H_2O$ in water [18].

The pH of the influent solutions was measured via a pH meter and adjusted via augmenting 0.1 M NaOH and/or 0.1 M HCl.

Table1: Independent variables of the three-level factorial design

Level of value	Reaction Time (h)	Initial Concentration of Pollutants (mg/L)	pH
-1	1	10	3
0	2	30	4.5
+1	3	50	6

Table 2: Powdered BAZLSC characteristics

Surface Area (m^2/g)	288.6
External Surface Area (m^2/g)	246.7
Micropore Area (m^2/g)	61.9
Micropore Volume (cc/g)	0.08

2.2. EO Reactor Characteristics

A reactor with a real capacity of 500 mL, width of 100 mm, length of 100 mm, and height of 80 mm was used for EO. An electrical current was employed via a constant-voltage/current-controlled DC power source. The Ti/RuO_2–IrO_2 (as electrodes) was employed as anode and cathode. The plate anode and the plate cathode of the same dimensions (3.5 cm×3 cm×1 cm, L×W×T) were arranged parallel to each other. On the basis of the preliminary experiments, we set the distance between anode and cathode at 30 mm. Koppad et al. [19] used a 30 mm distance between the anode and cathode during wastewater treatment by electrochemical oxidation. A magnetic stirrer at the bottom of the reactors was employed for mixing. Experiments were completed at room temperature. An electrolyte, $Na_2S_2O_8$, was employed at a concentration of 1 g/L to the samples before each experiment [3]. The current and voltage were fixed at 50 mA and 7 V and set according to the reported ranges by Bashir et al. [3] and Mojiri et al. [12], respectively.

2.3. Statistical Analysis

Computing the elimination effectiveness was finalized on the basis of Eq. 1.

$$\text{Removal (\%)} = \frac{(C_i - C_f)}{C_i} \times 100 \qquad \text{(Eq. 1)}$$

,

whereCi and Cf denote the preliminary and final concentrations of the features, respectively.

A three-level factorial design was created with the Design Expert 10.0.7 software for experiment design and data analysis. The three independent factors in this research were reaction time (1–3 h), initial concentration of contaminants (10–50 mg/L), and pH (3–6). The removals of ammonia, phenols, and Mo(VI) were selected as the response parameters. Certain experiments were functioned as a preliminary research to evaluate the narrow ranges of the procedure variables before carrying out the factorial design experiments. Kearney et al. [20] set the pH at 4 for ammonia elimination by EO. Asghar et al. [21] reported a 1 h contact time for treating aqueous solution by EO. Xu et al. [22] reported a 4 h contact time for the removal of cyanide from water by EO.

We considered increasing and decreasing our range for improved accuracy. The three independent factors and their corresponding levels are presented in Table 1. Eq. (2), an empirical second-order polynomial model, considers the performance of the scheme.

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_i \sum_{<j=2}^{k} \beta_{ij} X_i X_j + e_i, \qquad \text{(Eq. 2)}$$

where Y signifies the response; X_i and X_j denote the variables; β_0 is a fixed coefficient; β_j, β_{jj}, and β_{ij} denotes the interface coefficients of the linear, quadratic, and second-order terms, respectively; k denotes the quantity of considered factors; and e denotes the error. ANOVA was used to wholly analyze the consequences in the Design Expert software [23].

2.4. Fixed-Bed Adsorption Column

After treating the synthetic aqueous solution with an EO reactor, samples were transferred to the adsorption column by a water pump for further treatment.

2.4.1.Fixed-Bed Adsorption Column Preparation

Dynamic adsorption was performed in a 5–7 cm glass column filled with a 1 mm composite adsorbent named BAZLSC. On the basis of the preliminary experiment, the contact time of water with the adsorption column was set to approximately 10–15 min [24].

2.4.2. Composite Adsorbent (BAZLSC) Preparation

Bentonite, limestone, zeolite, cockleshell, activated carbon, and Portland cement were crushed, passed over a 300 µm mesh sieve, and then blended to obtain BAZLSC. The mixture was then lightly poured into a mold after adding water. The materials were eliminated from the mold after 24 h and immersed in water for approximately 2 days for the curing procedure. After letting the materials to dry for 3 days, they were ground and passed through a sieve. Before using BAZLSC in the experiments, they were dried at 105 ˚C for 24 h Table 2showS the structures of the BAZLSC analyses, respectively. BAZLSC can facilitate adsorption and ion exchange in a same time [12].

