Adsorption Studies on the Removal of Hazardous Acids like Acetic Acid and Trichloro Acetic Acid by Saraca Asoca(Rexb)de wilde as a Low-cost Adsorbent

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Abstract

The removal of environmental polluting carboxylic acids like acetic acid and trichloroacetic acid has been attempted by adsorption methods using Sulphonated Charcoal Saraca Asoca(Rexb) de Wilde(asoca pattai) (SCSAD) from waste water by tuning the various parameters like initial concentration, contact time dose of Saraca asoca de wilde(asoca pattai)charcoal form and particle size. It is being concluded from the observations that the adsorption capacity of Sulphonated Saraca asoca (Rex b) de wilde to adsorb Trichloroacetic acid is found to be higher than that of the Acetic acid and the result of this study will be useful in designing effluent treatment plant.

Key words: *Acetic acid, trichloro acetic acid, adsorption, Saraca asoca de wilde, contact time, particle size*

1. Introduction

Environmental Chemistry is the study of sources of reactions, transport and fact of chemical entities in the air, water and soil or land environment as well as their effects on human and the natural environment1. Environmental pollution has been receiving more and more attention in recent years. Of these different types of pollution, water pollution is of great significance and hence more attention has been paid towards the studies of water pollution in recent years. Water pollution is mainly caused by natural processes in which the decomposed vegetables, animals and weathered products of minerals and rocks are brought into water resources and discharge of wastewater from industries like tanneries, paper ,rubber textiles , sugar and distilleries , fertilizers , refineries , agricultural waste , carbon and domestic ,sewage , mining , pesticide etc[2]. The Chemical Pollution of water causes changes in acidity and alkalinity or pH, dissolved oxygen (DO), dissolved solids (ionic and non-ionic) and other gases in water.

Water and waste water treatment methods[3] include decomposition, coagulation[4] chemical / electrochemical reduction-oxidation , precipitation[5], complexing, solvent extraction[6] , ion-exchange[7], ion-flotation[8], reverse osmosis[9] and adsorption[10]. Among all the mentioned methods, adsorption is highly effective, very cheap, less troublesome, sludge free and cleaner/greener operation [11]. Treatment with activated charcoal provides an effective means for the removal of heavy metal ions and acids from waste water [12]. Adsorption is a surface phenomenon and greater the surface area per unit area of the adsorbent, the greater is the capacity for adsorption depends on the temperature and pressure [13].

A variety of adsorbent materials, like coconut shell charcoal, wood charcoal, fly ash, saw dust, clay, bone charcoal and coal [14] have been tried for treatment of effluent, in the place of activated carbon. Activated carbon [15] has been the most favoured material for adsorption of various materials, such as heavy metal ions, organic compounds, herbicides, detergents, chemical pollutants, dyes etc. Adsorptive properties of activated carbons are due to its complex structure which, in turn, is governed largely by the method of preparation [16]. The use of granular activated carbon for adsorption of mercury (II) species from aqueous solution and drinking water has been investigated [17]. The literature survey revealed that a large quantum of work has been reported on heavy metal ions and acid adsorption using activated carbon[18],[19] but only less attempt has been made with the studies on the removal of organic acids by the raw plant materials as such and sulphonated charcoal derived from the plant materials.

The following is the review of literature available on the removal of acids by adsorption. Ramu et al[20] studied the removal of carboxylic acid by

adsorption on commercially activated charcoal and activated carbon indigenously prepared from agricultural wastes and tested the applicability of Freundlich isotherm. Removal of oxalic acid was studied and reported by Kaistha and Bansal[21]by adsorption on the activated charcoal surface modified by oxidation with nitric acid, H_2O_2 and persulphate. They concluded that the efficiency of the activated charcoal can be increased by Surface modification process. The surface modified activated charcoal has been found to be a better adsorbent than activated charcoal itself for the removal of acids. Sharma et al[22] studied the removal of carboxylic acids and agro chemicals by activated charcoal and reported that the treated water is tolerable to bio systems. The removal of dicarboxylic acids viz., glutaric acid, adipic acid and pimelic acids has been studied by adsorption with acid washed activated charcoal. It has been reported[23] that the extent of adsorption of dicarboxylic acid increases with increase in chain length. Susarla and co-workers have studied adsorption and desorption process of aliphatic amines, amino acids, acetate and fatty acids on the clay minerals such as Raolinite, Montmorillonite and marine sediments. They also studied the adsorption-desorption characteristics of 2,4-dichloro phenoxyacetic acid, 2,4,5-trichlorophenoxyacetic acid, 2-methyl-I,4-dichlorophenoxyacetic acid and phenolic compounds in volcanic soil and described the obtained adsorption data with Freundlich type isotherms. Likewise marine sediments, have also been applied to adsorb and the removal of amines and amino acids by adsorption process.

