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KINETICS AND ISOTHERM STUDIES OF MERCURY AND IRON BIOSORPTION USING *SARGASSUM SP.*

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ABSTRACT

Biosorption is a process in which solids of natural origin are employed for binding heavy metals. It is a promising alternative method to treat industrial effluents, mainly because of its low cost and high metal binding capacity. In this work, the mercury and iron biosorption process by *Sargassum sp*. seaweed biomass was studied. The work considered the parameters of mercury and iron sorption such as pH, temperature, agitation and biomass size. The optimal conditions were : pH 4, temperature 30ºc, agitation 100 rpm and biomass size 0.7mg and the maximum metal uptake was 67.094mg/g, 64.32mg/g, 53.735mg/g, 41.883mg/g respectively for mercury. For iron the pH was 3, temperature 30ºc, agitation 150 rpm, biomass size 0. 3mg and the maximum metal uptake was 16.63mg/g,16.23 mg/g, 24.78mg/g and 14.62mg/g. The mercury and iron uptake was also quantitatively evaluated using adsorption isotherms. Results indicated that for iron, Langmuir model gave a better fit and for mercury Freundlich gave a better fit to the experimental data in comparison with the other isotherm models. Kinetic models such as pseudo first order and pseudo second order was also evaluated. The adsorption process follows pseudo second order kinetics for both the metals.

KEYWORDS : Biosorption, Mercury, Iron, Kinetics, Adsorption isotherm, *Sargassum.*

INTRODUCTION

Heavy metals released into the environment by technological activities tend to persist indefinitely, circulating and eventually accumulating throughout the food chain, becoming a serious threat to the environment. Biosorption is proven to be quite effective at removing metal ions from contaminated solution in a low cost & environment friendly manner. The major advantages of biosorption over conventional treatment methods include low cost, high efficiency of metal removal from dilute solution. Biosorption is a process which utilizes inexpensive dead biomass to sequester heavy metals from aqueous solutions. Among the most promising types of biosorbents, algae possess a high metal binding capacity **[10]**. This is due to the presence of various functional groups such as carboxyl, amino, sulphate & hydroxyl groups, which can act as binding sites for metals**[11].** Metal ions are adsorbed to the surface of cells by interactions between metals & functional groups displayed on the surface of cells. Metal ions bound on the surface can eluted by other ions, chelating agents or acids. The main polysaccharide in *Sargassum* seaweed is alginic acid, a polymer containing β→1,4 manuronic acid (M) associated to α→ 1,4 guluronic acid (G). These carboxylic groups are capable of forming complexes with cationic metals **[6].** The major factor that affect the biosorption process are: initial metal ion concentration, temperature, pH & biomass concentration in solution**[8].** Mercury is generally considered to be one of the most toxic metals found in the environment **[9].** Once mercury enters the food chain, progressively larger accumulation of mercury compounds takes place in humans and animals. The major sources of mercury pollution in environment are industries like paints, pulp and paper, oil refining, rubber processing and fertilizer **[7],** batteries, thermometers, fluorescent light tubes and high intensity street lamps, pesticides, cosmetics and pharmaceuticals **[3].** Methyl mercury causes deformities in the offspring, mainly affecting the nervous system (teratogenic effects). Children suffer from mental retardation, cerebral palsy and convulsions. Mercury also brings about genetic defects causing chromosome breaking and interference in cell division, resulting in abnormal distribution of chromosome. Mercury causes impairment of pulmonary function and kidney, chest pain and dyspnoea. Iron in water is generally present in the ferric state. The presence of iron at concentrations above 0.1mg/l will damage the gills of the fish. The free radicals are extremely reactive and short lived. The free radicals formed by the iron on the surface of the gills will cause oxidation of the surrounding tissue and this will lead to massive destruction of gill tissue and anemia. Iron is an essential element in human nutrition. It is contained in a number of biologically significant proteins, but ingestion in large quantities results in haemochromatosis where in tissue damage results from iron accumulation **[4].** The main objective was to evaluate mercury & iron biosorption by Sargassum sp., also to evaluate the influence of different parameters. The work also evaluate the isotherm and kinetic studies for the removal of mercury and iron using the biomass *Sargassum sp.*

