VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ADSORPTION OF COBALT AND ZINC FROM WASTEWATER BY NIGERIAN GRASS WASTE

Anish Salian, Anston Dsouza and C. R. Girish
Department of Chemical Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India
E-Mail: girishcr1@rediffmail.com

ABSTRACT

The Nigerian grass waste was used as an adsorbent for removing cobalt and zinc from the wastewater. The adsorption studies were conducted in single and binary solution. The waste was treated with sulphuric acid to enhance the properties like pore volume, particle size and surface area. The equilibrium data from the single component mode were checked with different models to investigate the adsorption mechanism. The equilibrium data were following Langmuir isotherm for cobalt and zinc. The adsorption in the binary solution mode showed synergism signifying that the addition of a component to a system increases the total adsorption capacity of the system.

Keywords: grass waste, cobalt, zinc, isotherm, interaction, synergism.

INTRODUCTION

Water is considered an essential source of life and energy [1]. The global world is faced with the problem of access to clean drinking water because of the rapidly growing industries and increasing population [1, 2]. Industries releases wastewater that contains organic, inorganic compounds, dyes and toxic metals [2]. Among these toxic metals are considered as one of the pollutants that are stable, non-degradable and cannot be broken down into simpler compounds by microorganisms present in the aquatic environment [3, 4]. Generally toxic elements such as zinc, cobalt, lead, mercury, chromium, copper and cadmium are released from the industries and causes harmful effect on human beings and the aquatic environment [5]. Thus the water pollution caused by these toxic elements is a major issue of environmental concern [6].

But importantly the industrial wastewater contains multiple components and each of these components interacts and competes with each other during the treatment process [7]. By investigating the synergistic or antagonistic behavior between the pollutants, the mobile nature of the pollutants in the wastewater system can be found. Therefore it is required to understand the behavior of the components in wastewater to improve the efficiency of the process [8]. Thus the present work studies the removal of cobalt and zinc from multicomponent wastewater.

Zinc which is one of the toxic metals is released from the wastewater of electroplating, refining and mining [9]. It has harmful effects such as nausea, fever, diarrhea, depression, restlessness and neurological symptoms [10]. Cobalt enters the aquatic life from the wastewater of nuclear power plants, mining, metal plating and petrochemical industries [10]. The exposure of human beings to cobalt results in damaging human blood cells and other diseases like leukemia and anemia [11].

Different treatment methods are used for removing the toxic elements from wastewater. The prominent among them are ion exchange, chemical precipitation, membrane process, biosorption, biodegradation and adsorption [12, 13]. Among these adsorption using is considered to be efficient method for removing the pollutant from wastewater [14]. The process is easy in operation, different types of adsorbent can be used and the adsorbent can be regenerated [8].

Since the adsorbent prepared from non-renewable resource is expensive, it is required to prepare adsorbent from low cost and environmentally friendly agricultural waste material [15]. Therefore in the current work the adsorbent has been prepared from a grass weed Nigerian grass and used to treat zinc and cobalt from wastewater.

SIMULTANEOUS ADSORPTION AND THE INTERACTION BETWEEN THE POLLUTANTS

A binary solution having two components, interaction happens between the pollutants and the adsorbent. The interaction mechanism can be found by the comparison of the adsorption capacity of the i^{th} component in the solution having single component ($q_{i,m}$) and the adsorption capacity of the same pollutant in the binary mixture($q_{i,b}$). The different types of possible interactions are various interactions are given as.

a) Synergism: The adsorption capacity of the component increases when it is in association with the other component in the solution i.e. $q_{i,b} > q_{i,m}$.

b) Antagonism: The adsorption decreases by the presence of other pollutant in the solution i.e. $q_{i,b} < q_{i,m}$.

c) Non interaction effect: The adsorption is not affected by the other components i.e. $q_{i,b} = q_{i,m}$. [16, 17, 18, 19]

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

MATERIALS AND METHODS

Chemicals used

Cobalt nitrate hexahydrate (Finar Ltd) and Zinc sulphate heptahydrate (Finar Ltd) were used for the preparation of the solutions. The reagents sodium hydroxide pellets (Fischer Scientific Limited) and sulphuric acid (Merck India Ltd) were taken for the experiments.

Adsorbent preparation and the characterization

The Nigerian grass waste (*Pennisetum pedicellatum*) was obtained from the shrubs found near the larger trees in Manipal, Karnataka. It was first shred and washed with distilled water for 3-4 times to remove the impurities. It was then dried in a hot air oven at 120°C to remove all the moisture content and then made into fine powder [20]. The 10 g of dried powder was mixed with 40 ml of 0.2 M sulphuric acid. Then the slurry was kept in a muffle furnace at 350°C for 1 hr to improve the properties of material. Later the dried sample was washed with distilled water to neutralize the pH of the sample to 7 [21]. It was later dried for one day to remove the moisture content. It was reduced to a particle size of lesser than 0.075mm. Finally it was dried and used for the experiments.

