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A STUDY ON THE REMOVAL OF MERCURY (II) IONS FROM AQUEOUS SOLUTION BY CHEMICALLY MODIFIED CELLULOSE GREEN ADSORBENT: KINETIC AND EQUILIBRIUM STUDIES

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ABSTRACT

A novel chemically modified cellulose (Cell-DMA) adsorbent using Schiff base tertiary amine-chelating group was synthesized for the removal of Hg^{2+} metal ions from aqueous solution. Mercury is a highly toxic, environmental pollutant, which requires new ecofriendly green adsorbent material for its removal from wastewater. The physical and chemical characteristics of the adsorbent (Cell-DMA) were determined by FTIR, ^{13}C NMR, SEM and EDAX analysis. The well-characterized chemically modified cellulose (Cell-DMA) was used for the removal of mercury (II) ions from aqueous solution using batch adsorption process. The obtained data were analyzed with various kinetic and isotherm models and it was found that the pseudo second order kinetic model and the Langmuir isotherm were well suited for the adsorption of mercury (II) ions from aqueous media.

Keywords: Cellulose, Tertiary amine, Schiff base, adsorption kinetics, adsorption isotherms.

INTRODUCTION

Atmospheric fluxes of heavy metals have been enhanced by human activity to a considerable degree. Urban and industrial activities generate heavy metals both particulate and gaseous phases[1]. Mercury is one of the most toxic heavy metal among all the commonly occurring metal pollutants. It is widely used in industries which produce electrical equipment's, paints, pesticides, pulp and paper, domestic thermometers, dental amalgams and mercury vapor lamps.[2] The high concentration of mercury poisoning includes tingling of fingers and lips, insomnia, abdominal discomfort**,** neuro-behavioral problems like dyslexia, deficit in attention , hyper activity disorders and intellectual retardation viz[3]. Hence developing an environmental friendly adsorbent for the removal of mercury from aqueous media is an essential and useful one. The various techniques developed to remove metal pollutants in aqueous solution includes reduction, precipitation, coagulation, ion exchange, reverse osmosis and adsorption[4-6]. Among these treatment methods adsorption using solid adsorbents is one of the most effective method to remove heavy metals from water bodies. The most widely used, adsorbent being activated carbon and despite its prolific views, it remains an expensive material. Therefore, the need for low cost solid adsorbents based on natural or synthetic polymers is ever growing. Our group has concentrated in developing synthetic polymeric adsorbents, modification of commercial polymers as adsorbent for various heavy metal ion adsorption from aqueous solution[7-11]. However, synthesis of these polymeric adsorbents is costlier and the disposal of spent adsorbent may cause environmental problems. Hence low cost cellulose based polymeric adsorbents may be effectively used to remove heavy metal contaminated water bodies.

The most abundant and renewable polymer resource available is cellulose worldwide. By photosynthesis, 10^{11}- 10^{12} tons of cellulose were periodically synthesized in a relatively stable and pure form[12] since native cellulose has a very poor metal adsorption capacity it is modified to have good adsorption capacity

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towards cellulose. The main approaches has been derived to convert the cellulose into modified cellulose bearing metal binding ligands which are efficient for the adsorption of metal ions from aqueous media. The primary approach is straight modification on the backbone of the cellulose with introduction of chelating or metal binding functionality groups, which produces a wide range of heavy metal adsorbent materials. The second approach is concentrated on grafting monomers on the cellulose backbone selectively to have required functional groups in the grafted polymer. There are only few articles on the removal of Hg^{2+} ions from aqueous media using chemically modified cellulose. Polyacrylamide grafted cellulose was selectively used as an adsorbent to remove the Hg^{2+} ions from wastewater [13]. Cellulose with chelating groups such as epichlorohydrine and polyethylene amine has been used for the removal of Hg^{2+} ions from aqueous media[14]. Recently our group has reported chemically modified cellulose bearing methyl benzalaniline chelating group for the effective removal of $Cu^{2+,}$ Pb^{2+} ions from aqueous solutions.[15] The prime objective of the present work was to synthesize chemically modified cellulose bearing *N,N*-dimethyl benzalaniline chelating group and examine its efficiency towards adsorption of Hg^{2+} ions. The electron donating methyl groups bonded to N increases the basicity and hence form an effective chelating site for the Hg^{2+} ions.

EXPERIMENTAL

Chemicals

Cellulose (Loba), p-toluidine (Alfa Aesar), sodium meta periodate (Sigma Aldrich), *N,N*-dimethyl benzaldehyde (Fluka), mercuric chloride (Hi media) was used without further purification. Mercuric chloride was used as a source for Hg^{2+} and used for preparing stock solution. Rhodamine 6G (Hi media) was used as complexing agent for estimation of Hg^{2+} ions.

Synthesis of Chemically modified cellulose

Cellulose was first oxidized with sodium meta periodate and then condensed with *N,N*-dimethyl benzaldehyde. Sodium meta periodate oxidation reaction which cleaves the bond between C2-C3 of the glycoside ring and converts into the 2,3– dialdehydic groups following the Malaprade reaction without significant side reactions[16, 17]. The dialdehydic cellulose was prepared using the method reported by our group. Typically 5 gm of cellulose was powdered and suspended in distilled water and mixed with 0.03N sodium meta periodate solution and flustered at room temperature in dark for 4 h. Under these reaction conditions approximately 20 carbonyl groups / 100 glucose units are achieved. After 4 h the dialdehydic cellulose developed was filtered and washed with deionised water to achieve the neutral conditions. The dialdehydic cellulose was dehydrated under vacuum at normal temperature to a constant weight. The powdered dialdehydic cellulose (2 gm) was suspended in a deionised water and flustered with 1.5 gm of *N,N*-dimethyl benzaldehyde catalysed by HCl at 70°C for 3 h. The dark brown coloured product was drained, washed several time with water and ethanol finally dried under vacuum. The chemically modified cellulose having the chelating group *N,N* -dimethyl benzal aniline (Cell-DMA) is utilised as an adsorbent for the removal of Hg^{2+} ions.