MATERIALS AND METHODS

Biomass preparation

Brown marine algae *Sargassum sp.* was collected from the southern coast of India. The samples were washed with distilled water and dried at 60^{o} c for 24 hours. Dried biomass was chopped and used as biosorbent for further studies **[1].**

PREPARATION OF METAL SOLUTIONS

Iron [Fe III] solution

A stock solution (1000mg/l) of Fe (III) ions was prepared using ferrous ammonium salt as follows: 7.022g of crystallized ferrous ammonium sulphate was dissolved in 500ml of water and 50 ml of 1:1 H_2SO_4 are added. The solution was warmed and oxidized with approximately 0.1% potassium permanganate solution until the solution remained faintly pink. The solution was diluted and made up to 1000ml. The pH of the solution was adjusted using 0.1N HCl or NaOH. Fresh dilutions were used for each study.

Mercury [Hg II] solution

Stock solution of 1000mg/l of Hg II was prepared by dissolving 1.354 g of Mercuric chloride in 700ml distilled water. Added 10 ml of concentrated HNO_3 and diluted to 1000ml.

All chemicals and reagents used for the experiments were AR grade (Merck, India).

BATCH MODE ADSORPTION STUDIES

Batch mode adsorption studies for metal compounds were carried out to investigate the effect of different parameters such as agitation, pH, temperature and biomass size. Solution containing adsorbate and adsorbent was taken in 250ml capacity beakers and agitated at 150 rpm in a mechanical shaker at predetermined time intervals. The adsorbate was decanted and separated from the adsorbent using whatman No.1 filter paper. Metal free and biosorbent free blanks were used as control. The residual ion concentration in the solution was analyzed using Atomic Absorption Spectrometry.

ADSORPTION ISOTHERM MODELS

LANGMUIR ISOTHERM

The Langmuir isotherm is used to obtain the maximum adsorption capacity produced from complete monolayer coverage of adsorbensurface. The Langmuir's equation is given by

$$\theta = \frac{q_e}{Q_m} = \frac{bC_e}{1 + bC_e} \qquad (1)$$

Where, b is adsorption equilibrium constant (1 mg^{-1}) that is related to the apparent energy of adsorption and Q_m is the quantity of adsorbate required to form a single monolayer on unit mass of adsorbent (mg/g) and q_e is the amount adsorbed on unit mass of the adsorbent (mg/g) when the equilibrium concentration is C_e (mg/g). Eq .1 can be rearranged to get the linear form, as given by Eq.2

$$\frac{C_e}{q_e} = \frac{1}{bQ_m} + \left(\frac{1}{Q_m} \right) C_e \qquad (2)$$

which shows that a plot of (C_e / q_e) vs. C_e should yield a straight line if the Langmuir equation is obeyed by the adsorption equilibrium. The slope and intercept of this line gives the value of constants Q_m and b.

A further analysis of the Langmuir equation can be made on the basis of a dimensionless equilibrium parameter $R_{L,}$ known as the separation factor given by Eq.3

$$R_L = \frac{1}{1+bC_e} \qquad (3)$$

The value of R_L lies between 0 and 1 for a favorable adsorption, while $R_L > 1$ represents an unfavorable adsorption, and $R_L = 1$ represents the linear adsorption, while the adsorption operation is irreversible if $R_L = 0$.

FREUNDLICH ISOTHERM

For adsorption from solution, the Freundlich isotherm is expressed as given by Eq.4

$$q_e = K_f C_e^{nF} \qquad (4)$$

where, K_f ($mg^{1-1/n}$ $1^{1/n}$ g^{-1}) is the Freundlich constant, which indicates the relative adsorption capacity of the adsorbent related to the bonding energy, and n_F is the heterogeneity factor representing the deviation from linearity of adsorption and is also known as Freundlich coefficient. The Freundlich coefficients can be determined from the plot of log q_e vs. log C_e on the basis of the linear form of Eq.5

$$\log q_e = \log K_f + n_F \log C_e \qquad (5)$$

REDLICH – PETERSON ISOTHERM

Redlich – Peterson Isotherm contains three parameters and is improvement over the Langmuir and the Freundlich isotherms. It can be described by Eq.6

$$q_e = \frac{AC_e}{1+BC_e^{g}} \qquad (6)$$

Where A,B and g (0<n<1) are the Redlich – Peterson parameters.

