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Removal of aluminium (III) from waste waters using bio-sorbents pertaining to *Withania somnifera* plant

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ABSTRACT

Removal of Aluminum (III) from waste waters using bio-adsorbents derived from plant materials of Withania somnifera has been investigated by varying various physicochemical parameters such as pH, time of equilibration, sorbent dosage, agitation time, initial concentration of Aluminum ions, temperature and presence of foreign ions using simulated waters and by adopting batch methods of extraction. Optimum conditions for the maximum extraction of Al (III) ions have been investigated. The adsorption process is analyzed with Freundlich, Langmuir, Temkin and Dubinin-Radushkevich (D-R) isotherm models and found that the Langmuir isotherm model better describes the adsorption process emphasizing the mono-layer formation of the Al (III) ions on the adsorbent and further, the mean free energy (E) and heats of sorption (B) of Temkin isotherm and Dubinin-Radushkevich isotherms indicate that the adsorption is 'physisorption' in nature. Kinetics of adsorption is quantified using pseudo first-order, pseudo second-order, Weber and Morris intraparticle diffusion, Bangham's pore diffusion and Elovich equations and found that the adsorption process has good correlation coefficient values with pseudo-second-order model.The endothermic nature of the adsorption is found on the analysis of the thermodynamic parameters, ΔH, ΔS and ΔG. Interference of common co-ions has been studied. The methodologies developed are successfully applied to industrial sewages and polluted natural waters.

Key words: Aluminum (III), pollution control, bio-sorbents, kinetics, adsorption isotherms, *Withania somnifera*

INTRODUCTION

Exploring the adsorption abilities of bio-sorbents derived from plant materials towards different pollutants in the removal of the latter from waste or polluted waters is being increasing investigated throughout the Globe. Our research group has been investigating on these bio-methods of pollution and successfully developed methods for the removal of Chromium (VI) (1-4), Zinc (5,6), Aluminium (III) (7-10), Fluoride (11-17), Nitrite (18,19), Nitrates (20), Ammonia(21-23),Phosphate (24,25) and Dyes (26-29). Further, bio-remediation methods are developed for the control of metal ions using oxidation ponds and different bio-masses *(30).* In the present work, bio-sorbents derived from plant material of *Withania somnifera* plant have been investigated for their effectiveness in the removal of toxic Aluminium (III) ions from polluted waters.

The presence of Aluminum (III) in water-bodies is harmful to aquatic life and it a neurotoxin (31) and its consumption by human beings, results in serious disorders such as kidney disorders, *Parkinson and Alzheimer's disease (32) , mellowing of bones (33), effecting the eye sight, pulmonary fibrosis and microcytic anemia (34).* Hence, as per WHO and US drinking waters standards, the maximum permissible limit of Aluminium (III) is: 0.2 ppm. Inadequately treated effluents from industries pertaining to food and beverages, dyeing, textile and drugs and residual aluminum in treated municipal waters, are the main source of contamination. Further, nearly 7% of Aluminium present in the earth's crust is leached into the nearby water bodies under acidic conditions and it becomes detrimental to the biota, micro-organisms and human beings.

The methods based on aeration/stripping, sedimentation and filtration are ineffective at micro levels and methods based on ion-exchange, reverse osmosis Electrodialysis are expensive (35-38). The non-conventional methods based on bio-adsorbents are being used in removing Aluminum ions from polluted waters. Algal biomass (39), powdered marble wastes (40), combination of active carbon as adsorbent and oleic acid as surfactant (41), water hyacinth (42), Chitosan (43), rice husk char and activated rice husk char (35,44) have been investigated for the removal of Aluminium ions from waste waters. Bio-absorbents derived from *Acacia Melanoxylon and Eichhornia Crassipes* Plants (7), *Moryngea Millingtonia* and *Cygium Arjunum Plant (9), Achiranthus aspera and Cassia Occidentalis (10), have been successfully used to remove Aluminium (III) from polluted waters.*

In the present work, bio-adsorbent derived from leaves and stems of *Withania somnifera* plant have been investigated by varying various physicochemical parameters to optimize the conditions of extraction for the maximum removal of Aluminium ions from polluted waters.

MATERIALS AND METHODS

Bi-adsorbent derived from the leaves and stems of *Withania somnifera* plant (Figure 1) are found to have *affinity for Aluminum (III) ions. Withania somnifera* (*ashwagandha)* is an herb in the Solanaceae family and it grows in wet lands. It has many medicinal values and this plants parts are used in the preparation of some Ayurvedic medicines in the cure of tumors, tubercular glands, carbuncles, and ulcers.

Figure 1: *Withania somnifera* plant

Adsorbents are prepared from the leaves and stems of *Withania somnifera* plant and are used in the extraction of Aluminium ions from polluted waters using batch methods of extraction (47-49).

Preparation of the Bi-adsorbents: The leaves and stems of *Withania somnifera* plant were cut, washed with tap water followed by distilled water and then sun dried. The dried materials were powdered to a fine mesh of size: < than 75 microns and activated at 105^{O} C in an oven and then employed in this study. Further, these leaves and stems were burnt to ashes and these ashes were also used in this work.

Extraction Method: Weighted quantities of adsorbents were taken in to previously washed 1 lit/500 ml stopper bottles containing 500ml/250 ml of Aluminum Potassium Sulphate solution of predetermined concentrations. The various initial pH values of the suspensions were adjusted with dil HCl or dil NaOH solution using pH meter. The samples were shaken vigorously in mechanical shakers and were allowed to be in equilibrium for the desired time. After the equilibration period, an aliquot of the sample was taken for Aluminum determination. Aluminum (III) was determined spectrophotometrically by using "Eriochrome cyanine R" method (50). In this work all chemical used were of analytical grade and double distilled water was used for the preparation of solution.

The sorption nature of the bio-adsorbents were studied by varying physicochemical parameters such as pH, time of equilibration, initial concentration of the adsobate, adsorbent dosage and temperature. The results were presented in the Graph No. 1 to 13 and Table 1-3.

Effect of Co-ions: The presence of tenfold excess of common co-ions on the % of extraction of the Aluminium ion was studied at other optimum conditions of extraction as inferred from the Graph No. 1-3 and the results were presented in the Table: 4.

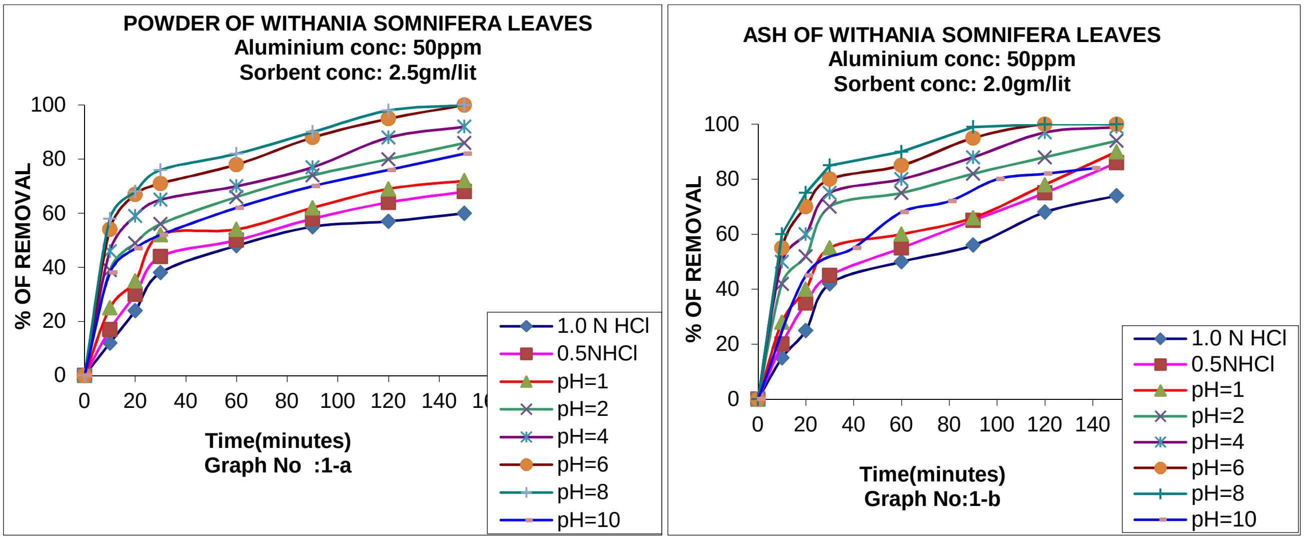
E: APPLICATIONS: The procedures developed for the extraction of Aluminium ions using synthetic simulated solutions, were applied to samples collected from the effluents of Aluminum based industries and the results were presented in the Table 5.