Characterization of Cell-DMA

IR spectra of Cell-DMA were performed using FT-IR Shimadzu spectrophotometer with KBr pellets. Cellulose and Cell-DMA were characterized using ^{13}C CP-MAS NMR Spectra at 100.52 MHz on a Bruker AMX -200 spectrophotometer. Leo Gemini 1530 Scanning Electron Microscope was used to analyse SEM images of Cell-DMA and Hg adsorbed Cell-DMA.

Sorption studies by batch process

Effect of pH

The adsorption experiments at different pH levels were carried out by placing 0.3 gm of dried Cell-DMA in a series of beakers containing 50 mL of Hg^{2+} at initial concentration of 5×10^{-2} M. By using NH_4Cl and NH_4OH, the pH was varied and examined. The flask was flustered on a Mechanical shaker at 300 rpm for 1 h. After the equilibration, time the residual concentration of Hg^{2+} was determined by UV-Visible Spectrophotometer with Rhodamine-6G as complexing agent at 575 nm.

Effect on Initial concentration

The initial concentration of the metal ions on the uptake value of the Cell- DMA was achieved by placing 0.3 gm of Cell-DMA in a series of flasks containing 50 mL of Hg^{2+} ions with various concentration at pH 5. The flasks were equilibrated on the mechanical shaker at different for 1 h. After equilibration time 5 mL of the solution from each flask taken for the determination of the concentration of Hg^{2+} ions as given above.

Effect of contact time

The effect of contact time on the metal ion uptake of Hg^{2+} was determined by placing 0.3 gm of dried Cell-DMA in a series of flasks. To each flask, 50 mL of Hg^{2+} at pH 5 with initial concentration (5×10^{-2} M) was added. The flask was shaken at room temperature and 5 mL of solution were taken at various time intervals. By using UV-Visible spectrophotometer, λ_{max} (575nm) with Rhodamine 6G as complexing agent the residual concentration of Hg^{2+} was determined

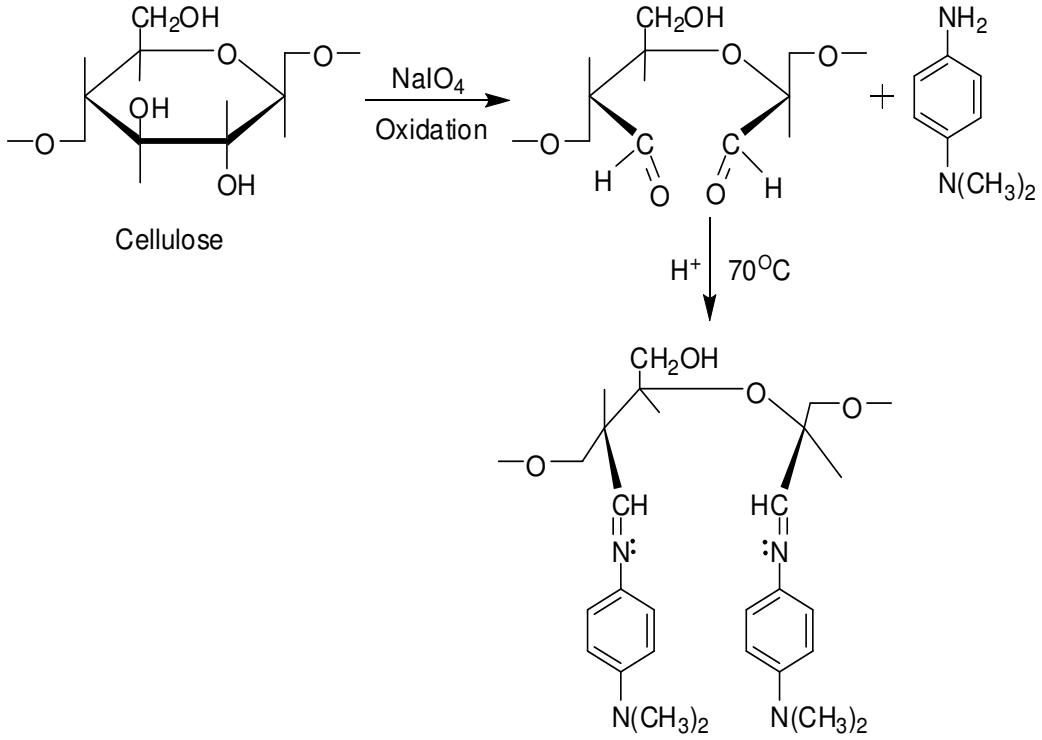
Effect of adsorbent dose

The effect of adsorbent dosage from uptake of Hg^{2+} by Cell-DMA was done by placing 5 to 40 gm of Cell-DMA in a set of flasks containing 50 mL of Hg^{2+} at pH 5. The content of flask was equilibrated on the shaker at room temperature for one hour. After filtration, the residual concentration of Hg^{2+} ions was determined as given above.

RESULTS AND DISCUSSION

Characterization of the adsorbent

Formation of Cell-DMA from cellulose is shown in Scheme-1.



Scheme-1: Formation of Cell-DMA from cellulose (Mechanism)

The IR spectrum of Cell- DMA is shown in Figure-1.