Formic acid, Acetic acid and Oxalic acid have pronounced adverse effects on plants and aquatic life8. Thus, it becomes imperative to remove Acetic acid and Trichloroacetic acid from industrial wastes before discharging into water or onto land. The literature review reveals that the removal of acids by various adsorbents separately, however the removal of carboxylic acids like Trichloroacetic acid and Acetic acid has not been studied by adsorption on Saraca asoca (Rexb) de Wilde (Asoca pattai) charcoal(SSAD) and activated charcoal (AC) under identical experimental condition for the purpose of comparison. The scope of the present work is to conduct adsorption studies in order to evaluate the efficiency of the activated Saraca asoca (Rexb) de wilde (Asoca pattai) Charcoal form in the removal of Acetic acid and Trichloroacetic acid from waste water under various experimental conditions, i.e.

initial concentration, Contact time, Dose of Saraca asoca (Rexb) de wilde (Asoca pattai) Charcoal form and Particle size variation.

The present investigation was carried out with the following aims and objectives:

- to investigate the effect of Initial concentration of acetic acid and Trichloroacetic acid.
- to study the effect of Contact time.
- to study the effect of particle size variation.
- to measure the effect of the dose of the adsorbent (Activated Charcoal and Powdered form of Sulphonated Saraca asoca (Rexb) de Wilde (Asoca pattai)) on the adsorption of these Carboxylic acids

2. Experimental
2.1 Materials
The following chemicals were employed for the present work:

- Trichloroacetic acid   -   Merck
- Acetic acid   -   Fischer
- Saraca asoca (Rexb) de wilde (Asoca pattai)
- Sulphonated charcoal (mesh size 90 microns)
- Saraca asoca (Rexb) de wilde Powdered form (mesh size 90 microns)
- Sodium hydroxide   -   Qualigens

The adsorbent employed in the present work was Saraca asoca (Rexb) de Wilde) Sulphonated charcoal form and Powdered form. Fresh sample of Saraca asoca (Rexb) de Wilde) was collected from Madurai and used as powdered and sulphonated form for all the experiments, after sieving for a constant particle size of 90 microns. Approximately O.IN solution of Trichloroacetic acid was prepared in a 500ml SMF using double distilled water. Acetic acid solution was prepared by using double distilled water. Sodium Hydroxide stock solution of approximately, 0.1 N sodium hydroxide was prepared by dissolving sodium hydroxide in double distilled water.

Activation of the Saraca asoca (Rexb) de Wilde:

The powdered Saraca asoca (Rexb) de Wilde was carbonized and sulphonated by adding con.H_2SO_4 and heated to ~90^{Co} in hot air-oven for 6 Hrs. It was then cooled, washed with distilled water for several times to remove the free acid and dried at 110 C^o for 12 Hrs. It was black in colour and labeled as Sulphonated Charcoal. It was sieved and used for a constant particle size of 105 microns.

The various experiments in this adsorption studies were carried out by employing the batch adsorption technique. In order to find out the

optimum experimental conditions, adsorption studies were carried out by varying the following experimental conditions.

- Initial concentration of adsorbate viz., acetic acid and trichloroacetic acid at constant dose of powdered Saraca asoca (Rexb) de wilde and Sulphonated Saraca asoca (Rexb) de wilde and contact time at 35 ± 10 C.
- Contact time, at constant dose of powdered and sulphonated charcoal and initial concentration of adsorbate (acids) at 35 ± 10 C.
- Dose of adsorbent (Powdered & SCSAD) at constant optimum contact time and initial concentration of adsorbates (acids) at 35 ± 10C.
- Particle Size of adsorbent (Powdered & SCSAD) at constant dose, initial concentration and contact time at $35 \pm 1°$C.