RESULTS AND DISCUSSION

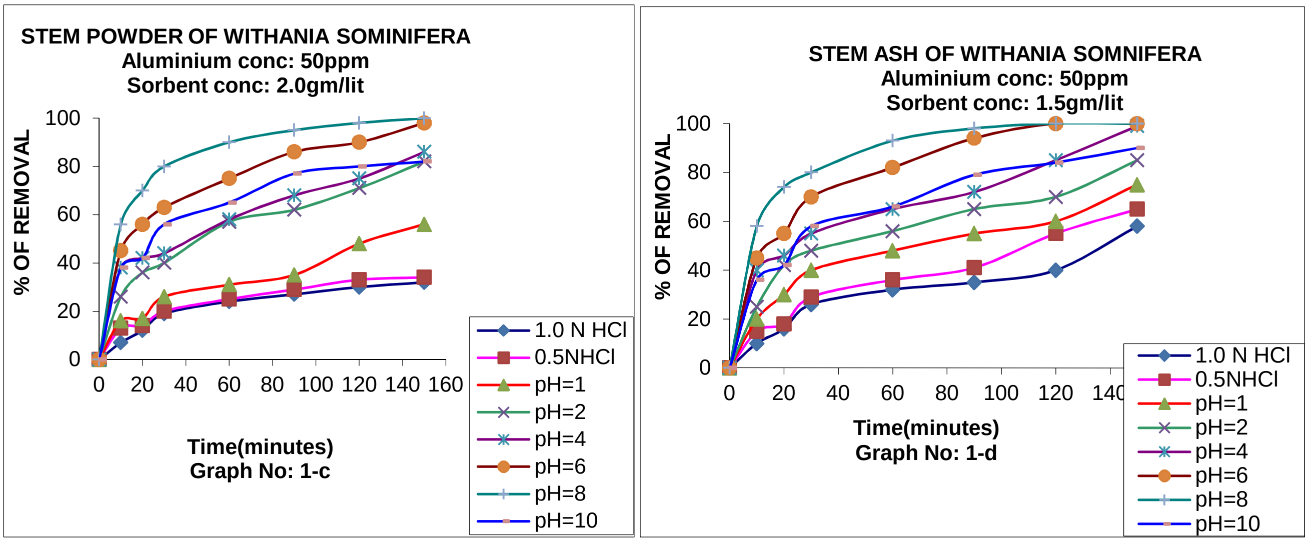
It is observed that the % of extraction is affected by pH, time of equilibration, sorbent dosage, temp., and initial concentration of the adsorbate.

A: Effect of Time of Equilibration:

With the increase in time of equilibration, % removal of Aluminium ions also increases and after certain time, no more adsorption is found (vide Graph Nos. A: 1-a to 1-d). For instance, at other optimum conditions of extraction, % removal is found to be: 58% at 10 minutes, 68 % at 20 minutes, 76% at 30 minutes, 82% at 60 minutes, 90% at 90 minutes, 98% at 120 minutes and 100% at 150 minutes or above with the bio-adsorbents pertaining to leaves powders (vide Graph No.1-a). The optimum time for agitation is found to be 150 minutes for bio-adsorbent pertaining to the leaves and stems at optimum pH: 8 while it is 120 minutes with their ashes. (vide Graph No: 1)

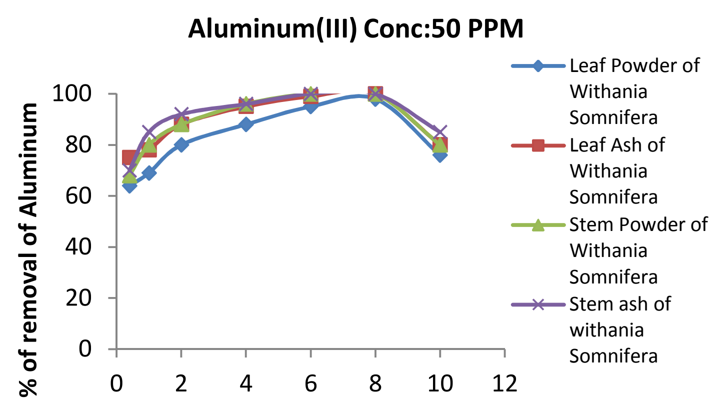


Graph Nos. 1-a & b: Removal of Aluminum (III) Vs Time of Equilibration with Leaves based bio-adsorbents of *Withania Somnifera* plant



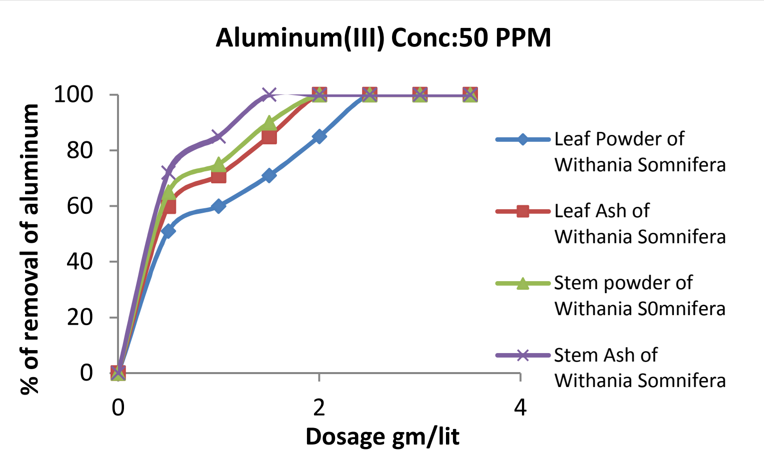
Graph Nos. 1-c & d: Removal of Aluminum (III) Vs Time of Equilibration with stem based bio-adsorbents of *Withania Somnifera* plant

B: Effect of pH: The optimum pH is found to be between 6 to 8 (Vide Graph: 2). 100% of removal of Aluminium is observed with all the bio-adsorbents developed in this work when all other conditions of extractions are optimized namely: equilibration time : 150 minutes and sorption dosage: 2.5gm/lit for leaves powders; equilibration time of 120 minutes and sorption dosage: 2.0 gm/lit for .leaves ashes; equilibration time : 150minutes and sorbent dosage:2.0gm/lit for stems powder and equilibration time of 120 minutes and sorbent dosage :1.5gm/lit for stem ashes.



Graph No: 2: pH Vs. %of Removal of Al (III)

C: Sorbent Dosage: The optimum sorbent dosage is found to be 2.5 gram/lit for the leaves bio-adsorbent and 2.0 gm/lit with its ashes. With stems bio-adsorbent, the dosage is found to be: 2.0gm/lit and 1.5 gm/lit. with their ashes (vide Graph No : 3:)



Graph No:3: Dosage Vs % of removal of Al (III)

D: Effect of Temperature:

The influence of temperature on the extraction of Aluminum was investigated at 303, 313 and 323K with simulated 5.0 mg/l Aluminum solutions and at other optimum conditions of extractions. The observations are presented as ln K_d Vs 1/T as shown in Graph No.4-a to 4-d. Thermodynamic parameters free energy (ΔG) (kJ/mole), change in enthalpy (ΔH) (kJ/mole) and change in entropy (ΔS) (J/K/mole) were determined at different temperatures by using the equations [51-53], $\Delta G = -RT \ln K_d$; $\ln K_d = \Delta S/R - \Delta H/RT$; $K_d = q_e/C_e$ and $\Delta G = \Delta H - T\Delta S$, where K_d is the distribution coefficient for the adsorption, q_e is the amount of Aluminum ion adsorbed on the adsorbent per liter of solution at equilibrium, C_e is the equilibrium concentration of Aluminum(III) ion solution, T is the absolute temperature in Kelvin, R is the gas constant. The values of ΔH and ΔS were obtained from the slope and intercept of a plot between ln Kd and 1/T and ΔG values were obtained from the equation ΔG = ΔH-TΔS and tabulated (vide Table 1) [54, 55].

Table 1: Thermodynamic parameters of Aluminum (III) ion adsorption on Bio-adsorbents

Parameter	ΔH(kJ/mol)	ΔS(J/mol/K)	ΔG (kJ/mol)			R^2
Temperature(K)			303	313	323	
Leaf Powder	11.88	40.273	-0.3227	-0.7251	-1.1281	0.9888
Leaf ash	12.22	42.509	-0.65922	-1.0843	-1.5094	0.9771
Stem Powder	45.169	158.04	-2.7171	-4.2975	-5.8779	0.9772
Stem ash	67.459	234.122	-3.480	-5.8211	-8.1624	0.9805

As the temperature increases from 303 to 323K (30 to 50^{0}C), the % extraction Aluminum(III) ion increases from 71.5 to 75.5% in the case leaves bio-sorbent; 80.0 to 86.5% with ahses of leaves; 74.5to 79.5% with stems bio-sorbent; 83.0 to 88.5% with stems ash. With the increase in temperature, the diffusion of Al^{3+} into the surface layers of the adsorbent is more facilitated due to the increase in K.E. of the ions and decrease in the density of outer surface of the adsorbent.

From the Table 1, it can be inferred that the adsoprtion process is:
- endothermic in nature as the R^2 is near to "one" and ΔH is positive
- physisorption as the ΔH is positive [56]
- increased disorder and randomness at the solid solution interface as the ΔS is positive [57].
- spontaneous nature as ΔG is negative [58].

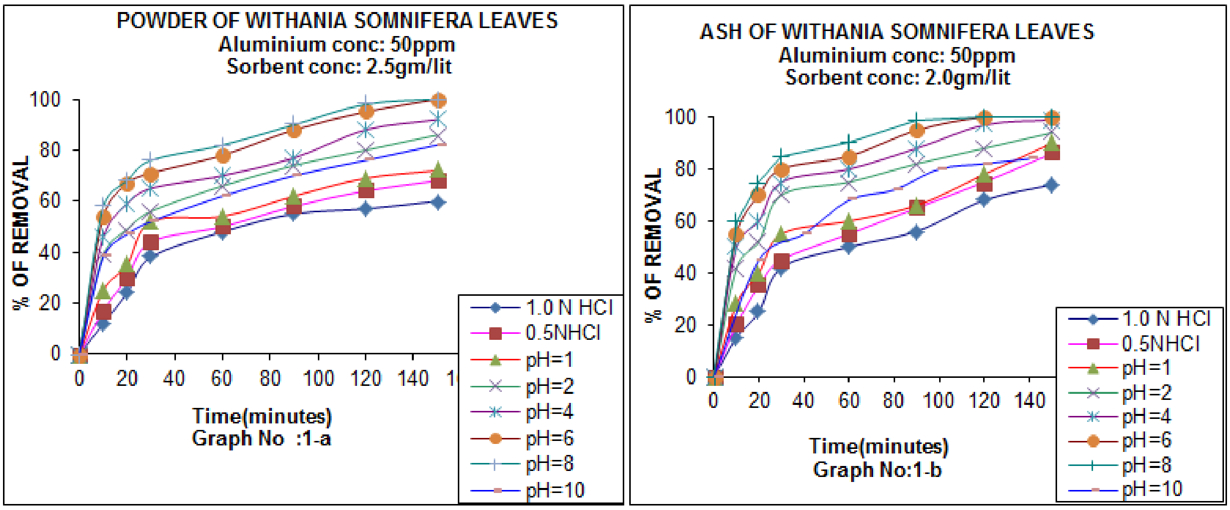
E: Adsorption Isotherms:

Freundlich [59], Langmuir [60], Temkin [61] and Dubinin-Radushkevich [62] isotherms are used to evaluate the nature of adsorption.