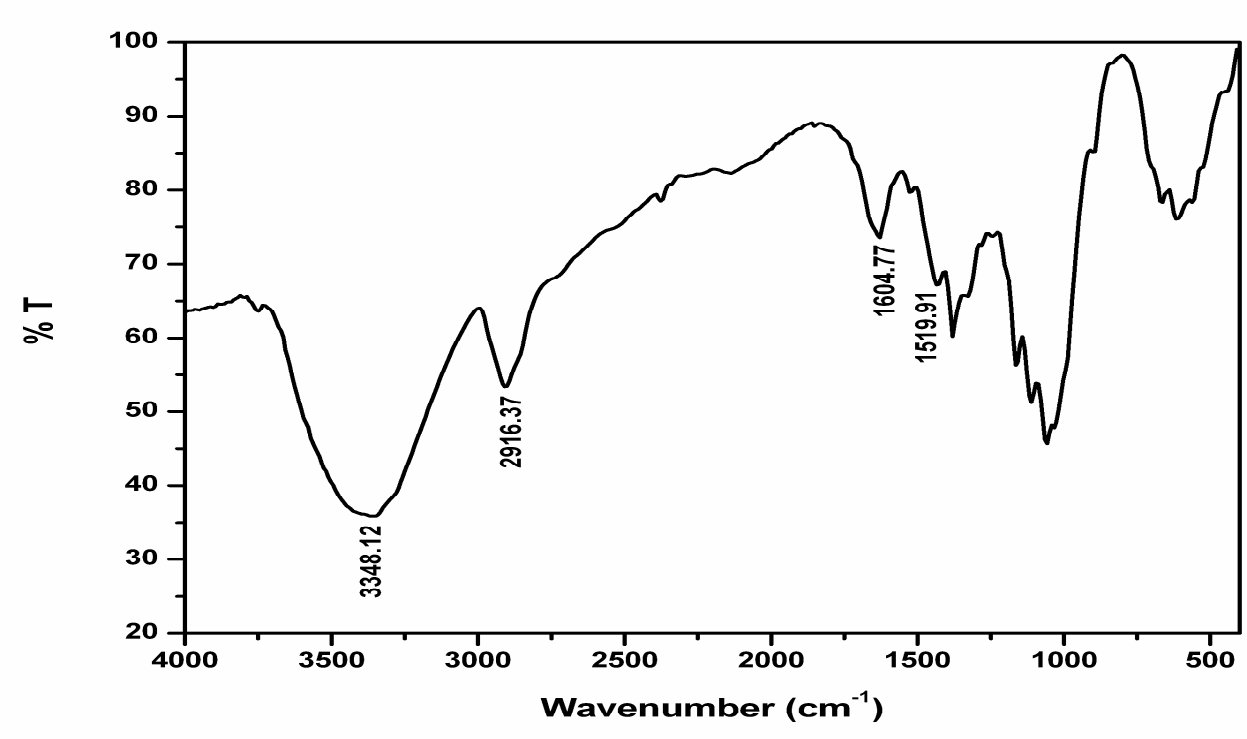


Fig.-1: IR Spectrum of Cell-DMA

From the figure, it is observed that the –OH stretching frequency appeared as a broad band around 3348 cm^{-1}.The imine –CH stretching frequency appeared at 2916 cm^{-1} and –CH=N- stretching frequency was adsorbed as a strong band at 1604 cm^{-1}. The –CN stretching frequency appeared at 1519 cm^{-1} which confirms the formation of pendent *N, N* – dimethylbenzal aniline chelating groups in the cellulose chain. This fact is further confirmed with the ^{13}C CP-MAS NMR spectrum of Cell-DMA (Figure-2). The Cellulose carbons appeared between δ 73 to 11.9 ppm. The $–CH_2$ carbon of cellulose appeared at δ 31.1ppm. Appearance of new carbon signals in the ^{13}C CP-MAS NMR spectrum of at δ 130.5 ppm is accounted for the aromatic carbons. The azomethine carbon appeared at δ 179.7 ppm and $–N(CH_3)_2$ carbon shows signal at δ 19.5 ppm. The above observations confirms the formation of *N,N* -dimethyl benzalaniline in the cellulose chain.

Effect of Solution pH on metal ion adsorption

The pH of the solution is an important parameter, which affects the capacity of the adsorbent. The hydrogen ion concentration on the adsorption of Hg^{2+} ions was measured by varying the pH of metal solution in the range of 2.0 to 10.0.The effect of pH on Hg^{2+} metal ion on was shown in Figure-3.

When the pH of the medium increases the adsorption capacity of Cell- DMA increases and the maximum value was reached at 93.8 mg/L at the pH range of five. Further increase in pH beyond five results in a slight decrease in metal ion uptake. When the pH value is very low, the concentration of H^+ ions exceeds that of the Hg^{2+} metal ions and the H^+ competes with Hg^{2+} metal ions, which would hinder the Hg^{2+} ions from reaching the binding sites of the Cell-DMA caused by repulsive forces. At pH range of five, the main functional groups present in the Cell-DMA was deprotonated and hence the binding capacity of the metal was increased. Therefore, an optimum pH value of five was fixed for the batch adsorption experiments.

Effect of adsorbent dose

The dosage of the adsorbent is yet a decisive factor since this decides the capacity of the adsorbent for an initial concentration. The uptake of Hg^{2+} by Cell- DMA with increasing amount of the adsorbent which shown in Figure-4.