The stock solution of the carboxylic acid (- O.IN) was suitably diluted to the required initial concentrations with double distilled water to a total volume of 100mI in 250mI leak-proof bottles. Concentration of the acids were calculated from the concentration of stock solution or titrimetrically estimated.Required amount of adsorbent (Powdered & Sulphonated form) (2.5 - 30 gL-1) was then exactly weighed and transferred into each one of these bottles. The bottles were then placed in a mechanical shaker and shaken vigorously for a required period of contact time (range 0-60 min.). After attaining equilibrium, the bottles were kept aside for 10 min. at room temperature ($35 \pm$ IOC) in order to allow the adsorbent (Powdered & Sulphonated charcoal- mesh 90 microns) particles to settle down.

The solutions were then filtered through Whatmann No.1 filter paper. The first 10mI portion of the filtrate was rejected in each bottle in order to eliminate the effect of adsorption of adsorbates (acids) on filter paper. The filtration was then continued and the filtrate (acids) from each bottle was collected in a separate clean dry conical flask. Then, 10mi of filtrate (acid) from each bottle was pipetted out into a clean dry conical flask and one or two drops of phenolphthalein was added and titrated against standardized sodium hydroxide solution.

The same procedure was followed for all the adsorption experiments under the specified experimental conditions. The titre values after attaining the equilibrium give the equilibrium concentration of adsorbate (acid) (Ce) remaining in solution after adsorption on the adsorbent at the room temperature (35 ± 1 OC) and other experimental conditions.

2.2. Methods

The main. In all the adsorption experiments, the percentage removal of adsorbate on the Powdered &Sulphonated charcoal have been calculated using the relationship.

$$\% \ Removal = \left(\frac{C_i - C_e}{C_i}\right) X \ 100$$

The amount adsorbed (q) per unit mass of the adsorbent have been calculated by using the following equation.

$$\% \ Amount \ adsorbed(q) = \left(\frac{C_i - C_e}{m}\right) = \frac{x}{m}$$

Where, 'm' is the dose of adsorbent (in gL-1) added in the adsorption experiment; Ci and Ce are the initial and equilibrium concentration of acids, in geqL-1 and x is the amount of acid adsorbed by 'm' g of adsorbent.

2.2.1. Effect of initial concentration

In this adsorption experiments, dose of activated adsorbent charcoal (SCSAD) (l0 gL-1) was kept constant in all the bottles and different initial concentrations of Acetic acid (0.01 - 0.1N) and Trichloroacetic acid (0.01 - 0.1 N) were taken. The bottles were then shaken for a period of 5 min. The equilibrium concentration (Ce, in g eq L-1)of the acids had been estimated in each and every bottle and the readings were tabulated. From the readings, the percentage of removal of the acids were computed and the applicability of the Freundlich adsorption isotherm was tested by plotting log(x/m)Vs log Ce

2.2.2. Effect of contact time

In this adsorption experiments, an initial concentration of adsorbate viz., Acetic acid and Trichloroacetic acid (0.05N) and a constant dose of Sulphonated form charcoal (l0 gL-1) were taken in all the bottles. All the bottles were placed in a mechanical shaker and while the shaking was started simultaneously, a stop watch was also started, to note the contact or shaking time. The bottles were then withdrawn at different time intervals i.e., 1, 2, 3, 4, 5, 10, 20, 30, 40, 50 and 60 minutes and the other procedures were repeated to estimate the equilibrium

concentration (Ce) of the acid. The results were noted and the percentage of removal was plotted against the contact time.

2.2.3. Effect of dose of adsorbent

In this adsorption experiments, the initial concentration of adsorbate viz., Acetic acid and Trichloroacetic acid (0.05N) was kept constant with a varying amount of sulphonated charcoal (dose 2.5-30gL-1) and constant contact time (05 min.). Other procedure followed was similar to the general procedure for adsorption studies. From the adsorption data, the optimum dose was obtained. The percentage of removal was plotted against the dose of adsorbent.