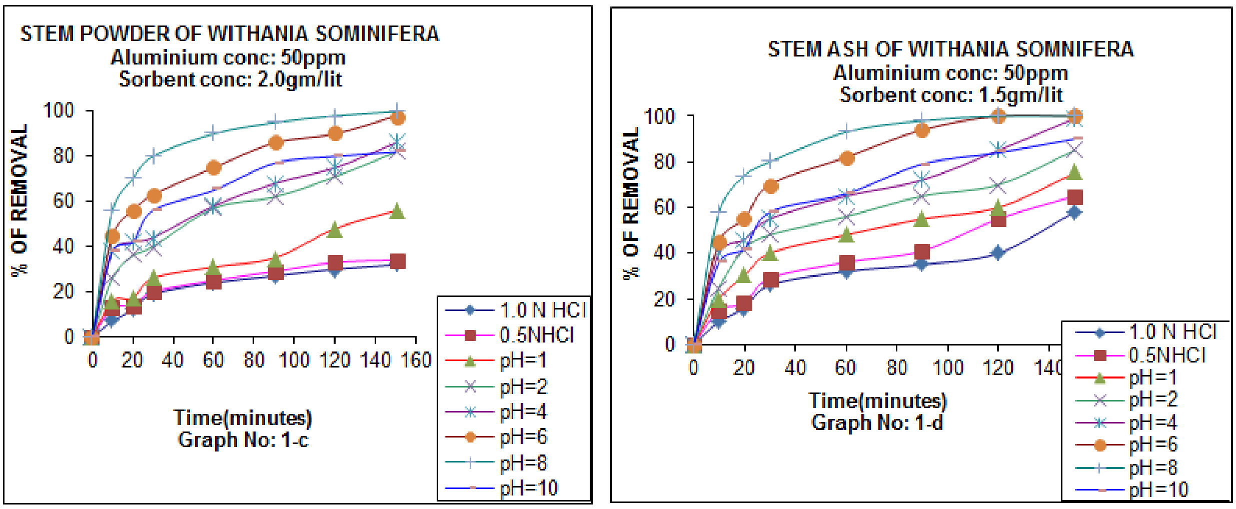
Linear form of Freundlich equation is $\mathbf{\log (q_e) = \log k_f + (\frac{1}{n}) \log C_e}$ and Langmuir equation is $\mathbf{C_e/q_e = (a_L/k_L)Ce + 1/k_L}$ Significant feature of the Langmuir isotherm model is the dimensionless separation factor, $\mathbf{R_L = 1/ (1+ a_L C_i)}$. According to Hall et al [63], the nature of the adsorption process is unfavorable if $R_L > 1$, linear if $R_L = 1$, favourable if: $0 < R_L < 1$ and irreversible if :$R_L = 0$.

The linear results are presented in Graph. No :5-a to d & 6-a to d and isothermal constants along with the correlation coefficient values are presented in Table 2-A.

The high correlation coefficient (R^2=0.9985, 0.9938, 0.9689 and 0.9983) values than Freundlich isotherm and dimensionless separation factor (R_L= 0.01594, 0.0142, 0.0212 and 0.01174) values in the range of 0-1, suggest that the favorable model for the adsorption process is Langmuir isotherm, and hence indicates the mono layer coverage of the adsorbent surface with the adsorbate is favorable.



Graph Nos. 1-a & b: Removal of Aluminum (III) Vs Time of Equilibration with Leaves based bio-adsorbents of *Withania Somnifera* plant

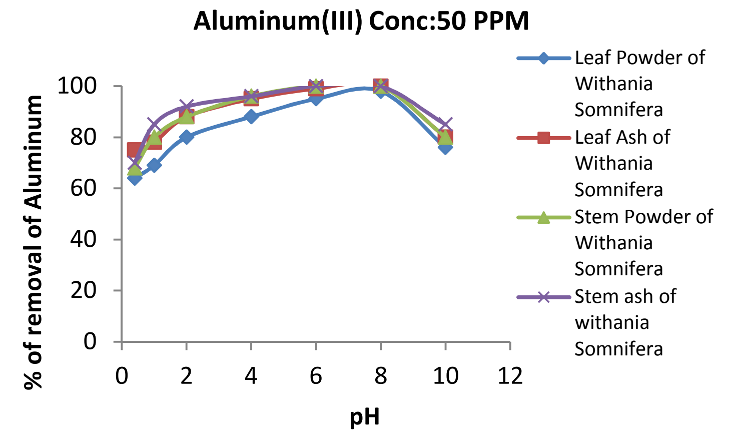


Graph Nos. 1-c & d: Removal of Aluminum (III) Vs Time of Equilibration with stem based bio-adsorbents of *Withania Somnifera* plant

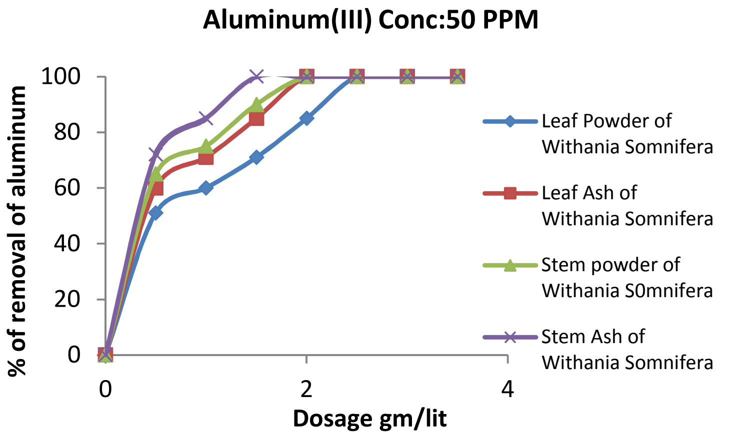
Table 2-A: Adsorption isothermal parameters of Freundlich and Langmuir plots on different bio-adsorbents of *Withania somnifera* plant

S.No:	Adsorption isotherms	Bio-sorbent		Slope	Intercept	R^2
1	Freundlich isotherms	Leaf Powder		0.223	0.9485	0.8868
		Leaf ash		0.2033	1.0761	0.8605
		Stem Powder		0.2123	1.0558	0.8591
		Stem ash		0.1453	1.2408	0.9087
			R_L	Slope	Intercept	R^2
2	Langmuir isotherms	Leaf Powder	0.01594	0.0545	0.0341	0.9985
		Leaf ash	0.0142	0.0463	0.0259	0.9938
		Stem Powder	0.0212	0.0456	-0.0315	0.9689
		Stem ash	0.01174	0.0352	0.0219	0.9983

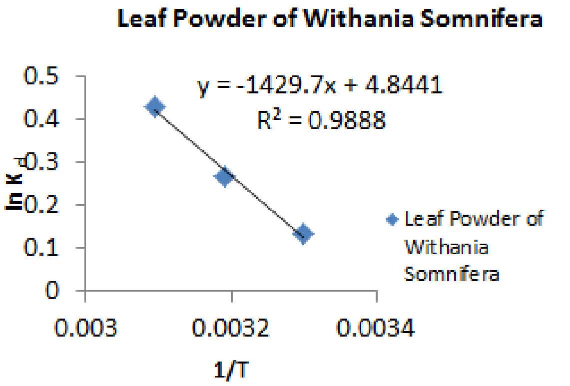
Further, the adsorption process is modeled with Linear form of Temkin equation: $\mathbf{q_e = BlnC_e + BlnA}$ where $\mathbf{RT/b = B}$; Linear form of Dubinin-Radushkevich equation : $\mathbf{lnq_e = -\beta\varepsilon^2 + ln\ q_m}$, where $\mathbf{\varepsilon = RT\ ln(1+1/Ce)}$. The linear plots of these two adsorption isotherms are depicted in Graph.No :7-a to d & 8-a to d and isothermal constants along with the correlation coefficient values are presented in Table 2-B.