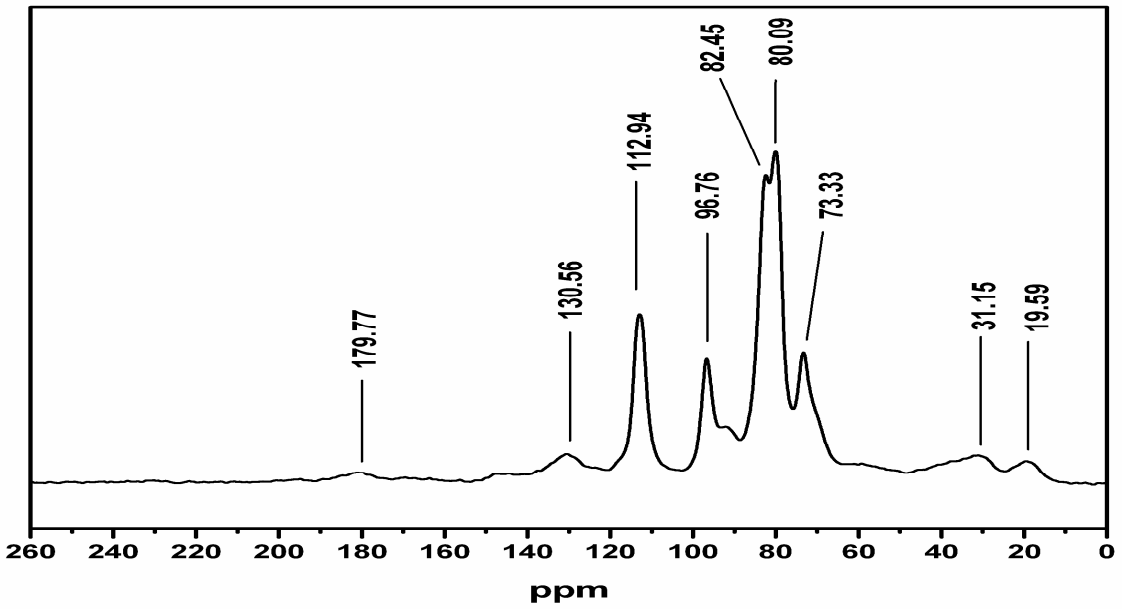


Fig.-2: 13C-NMR Spectrum of Cell-DMA

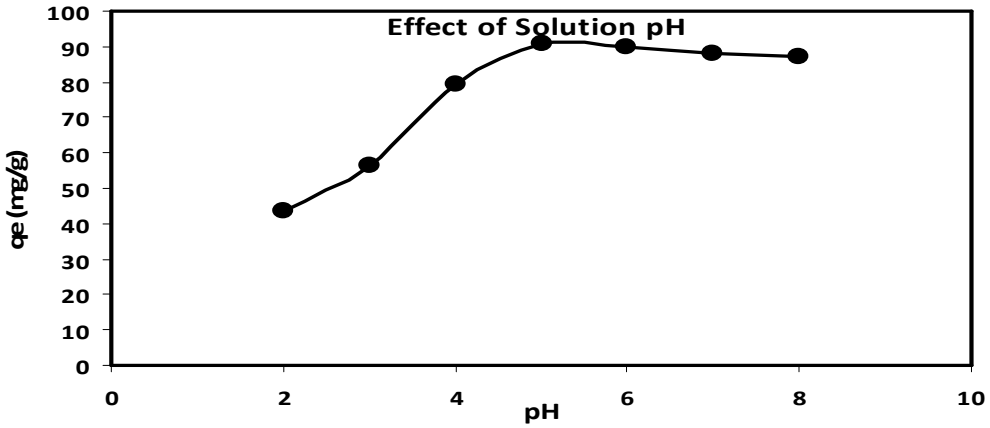


Fig.-3: Effect of pH onto metal sorption (Initial metal ion concentration=100 mg/L, adsorbent dose=20 mg/L and Contact time=60 min.)

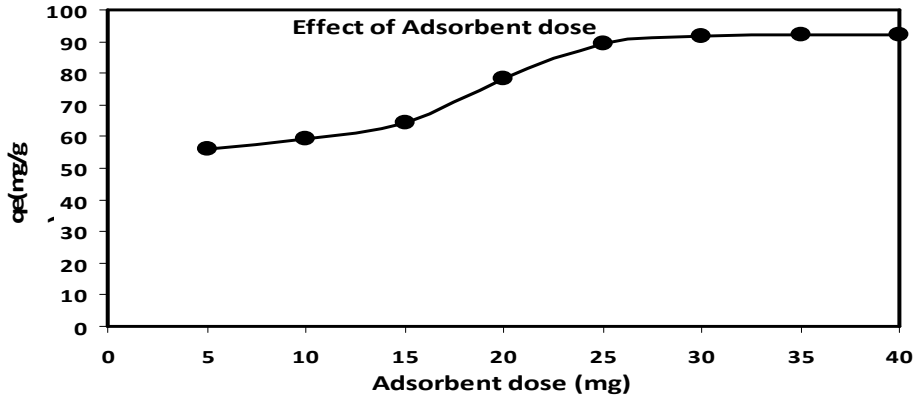


Fig.-4: Effect of adsorbent dose onto metal sorption (Initial metal ion concentration = 100 mg/L, optimized pH = 6 and Contact time = 60 min.)

With increase in the dose of Cell-DMA, the adsorption also increases due to the availability of free binding sites on the surface at higher concentration of the adsorbent for complexation with Hg^{2+} ions.[18] Beyond 0.3g/L adsorbent dose the uptake of Hg^{2+} almost remains constant. This is also due to the reason that all the Hg^{2+} ions were removed at a dosage of 0.3 g/L. For further experiments to determine the kinetics and adsorption isotherms the dosage of 0.3 g/L of Cell-DMA was chosen.