2.2.4. Effect of particle size of adsorbent

In this adsorption experiments, an initial concentration of adsorbate viz., Acetic acid and Trichloroacetic acid (0.05N) was kept constant amount of sulphonated charcoal (dose 10g/l) and constant contact time (05 min.) and with a varying of the particle size. Other procedure followed was similar to the general procedure for adsorption studies. From the adsorption data, the optimum particle size of adsorbent was obtained. The percentage of removal was plotted against the particle size of adsorbent

3. Results and Discussions

The present investigation deals with the study on the removal of carboxylic acids (Acetic acid and Trichloroacetic acid)by Powdered and Sulphonated Charcoal of Saraca asoca (Rexb) de wilde (Asoca pattai) (SCSAD). This is an endeavor to present data for the design of an economical and flexible wastewater treatment unit for the removal of carboxylic acid from the effluents discharged from the industries.

In order to study their effects of process parameters on the adsorption of carboxylic acids on powdered and sulphonated charcoal, the adsorption experiments were carried out at room temperature (35 ± 10 C). The results are analyzed and discussed as follows.

3. 1.Effect of initial concentration:

The adsorption study of carboxylic acids (Acetic acid and Trichloroacetic acid) on Powdered and

Sulphonated form of Saraca asoca (Rexb) de wilde (SAD) at fixed amount of adsorbent i.e., 10gL-1 which means that 1g per 100mI of volume at different initial concentration (0.01 - 0.1 N) of carboxylic acids were carried out. The data obtained in these experiments are given in Tables 1 - 4. The variation of percentage of removal of acid with respect to the initial concentration is graphically represented in Figures 1 &2.

Table1: Effect of variation of initial concentration of Acetic acid
Powdered Saraca asoca (Rexb) de wilde (m)(mesh size 90 microns)   10g L-1

Contact Time   = 05 min.
Temperature   = 35 ± 1°C

S. No.	[CH₃COOH] (N)	C_e (N)	X=Ci-C_e(N)	% Removal of Acid	Amount adsorbed q=x/m, (g.eq.g⁻¹) (1 x 10⁻⁴)
1	0.01	0.0089	0.0011	11.0	1.1
2	0.02	0.0179	0.0021	10.5	2.1
3	0.03	0.0273	0.0027	09.1	2.7
4	0.04	0.0367	0.0033	08.1	3.3
5	0.05	0.0454	0.0046	08.0	4.6
6	0.06	0.0550	0.0050	07.9	5.0
7	0.07	0.0648	0.0052	07.4	5.2
8	0.08	0.0745	0.0055	06.9	5.5
9	0.09	0.0837	0.0063	07.0	6.3
10	0.10	0.0930	0.0070	07.2	7.0

Table: 2 Effect of variation of initial concentration of Acetic acid

Sulphonated Saraca asoca (Rexb) de wilde (m)

(mesh size 90 microns)   =10g L-1

Contact Time   = 05 min.

Temperature   = 35 ± 1°C

S. No.	$[CH_3COOH]$ (N)	C_e (N)	$X=C_i-C_e$ (N)	% Removal of Acid	Amount adsorbed $q=x/m$, $(g.eq.g^{-1})$ (1×10^{-4})
1	0.01	0.0072	0.0028	28.0	2.8
2	0.02	0.0160	0.0040	20.0	4.0
3	0.03	0.0258	0.0042	17.0	4.2
4	0.04	0.0355	0.0045	16.3	4.5
5	0.05	0.0424	0.0076	15.2	7.6
6	0.06	0.0518	0.0082	13.6	8.2
7	0.07	0.0614	0.0086	12.3	8.6
8	0.08	0.0712	0.0088	11.0	8.8
9	0.09	0.0810	0.0090	10.0	9.0
10	0.10	0.0910	0.0090	09.0	9.0

Figure.2. Plot of % removal of trichloroacetic acid vs concentration of trichloroacetic acid at 298K

Table: 3 Effect of variation of initial concentration of Trichloroacetic acid

Powdered Saraca asoca (Rex b) de wilde (m)

(meshsize 90 microns): = 10g L-1

Contact Time   = 05 min.