2.5. Analytical Methods

Standard Methods for the Investigation of Water and Wastewater [25] were followed to analyze wastewater. A YSI 556 MPS (YSI Incorporated, USA) was employed to record the temperature (°C), pH, electrical conductivity (mS/cm), oxidation–reduction potential (mV) and salinity (g/L), values. ICP (ICP Varian, OES 715) and HACH 2500 were used to measure the components.

III. RESULTS AND DISCUSSION

In this study elimination of ammonia, phenols, and Mo from contaminated water were investigated via EO and adsorption methods. Tables 1 and 3 show the independent variables of the three-level factorial design and the response values for the diverse experimental situations, respectively. Table 4 presents the ANOVA consequences for the response parameters.

3.1. AmmoniaandMo(VI) Removal using EO

The elimination of ammonia has attracted considerable attention due to the need to control nitrogen and prevent eutrophication in water sources. However, present methods, such as ion exchange, biological removal, and air stripping, cause contaminant transfer into other media and are expensive. The electrochemical process is a promising method. Table 3 specifies that the lowest elimination effectiveness for ammonia was 69.5% (reaction time = 1 h, pH = 3, and preliminary concentration of ammonia = 50 mg/L) and the highest elimination effectiveness was 90.9% (contact time = 3 h, pH = 6, and preliminary concentration of ammonia = 50 mg/L) in current study. At the optimum condition (contact time = 3 h, pH= 6, and preliminary concentration of ammonia = 44.8 mg/L), ammonia removal was approximately 91.0%. He et al. [26] investigated ammonia removal by the EO method at pH = 6.5 in the presence of Ru–Ir/TiO_2 and Na_2SO_4. Ding et al. [27] removed 90% of ammonia using Ti/RuO_2-Pt electrodes by the EO method. Li et al. [28] reported 89% ammonia removal at an initial concentration of 30 mg/L using a vermiculite-packed electrochemical reactor. Therefore, the ammonia elimination efficiency in the current study is approximately similar to that in previous studies.

Heavy metals, such as Mo, are present in numerous kinds of industrial effluents and accountable for environmental contamination. Table 3 shows that the lowest elimination effectiveness for Mo was 34.1% (reaction time = 1 h, pH = 6, and initial concentration of Mo = 50 mg/L) and the highest elimination effectiveness was 59.4% (contact time = 2 h, pH = 4.5, and initial concentration of Mo = 30 mg/L). At the optimum condition (contact time = 2.4 h, pH = 4.1, and initial concentration of Mo = 28.5 mg/L), Mo removal was approximately at 59.5%. Tran et al. [29] investigated metal elimination from an aqueous solution by the EO method at a voltage of 10 V. Chen et al. [8] reported heavy metal wastewater treatment by EO.

3.2. Thermal Fatigue behaviours of TBCs systems

In this study, the synthetic aqueous solution was initially treated in the EO reactor at optimum performance before being transferred to the adsorption column for the second stage. The performance of EO combined with adsorption enhanced the elimination efficiencies for ammonia, and Mo from 79.4% to 99.9%, and 55.9% to 99.9%, respectively.

In this research, the current composite adsorbent could simultaneously perform adsorption and ion exchange as it was produced from certain low-cost materials, such as bentonite, zeolite, activated carbon, cockleshell, cement, and limestone. Mazloomi and Jalali [30] reported that zeolite can be used to eliminate NH_4^+ from domestic and industrial wastewater. Halim et al. [14] reported that activated carbon is effective in removing ammonia. Haseena et al. [31] investigated the potential use of bentonite in eliminating ammonia from aqueous solutions. On the basis of the literature [32, 33], we concluded that bentonite and zeolite can be used to remove metals from water.