The proximate analysis was conducted to determine the parameters moisture, ash content, volatile matter and fixed carbon [22]. The average particle size was measured with the help of particle size analyzer (CILAS 1064). The pore volume and surface area were estimated using BET equipment (Smart Instruments, India). The chemical bonds and functional groups present on the adsorbent surface were found by FTIR instrument, Shimadzu, Japan. The surface morphology of the adsorbent was investigated by Scanning Electron Microscopy (SEM), Zeiss Company, Germany. The presence of metal ions on the adsorbent were confirmed out using Energy dispersive X-ray (EDX).

Adsorption studies

The adsorption studies were carried out in 250 mL flask containing 200 mL of cobalt solution of 2, 4, 6, 8 and 10 mg/L concentration and 200 mL of zinc solution of2, 5, 10, 15 and 20 mg/L in the single component solution. The experiments in binary mixture were conducted by taking 100 mL of cobalt solution and 100 mL of zinc solution of various concentration values as represented in Table-2. The effect of experimental conditions on the adsorption were found by the variation of pH from 4 to 8 and adsorbent dosage of 0.1 to 2 g. The optimum conditions of pH and dosage were determined as 7 and 2 g respectively. The equilibrium time was determined as 3.5 hours. The isotherm studies in the single solutions were carried out by stirring the solution with the adsorbent at pH 7. The solution was agitated in a shaker at 120 rpm speed, temperature of 298 K for 3.5 hrs. After the experiments, the concentration of cobalt and zinc were measured using atomic absorption spectrophotometer (Thermo Scientific, Australia) at a wavelength of 213.9 nm and 240.8 nm respectively.

RESULTS AND DISCUSSIONS

Adsorbent characterization

The pore volume and surface area and pore volume were measured as 250.13 m^2g^{-1} and 0.1391 cm^3g^{-1} respectively showing that capability of the adsorbent to remove the pollutant. The average particle size was found to be 54.11 µm and it shows that adsorbent has enhanced efficiency. The proximate analysis was carried to determine the moisture, ash, volatile matter and fixed carbon content and were found to be 5%, 31.5%, 21.5% and 42% respectively. The value of fixed carbon signifies that the adsorbent has better adsorption capacity for removing the adsorbate from wastewater [23].

FTIR analysis

The FTIR results of the adsorbent are represented in Figures 1 and 2. It was found that the peak obtained at 3608.81 and 3626.17 cm^{-1} are because of the O-H bonding from the phenol group [24], the peak formed at 3487.30 and 3485.37 cm^{-1} are due to the O-H stretching vibration band of hydroxyl group [25]. The peak at 1130.29 and 1103.28 cm^{-1} exhibits C–N stretching [26] and the peak band at 1581.63 cm^{-1} shows C=C stretching vibration [27]. The peak at 1710.86 cm^{-1} were because of the stretching vibration from C=O bond because non-ionic carboxyl groups [28]. These bonds play a role in the adsorption of the pollutant on the adsorbent surface.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

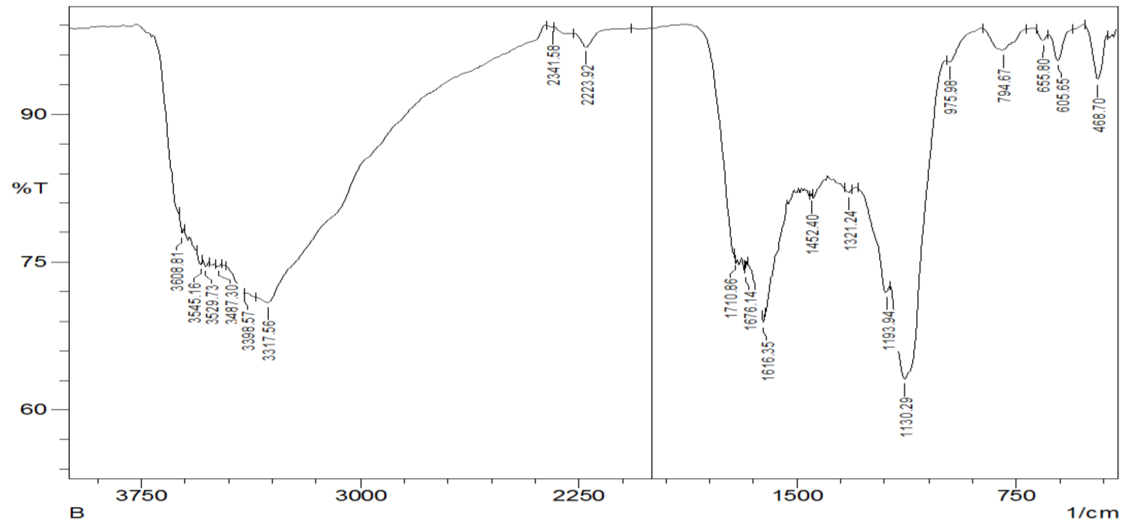

Figure-1. The FTIR analysis of the adsorbent before the adsorption.