Temperature   = 35 ± 1°C

S. No.	$[CH_3COOH]$ (N)	C_e (N)	$X=C_i-C_e$ (N)	% Removal of Acid	Amount adsorbed $q=x/m$, $(g.eq.g^{-1})$ (1×10^{-4})
1	0.01	0.0050	0.005	50.0	5.0
2	0.02	0.0157	0.0043	21.5	4.3
3	0.03	0.0233	0.0067	22.3	6.7
4	0.04	0.0256	0.0072	18.0	7.2
5	0.05	0.0415	0.0085	17.0	8.5
6	0.06	0.0509	0.0091	15.2	9.1
7	0.07	0.0604	0.0096	13.7	9.6
8	0.08	0.0690	0.0110	13.7	11.0
9	0.09	0.0778	0.0122	13.5	12.2
10	0.10	0.0868	0.0132	13.2	13.2

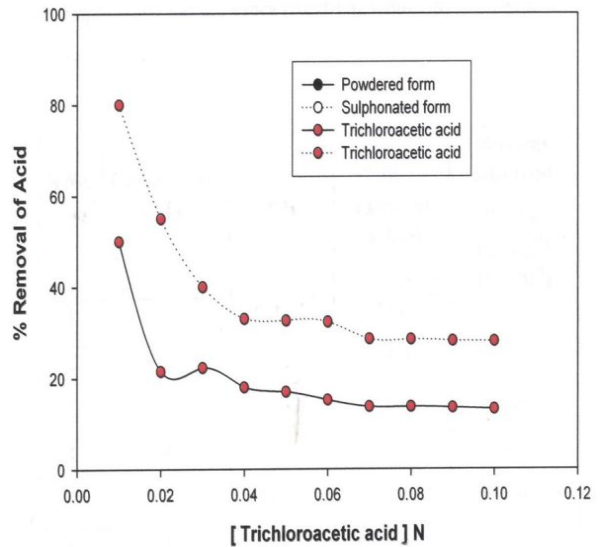Figure.1. Plot of % removal of acetic acid vs concentration of acetic acid at 298K

Table 4: Effect of variation of initial concentration for Trichloroacetic acid

Sulphonated Saraca asoca (Rexb) de wilde (m)(mesh size 90 microns)=10g L-1

Contact Time = 05 min.

Temperature = 35 ± 1°C

S. No.	[CH$_3$COOH] (N)	C$_e$ (N)	X=Ci-C$_e$(N)	% Removal of Acid	Amount adsorbed q=x/m, (g.eq.g^{-1}) (1 x 10^{-4})
1	0.01	0.002	0.0080	80.0	08.0
2	0.02	0.0090	0.0110	55.0	10.5
3	0.03	0.0180	0.0120	40.0	12.2
4	0.04	0.0272	0.0128	33.0	12.8
5	0.05	0.0337	0.0163	32.6	13.5
6	0.06	0.0406	0.0194	32.3	19.8
7	0.07	0.0500	0.0200	28.6	20.0
8	0.08	0.0572	0.0228	28.5	22.8
9	0.09	0.0646	0.0254	28.2	25.4
10	0.10	0.0719	0.0281	28.1	28.1

Table 5: Effect of variation of contact time for acetic acid

Initial concentration = 0. 05 N

SulphonatedSaraca asoca (Rexb) de Wilde (m) = 10g L-1

Temperature = 35 ± 10C

S. No.	Contact time (min)	C$_e$(N)	% Removal of Acid	Amount adsorbed q=x/m, (g.eq.g^{-1}) (1 x 10-⁴)
1	1	0.0427	14.6	7.3
2	2	0.0430	14.0	7.0
3	3	0.0420	16.0	8.0
4	4	0.0419	16.2	8.3
5	5	0.0424	15.2	7.6
6	10	0.0425	15.0	7.5
7	15	0.0426	14.8	7.4
8	20	0.0425	15.0	7.5
9	30	·0.0424	15.2	7.6
10	40	0.0448	10.4	5.2
11	60	0.0438	12.4	6.2

The range of percentage of removal of Acetic acid by powdered form of adsorbent is in the range of 7.2 - 11.0 and Trichloroacetic acid in the range 13.2 - 50.0. The range of percentage of removal of Acetic acid by sulphonated form of adsorbent is in the range of 9.0 - 28.0 and Trichloroacetic acid in the range 28.1 - 80.0. An increase in the initial concentration of carboxylic acid results in the reduction in the percentage of adsorption. This indicates the reduction is due to immediate solute adsorption thereby resulting in the   reduction in the available active sites for the adsorbent.