Table 3. Response values for different experimental conditions

Run	Contact Time (h)	Initial Concentration (mg/L)	pH	Ammonia rem.* (%)	Mo rem. (%)
1	3.0	50.0	6.0	90.95	37.64
2	2.0	30.0	4.5	77.00	58.95
3	2.0	30.0	6.3	90.11	38.00
4	1.0	50.0	3.0	69.53	44.00
5	2.0	30.0	2.7	71.17	47.11
6	1.0	10.0	3.0	72.11	49.87
7	3.0	10.0	6.0	84.13	43.45
8	1.0	10.0	6.0	82.62	40.13
9	2.0	54.0	4.5	72.00	47.11
10	2.0	30.0	4.5	76.92	58.74
11	1.0	50.0	6.0	81.11	34.18
12	2.0	30.0	4.5	77.11	59.49
13	0.8	30.0	4.5	74.17	49.64
14	3.0	50.0	3.0	71.64	50.13
15	2.0	30.0	4.5	77.12	58.00
16	2.0	30.0	4.5	77.00	58.76
17	2.0	6.0	4.5	74.31	46.11
18	2.0	30.0	4.5	76.93	59.00
19	3.2	30.0	4.5	73.18	53.90
20	2.0	30.0	4.5	76.93	59.40
21	3.0	10.0	3.0	73.46	48.69
22	2.0	30.0	4.5	77.71	59.10

*** Rem. means removal**

Table 4. ANOVA results for response parameters

Response	Final equation in terms of actual factor	R^2	Adj. R^2	Adec. P.	SD	CV	PRESS
Ammonia	$94.27 + 1.032A - 12.849C + 1.655C^2$	0.9422	0.8988	18.19	1.80	2.40	334.32
Mo(VI)	$-22.835 + 30.369C - 0.013B^2 - 3.634C^2$	0.9202	0.8604	11.98	3.06	6.65	712.52

***R^2: Coefficient of determination; Adj. R^2: Adjusted R^2; Adec. P.: Adequate precision; SD: Standard deviation; CV: Coefficient of variance; PRESS: Predicted residual error sum of square**

****In final equations, where A is Electrochemical Oxidation Reaction Time (h), B is Initial Concentration of Pollutants (mg/L) and C is pH.**

*****Significant in 0.05**

CONCLUSIONS

Water contamination is a worldwide problem. Ammonia, phenols and molybdenum from aqueous solution were eliminated by combined electrochemical oxidation and adsorption column. Response surface methodology was used to design experiments.

The key outcomes of this research indicated that firstly the electrochemical oxidation reactor could be able to remove 79.4%, and 55.9 % of ammonia, and Mo, respectively at the optimum conditions (contact time= 2.4 h, pH= 4.9, initial concentrations= 27.5) with fixed current and voltage on 50 mA and 7 V; secondly water was moved to adsorption column which was filled by composite adsorbents, namely BAZLSC. Adsorption method improved the removal efficiency to 99.99% for ammonia and Mo(VI).

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REFERENCES

[1] B. Barkhordar, M.Ghiasseddin,"Comparision of Langmuir and Freundlich Equilibriums in Cr, Cu and Ni Adsorption by Sargassum Iran", J. Environ. Health Sci. Eng.,vol. 1, pp. 58–64, 2004

[2] X. Du, "A review on the electrochemical treatment of the salty organic wastewater", IOP Conf. Series: Materials Science and Eng.,, vol. 87, 012037, 2015, doi:10.1088/1757-899X/87/1/012037

[3] M.J.K. Bashir, M.H. Isa, S.R.M.Kutty, Z.B.Awang, H.A. Aziz, S.Mohajeri, I.H.Farooqi, "Landfill leachate treatment by electrochemical oxidation", Waste Manag., vol. 29, pp. 2534–2541, 2009,doi: 10.1016/j.wasman.2009.05.004

[4] S.Q. Aziz, H.A. Aziz, M.S.Yusoff, "Powdered activated carbon augmented double react-settle sequencing batch reactor process for treatment of landfill leachate",

Desalination, vol. 277, pp. 313–320, 2011,doi: 10.1016/j.desal.2011.04.046

[5] M. Caetano, C.Valderrama, A.Farran, J.L. Cortina, "Phenol removal from aqueous solution by adsorption and ion exchange mechanisms onto polymeric resins", J. Colloid Interface Sci., vol. 338(2), pp. 402-409, 2009,doi: 10.1016/j.jcis.2009.06.062