Adsorption kinetic studies

The important factor in the batch adsorption system, is contact time because this can make a significant effect on the kinetics of an adsorbent for a given metal ion concentration. The adsorption kinetic studies for Hg^{2+} ions were done by using an adsorbent concentration of 40 mg/L. The contact time was changed from 10-100 min for effective adsorption. The effect of contact time on Cell-DMA was shown in Figure-5.

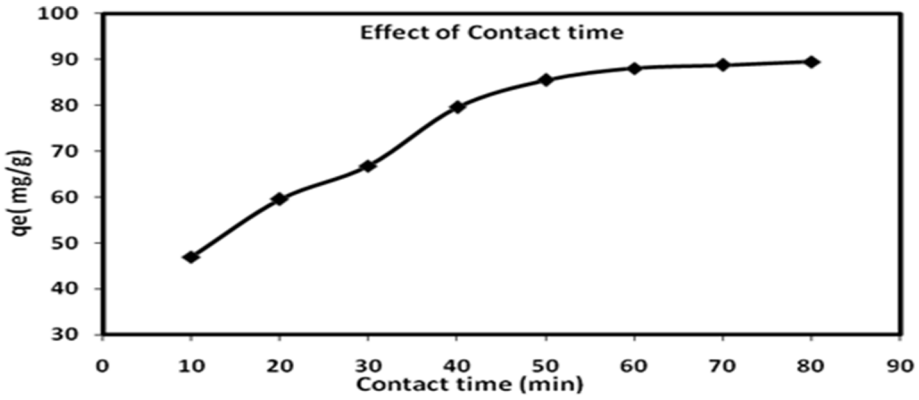


Fig.-5: Effect of contact time onto metal sorption (Optimized adsorbent dose = 40 mg/L, optimized pH=6 and Optimized initial metal ion concentration = 100 mg/L)

From the above figure it is clear that the efficiency of the adsorption increases tremendously with the initial adsorption stage and continues to increase at a slow speed and reaches equilibrium at 60 min beyond which constant adsorption was examined. The maximum Hg^{2+} metal ion adsorption on to the Cell - DMA was attained in 60 min and a constant time of 60 min was determined for further adsorption experiments. Adsorption kinetics gives a valuable information about the controlling mechanism of the adsorption process. To fix the rate of reaction for the adsorbate uptake, which is required to select the optimum operating conditions for the batch process, with adsorption kinetics studies the kinetic models such as pseudo first order[16], Pseudo second order [17], Elovich [15] and intra particle diffusion models [18] were used for the experimental data.

Pseudo-First Order Kinetic models

The Pseudo-First Order equation, which gives the relationship between the adsorption rates to the metal adsorbed amount at time t as given by:

$$\frac{dq_t}{dt} = k_1 (q_e - q_t) \quad (1)$$

Where, q_e and q_t are the adsorbed amount of the metal ions at equilibrium and time (t) respectively expressed as mg/g and k_1 is the pseudo first order kinetic constant expressed as (min-1). Equation integration and rearrangement yield the linear form:

$$\frac{dq_t}{dt} = k_1 (q_e - q_t) \quad (2)$$

From the plots of log (qe -qt) Vs t the kinetic parameters were calculated and are presented in the Table-1. The R^2 values are low when compared to the other kinetic models examined. From this value, it is suggested that the adsorption process does not fit well following the pseudo first order kinetic model.

Pseudo Second order kinetic model

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (3)$$

Where, k_2 (g $mg^{-1}min^{-1}$) is second order kinetic constant the differential equation is usually integrated and transforms in its linear form.

$$\frac{t}{q_t} = \frac{1}{k_2 q^2} + \frac{t}{q_e} \quad (4)$$

The plot of t/qt Vs t gives a linear straight line which implies that the adsorption process follows the pseudo second order kinetic model. The kinetic parameters calculated for pseudo second order kinetic models were presented in Table-1. From the table it is clear that the co relation co-efficient (R^2) is high and almost tends to unity when compared to the other kinetic co-efficient values. This shows that the adsorption of the Cell-DMA follows pseudo second order rate equation.

Elovich Kinetic Model

The experimental data were applied to the Elovich kinetic model which is given in the below equation as:

$$q_t = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln t \quad (5)$$

Where, α is the initial adsorption rate constant (mg/g min) and the parameter β is related to the extent of the surface coverage activation energy for chemisorption (g/mg) from the plot of qt vs lnt. The values of α, β and R^2 were calculated and presented in the Table-1. It is clear from the table that the co-relation coefficient R^2 is lower than that of Pseudo Second order kinetic model expression. The model suggests that the adsorption process does not suited well with the experimental values.

Table-1: Adsorption kinetics Studies

Kinetic models	Parameters	Hg(II) ion
Pseudo first order	K ($gmg^{-1}min^{-1}$) qe ,cal (mg/g) R^2	-0.0314 2.146 0.9876
Pseudo-Second order	K ($gmg^{-1}min^{-1}$) qe ,cal (mg/g) R^2	-0.0309 3.6 0.9905
Elovich model	α (□mg/g min) β (g/mg) R^2	20.39 0.6887 0.9511
Intraparticle diffusion model	Kp (mg/g/min ½) C R^2	0.8975 53.75 0.7859

Intra-Particle Diffusion Kinetic model

The Intra-Particle Diffusion Kinetic model given by Weber and Morris is:

$$q_t = k_p t^{1/2} + C \quad (6)$$

Where, k_p is the intra particle diffusion rate constant (mg/g min) and t is the time (min).The constants of intra particle diffusion model were obtained from the plot of qt against $t^{1/2}$ and presented in the Table-1.