TEMPKIN ISOTHERM

The nonlinear form of Tempkin equation is given by Eq. 7

$$q_e = \frac{RT}{b_T} \ln(A_T C_e) \qquad (7)$$

equation (7) can be linearized as given by Eq.8

$$q_e = B_T \ln A_T + B_T \qquad (8)$$

where $B_T = (RT) / b_T$, T is the absolute temperature in Kelvin and R is the universal gas constant, 8.314 J mol^{-1} K^{-1}. The constant b_T is related to the heat of adsorption, A_T is the equilibrium binding constant (1 min^{-1}) corresponding to the maximum binding energy. The slope and intercept from a plot of q_e vs. ln C_e determines the isotherm constants A_T and $b_{T.}$

ADSORPTION KINETICS

Pseudo First – Order Kinetics

The non linear form of pseudo first order equation is given by Eq. 9

$$\frac{dq_t}{d_t} = k_{ad}\,(q_e - q_t) \quad (9)$$

where, q_e and q_t are the amounts of metal adsorbed (mg g^{-1}) at equilibrium time and at any instant of time, t respectively, and k_{ad} (1 min^{-1}) is the rate constant of the pseudo first order adsorption operation. The integrated rate law after application of the initial condition of $q_t = 0$ at $t = 0$, becomes a linear equation as given by Eq.10

$$\log(q_e - q_t) = \log q_e - k_{ad}t/2.303 \quad (10)$$

plot of log $(q_e - q_t)$ vs. t gives a straight line for the first order adsorption kinetics, which allow the computation of the adsorption rate constant, k_{ad} .

Pseudo Second- Order Kinetics

Applicability of the second order kinetics has to be tested with the rate equation given by Eq.11

$$\frac{dq_t}{dt} = k_2\,(q_e - q_t)^2 \quad (11)$$

where k_2 (g mg^{-1} min^{-1}) is the second order rate constant. From the boundary conditions, t = 0 to t = t and $q_t = 0$ to $q_t = q_t$, the integrated form of the equation becomes as given by Eq. 12

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_2t \quad (12)$$

Eq. 12 can be written in a linear form, as given by Eq.13

$$\frac{t}{q_t} = \frac{1}{h} + \left(\frac{1}{q_e}\right) t \quad (13)$$

→

Where $h = k_2q_e^2$ that can be regarded as the initial sorption rate as t 0. Under such circumstances, the plot of t/q_t vs. t should give a linear relationship, which allows the computation of q_e, k_2 and h.

RESULT AND DISCUSSION

Effect of pH

Marine algae contain high content of ionizable groups (carboxyl from mannuronic and guluronic acids) on the cell wall polysaccharides, which suggests that the biosorption process could be affected by changes in the solution pH **[5,2].** It was observed that the uptake of mercury was higher at pH4 and iron at pH3 Fig(**1&2**). The maximum uptake of mercury and iron is 67.09mg/g and 16.633 mg/g respectively.

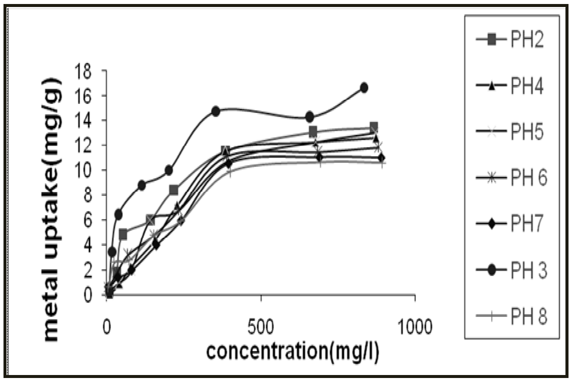


Fig (**1**) Removal of Iron by *Sargassum sp.* at

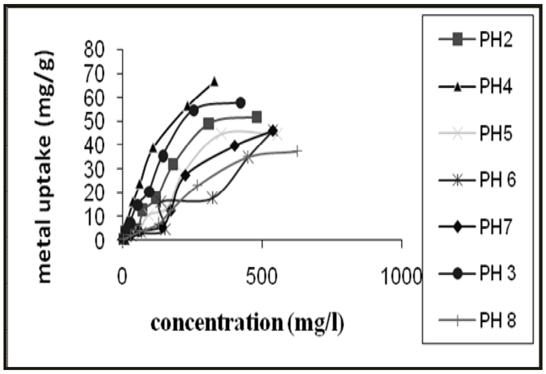


Fig (**2**) Removal of mercury by *Sargassum sp.* at different different pH conditions
pH conditions

Effect of algae size

The effect of Sargassum sp. (biomass) on the removal of mercury and iron was studied in the size range of 0.1 - 1 mg. Fig(**3 &4**) showed the maximum uptake was attained at the size of 0.7mg for mercury and 0.3mg for iron and the maximum uptake of mercury and iron is 41.88 mg/g and 14.62 mg/g respectively.