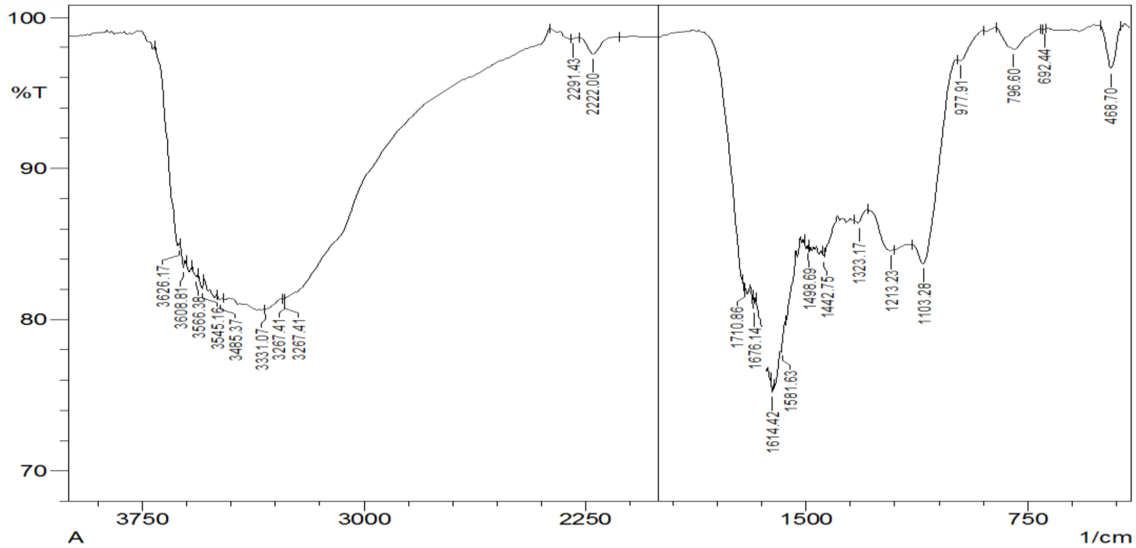

Figure-2. The FTIR analysis of the adsorbent after adsorption.

SEM and EDX analysis

SEM is a method employed for observing the surface structure of the adsorbent [29]. The surface morphology images of the adsorbent are shown in Figures 3 and 4. It can be analyzed from the SEM image that adsorbent surface is having porous structure and thus it provides required active sites for the adsorption process [30]. It also signifies that the pores are found to be responsible for the accommodating the pollutant on the adsorbent surface [31]. It was also observed that after the adsorption, the adsorbent surface becomes rough. This is because of the reason that the pores are occupied by adsorbate molecules [32].

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

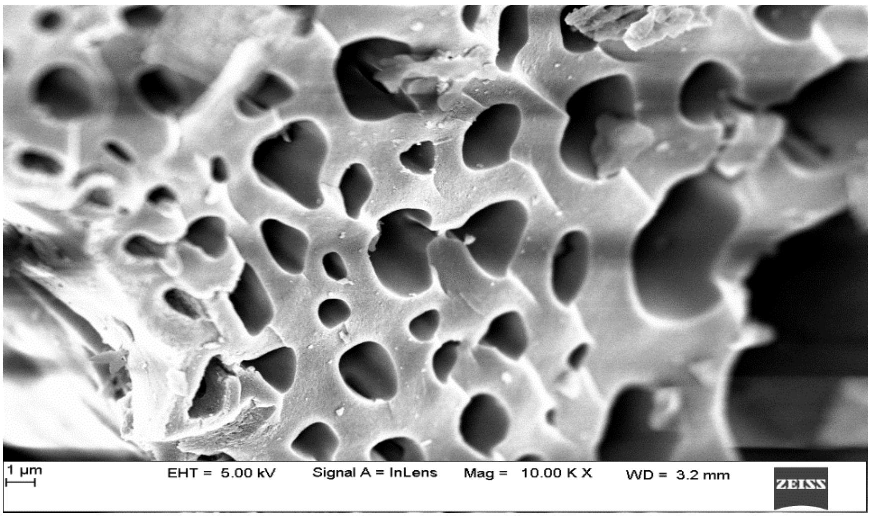

Figure-3. SEM image of the adsorbent before the adsorption.

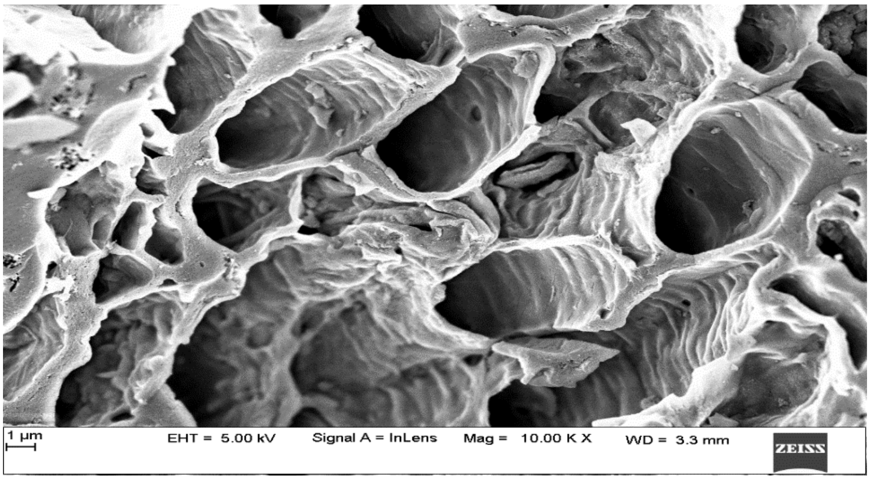

Figure-4. SEM image of the adsorbent after the adsorption.