The co relation co efficient (R^2) value seems to be far lower when compared to Pseudo second order kinetic expression. It is suggested that the adsorption of Hg^{2+} ions on to the Cell-DMA does not follow the Intra particle diffusion model kinetics model. An analysis of all the four kinetic models suggests that the adsorption suited well with that of Pseudo second order kinetic model equation and hence the adsorption of Hg^{2+} ions on to be the Cell-DMA follows the second order kinetic model.

Adsorption Isotherms

The initial concentration provides the necessary information about the driving force to overcome the resistance to the mass transfer of Hg^{2+} ions between the aqueous phase and the solid phase. The initial metal ion concentration was varied from 20-100 mg/L at a constant pH 5 and the reaction mixtures were flustered for 60 min at ambient temperature. It was observed that with the high concentration of metal ions there is a competition between metal ions to adsorb on the active site of adsorbent because the least act of participating sites is available as compared to the metal ions.[19] The non-linear form of the Langmuir [20], Freundlich [21] Redlich-Peterson [22] and Temkin adsorption isotherm models were used to examine the experimental data of adsorption using MATLABR2009a.

Langmuir Adsorption isotherm

The Langmuir isotherm model is used for the adsorption of metal ions on a completely homogeneous surface with negligible interaction between the adsorbed molecules. It is the assumption from this model that the uniform adsorption energies on to the surface and the maximum adsorption of the metal ions depends on saturation level of the monolayer. The mathematical description of this model is given by:

$$q_e = \frac{q_m k_L C_e}{1+k_L C_e} \quad (7)$$

Where, Ce is the equilibrium concentration of the metal ions in the solution (mg/L), q_e is the adsorbed value of the metal ion at equilibrium concentration (mg/g), q_m is the maximum adsorption capacity (mg/g) and k_L is the Langmuir binding constant. The data obtained qe, k_L and correlation co-efficient (R^2) values are reported in Table 2.The Langmuir isotherm dimensionless constant of separation factor or equilibrium parameters (R_L) can be used to decide whether the adsorbents are favorable or unfavorable to the adsorption system.

$$R_L = \frac{1}{1+bC_0} \quad (8)$$

Where, b- Langmuir adsorption equilibrium constant and Co- Initial metal ion concentration

R_L values between 0 to 1 indicates that the adsorbent metal systems is favorable to the adsorption process, or it is an unfavorable adsorption. The isotherm parameter are given in Table-2 .The R_L value for Hg^{2+} ions adsorption was found to be 0.4212 which lies between 0-1 indicates the adsorption process is a favorable one.

Table-2: Adsorption isotherm models

Isotherm model	Parameters	Hg (II) ion
Langmuir	$q_{m\ (mg/g)}$	90.59
	$K_{L(mg/g)}$	31.67
	R^2	0.9755
Freundlich	n	0.346
	R^2	0.9852
Redlich-Peterson	$K_{F\ (mg/g)}$	58.32
	$\alpha_{R\ (L/mg)}$	1
	$\beta\ (mg^{-1})$	0.8512
	R^2	0.9927

Temkin	B	7.306
	A	6.868
	R^2	0.9874

Freundlich isotherm model

The model is related to multilayer adsorption and for adsorption of metal ions on a heterogeneous surface. The non-linear forms of this equation is given by:

$$q_e = K_f C_e 1/n \quad (9)$$

Where, K_f is Freundlich constant [(mg/g) $(L/mg)_{1/2}$] which indicates the adsorption capacity and represents the strength of the adsorption bond. *N* is the heterogeneity factor, which represents the bond distribution. The R^2 values and all the isotherm values are given in the Table-2. The n values for Hg^{2+} ions found to be 0.346 with the cellulose adsorbent [23]

Redlich-Peterson isotherm model

The Redlich-Peterson is used to examine the homogeneous and heterogeneous system of Hg^{2+} ions and it incorporates the features of Langmuir and Freundlich model. The non-linear Redlich-Peterson equation is expressed by:

$$q_e = q_m K_R Ce/1+\alpha RC\beta e \quad (10)$$

Where, K_R (L/g) and (L/mg) are Redlich Peterson constants and β is Redlich Peterson exponent which lies between 0 to 1 .The experimental data were well fitted to the non-linear Redlich Peterson isotherm and the values were calculated and listed in Table-2. When the exponent β = 1the Langmuir model is given by:

$$q_e = K_R Ce/1+ \alpha RCe \quad (11)$$

It could be seen that the β value of this isotherm was approaching unity, which means that the experimental data fits well with Langmuir model. The values of R^2 were found to be higher for the freundlich isotherm (0.985) compared to the Langmuir isotherm (0.975) and Redlich Peterson isotherm (0.972). Moreover the 1/n value = 0.346, the value below unity implies the adsorption is primarily through chemisorption process.[24] The force that drives the adsorption is the change in entropy. The change in standard free energy (ΔG, KJ/mol), standard enthalpy (ΔH, KJ/mol) and standard entropy (ΔS, J/mol/k) were calculated in order to determine the thermodynamics of the adsorption process. The values of ΔH^0 and ΔS^o can be determined from the following equations:

$$\Delta G° = -RTln\left(\frac{C_{Ae}}{C_e}\right) = -RTlnk_c \quad (12)$$

$$\log\ k_c = \frac{\Delta S°}{3.303R} - \frac{\Delta H°}{2.303RT} \quad (13)$$

R is a gas constant (8.314 J/mol/k), T is the temperature (K), C_{Ae} is the equilibrium concentration of Hg^{2+} ions in solution (mg/L) and Kc is the equilibrium constant. The linear plots of log Kc Vs (1/T) for the different initial Hg^{2+} ion concentrations were shown in Figure-6.