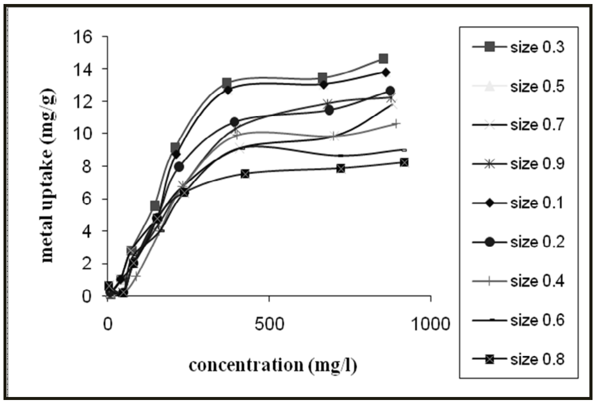


Fig (**3**) Effect of algal size on the removal of Iron

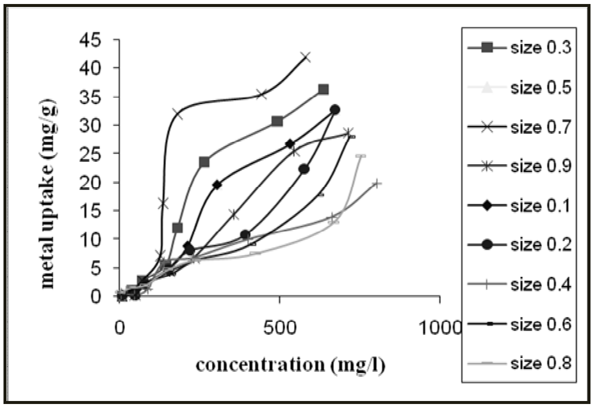
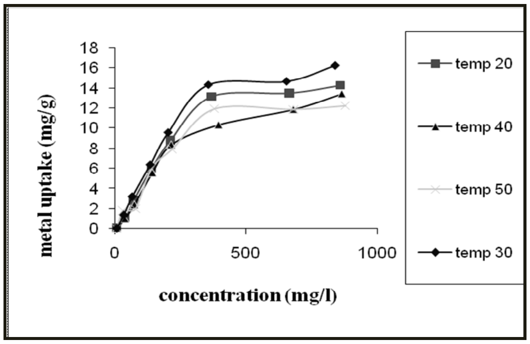


Fig (**4**) Effect of algal size on the removal of mercury

Effect of temperature

The uptake of mercury and iron by *Sargassum sp.* was evaluated by varying the temperature from 20-50°c. Fig(**5&6**) shows that mercury and iron uptake was increases at room temperature and the maximum uptake was 64.32mg/g and 16.23mg/g respectively.



Fig(**5**) Effect of temperature on the removal of Iron

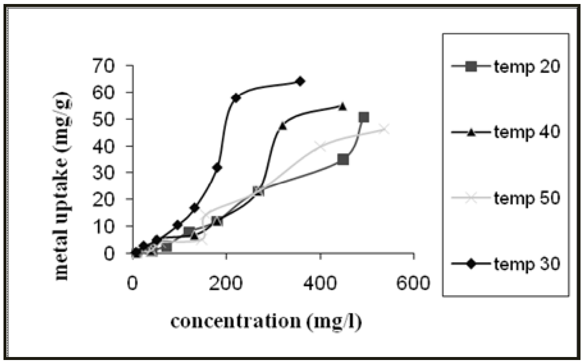


Fig (**6**) Effect of temperature on the removal of Mercury

Effect of agitation

The maximum uptake was attained at 100 rpm for mercury and 150rpm for iron. Fig(**7&8**) showed the maximum uptake of mercury and iron was 53.73mg/g and 24.78mg/g respectively