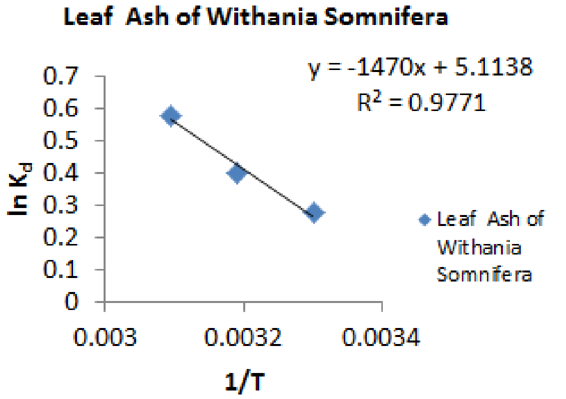
Graph No: 2: pH Vs. %of Removal of Al (III)



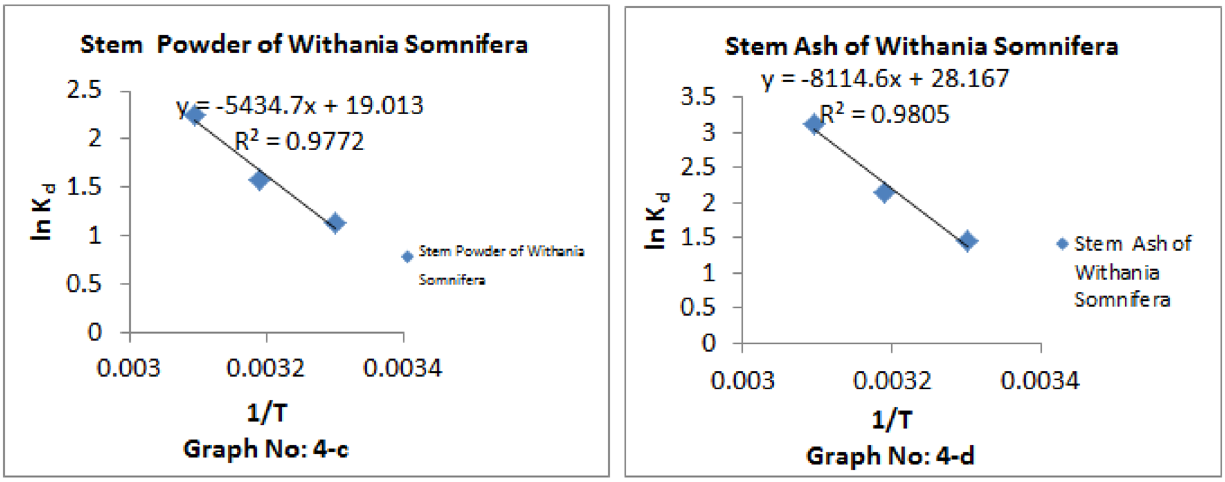
Graph No:3: Dosage Vs % of removal of Al (III)



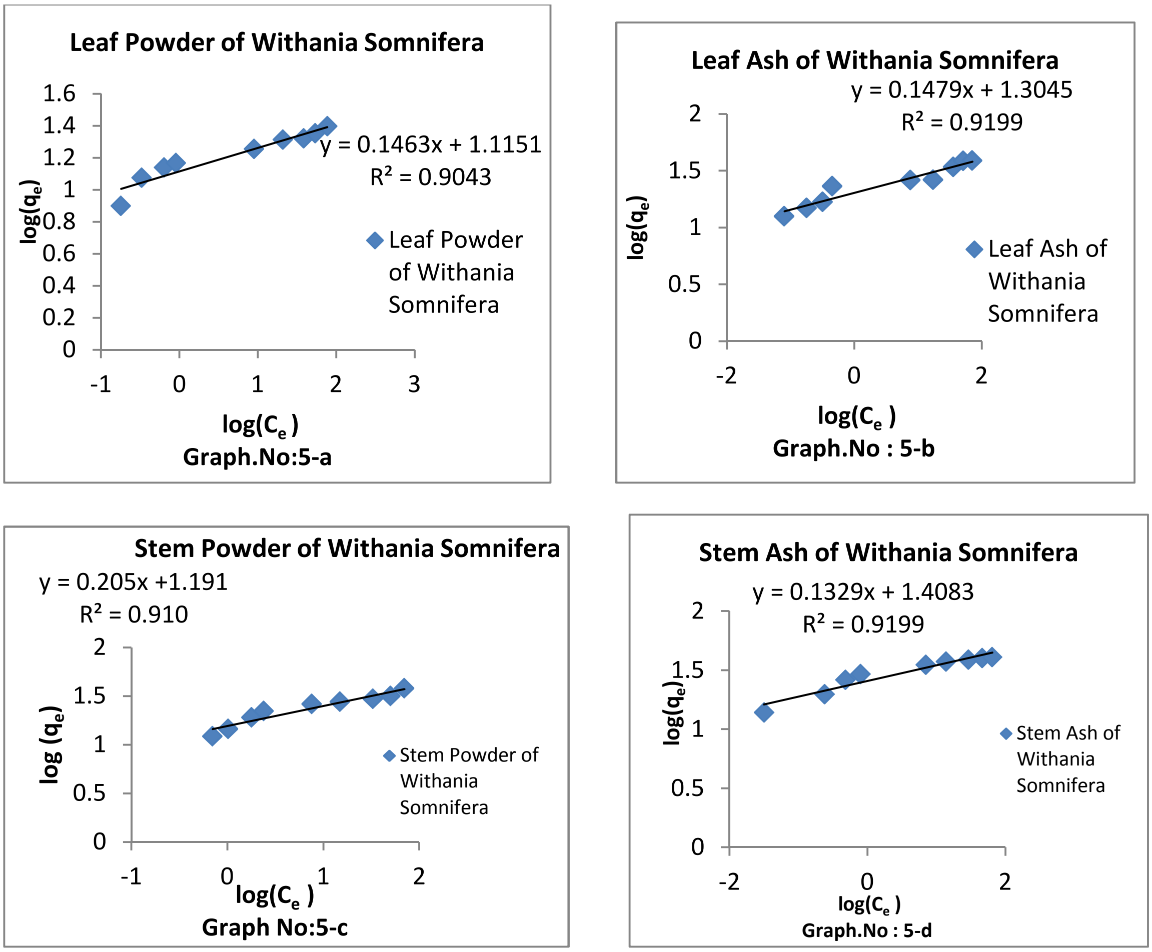
Graph N0:4-a



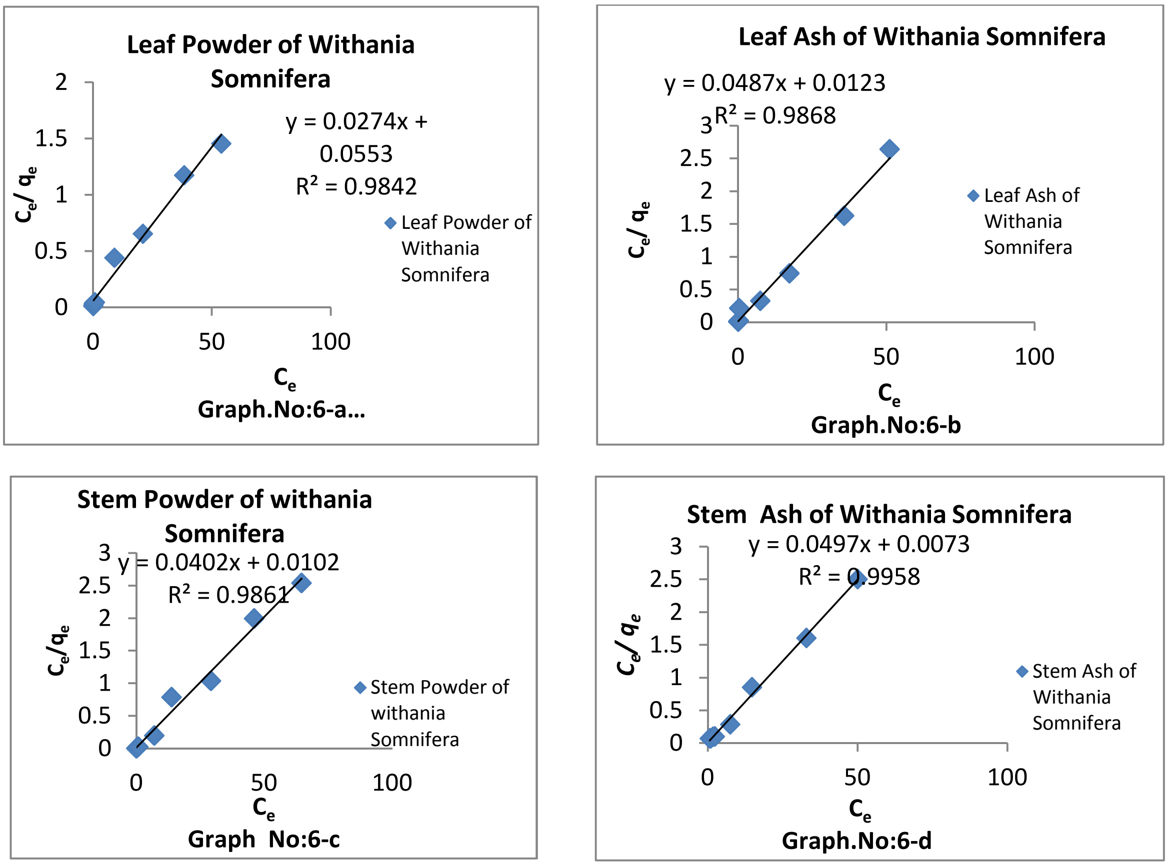
Graph No: 4-b



Graph Nos 4-a to 4-d: Effect of temperature on % removal of Aluminium(III) ion with different Sorbents