Energy-dispersive X-ray spectroscopy (EDX) analysis was used to determine the chemical composition of the molecules on the adsorbent [33]. The EDX analysis of the adsorbents before and after the adsorbing the pollutant are shown in Figures 5 and 6. The EDX analysis before adsorption indicates the peaks for Ca^{2+}, K^{+}, Mg^{2+}, Si which is because of the presence of plant nutrients in the grass waste [34]. It was observed that after the adsorption, peaks were obtained for metal ions Zn^{2+} and Co^{2+} on the surface of adsorbent. This shows the adsorption of metal ions on the surface through the ion exchange process [35, 36].

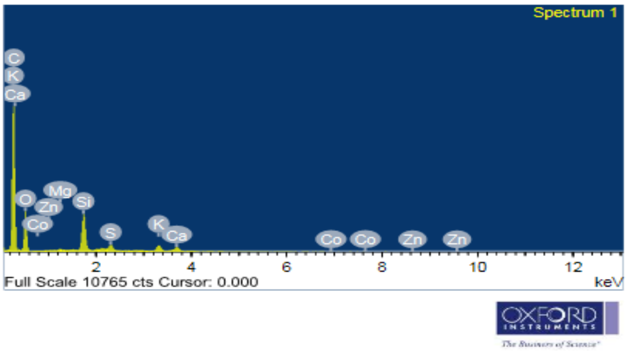

Figure-5. EDX analysis of the adsorbent before adsorption.

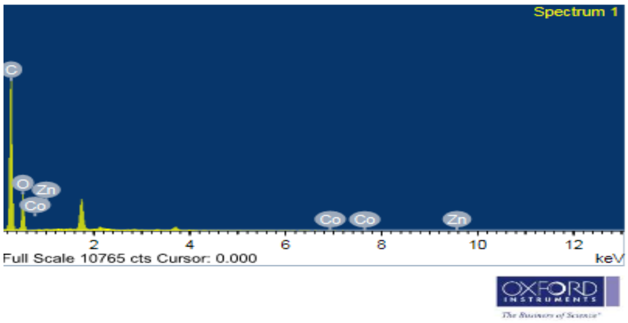

Figure-6. EDX analysis of the adsorbent after the adsorption

Isotherm studies.

Isotherm studies are important for analyzing and designing of adsorption separation process [37]. This is explained by establishing the equilibrium relation formed and the interactions between the solute molecules and the adsorbent [38].Various models such as Langmuir, Freundlich, Temkin and Dubinin-Radushkevich (D-R) models were used for understanding the adsorption mechanism.

Langmuir isotherm is developed on the assumption that the surface of adsorbent is homogeneous with uniform active sites [39]. It also explains that homogeneous solid surface has the affinity towards the solute molecules resulting in adsorption in a single layer [40]. It also discusses that the sorption energy associated with each of the molecules is uniform [41]. It is given in the linearized form as

$$\frac{C_{eq}}{q_{eq}} = \frac{C_{eq}}{q_{mn}} + \frac{1}{k_{ln} q_{mn}} \qquad (1)$$

k_{ln} (L mg^{-1}) the affinity of the pollutant to the solid surface and q_{mn}(mg g^{-1}) the maximum adsorption capacity and q_{eq} (mg g^{-1}) and C_{eq} (mg L^{-1}) are the adsorption capacity and pollutant concentration at equilibrium. The constants are obtained by plotting $1/q_{eq}$ against $1/C_{eq}$.

Freundlich isotherm is based on assumption that the adsorbent surface is heterogeneous, the solutes adsorbing on the surface increases with the concentration of solution [15, 42]. The surface sites will be occupied by many solute molecules and results in multilayer adsorption [43]. It is represented in the linear form

$$log q_{eq} = log k_{fn} + (1/n)\, log C_{eq} \qquad (2)$$

The model constants are evaluated from the plot of $logC_{eq}$v/s $logq_{eq}$. The constant n is the adsorption intensity and $k_{fr}$the Freundlich constant.

Temkin isotherm explains that the adsorption energy decreases when the solute is adsorbed onto the solid surface and is because of the interaction happening between the solute molecules and the adsorbent [10, 44]. It is given as

$$q_{eq} = B_T lnA_T + B_T lnC_{eq} \qquad (3)$$

and B_T the model constant which relates to heat of sorption and A_T the model constant The constants are calculated by plotting q_{eq} v/s lnC_{eq}.

D- R model is employed for determining the apparent free energy of adsorption and represented as [29, 44]

$$\ln q_{eq} = \ln q_{dr} + \beta \epsilon^2 \qquad (4)$$

$q_{dr}$the adsorption capacity (mg/g), β the constant related to sorption energy and the constants are evaluated by plotting lnq_{eq} v/s ϵ^2 .$\epsilon$the model constant is obtained from

$$\epsilon = RT \ln\left(1 + \frac{1}{C_{eq}}\right) \qquad (5)$$

Table-1. The isotherm constants from various models for cobalt and zinc.