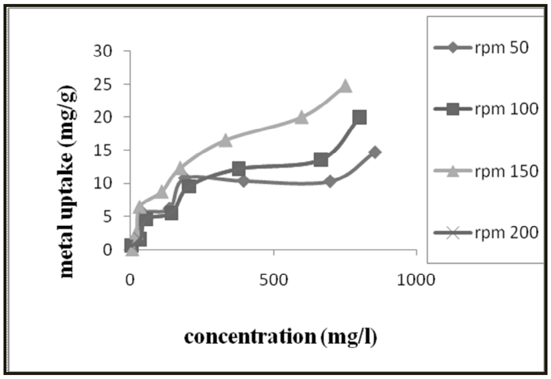
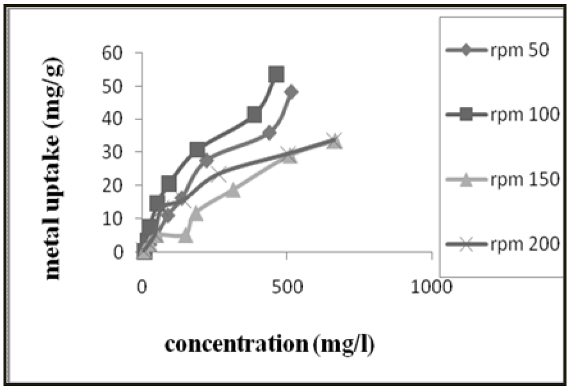


Fig (**7**) Effect of agitation on the removal of Iron



Fig(**8**) Effect of agitation on the removal of Mercury

Adsorption isotherm study

In the present study, four equilibrium models are analyzed to investigate the suitable adsorption isotherm.

Iron				**Mercury**			
pH	**Q_m**	**b**	**R^2**	**pH**	**Q_m**	**b**	**R^2**
3	17.54368	0.01189	0.988	2	100	0.002586	0.784
2	16.12903	0.005927	0.985	3	100	0.003644	0.848
4	17.24138	0.003469	0.923	4	142.8571	0.003211	0.815
5	20.40816	0.002278	0.93	5	76.92308	0.003006	0.835
6	14.92537	0.000455	0.949	6	76.92308	0.002217	0.857
7	14.49275	0.004478	0.939	7	66.66667	0.003763	0.893
8	12.98701	0.005572	0.944	8	71.42857	0.001933	0.942
Temp	**Q_m**	**b**	**R^2**	**Temp**	**Q_m**	**b**	**R^2**
20	20	0.00327	0.926	20	83.33	0.002541	0.854
30	22.72727	0.003205	0.949	30	90.90909	0.005119	0.848
40	17.54386	0.003444	0.921	40	75.75758	0.002652	0.854
50	14.92537	0.005756	0.977	50	71.42857	0.003087	0.855
Size	**Q_m**	**b**	**R^2**	**Size**	**Q_m**	**b**	**R^2**
0.1	18.51852	0.000381	0.947	0.1	58.82353	0.001844	0.896
0.2	17.54386	0.003115	0.966	0.2	71.42857	0.001135	0.819
0.3	21.73913	0.002679	0.911	0.3	66.6667	0.001705	0.828
0.4	13.15789	0.004756	0.952	0.4	25	0.003895	0.92
0.5	21.73913	0.003893	0.926	0.5	41.6667	0.003189	0.938
0.6	11.49425	0.00456	0.964	0.6	71.42857	0.003087	0.855
0.7	15.38462	0.003215	0.984	0.7	15.625	0.004167	0.887
0.8	9.259259	0.008353	0.989	0.8	32.25806	0.00158	0.872
0.9	16.39344	0.003578	0.933	0.9	62.5	0.001276	0.875
Rpm	**Q_m**	**b**	**R^2**	**Rpm**	**Q_m**	**b**	**R^2**
50	15.625	0.005541	0.909	50	100	0.001632	0.837
100	22.22222	0.003916	0.889	100	90.90909	0.00288	0.849
150	31.25	0.003926	0.952	150	52.63158	0.002302	0.82
200	22.22222	0.003417	0.881	200	55.55556	0.002468	0.861