The values of ΔS and ΔH were calculated from the slope and the intercept of the plot of log Kc Vs 1/T and the values were given in Table-3.

Table-3: Thermodynamic studies

ΔH (kJ mol^{-1})	ΔS (Jk^{-1} mol^{-1})	ΔG (kJ mol^{-1})
-15.38	540.41	308 = -148.52 313 = -184.76 318 = -219.43 323 = -255.11

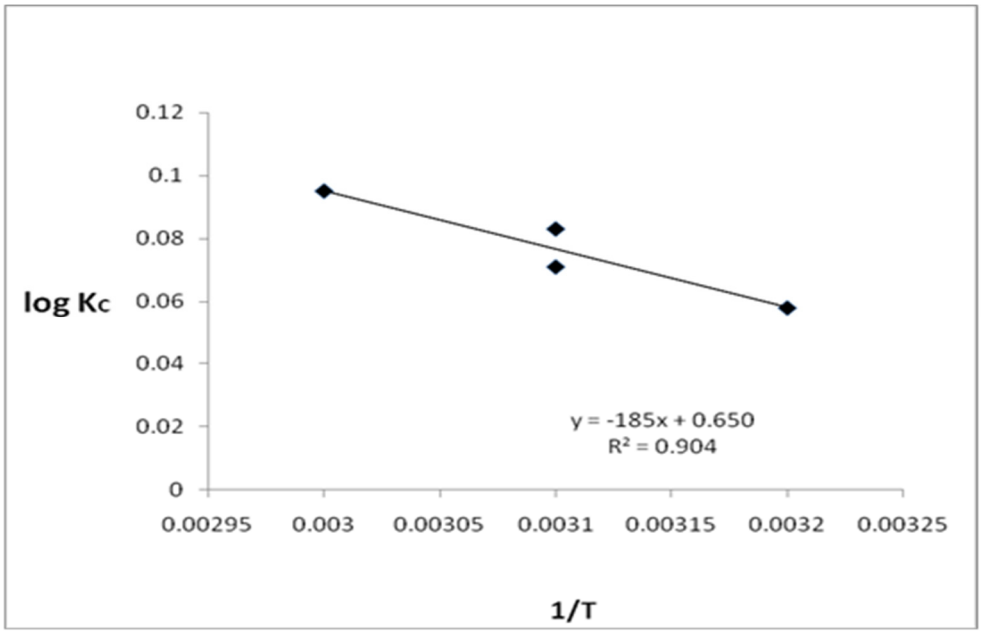


Fig.-6: The linear plots of log Kc Vs (1/T) for the different initial Hg(II) ion concentrations

The increase in temperature from 308 to 313 º C, increases the magnitude of free energy change (ΔG^o) shifted to a higher negative value proves that adsorption was fast and spontaneous. The values of ΔG^o also explained the type of adsorption. The importance of ΔG is: -20 to 0 KJ/mol (physical adsorption) and -80 to -400 KJ/mol (Chemical adsorption). In the present case Hg^{2+} ions – Cell-DMA adsorbent system, the values of ΔG were observed between -148 to -255 K /mol and all the observed temperatures, which showed the adsorption was takes place through chemical process. The negative values of ΔH^o show the adsorption of Hg^{2+}ions on to Cell-DMA was exothermic in nature. From the positive values of ΔS^0 suggested that increase in randomness at the solid solutions interface during the adsorption of Hg^{2+} ions on to the Cell-DMA. The amount adsorbed at equilibrium must increase with increasing temperature, because standard free energy decreases with increasing temperature of the solution .[25] The SEM image of Hg^{2+}ions loaded Cell-DMA has different surface morphology when compared to the SEM image of Cell-DMA and the presence of pores suggests the possibility of the metal ions to be trapped and adsorbed onto the surface. These cavities are large enough to allow the metal ions to penetrate into the surface, and interact there in with the surface chelating groups The EDAX and SEM of Cell-DMA and Hg(II) loaded Cell- DMA are given in Figures-7 and 8.

Evidence to support the formation of coordination bond between metal ions and the chelating sites was obtained from the spectrum of Hg^{2+} loaded Cell-DMA is given in Figure-9.

CONCLUSION

The removal of Hg (II) ions was carried out by green cellulose adsorbent (Cell-DMA) bearing *N,N* - dimethyl benzalaniline chelating group. It is clear from the adsorption isotherms and kinetic studies examined, this adsorption process is well suited with the Langmuir adsorption isotherm and follows pseudo second order kinetic model. These results are further confirmed with the fact that the Hg^{2+} ions loaded with Cell-DMA apart from peaks of C and O, the peaks corresponding to Hg^{2+} metal ions also supports that the adsorption of Hg^{2+} ions on to the Cell-DMA is more effective process. The shift in the characteristic peak of –CH=N- from 1604 cm^{-1} to 1627 cm^{-1} and the shift in imine –CH frequency from 2416 cm^{-1} to 2908 cm^{-1} indicate that the –C=N- bond is the primary adsorption site for the Hg^{2+} ions. Moreover, the $–N(CH)_3$ stretching frequency was shifted from 1519 cm^{-1} to 1435 cm^{-1} is a clear indication that the dimethyl amine

is also the main adsorption site for the Hg^{2+} ion adsorption. Thermodynamic studies of Cell-DMA showed that the adsorption process is feasible and exothermic in nature.