	Langmuir model			**Freundlich model**		
Component	q_{mn}**(mg/g)**	k_{ln}	R^2	k_{fn}	n	R^2
Cobalt	1.3165	1.8736	0.9973	0.8231	1.4836	0.8128
Zinc	1.0708	1.6369	0.9326	0.7384	2.8008	0.6943
	Temkin model			D-R model		
	A_T(L/g)	B_T(J/mol)	R^2	q_{dr}(mg g^{-1})	β	R^2
Cobalt	4.1493	3.3573	0.6115	0.5710	7×10^{-8}	0.7468
Zinc	2.7497	1.1314	0.6582	0.4516	5×10^{-7}	0.668

The isotherm studies are conducted by varying the cobalt concentration in the range of 0 to 10 mg/L and zinc concentration from 0 to 20 mg/L. Various isotherm model equations were checked with equilibrium data obtained for single component solution. The model parameters calculated from the models and the regression coefficient values for the components cobalt and zinc are given in Table-1. Based on the regression coefficient values, it is studied that the equilibrium data was fitting best with the Langmuir model which shows that the adsorption happens in monolayer and it is chemical in nature [45]. The larger the k_{ln}value for a component, the component will have

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

more affinity to the adsorbent. Thus it can be inferred that the cobalt is having higher affinity towards the adsorbent [46]. The adsorption intensity shows the favourability of the process. The n value higher than unity for both the components signifies that the process is favorable [43, 47]. The A_T value calculated for maximum for cobalt showing that the cobalt adsorption was more on the surface of the adsorbent [10].

The simultaneous adsorption of pollutants and the interaction effect in the binary solution

The isotherm studies were performed at different concentrations of cobalt and zinc. The adsorption capacity, percentage removal in the single and binary mixture and the interaction effect are represented in Table-2. The interaction effect was determined using additive rule. The comparison of total adsorption capacity of the pollutants in single solution and binary mixture were done. The adsorption capacity of the pollutants in the single solution $(\sum_{j=1}^{2} q_{j,m})$ and binary solution mode $(\sum_{j=1}^{2} q_{j,b})$ are obtained as

$$\sum_{j=1}^{2} q_{j,m} = q_{i,m} + q_{j,m} \tag{6}$$

$$\sum_{j=1}^{2} q_{j,b} = q_{i,b} + q_{j,b} \tag{7}$$

If the value of $(\sum_{j=1}^{2} q_{j,b}) > (\sum_{j=1}^{2} q_{j,m})$ then synergism plays a significant role in the system. The value of $(\sum_{j=1}^{2} q_{j,b}) < (\sum_{j=1}^{2} q_{j,m})$ shows that antagonistic mechanism becomes the controlling factor [48].

The total percentage removal $(total\ rem\%)$ for the total and individual system was calculated as

$$total\ rem\% = \frac{\left((C_{o,i}-C_{e,i})+(C_{o,j}-C_{e,j})\right)}{(C_{o,i}+C_{o,j})} \tag{8}$$

where $C_{o,i}$ and $C_{e,i}$ are the initial and final concentrations for the components.

Table-2. The adsorption capacity and percentage removal of cobalt and zinc in single and binary component system.

C_o, cobalt (mg/l)	C_o, zinc (mg/l)	q_{eq}, cobalt (mg/g)	q_{eq}, zinc (mg/g)	$(\sum_{j=1}^{2} q_{j,b})$ (mg/g) binary	$(\sum_{j=1}^{2} q_{j,m})$ (mg/g) single	% rem, cobalt	% rem, zinc	(total rem%), com	(total rem%), ind
0	0	0	0	0		0	0	0	
2	0	0.1678	0	0.1678		83.9	0	83.9	
4	0	0.184	0	0.184		46	0	46	
6	0	0.4848	0	0.4848		80.8	0	80.8	
8	0	0.4147	0	0.4147		51.83	0	51.83	
10	0	0.8817	0	0.8817		88.17	0	88.17	
0	2	0	0.12	0.12		0	60	60	
2	2	0.1768	0.108	0.2848	0.2878	88.4	54	71.2	71.95
4	2	0.3819	0.1599	0.5418	0.304	95.47	79.95	90.3	50.66
6	2	0.5909	0.1437	0.7346	0.6048	98.48	71.85	91.825	75.6
8	2	0.7772	0.1172	0.8944	0.5347	97.15	58.6	89.44	53.47
10	5	0.9621	0.1322	1.0943	1.0017	96.21	66.1	91.19	83.475
0	5	0	0.4066	0.4066		0	81.32	81.32	
2	5	0.165	0.3944	0.5594	0.5744	82.5	78.88	79.91	82.05
4	5	0.3559	0.4018	0.7577	0.5906	88.9	80.36	84.18	65.62
6	5	0.5629	0.3625	0.9248	0.8914	93.71	72.5	84.07	81.03
8	5	0.7709	0.4209	1.1918	0.8213	96.36	84.18	91.67	63.17
10	5	0.9428	0.4145	1.3573	1.2833	94.28	82.9	90.48	85.88
0	10	0	0.8167	0.8167		0	81.67	81.67	
2	10	0.1502	0.691	0.8412	0.9845	75.1	69.1	70.1	82.04
4	10	0.383	0.8423	1.2253	1.0007	95.75	84.23	87.52	71.47
6	10	0.5734	0.8608	1.4342	1.3015	95.56	86.08	89.63	81.34
8	10	0.7486	0.8795	1.6281	1.2314	93.57	87.95	90.45	68.41
10	10	0.9426	0.8778	1.8204	1.6984	94.26	87.78	91.02	84.92
0	15	0	1.3193	1.3193		0	87.95	87.95	
2	15	0.197	1.3905	1.5875	1.4871	98.5	92.7	93.88	87.47
4	15	0.3738	1.3939	1.7677	1.5033	93.45	92.92	93.03	79.12
6	15	0.5888	1.4029	1.9917	1.8041	98.13	93.52	94.84	85.90
8	15	0.769	1.3879	2.1569	1.733	96.125	92.52	93.77	75.33
10	15	0.9181	1.3625	2.2806	2.201	91.81	90.83	91.22	88.04
0	20	0	1.7158	1.7158		0	85.79	85.79	
2	20	0.1672	1.7689	1.9361	1.8836	83.6	88.44	88.00	85.61
4	20	0.3878	1.8589	2.2467	1.8998	96.95	92.94	93.61	79.15
6	20	0.5773	1.8583	2.4365	2.2006	96.21	92.91	93.67	84.63
8	20	0.7666	1.8647	2.6313	2.1305	95.82	93.23	93.97	76.08
10	20	0.9302	1.8685	2.7987	2.5975	93.02	93.42	93.29	86.58