3.2. Effect of contact time:

Contact time plays an important role in the adsorption system irrespective of the values of other parameters affecting adsorption kinetics. In order to study the kinetics of adsorption of carboxylic acids, the adsorption experiments were carried out at different contact time ranging from 1 - 60 minutes at constant optimum initial concentrations (0.05N) of carboxylic acids and the relevant data are given Table 5 - 6 (Figure 3).

Table 6: Effect of variation of contact time for trichloroacetic acid

Initial concentration=0.0.5N

*Sulphonated*Saraca asoca (Rexb) de wilde (m) =10g L^{-1}

Temperature   =   35 ± 1^{0}C

S. No.	Contact time (min)	C$_e$(N)	% Removal of Acid	Amount adsorbed q=x/m, (g.eq.g^{-1}) (1 x 10^{-4})
1	1	0.0410	18.0	09.0
2	2	0.0410	18.0	09.0
3	3	0.0360	28.0	14.0
4	4	0:0340	32.0	16.0
5	5	0.0337	32.6	16.3
6	10	0.0395	27.0	11.0
7	15	0.0380	24.0	12.0
8	20	0.038	24.0	12.0
9	30	0.039	22.0	11.0
10	40	0.039	22.0	11.0
11	60	0.037	26.0	13.0

The uptake of carboxylic acid by Sulphonated form of Saraca asoca (Rexb) de wilde (SSAD) is found to be rapid at the initial phase of adsorption, but it is becoming more or less constant or attains the equilibrium state, as it is expected in such cases of both acids.

The percentage of removal of carboxylic acids by adsorption on Saraca asoca (Rexb) de wilde (SSAD) slightly increases with increase in contact time and reaches a limiting value.
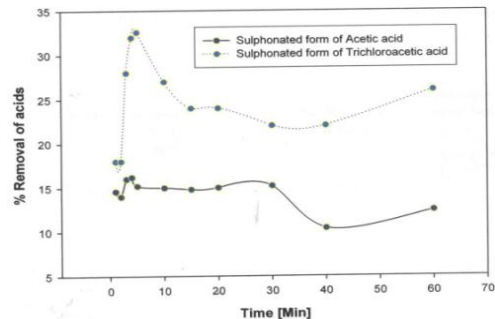

Figure.3. Plot of % removal of sulphonated form acetic acid and sulphonated form trichloroacetic acid vs time at 298K
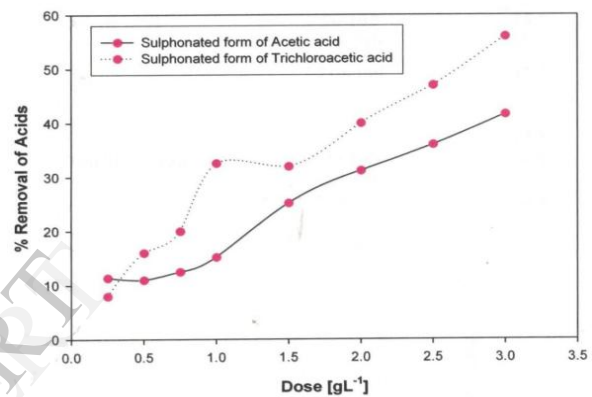

Figure.4. Plot of % removal of sulphonated form acetic acid and sulphonated form trichloroacetic acid vs dose at 298K

Table7: Effect of variation of dose of Sulphonated Saraca asoca (Rexb) de wilde for Acetic acid

Initial concentration   = 0.05 N

Contact Time   = 05 Min.

Temperature   = 35± l0C

S. No.	Amount of SSAD (g/L)	C$_e$ (N)	%Removal of Acid	Amount adsorbed q=x/m (g.eq.g^{-1}) (1 x 10^{-4})
1	0.25	0.0443	11.4	5.7
2	0.50	0.0445	11.0	5.5
3	0.75	0.0438	12.5	6.2
4	1.00	0.0424	15.2	7.6
5	1.50	0.0374	25.2	12.6
6	2.00	0.0344	31.2	15.6
7	2.50	0.0320	36.0	18.0
8	3.00	.0.0292	41.6	20.8

Table8: Effect of Variation of Dose of Sulphonated

Saraca asoca (Rexb) de wilde for Trichloroacetic acid

Initial concentration   =   0.05 N
Contact Time   =05 min
Temperature   =   35 ± l0^C