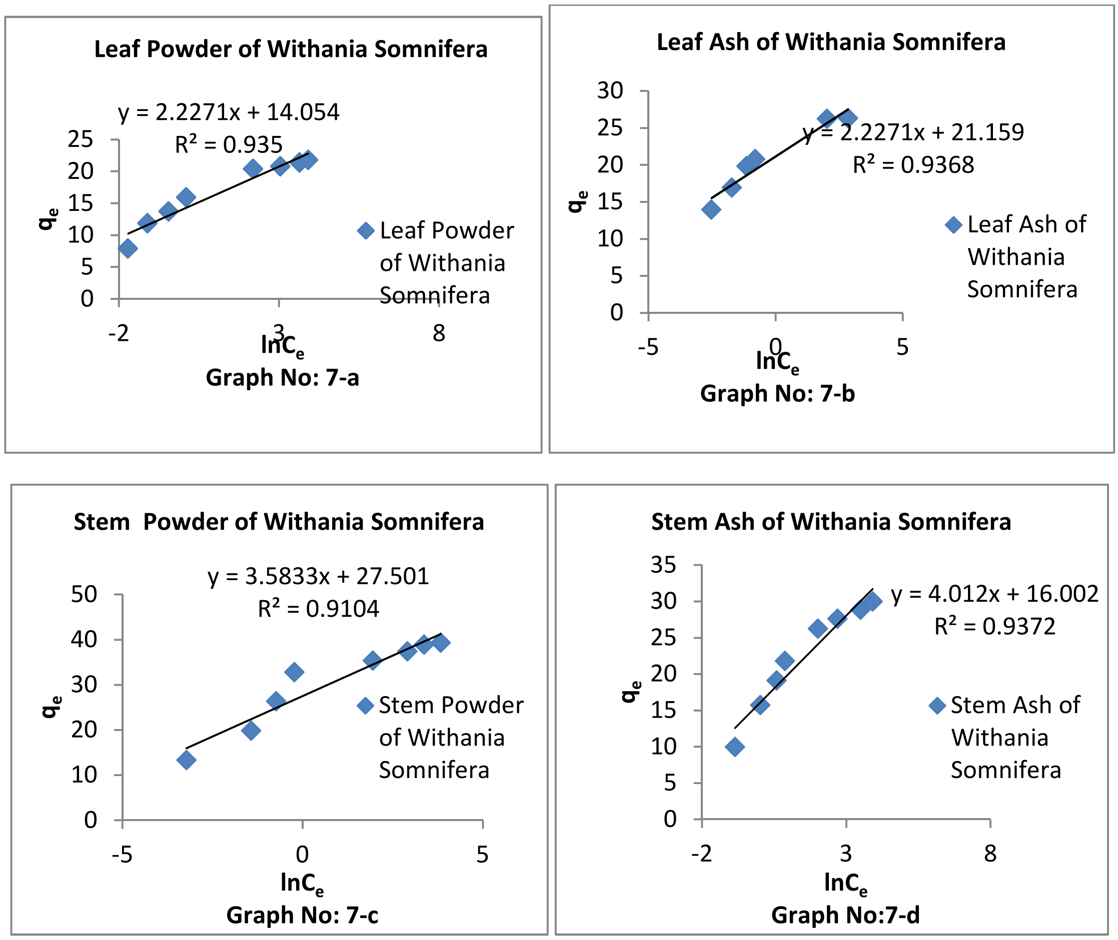


Graph No. 5-a to 5-d: Freundlich isotherms of Different Bio-adsorbents



Graph Nos. 6-a to 6-d Langmuir isotherms with different Bio-sorbents

	Table 2-B: Adsorption isothermal parameters of Temkin and Dubinin Radushkevich plots on Bio-sorbents of *Withania somnifera*				
1	**Temkin Isotherm**	**B**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	2.271J/mol	2.271	14.05	0.935
	Leaf ash	2.2271J/mol	2.2271	21.159	0.9368
	Stem Powder	3.5833J/mol	3.5833	27.501	0.9104
	Stem ash	4.012J/mol	4.012	16.002	0.9372
2	**Dubinin-Radushkevich isotherm**	**E**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	5.0KJ/mol	-2E-08	-6.6101	0.9595
	Leaf ash	1.2909KJ/mol	-3E-07	-6.8447	0.9679
	Stem Powder	5.0KJ/mol	-2E-08	-6.8702	0.9676
	Stem Ash	3.162KJ/mol	-5E-08	-7.1041	0.9755



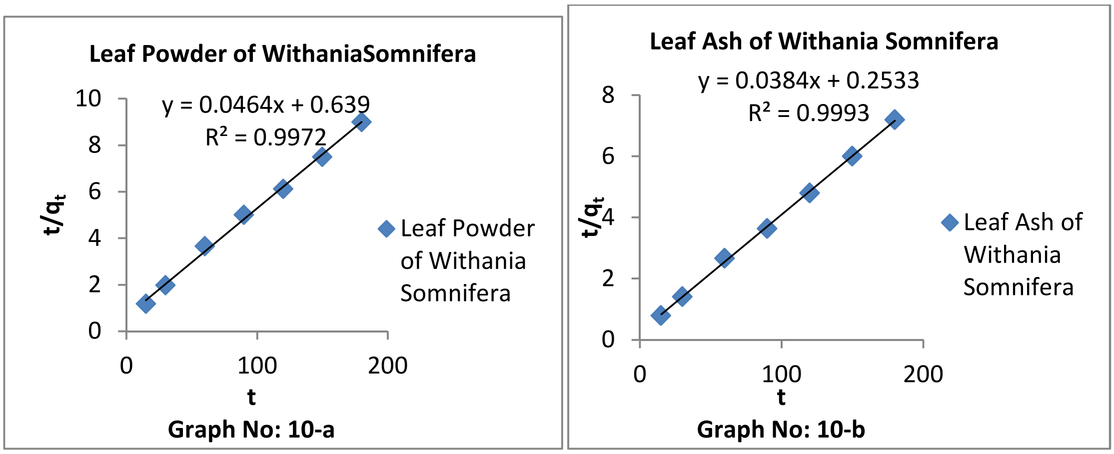
Graph No: 7-a to 7-d: Temkin isotherms of different bio-sorbents of Withania somnifera

R^2-values near to unity indicate the applicability of these two model adsorption isotherms confirming the heterogeneous surface of the adsorbent. The mean free energy (E) and heats of sorption (B) are characteristics of adsorption and as E values are less than 8 kJ/mol and B are less than 20kJ/mol, the adsorption is "physisorption" in nature i.e. non-specific adsorption due long range weak Vander Waals forces [64-68].

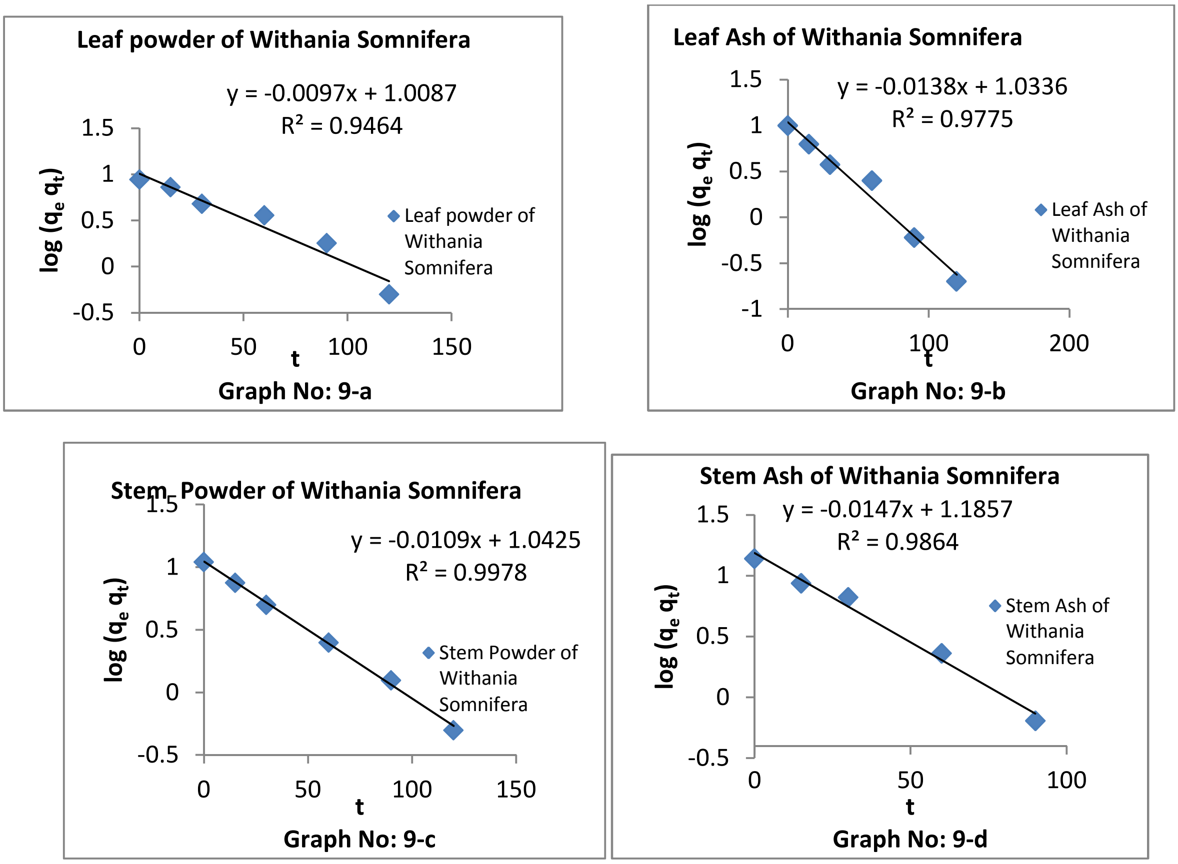
F: Adsorption Kinetics

Kinetics of adsorption is s studied using pseudo first-order model [69, 70], pseudo second-order model [70, 71], Weber and Morris intraparticle diffusion model [72], Bangham's pore diffusion model[73] and Elovich equations[74,75]. The pseudo first-order equation is $\mathbf{\log (q_e - q_t) = \log q_e - k_1 t/2.303}$; the pseudo second-order equation is $\mathbf{t/q_t = 1/k_2 q_e^2 - (1/q_e)\, t}$; Weber and Morris intraparticle diffusion equation is $\mathbf{q_t = k_{ip} t^{1/2} + c}$; Bangham's pore diffusion equation is $\mathbf{\log [\log (C_i/C_i - q_t m)] = \log (k_o/2.303V) + \alpha \log(t)}$; Elovich equation is $\mathbf{q_t = 1/\beta \ln(\alpha\beta) + 1/\beta \ln(t)}$

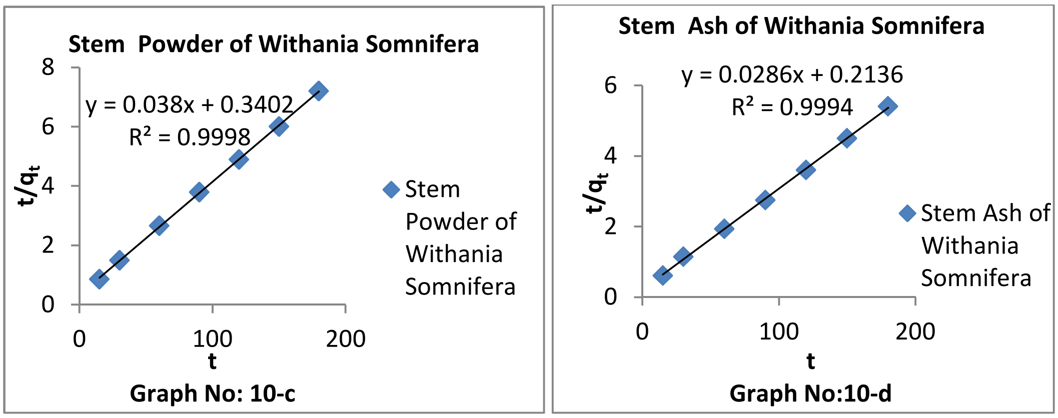
The data of these five kinetic models are presented in Graph Nos: 9-a to d, 10-a to d, 11-a to d, 12-a to d & 13-a to d and rate constants along with the correlation coefficient values are presented in Table 3.