It was investigated from the Table-2 that the total adsorption capacity $(\sum_{j=1}^{2} q_{j,b})$for the binary solution was higher than adsorption capacity$(\sum_{j=1}^{2} q_{j,m})$ for the individual components. This shows that the system follows synergistic type of behaviour. Similar nature of results was observed with total percentage removal in the combined and individual mode. The possible reasons are because of the solute properties such as ionic potential, ionic size, molecular polarity, affinity towards the adsorbent, molecular weight, and also the properties of the adsorbent like surface properties, porosity and functional groups [49, 50].

CONCLUSIONS

The current studies showed that the capability of the grass waste to adsorb cobalt and zinc from wastewater. The surface properties were found to be improved after the chemical treatment. The FTIR analysis showed the peaks which were responsible for adsorption and SEM analysis exhibited the adsorption of the pollutant on the adsorbent. The isotherm data fitted with Langmuir isotherm showing that the process follows chemical adsorption. The monolayer adsorption capacity was obtained as 1.3165 mg/g and 1.0708 mg/g for cobalt and zinc respectively. The total adsorption capacity of the binary solution was higher than that of single component solution demonstrating that the system follows synergistic behaviour.

REFERENCES

[1] A. Bhatnagar, M. Sillanpää. 2010. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment-a review. Chemical Engineering Journal. 157(2-3): 277-296.

[2] A. Bhatnagar, M. Sillanpää. 2009. Applications of chitin-and chitosan-derivatives for the detoxification of water and wastewater-a short review [.Advances in Colloid and Interface Science. 152(1-2): 26-38.

[3] S. M. Mohan. 2014. Simultaneous adsorption and biodegradation process in a SBR for treating wastewater containing heavy metals. Journal of Environmental Engineering. 140(4): 04014008.

[4] A. Demirbas. 2008. Heavy metal adsorption onto agro-based waste materials: a review. Journal of Hazardous Materials. 157(2-3): 220-229.

[5] W. W. Ngah, M. A. K. M Hanafiah. 2008. Removal of heavy metal ions from wastewater by chemically modified plant wastes as adsorbents: a review. Bioresource Technology. 99(10): 3935-3948.

[6] M. A. Acheampong, R. J. Meulepas, P. N. Lens. 2010. Removal of heavy metals and cyanide from gold mine wastewater. Journal of Chemical Technology & Biotechnology. 85(5): 590-613.

[7] Y. Sudhakar, A. K. Dikshit. 2010. Competitive sorption of pesticides onto treated wood charcoal and the effect of organic and inorganic parameters on adsorption capacity. Journal of Environmental Engineering. 136(10): 1096-1104.

[8] A. L. Arim, G. Guzzo, M. J. Quina, L. M. Gando-Ferreira. 2018. Single and binary sorption of Cr (III) and Ni (II) onto modified pine bark. Environmental Science and Pollution Research. 25(28): 28039-28049.

[9] V. Thangaraj, K. Aravamudan, R. Lingam, S. Subramanian. 2019. Individual and simultaneous adsorption of Ni (II), Cd (II), and Zn (II) ions over polyamide resin: Equilibrium, kinetic and thermodynamic studies. Environmental Progress & Sustainable Energy. 38(s1): S340-S351.

[10] J. Ray, S. Jana, S. K. Bhanja, T. Tripathy. 2018. Efficient removal of Co (II), Ni (II), and Zn (II) metal ions from binary and ternary solutions using a pH responsive bifunctional graft copolymer. Colloid and Polymer Science. 296(8): 1275-1291.