Table 1: Langmuir isotherm model parameters for iron and mercury

Iron				Mercury			
pH	**K_F**	**n_F**	**R^2**	**pH**	**K_F**	**n_F**	**R^2**
3	0.74131	2.178649	0.889	2	0.406443	1.893939	0.972
2	0.370681	1.785714	0.961	3	0.406443	1.893939	0.813
4	0.237684	1.642036	0.972	4	0.717794	1.221001	0.952
5	3.664376	-1.125	0.955	5	0.41	1.893939	1
6	0.261818	1.709402	0.985	6	0.403645	1.308901	0.965
7	0.232274	1.663894	0.958	7	2.754229	1.64	0.967
8	0.342768	1.897533	0.964	8	0.221309	1.207729	0.99
Temp	**K_F**	**n_F**	**R^2**	**Temp**	**K_F**	**n_F**	**R^2**
20	0.202302	1.515152	0.963	20	0.437522	1.29199	0.979
30	0.201837	1.466276	0.972	30	1.606941	1.628664	0.987
40	0.239883	1.639344	0.962	40	0.398107	1.272265	0.977
50	0.369828	1.838235	0.969	50	0.642688	1.453488	0.988
Size	**K_F**	**n_F**	**R^2**	**Size**	**K_F**	**n_F**	**R^2**
0.1	0.226464	1.564945	0.973	0.1	0.264241	1.32626	0.99
0.2	0.125893	1.390821	0.964	0.2	0.148252	1.207729	0.995
0.3	0.109648	1.293661	0.939	0.3	0.261818	1.305483	0.994
0.4	0.191426	1.592357	0.949	0.4	0.372392	1.647446	0.978
0.5	0.171396	1.36612	0.897	0.5	0.384592	1.481481	0.977
0.6	0.111686	1.519757	0.952	0.6	0.647143	1.445087	0.989
0.7	0.118032	1.412429	0.968	0.7	0.249459	1.669449	0.923
0.8	0.341979	2.132196	0.972	0.8	0.142561	1.293661	0.944
0.9	1.709402	0.260016	0.978	0.9	0.124738	1.17096	0.987
RPM	**K_F**	**n_F**	**R^2**	**RPM**	**K_F**	**n_F**	**R^2**
50	0.260016	1.709402	0.978	50	0.639735	1.430615	0.946
100	0.276694	1.569859	0.98	100	0.431519	1.239157	0.952
150	0.33037	1.488095	0.925	150	0.421697	1.424501	0.939
200	0.165959	1.381215	0.95	200	0.187068	1.172333	0.942

Table 2 : Freundlich isotherm model parameters for iron and mercury

Iron				Mercury			
pH	**A**	**B**	**R^2**	**pH**	**A**	**B**	**R^2**
3	0.256365	7.519	0.974	2	0.326	62.86566	0.896
2	0.362315	6.661	0.946	**3**	0.11	262.1718	0.468
4	0.42395	6.763	0.873	4	0.321	4.486173	0.898
5	2.350474	6.694	0.91	5	0.414	73.25892	0.847
6	1.197658	5.392	0.848	6	0.431	36.56165	0.953
7	7.117518	5.247	0.859	7	0.415	64.26403	0.821
8	1.183255	4.64	0.858	8	0.312	118.7476	0.833
Temp	**A**	**B**	**R^2**	**Temp**	**A**	**B**	**R^2**
20	0.425145	7.792	0.886	20	0.322	68.03348	0.907
30	0.430882	8.857	8.857	**30**	0.27	47.27587	0.843
40	0.42219	6.857	0.901	40	0.098	395.0451	0.311

50	0.384487	6.451	0.916	50	0.165	241.2901	0.386
Size	**A**	**B**	**R^2**	**Size**	**A**	**B**	**R^2**
0.1	0.406539	7.233	0.88	0.1	0.351	34.74376	0.904
0.2	0.416946	6.526	0.903	0.2	0.28	120.061	0.827
0.3	0.426804	7.943	0.898	0.3	0.334	45.69551	0.93
0.4	0.346807	4.973	0.878	0.4	0.272	248.6385	0.873
0.5	0.378681	8.389	0.956	**0.5**	0.35	16.92852	0.914
0.6	0.375188	4.585	0.878	0.6	0.245	411.5786	0.755
0.7	0.466298	0.708	0.968	0.7	0.35	107.1254	0.946
0.8	0.249793	3.533	0.918	0.8	0.345	237.2229	0.651
0.9	0.38584	6.513	0.871	0.9	0.094	859.1985	0.626
RPM	**A**	**B**	**R^2**	**Rpm**	**A**	**B**	**R^2**
50	0.406695	6.153	0.871	50	0.458	5.606911	0.947
100	0.344868	7.631	0.827	100	0.418	47.56038	0.748
150	0.382334	8.058	0.844	**150**	0.541	1.197217	0.978
200	0.382334	8.058	0.844	200	0.262	94.63241	0.772