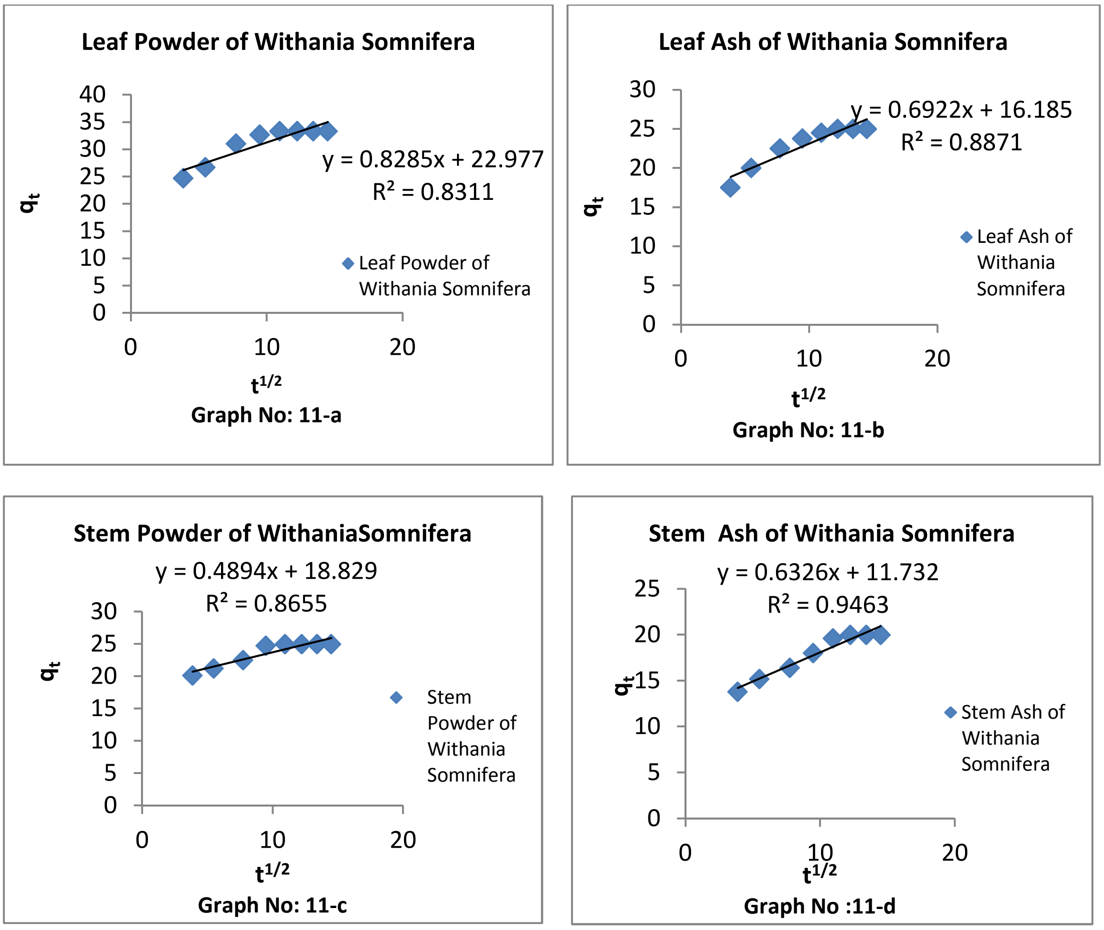
Graph.No :10-a & b : Pseudo second-order model for Leaf Bio-sorbents



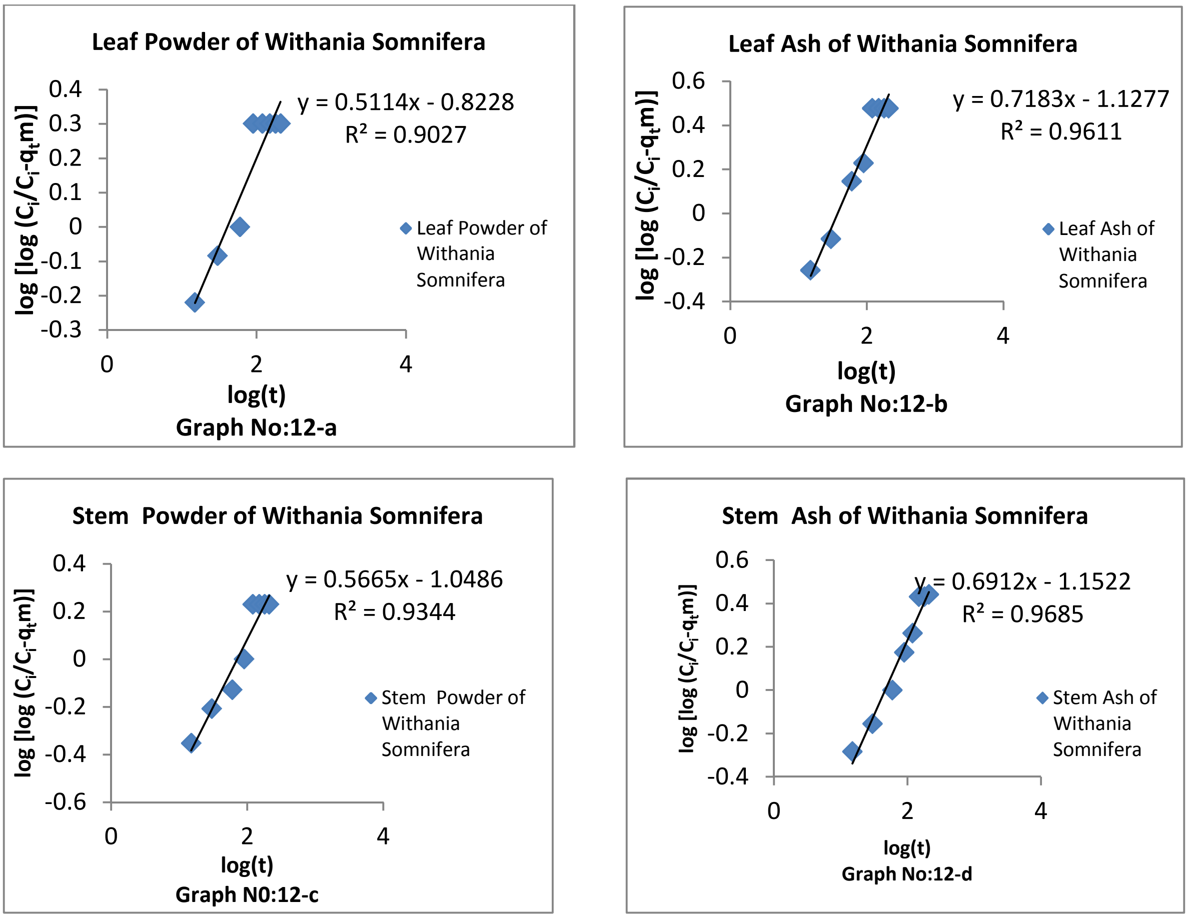
Graph.No :9-a to 9-d Pseudo second-order model for different bio-sorbents



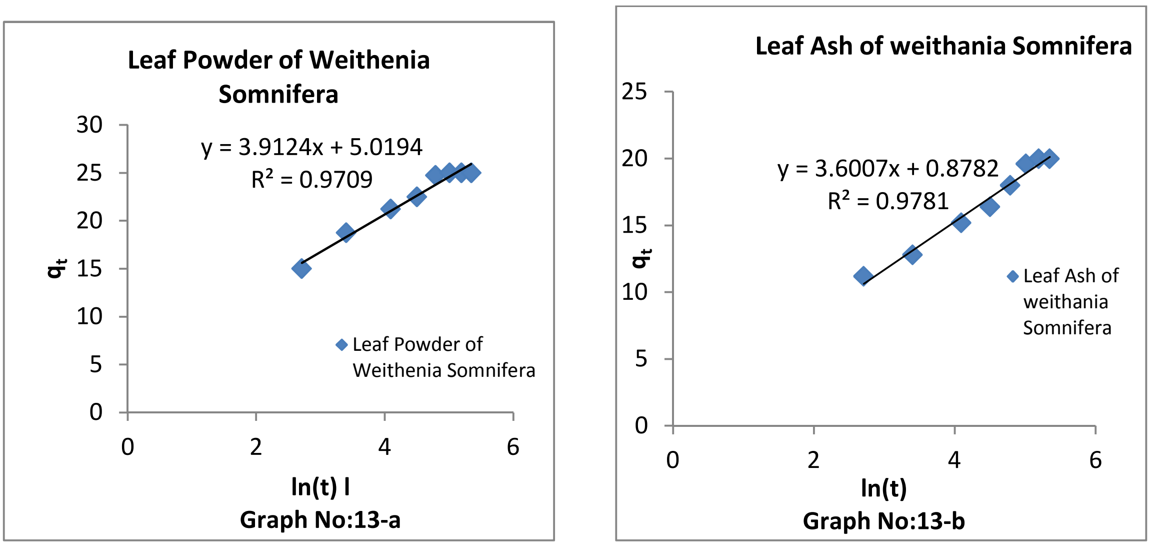
Graph.No :10-c & d : Pseudo second-order model for Stem Bio-sorbents