[11] W. Hu, S. Lu, W. Song, T. Chen, T. Hayat, N. S. Alsaedi, C. Chen, H. Liu. 2018. Competitive adsorption of U (VI) and Co (II) on montmorillonite: a batch and spectroscopic approach. Applied Clay Science. 157: 121-129.

[12] Q. U. Jiuhui. 2008. Research progress of novel adsorption processes in water purification: A review. Journal of Environmental Sciences. 20(1): 1-13.

[13] A. Dutta, L. Zhou, C. O. Castillo-Araiza, E. De Herdt. 2015. Cadmium (II), lead (II), and copper (II) biosorption on baker's yeast (*Saccharomyces cerevesiae*). Journal of Environmental Engineering. 142(9): C6015002.

[14] D. H. Carrales-Alvarado, R. Leyva-Ramos, J. I. Martínez-Costa, R. Ocampo-Pérez. 2018. Competitive Adsorption of Dimetridazole and Metronidazole Antibiotics on Carbon Materials from Aqueous Solution. Water, Air, & Soil Pollution. 229(4): 108.

[15] S. J. Cobbina, A. B. Duwiejuah, A. K. Quainoo. 2018. Single and simultaneous adsorption of heavy metals onto groundnut shell biochar produced under fast and slow pyrolysis. International Journal of Environmental Science and Technology. 1-10.

[16] F. Bouhamed, Z. Elouear, J. Bouzid, B. Ouddane. 2016. Multi-component adsorption of copper, nickel and zinc from aqueous solutions onto activated carbon

prepared from date stones. Environmental Science and Pollution Research. 23(16): 15801-15806.

[17] Z. Aksu, Ü. Açıkel, T. Kutsal. 1997. Application of multicomponent adsorption isotherms to simultaneous biosorption of iron (III) and chromium (VI) on C. vulgaris. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental and Clean Technology. 70(4): 368-378.

[18] B. Agarwal, C. Balomajumder. 2015. Removal of phenol and cyanide in multi-substrate system using copper impregnated activated carbon (Cu-GAC). Environmental Progress & Sustainable Energy. 34(6): 1714-1723.

[19] N. Singh, A. Kumari, C. Balomajumder. 2018. Modeling studies on mono and binary component biosorption of phenol and cyanide from aqueous solution onto activated carbon derived from saw dust. Saudi Journal of Biological Sciences. 25(7): 1454-1467.

[20] A. H. Mahvi, A. Maleki, A. K. B. A. R. Eslami. 2004. Potential of rice husk and rice husk ash for phenol removal in aqueous systems. American Journal of Applied Sciences. 1(4): 321-326

[21] B. H. Hameed, R. R. Krishni, S. A. Sata. 2009. A novel agricultural waste adsorbent for the removal of cationic dye from aqueous solutions. Journal of Hazardous Materials. 162(1): 305-311.

[22] APHA.1989. Standard Methods for the Examination of Water and Wastewater, American Water Works Association, New York, NY, USA, 17th edition.

[23] M. Sathishkumar, A. R. Binupriya, D. Kavitha, S. E. Yun. 2007. Kinetic and isothermal studies on liquid-phase adsorption of 2, 4-dichlorophenol by palm pith carbon. Bioresource Technology. 98(4):866-873.

[24] R. T. Morrison, R. N. Boyd. 2004. Organic Chemistry, Pearson Education, Singapore, 6th edition.

[25] A. T. M. Din, B. H. Hameed, A. L. Ahmad. 2009. Batch adsorption of phenol onto physiochemical-activated coconut shell. Journal of Hazardous Materials. 161(2-3): 1522-1529.

[26] B. H. Hameed, I. A. W. Tan, A. L. Ahmad. 2008. Adsorption isotherm, kinetic modeling and mechanism of 2, 4, 6-trichlorophenol on coconut husk-based activated carbon. Chemical Engineering Journal. 144(2): 235-244.

[27] I. A. W. Tan, A. L. Ahmad, B. H. Hameed. 2008. Preparation of activated carbon from coconut husk: optimization study on removal of 2, 4, 6-trichlorophenol using response surface methodology. Journal of Hazardous Materials. 153(1-2): 709-717.

[28] M. Iqbal, A. Saeed, S. I. Zafar. 2009. FTIR spectrophotometry, kinetics and adsorption isotherms modeling, ion exchange, and EDX analysis for understanding the mechanism of Cd^{2+} and Pb^{2+} removal by mango peel waste. Journal of Hazardous Materials. 164(1): 161-171.

[29] M. Kilic, E. Apaydin-Varol, A. E. Pütün. 2011. Adsorptive removal of phenol from aqueous solutions on activated carbon prepared from tobacco residues: equilibrium, kinetics and thermodynamics. Journal of Hazardous Materials. 189(1-2): 397-403.

[30] T. S. Anirudhan, S. S. Sreekumari, C. D. Bringle. 2009. Removal of phenols from water and petroleum industry refinery effluents by activated carbon obtained from coconut coir pith. Adsorption. 15(5-6): 439.

[31] J. M. R. R. Arana, R. R. Mazzoco. 2010. Adsorption studies of methylene blue and phenol onto black stone cherries prepared by chemical activation. Journal of Hazardous Materials, 180(1-3): 656-661.