S. No.	Amount of SCTCR (g/L)	$C_e(N)$	%Removal of Acid	Amount adsorbed q=x/m (g.eq.g^{-1}) (1 x 10^{-4})
1	0.25	0.046	08.0	4.0
2	0.50	0.042	16.0	8.0
3	0.75	0.040	20.0	10.0
4	1.00	0.0342	32.6	15.8
5	1.50	0.0340	32.0	16.0
6	2.00	0.0300	40.0	20.0
7	2.5	0.0273	47.0	22.7
8	3.0	0.0220	56.0	28.0

The variation in the percentage of removal with the dose of Powdered and Sulphonated Saraca asoca (Rexb) de wilde is graphically represented. The percentage of removal of Acetic acid and Trichloroacetic acid is found to increase with increase in the dose of the adsorbent (TCR). This is due to the increased availability of adsorption sites. The increase in the effective surface area resulting from the conglomeration of the adsorbent especially at higher adsorbent concentration is also responsible for this observation. The adsorption of Acetic acid and Trichloroacetic acid obeys the classical adsorption isotherm, i.e. Freundlich adsorption isotherm.   This is being proved by plotting log(x/m)Vs log Ce. The linearity of the curve is the evidence for the above argument.(Figures 5-6)
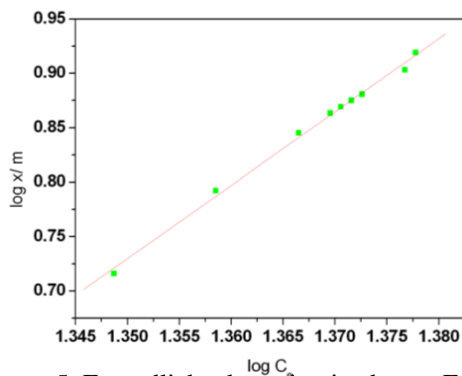

Figure.5. Freundlich adsorption isotherm- Effect of variation of contact time for acetic acid
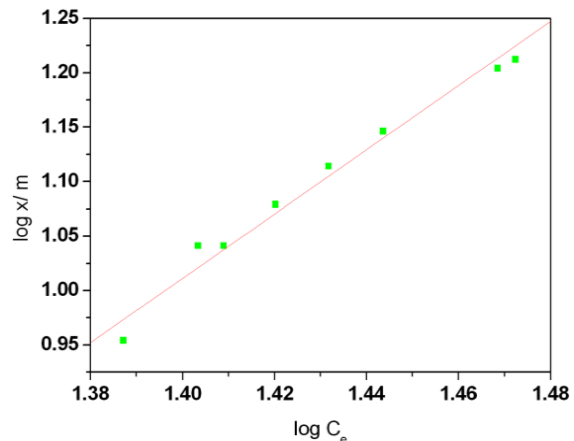

Figure.6. Freundlich adsorption isotherm- Effect of variation of contact time for trifluoroacetic acid

The observed results indicate that as the ratio of adsorbate to adsorbent decreases and the percentage of removal of the acids increases

Table 9: Comparison of the results of both the acids

Carboxylic acid	% of Removal (powdered Form)	% of Removal (sulphonated Form)
Trichloroacetic acid	17.0	32.6
Acetic acid	08.0	15.2

The comparison of results on the % removal of acids by adsorption of both Powdered and Sulphonated Saraca asoca (Rexb) de wilde(Table 9) indicates that the removal of Trichloroacetic acid is higher than acetic acid.

Conclusion

The results of the present investigation conclude that the Sulphonated Saraca asoca (Rexb) de wilde (mesh size 90 micron) can be used as an adsorbent for the removal of Acetic acid and Trichloroacetic acid from water or industrial wastewater. This result of this study will be useful in designing the effluent treatment plant. The adsorption capacity of Sulphonated Saraca asoca (Rexb) de wilde to adsorb Trichloroacetic acid is found to be higher than that of the Acetic acid. Thus, from the results of the present study, it is found that the Sulphonated Saraca asoca (Rex b) de wilde is a very good adsorbent than the Powdered Saraca asoca (Rexb) de wilde for the removal of Acetic acid and Trichloroacetic acid from aqueous solutions at diluted condition.

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