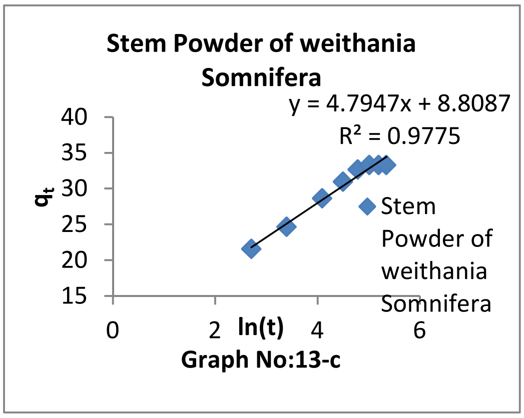
Graph.No 11-a to 11-d: Weber and Morris intra particle diffusion for different adsorbents of Withania Somnifera

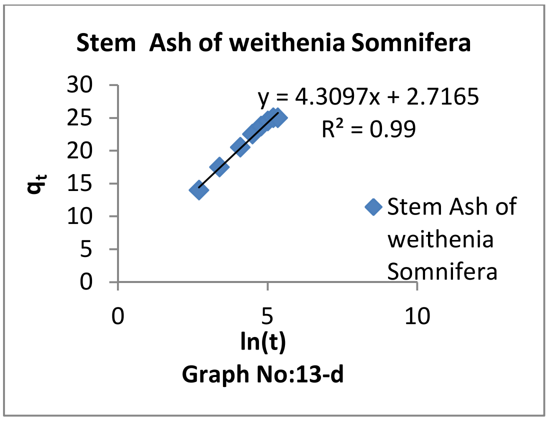


Graph.No:12-a to 12-d Bangham's pore diffusion for different bio-sorbents of *Withania somnifera*



Graph.No:13-a & b: Elovich model Leaf based bio-sorbents of *Withania Somnifera* plant





Graph.No:13-c & d : Elovich model Leaf powder for Stem based bio-sorbents of f Withania Somnifera plant

Table 3: Kinetic parameters

S.No:	Adsorption Kinetics			
1	**pseudo first-order**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	-0.0097	1.0087	0.9464
	Leaf ash	-0.0138	1.0336	0.9775
	Stem Powder	-0.0109	1.0425	0.9978
	Stem ash	-0.0147	1.1857	0.9864
2	**pseudo second-order**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	0.0464	0.639	0.9972
	Leaf ash	0.0384	0.2533	0.9993
	Stem Powder	0.038	0.3402	0.9998
	Stem ash	0.0286	0.2136	0.9994
3	**Weber and Morris intraparticle diffusion**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	0.8285	22.977	0.8311
	Leaf ash	0.6922	16.185	0.8871
	Stem Powder	0.4894	18.829	0.8655
	Stem ash	0.6326	11.732	0.9463
4	**Bangham's pore diffusion**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	0.5114	- 0.8228	0.9027
	Leaf ash	0.7183	- 1.1277	0.9611
	Stem Powder	0.5665	- 1.0486	0.9344
	Stem ash	0.6912	-1.1522	0.9685
5	**Elovich model**	**Slope**	**Intercept**	**R^2**
	Leaf Powder	3.9124	5.0194	0.9709
	Leaf ash	3.6007	0.8782	0.9781
	Stem Powder	4.7947	8.8087	0.9775
	Stem ash	4.3097	2.7165	0.99

On perusal of the correlation coefficient (R^2) values, it may be inferred that the kinetics of adsorption follows the order: pseudo second-order > Elovich model >pseudo first-order > Bangham's pore diffusion > Weber and Morris intraparticle diffusion. Hence, the adsorption kinetics can be well defined by pseudo second-order and least by Weber and Morris intra-particle diffusion model.

G: Interfering Ions:

TABLE: 4: Effect of Interfering Ions on the Extractability of Aluminum (III) With Different Bio-sorbents													
S.No	***Adsor-bent***	***Maximum extractability at optimum condition***	***% of Extractability of Aluminum (III) in the presence of tenfold excess of interfering ions at optimum extraction conditions***										
			SO_4^{2-}	NO_3^-	Cl^-	PO_4^{3-}	F^-	CO_3^{2-}	Ca^{2+}	Mg^{2+}	Cu^{2+}	Zn^{2+}	Ni^{2+}
1.	Leaves powder	100.0%; pH:6; 150 min.; 2.5gm/lit	94.4	94.1	64.1	100.0	60.1	92.6	91.0	94.2	93.1	93.9	91.3
2.	Leaves Ash	100.0%; pH:6;120 min. 2.0 gm/lit	98.4	98.1	71.1	100.0	63.1	97.1	95.2	98.4	97.0	97.9	95.8
3.	Stems powder	98.0% ; pH:6;150 min., 2.0 gm/lit	97.5	97.1	70.2	100.0	62.1	96.3	94.1	97.6	96.1	97.0	94.6
4.	Stems Ash	100.0%; pH:6;120 min., 1.5gm/lit	99.5	99.1	69.2	100.0	65.2	98.2	96.2	99.4	97.4	98.5	96.6

The effect of the presence of tenfold excess of common co-ions viz., Sulphate, Nitrate, Chloride, Phosphate, Fluoride, Carbonate, Calcium, Magnesium, Copper, Zinc and Nickel ions on the % removal of Aluminium ions from synthetically simulated waters has been studied and the results are presented ***in Table No.4***.

Cations have *marginal effect and* % of removal never comes down below 91.0% (Vide Table 4: Columns: 10-14).

Anions like SO_4^{2-}, NO_3^- and CO_3^{2-} marginally affected the % of extraction but Chloride and Fluoride affected the % of extraction significantly but Phosphates synergistically maintained at 100% of extraction.

APPLICATIONS

The methodologies developed in the present investigation have been applied to the samples collected from industrial effluents and polluted natural waters and the results are presented in the ***in the Table No: 5***. It is inferred from the Table that the methods developed are successful as more than 90.0% of extraction is observed.

Table No: 5: Applications: Extraction of Aluminum (III) from Industrial Effluents and Natural polluted Lake Samples using Bio-sorbents developed in this work					
SAMPLES COLLCETED AT DIFFERENT PLACES	***Conc. of Al(III) in the Sample***	***% of Maximum extraction of Aluminum(III)*** ***Withania somnifera***			
		Leaves Powders (mesh:75 µ) :pH:6;150 min& 2.5 g/lit	***Leaves Ashes pH: 6;120 min & 2.0 g/lit***	***Stem Powders (mesh:75 µ) pH:6;150 min& 2.0 g/lit***	***Stem Ashes pH: 6;120 min & 1.5 g/lit***
Alum Industry effluents: 1 2 3	20.0 ppm 25.0 ppm 30.5 ppm	95.5% 93.4% 90.5%	93.5% 91.0% 95.0%	90.5% 91.4% 92.5%	93.0% 92.5% 90.5%
Natural polluted Lake Samples(fed with known amounts of Aluminum (III)): 1 2 3	10.0 ppm 15.0 ppm 22.5ppm	96.5% 97.6% 98.7%	96.5% 97.6% 98.0%	96.5% 97.5% 98.5%	95.5% 96.5% 97.0%

CONCLUSION

- Bio-adsorbents from the leaves and stems of *Withania somnifera plant have been prepared.* Their affinity towards the removal of Aluminum (III) has been investigated with respect to pH, time of equilibration, sorbent dosage, agitation time, initial concentration of Aluminum ions, temperature, and presence of co-ions using simulated waters and by adopting batch methods of extraction. Optimum conditions for the maximum removal have been established. The interference of the common co-ions present in waters on the % of extraction, has been studied

- The adsorption process is analyzed with Freundlich, Langmuir, Temkin and Dubinin-Radushkevich (D-R) isotherm models and found the suitability of the Langmuir isotherm model indicating the mono-layer formation of the adsorbate on the adsorbent. The 'Physisorption' nature of the adsorption process has been inferred from Temkin and Dubinin-Radushkevich isotherm models and by calculating the mean free energy (E) and heats of sorption (B) form the plots of the isotherms.

- The kinetics of adsorption process has been analyzed using pseudo first-order, pseudo second-order, Weber and Morris intraparticle diffusion, Bangham's pore diffusion and Elovich equations and found that the adsorption process is well described by the pseudo-second-order model.
- The endothermic nature of the adsorption is found on the analysis of the thermodynamic parameters, ΔH, ΔS and ΔG.
- The methodologies developed are successfully applied to industrial sewages and polluted natural water samples.