[6] L.A. Rodrigues, M.L.C.Pintoda Silva, M.O. Alvarez-Mendes, A. dos Reis Coutinho, G.P.Thim, "Phenol removal from aqueous solution by activated carbon produced from avocado kernel seeds", Chem. Eng. J., vol. 174(1), pp. 49-57, 2009,doi: 10.1016/j.cej.2011.08.027

[7] A. Mojiri, H.A. Aziz, N.Q.Zaman, S.Q. Aziz, M.A.Zahed, "Metals removal from municipal landfill leachate and wastewater using adsorbents combined with biological method", Desalination and Water Treat.,vol. 57(6), pp. 2819-2833, 2016,doi: 10.1080/19443994.2014.983180

[8] X. Chen, G. Huang, J. Wang, "Electrochemical Reduction/Oxidation in the Treatment of Heavy Metal Wastewater", J. Metall. Eng., vol. 2(4), pp. 161-164, 2013.

[9] F. Duan, Y. Li, Y. Cao, Y. Wang, J.C. Crittenden, Y. Zhang, "Activated carbon electrodes: Electrochemical oxidation coupled with desalination for wastewater treatment:, Chemosphere, vol. 125, pp. 205–211, 2015.doi: 10.1016/j.chemosphere.2014.12.065

[10] Q. Du, S. Liu, Z. Cao, Y. Wang, "Ammonia removal from aqueous solution using natural Chinese clinoptilolite", Sep. Purif. Technol., vol. 44(3), pp. 229-234, 2005.doi: 10.1016/j.seppur.2004.04.011

[11] R. Cossu, A.M. Polcaro, "Lavagnolo, M.C.; Mascia, M.; Palmas, S.; Renoldi, F. (1998) Electrochemical treatment of landfill leachate: oxidation at Ti/PbO_2 and Ti/SnO_2 anodes", Environ. Sci. Technol., vol. 32, pp. 3570–3573, 1998.

[12] A. Mojiri, L.Ziyang, W.Hui, Z. Ahmad, R.M.Tajuddin, S.S. Abu Amr, T.Kindaichi,H.A. Aziz, H. Farraji, "Concentrated landfill leachate treatment with a combined system including electro-ozonation and composite adsorbent augmented sequencing batch reactor process", Process. Saf. Environ. Prot.,vol. 111, pp. 253–262. 2017.doi: 10.1016/j.psep.2017.07.013

[13] H.Y. Foo, B.H.Hameed, "An overview of landfill leachate treatment via activated carbon adsorption process", J. Hazard. Mater.,vol. 171, pp. 54–60, 2009.doi: 10.1016/j.jhazmat.2009.06.038

[14] A.A. Halim, H.A. Aziz, M.A.M.Johari, K.S. Ariffin, M.J.K. Bashir, "Semi-Aerobic Landfill Leachate Treatment Using Carbon–Minerals Composite Adsorbent", Environ. Eng. Sci., vol. 29(5), pp. 306-312, 2012.doi: 10.1089/ees.2010.0204

[15] I. Risnawati, T.P. Damanhuri, "Institute Technology Bandung", Faculty Civil and Environmental Engineering SW5-1 to SW5-11, 2010.

[16] I. Chaari, M.Medhioub, F.Jamoussi, "Use of Clay to Remove Heavy Metals from Jebel Chakir Landfill Leachate", J. App. Sci. Environ. Sanit., vol. 6(2), pp. 143-148, 2011.

[17] S.N. Ashrafizadeh, Z. Khorasani, "Ammonia removal from aqueous solutions using hollow-fiber membrane contactors", Chem. Eng. J., vol. 162, pp. 242–249, 2010.doi: 10.1016/j.cej.2010.05.036

[18] F. Kafshgari, F.Keshtkar, M.A.Mousavian, "Study of Mo (VI) removal from aqueous solution: application of different mathematical models to continuous biosorption data", Iranian J. Environ. Health Sci. & Eng.,vol. 10, pp. 14, 2013.

[19] V.B. Koppad, "Performance Evaluation of Electrochemical Oxidation System to Treat Domestic Sewage", Inter. J. Eng. Res. Techol., vol3(6), pp. 765-771, 2014.