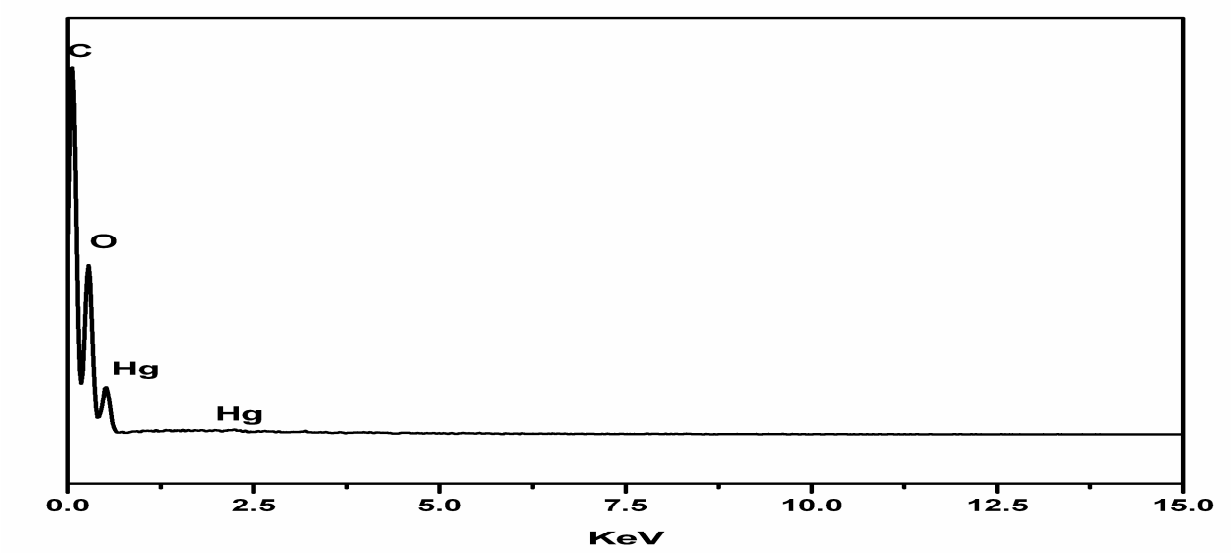


Fig.-7: EDAX of Cell-DMA

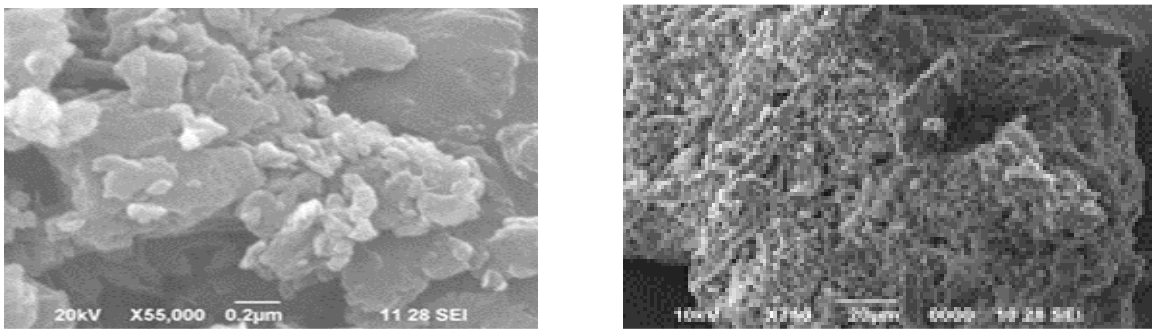


Fig.-8: SEM image of Hg(II) and Hg(II) loaded Cell-DMA

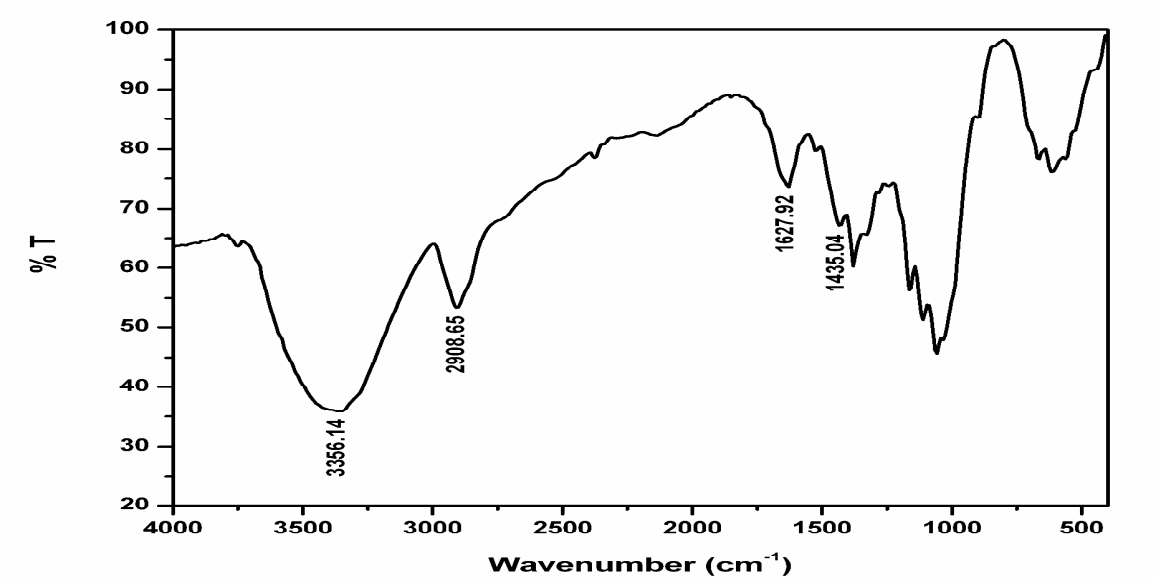


Fig.-9: IR spectrum of Hg(II) loaded Cell-DMA

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