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REFERENCES

[1] O Sree Devi, K Ravindhranath, *Indian Journal of Environment Protection*, **2012**, 32(11), *943-951.*
[2] A Naga Babu, G V Krishna Mohan, K Ravindhranath, *International Journal of ChemTech Research*, **2016**, 9 (3): 506-516.
[3] Y Hanumantha Rao, K Ravindhranath, *Der Pharma Chemica,* **2015**, *7(12):286-298*.
[4] K P C Sekhar, R V Vishnu Babu, D Srividhya, K Ravindhranath, *Der Pharma Chemica*, **2012**, *4 (2):664-673.*
[5] K Papodu, Y Hanumantha Rao, K Ravindhranath, *Der Pharma Chemica*, **2014**, 6(6):19-34
[6] Y Hanumantha Rao, G V Krishna Mohan, K Ravindhranath, *Journal of Chemical and Pharmaceutical Research*, **2015**, *7(9):794-808.*
[7] Anna Aruna, K Ravindhranath , *Journal of Chemical and Pharmaceutical Research,* **2012**, *4 (5) : 2836-2849*.
[8] Anna Aruna Kumari, K Ravindhranath, *Asian Journal of Research in Chemistry,* **2012**, *5(7): 882-892.*
[9] Anna Aruna Kumari, K Ravindhranath, *International Journal of ChemTech Research,* **2012**, 4 (4), 1733-1745.
[10] Anna Aruna Kumari, K. Ravindhranath, *International Journal of Water Resources and Environmental Sciences*, **2012**, *1(1), 08-19*
[11] M Suneetha, B Syama Sundar, K Ravindhranath, *Journal of Analytical Science and Technology,* **2015**, 6:15.
[12] M Suneetha, B Syama Sundar, K Ravindhranath, *J of Chemical and Pharmaceutical Research*, **2014**, *6(10):574-592.*
[13] M Suneetha, B Syama Sundar, K Ravindhranath, *International Journal of ChemTech Research* **2014**-15, 07(01),pp 93-107
[14] M. Suneetha, B. Syama Sundar, K. Ravindhranath, *Asian Journal of Water, Environment and Pollution* (IOS) , **2015**, 12 (3), 33–49.
[15] M Suneetha, B Syama Sundar, K Ravindhranath, *International Journal of Environmental Technology and Management*, **2015**, 18 (3) 420-447.
[16] Hanumantharao, Medikondu Kishore, K Ravindhranath, *International Journal of ChemTech Research*, **2012**, 4(4): 1686-1700.
[17] V Hanumantharao, Medikondu Kishore, K Ravindhranth, *Electronic Journal of Environmental, Agricultural and Food Chemistry,* **2012**, 11(5), 442-458.
[18] M Suneetha, K Ravindhranath, *J of Chemical and Pharmaceutical Research,* **2014**, 6(8), 408-420.
[19] M Suneetha, K Ravindhranath, *International Journal of Chemical, Environmental and Pharmaceutical Research,* **2012**, 3(1), 24-34.
[20] M Suneetha, K Ravindhranth, *Journal of Pharmaceutical And Biomedical Sciences,* **2012**, 25(25):322-329.
[21] K Prameela Rani, K Ravindhranath, *Der Pharma Chemica 6(3):56-63.*
[22] M Suneetha, K Ravindhranath, *Der Pharma Chemica,* **2012**, *4 (1):214-227*.
[23] K Prameela Rani, K Ravindhranath, *Journal of Chemical and Pharmaceutical Research*, 2014, *6(5), 889-900*
[24] Y. Hanumantha Rao, K. Ravindhranath, *International Journal of ChemTech Research,* **2015**, *8(12), 784-796.*
[25] M Divya Jyothi, K Rohini Kiran, K Ravindhranath, *International Journal of Applied Environmental Sciences*, **2012**, 7 (2), 127-140.
[26] B Srinivasa Reddy, K Ravindhranath, *International J of Chem. Tech Research,* **2014**, 6(14), 5612-5624.
[27] B Srinivasa Reddy , B Krishna Veni, K Ravindhranath , *Journal of Chemical and Pharmaceutical Research,* **2012**, 4 (11): 4682.
[28] Shaik Karimulla, K Ravindhranath, *Der Pharma Chemica*, **2014**, *6(4): 333-334.*
[29] B Srinivasa Reddy, K Ravindhranath, *Der Pharmacia Lettre,* **2015**, 7 (1):159-171.
[30] Y Hanumantha Rao, K Rohini Kiran, K Ravindhranath, *J of Chemical and Pharmaceutical Research* (Scopus Indexed), **2014**, 6(9), 48-54.
[31] T P Flaten, A C Alfrey, J D Brichall, J Savory, R A Yokel, *J. Toxicol. Environ. Health*, **1996**, 48:525.
[32] T P Flaten, *Brain Res. Bull*., **2001**, 55:187.
[33] J McClure, P S Smith, *J. Path*., **1984**, 142:293.
[34] J Desccotes, "*Immune-Toxicology of Drugs and Chemicals*" **1988**, Elsevier, Amsterdam

[35] P T Srinivasan, T Viraraghavan, K S Subramanian, “Aluminium in drinking water: An overview”, Water, *SA*, **1999**, *25*(1): 47-56.
[36] M Pesavento, G Alberti, R Bieuz , *Anal. Chim. Acta*, **1998**, *367* (1-3): 215-222.
[37] P Matus, J. Kubova, *Journal of Inorganic Biochemistry*, **2005**, 99: 1769-1778.
[38] Singh T S, K K Pant *Sep. Pur. Technol.*, **2004**, 36 (2) 139-147.
[39] B Paul, R Oaykmr. Zimnik, Joseph Sneddon, *Analytical letters*, **1988**, 21: 1383-1396.
[40] S E Ghazy , S E Samra , A.M. Mahdy, S M El-Morsey , *Separation Science and Technology*, **2005**, 40. 1797-1815.
[41] Shaban El-Sayed GHAZY, Salem El-Sayed SAMRA, Abd El-Fattah Mohammed MAHDY, and Sherin Mohammed EL-Morsy, *Analytical Sciences*, **2006**, *22:*377.
[42] M W Javaweera, J C Kasturiarachchi, R K Kularatne, S L Wijeyekoon, *J. Envi. Sci. Health A. Tox Hazard Subsst.Envirfon Eng.*, **2007**, *42*(2):185-191 (2007).
[43] C Septhum, S Rattanaphani, J B Bremner, V. Rattanaphani, *J of Hazardous Materials*, 2007, *148*:185-191.
[44] Tony Sarvinder Singh, Bhavik Parikh, K.K. Pant, *Water SA Vol.* **2006**, 32 (1).
[45] D R Crapper, McLachlan, V De Boni, *Neurotoxicology*, **1980**, 1:3 (1980).
[46] Lenore S, Clesceri., Arnold E, Greenberg and Andrew D, Easton (Editors), *Standard Methods for the Examination of Water and Wastewater*,20th Edition, American Public Health Association, **1998**, 3, 65.
[47] R K Trivedy, “*Pollution Management in Industries*”, Environmental Publications, KARAD, INDIA (1979)
[48] Gerard Kiely, *Environmental Engineering*, McGraw-hall International Editions (**1998**)
[49] Metcalf and Eddy, *Wastewater Engineering: Treatment of Reuse*. 4th. Ed., McGraw Hill Co., New York (**2003**).
[50] *Vogel’s Textbook of Quantitative Chemical Analysis* (revised by G.H. Jeffery, J J. Bassett, J. Mendham and R.C. Denney) Fifth Edition,1989, Addison Wesley Longman Limited, page: 678.
[51] G Alagumuthu, M Rajan, *Hem. Ind.*, **2010**, 64(4), 295-304.
[52] G Karthikeyan, S Siva Elango, *Iran J. Environ. Health. Sci. Eng.*, **2007**, 4(1), 21-28.
[53] M Sekar,V Sakthi, S Rengaraj, *J. Colloid Interface Sci.*, **2004**, 279,307-313.
[54] M Horsfall, A Spiff, *J. Biotechnol.*, **2005**, 8, 162-169.
[55] N Viswanathan, S Meenakshi, *J. Hazard. Mater.*, **2010**, 178, 226-232.
[56] Z Bouberka, S Kaoha, Kamecha, S Elmaleh, Z Derriche, *J. Hazard. Mat.*, **2005**,119, 117-124.
[57] C Sairam Sundaram, N Viswanathan, S Meenakshi, *J. Hazard.Mater.*, **2009**, 163(2-3), 618-624.
[58] A K Chaturvedi, K C Pathak, V N Singh, *Appl. Clay Sci.*, **1988**, 3,337-346.
[59] H M F Freundlich, *J. Phys. Chem.*, **1906**, 57, 385-471.
[60] Langmur, *J. Am. Chem. Soc.*, **1918**, 40, 1361-1368.
[61] M .J Temkin, V Pyzhev, Recent modifications to Langmuir isotherms, *Acta Physiochim*. U.S.S.R., **1940**, 12, 217-222.
[62] M M Dubinin, L.V. RadushKevich, *Phys. Chem. Sect.*, **1947**, 55, 331.
[63] K R Hall, L.C Eagleton, A Acrivos, T Vermevlem, *Ind. Eng. Chem. Fundam.*,**1966**, 5, 212-219.
[64] B H Hameed, *J. Hazard.Mater.*, **2009**, 162, 939-944.
[65] A A Nunes, S A Franca, L S Olievera, *Bioresource Technology*, **2009**, 100, 1786-1792.
[66] M S Onyango, Y Kojima, O Aoyi, E C Bernardo, H Matsuda, *J. Colloid Interface Sci.*, **2004**, 279, 341-350.
[67] J Monika, V Garg, K Kadirvelu, *J. Hazardous materials*, **2009**, 162, 365-372.
[68] P Atkins, Physical chemistry 6th Edn. Oxford University press, London, **1999**, 857-864.
[69] S Lagergren, *Handlingar*, **1898**, 24(4), 1-39.
[70] Y S Ho, G McKay, *Process Biochem.*, **1999**, 34, 451–465.
[71] Y S Ho, J C Y Ng, G McKay, *Sep. Purif. Methods*, **2000**, 29, 189-232.
[72] W J Weber Jr, C. Morris, *J. Sanit. Eng. Div.*, **1963**, 89, 31-59.
[73] C Aharoni, M Ungarish, *J. Chem. Soc. Faraday Trans, 1: Phys. Chem. Condens. Phases.* **1977**, 73(3), 456-464.
[74] M Ozacar, I A Sengil, *Process Biochem.*, **2005**, 40, 565-572.
[75] C Gerente, V K C Lee, P Le Cloirec, G.McKay, *Crit. Rev. Environ. Sci.Technol.*, **2007**, 37, 41-127,