[32] B. H. Hameed, M. I. El-Khaiary. 2008. Sorption kinetics and isotherm studies of a cationic dye using agricultural waste: broad bean peels. Journal of Hazardous Materials. 154(1-3): 639-648.

[33] V. K. Rathore, D. K. Dohare, P. Mondal. 2016. Competitive adsorption between arsenic and fluoride from binary mixture on chemically treated laterite. Journal of Environmental Chemical Engineering. 4(2): 2417-2430.

[34] P. Girods, A. Dufour, V. Fierro, Y. Rogaume, C. Rogaume, A. Zoulalian, A. Celzard. 2009. Activated carbons prepared from wood particleboard wastes: Characterisation and phenol adsorption capacities. Journal of Hazardous Materials. 166(1): 491-501.

[35] A. Gupta, C. Balomajumder. 2015. Simultaneous adsorption of Cr (VI) and phenol onto tea waste biomass from binary mixture: multicomponent adsorption, thermodynamic and kinetic study. Journal

of Environmental Chemical Engineering. 3(2): 785-796.

[36] H. Lu, Z. Zhu, H. Zhang, J. Zhu, Y. Qiu. 2015. Simultaneous removal of arsenate and antimonate in simulated and practical water samples by adsorption onto Zn/Fe layered double hydroxide. Chemical Engineering Journal. 276: 365-375.

[37] J. Febrianto, A. N. Kosasih, J. Sunarso, Y. H. Ju, N. Indraswati, S. Ismadji. 2009. Equilibrium and kinetic studies in adsorption of heavy metals using biosorbent: a summary of recent studies. Journal of Hazardous Materials. 162(2-3): 616-645.

[38] M. L. Soto, A. Moure, H. Domínguez, J. C. Parajó. 2011. Recovery, concentration and purification of phenolic compounds by adsorption: a review. Journal of Food Engineering. 105(1): 1-27.

[39] Q. S. Liu, T. Zheng, P. Wang, J. P. Jiang, N. Li. 2010. Adsorption isotherm, kinetic and mechanism studies of some substituted phenols on activated carbon fibers. Chemical Engineering Journal. 157(2-3): 348-356.

[40] H. Cherifi, S. Hanini, F. Bentahar. 2009. Adsorption of phenol from wastewater using vegetal cords as a new adsorbent. Desalination. 244(1-3): 177-187.

[41] Y. Babaee, C. N. Mulligan, M. S. Rahaman. 2018. Removal of arsenic (III) and arsenic (V) from aqueous solutions through adsorption by Fe/Cu nanoparticles. Journal of Chemical Technology & Biotechnology. 93(1): 63-71.

[42] K. H. Park, M. S. Balathanigaimani, W. G. Shim, J. W. Lee, H. Moon. 2010. Adsorption characteristics of phenol on novel corn grain-based activated carbons. Microporous and Mesoporous Materials, 127(1-2): 1-8.

[43] M. Bozorgi, S. Abbasizadeh, F. Samani, S. E. Mousavi. 2018. Performance of synthesized cast and electrospun PVA/chitosan/ZnO-NH_2 nano-adsorbents in single and simultaneous adsorption of cadmium and nickel ions from wastewater. Environmental Science and Pollution Research. 25(18): 17457-17472.

[44] M. Omidinasab, N. Rahbar, M. Ahmadi, B. Kakavandi, F. Ghanbari, G. Z. Kyzas, S. S. Martinez, N. Jaafarzadeh. 2018. Removal of vanadium and palladium ions by adsorption onto magnetic chitosan nanoparticles. Environmental Science and Pollution Research. 25(34): 34262-34276.

[45] C. R. Girish, P. Singh, A. K. Goyal. 2017. Removal of Phenol from Wastewater Using tea waste and optimization of conditions using response surface methodology. International Journal of Applied Engineering Research. 12(13): 3857-3863.

[46] V. C. Srivastava, I. D. Mall, I. M. Mishra. 2009. Competitive adsorption of cadmium (II) and nickel (II) metal ions from aqueous solution onto rice husk ash. Chemical Engineering and Processing: Process Intensification. 48(1): 370-379

[47] M. Caetano, C. Valderrama, A. Farran, J. L. Cortina. 2009. Phenol removal from aqueous solution by adsorption and ion exchange mechanisms onto polymeric resins. Journal of Colloid and Interface Science. 338(2): 402-409.

[48] T. Bohli, A. Ouederni, I. Villaescusa. 2017. Simultaneous adsorption behavior of heavy metals onto microporous olive stones activated carbon: analysis of metal interactions. Euro-Mediterranean Journal for Environmental Integration. 2(1): 19.

[49] H. Sukpreabprom, O. Arqueropanyo, W. Naksata, P. Sooksamiti, S. Janhom. 2015. Single and binary adsorption of Cd (II) and Zn (II) ions from aqueous solutions onto bottom ash, Korean Journal of Chemical Engineering. 32(5): 896-902.

[50] A. Erto, F. Di Natale, D. Musmarra, A. Lancia. 2015. Modeling of single and competitive adsorption of cadmium and zinc onto activated carbon. Adsorption. 21: 611-621.