Table 3 : Redlich – Peterson isotherm model parameters for iron and mercury

Iron				**Mercury**			
pH	**A_T**	**B_T**	**R^2**	**pH**	**A_T**	**B_T**	**R^2**
3	0.256365	7.519	0.974	3	0.472592	26.15	0.813
2	0.362315	6.661	0.946	2	0.400173	24.72	0.818
4	0.42395	6.763	0.873	4	0.347482	42.25	0.962
5	2.350474	6.694	0.91	**5**	0.339842	24.22	0.846
6	1.197658	5.392	0.848	6	0.405348	19.28	0.826
7	7.117518	5.247	0.859	7	0.676326	15.36	0.806
8	1.183255	4.64	0.858	8	0.363627	17.2	17.2
Temp	**A_T**	**B_T**	**R^2**	**Temp**	**A_T**	**B_T**	**R^2**
20	0.453	0.440872	0.882	20	0.319075	26.98	0.885
30	0.424	0.448431	0.905	**30**	0.37714	32.18	0.857
40	0.486	0.505605	0.915	40	0.309464	26.95	0.856
50	0.534	0.582166	0.96	50	0.313883	25.01	0.856
Size	**A_T**	**B_T**	**R^2**	**Size**	**A_T**	**B_T**	**R^2**
0.1	0.457	0.494109	0.944	0.1	0.299711	17.42	0.857
0.2	0.382	0.435178	0.84	0.2	0.282271	16.12	0.802
0.3	0.343	0.350638	0.528	0.3	0.288622	18.34	0.816
0.4	0.464	0.506617	0.898	0.4	0.369368	8.912	0.86
0.5	0.386	0.371205	0.508	**0.5**	0.330268	14.65	0.911
0.6	0.467	0.311611	0.884	0.6	0.318004	25.19	0.88
0.7	0.387	0.455208	0.863	0.7	0.413304	5.497	0.85
0.8	0.589	0.542265	0.986	0.8	0.457866	7.353	0.883
0.9	0.572	0.265007	0.877	0.9	0.291035	14.98	0.858
Rpm	**A_T**	**B_T**	**R^2**	**Rpm**	**A_T**	**B_T**	**R^2**
50	0.513	0.510176	0.955	50	0.337356	24.36	0.905

100	0.486	0.426135	0.961	100	0.336703	28.57	0.935
150	0.492	0.315058	0.846	150	0.385237	15.4	0.923
200	0.382	0.41189	0.741	200	0.358931	16.65	0.911

Table 4 : Tempkin isotherm model parameters for iron and mercury

The rate constants, predicted equilibrium uptakes and the corresponding correlation coefficients for all concentrations tested have been calculated for Langmuir, Freundlich, Redlich – Peterson and Tempkin isotherm model were summarized in Table 1,2.3 and 4. By comparing all the R^2 value it was observed that for iron the R^2 values were found to be higher in Langmuir and for mercury Freundlich were found to be higher when compare to other isotherm models.

Adsorption Kinetics

In order to understand the kinetics of metal absorption using Sargassum sp. as an adsorbent, pseudo first – order and second- order kinetic models are tested with the experimental data.

The plot of log(q_e-q_t) versus t gives a straight line which represents the pseudo first – order kinetics for the removal of iron and mercury using *sargassum sp.*The values of first – order rate constants, K_1 and q_e are calculated and listed in Table 5. Application of second- order kinetics by plotting t/q_t vs t, yielded the second – order rate constant k_2, calculated equilibrium capacity qe, and regression correlation coefficient for the iron and mercury using *Sargassum sp.* were shown in Table 5.