[20] D. Kearney, O.Dugauguez, D.Bejan, N.J.Bunce, "Electrochemical Oxidation for Denitrification of Ammonia: A Conceptual Approach for Remediation of Ammonia in Poultry Barns", ACS Sustainable Chem. Eng., vol. 1, pp. 190−197, 2013.doi: 10.1021/sc300097p

[21] H.M.A. Asghar, T. Ahmad, S.N.Hussain, H.Sattar, "Electrochemical Oxidation of Methylene Blue in Aqueous Solution", Inter. J. Chem. Eng. Appl.,vol. 6(5), pp. 352-355, 2015.doi: 10.7763/IJCEA.2015.V6.508

[22] H. Xu, A. Li, L.Feng, X. Cheng, S. Ding, "Destruction of Cyanide in Aqueous Solution by Electrochemical Oxidation Method", Int. J. Electrochem. Sci.,vol. 7, pp. 7516-7525, 2012.

[23] A. Mojiri, H.A. Aziz, S.Q. Aziz, "Trends in Physical-Chemical Methods for Landfill Leachate Treatment", Inter. J. Sci. Res. Environ. Sci., vol. 1(2), pp. 16-25, 2013.doi: 10.12983/ijsres-2013-p016-025

[24] S. Biswas, U. Mishra, "Continuous Fixed-Bed Column Study and Adsorption Modeling: Removal of Lead Ion from Aqueous Solution by Charcoal Originated from Chemical Carbonization of Rubber Wood Sawdust", J. Chem., Article ID 907379, 9 pages, 2015.doi: 10.1155/2015/907379

[25] APHA,"Standard Methods for the Examination of Water and Wastewater", 21st ed. American Public Health Association, Washington DC, p. 541, 2005.

[26] S. He, Q. Huang, Y. Zhang, L. Wang, Y.Nie, "Investigation on Direct and Indirect Electrochemical Oxidation of Ammonia over Ru−Ir/TiO_2 Anode", Ind. Eng. Chem. Res.,vol. 54, pp. 1447−1451, 2015.doi: 10.1021/ie503832t

[27] Ding, J.; Zhao, Q.L.; Wei, L.L.; Chen, Y.; Shu, X. Ammonium nitrogen removal from wastewater with a three-dimensional electrochemical oxidation system. Water Sci. Technol. 2013, 68(3), 552-559, 2013.doi: 10.2166/wst.2013.262.

[28] L. Li, J. Yao, X. Fang, Y. Huang, Y. Mu, "Electrolytic ammonia removal and current efficiency by a vermiculite-packed electrochemical reactor", Sci. Rep., vol. 7, pp. 41030, 2017.doi: 10.1038/srep41030

[29] T.K. Tran, K.F. Chiu, C.Y. Lin, H.J. Leu, "Electrochemical treatment of wastewater: Selectivity of the heavy metals removal process", Int. J. Hydrogen Energy, vol. 42(45), pp. 27741-27748, 2017.doi: 10.1016/j.ijhydene.2017.05.156

[30] F. Mazloomi, M.Jalali, "Ammonium removal from aqueous solutions by natural Iranian zeolite in the presence of organic acids, cations and anions", J. Environ. Chem. Eng., vol. 4(2), pp. 1664-1673, 2016.doi: 10.1016/j.jece.2015.11.031

[31] P.V. Haseena, K.S.Padmavathy, P.Rohit Krishnan, G.Madhu, "Adsorption of Ammonium Nitrogen from Aqueous Systems Using Chitosan-Bentonite Film Composite",Procedia Technol., vol. 24, pp. 733–740, 2016.doi: 10.1016/j.protcy.2016.05.203

[32] M. Leili, J.Faradmal, F.Kosravian, M.A. Heydari, "Comparison Study on the Removal of Phenol from Aqueous Solution Using Organo-modified Bentonite and Commercial Activated Carbon", Avicenna J. Environ. Health Eng., vol. 2(1), pp. e2698, 2015.

[33] Y. Taamneh, S. Sharadqah, "The removal of heavy metals from aqueous solution using natural Jordanian zeolite", Applied Water Sci., vol. 7(4), pp. 2021-2028, 2017.doi: 10.1007/s13201-016-0382-7

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