Pseudo I order kinetics				**Pseudo II order kinetics**		
Metals	**K_1x10^3**	**qe**	**R^2**	**K_2x10^3**	**qe**	**R^2**
Mercury	0.06	883.08	0.938	0.0004	1000	0.947
Iron	0.02	214.29	0.918	0.00062	200	0.981

Table :5 pseudo first – order and second- order kinetic models for mercury and iron

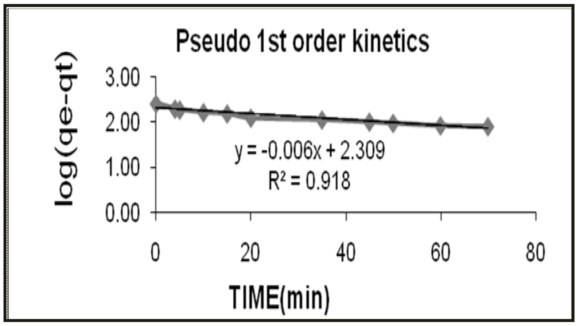
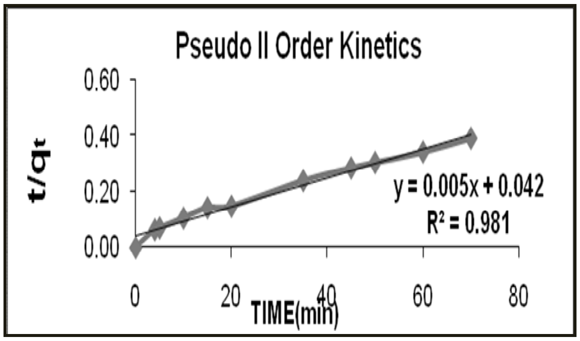
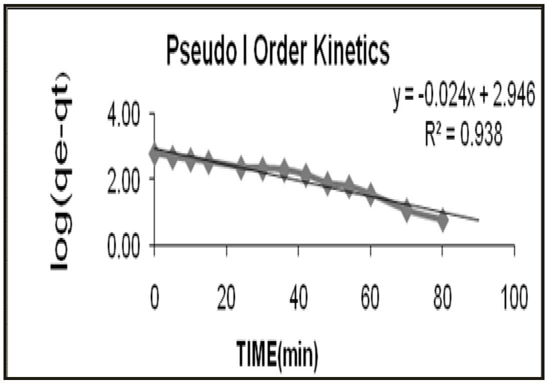


Fig (**9**) Pseudo I st order kinetics for iron



Fig(**10**) Pseudo II order kinetics for iron



Fig(11) Pseudo I st order kinetics for mercury

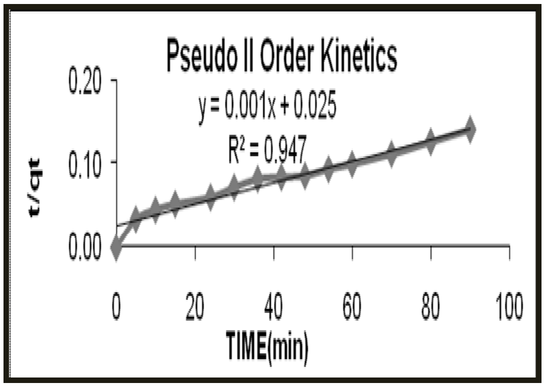


Fig (12) Pseudo II order kinetics for mercury

The rate constants, predicted equilibrium uptakes and corresponding correlation coefficients for both the metals tested have been calculated and summarized in Table: 5. The maximum correlation coefficient were obtained in pseudo second- order kinetic for iron and mercury was found to be 0.981 and 0.947 .This was consistent with the better results obtained with the pseudo second order model (Table:5).

Conclusion

Biosorption of heavy metals is one of the promising technologies involved in the removal of heavy metals from waste waters. *Sargassum sp*. was selected for studying biosorption due to its originality as well as to assess the possibility of utilizing a waste biomass for heavy metal removal. Batch experiments provided fundamental information regarding optimum pH, temperature, agitation, biomass size and maximum metal uptake. The adsorption isotherms could be well fitted by the Langmuir equation for iron and Freundlich equation for mercury. The kinetics of the biosorption of iron and mercury was best described with second order kinetics. The obtained kinetic information has a significant practical value for technological applications, since kinetic modeling successfully replaces time and material consuming experiments, necessary for process equipment design.

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