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Low cost water technique for the removal of Arsenic from groundwater

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Abstract

The main focus of this study to remove Arsenic (As) content from groundwater using Sand Filtration Technique (SFT). Two treatments i.e. T1 (Charcoal) and T2 (Iron nails) were used to study the removal efficiency of Arsenic (As) from groundwater by column experiments at room temperature (20–25°C) for 30 days. Column experiments were conducted to examine the removal efficiency of Arsenic (As) in Charcoal and Iron nails Filters. The study of Adsorption involved in removal of Arsenic (As) concentrations by adsorbent materials. The Charcoal Sand filter showed the maximum removal efficiency Arsenic (As)is 96% and adsorbed Arsenic (As) concentrationis 1.92 mg and the presence of Iron nails in sand filter showed the removal efficiency of Arsenic (As) is 85% in 30 days. The sand filter embedded with Charcoal was the most constant and effective than the filter embedded with Iron nails under the similar conditions. This features the positive effect on arsenic removal in Charcoal sand filter than the Iron nails. The Sand filters serve as good option for the treatment of ground water contained Arsenic, recommended for the developing countries.

Keywords: *Groundwater, Arsenic (As), Charcoal, Iron nails, Sand filters, filtration;*

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INTRODUCTION

The safety of human health is kept at threat due to the presence of Arsenic (As) in groundwater. In Asia, many countries have been found high Arsenic content in groundwater including India (West Bengal), China, Bangladesh, Nepal, Myanmar, Cambodia, and Thailand. Prolonged consumption of ground water comprising high levels of arsenic will cause severe health issues like skin cancer, lungs, and kidney. Arsenic (As) presents in the environment by different industrial, commercial, domestic & mineral sources [1]. About 33% of the global population is affected by the scarcity of water [2]. If the rate of consumption of water won't be any change, the quantity of water needed for this fast-growing population will soon become double within a span of 50 years from today [3, 4]. Arsenic can be removed by various methods & materials, like coagulation, flocculation, oxidation, filtration and adsorption. These technologies have their own advantages & drawbacks [7].

To supply potable water, Sand filters (SF) are most effectively used in rural areas of developing countries. The operation of 'Sand Filter' is based on the principle of slow sand filtration technique, in which the portion of standing water enables the creation of a biofilm, which is biologically active & aids in the removal of microbial pollution. Sand filter (SF) could be an advanced technique for the treatment of impure water. The SF is small and can be easily used at every house [4]. The SF can be effectively used for the treatment of various sources of water like rivers, groundwater, rainwater, lakes etc. [8]. The contaminants like organic matter, worms, viruses, bacteria, protozoa and inorganic matter can be removed by Sand filters [12].

In present study, the focus was on the design of Sand Filter for the treatment of ground water containing Arsenic (As) by using low cost local materials like local sand, Charcoal and rusted Iron nails in the Sand filters. In this filter, arsenic is removed due to the formation of iron (III) oxides in water due to the oxidization of Iron nails. When the Iron nails react with water containing oxygen, fresh insoluble hydroxides are formed which removes soluble Arsenic by sorption & co-precipitation. The precipitate thus formed gets trapped in the voids of sand leaving the water to flow. The 'Charcoal Sand Filter' also comprises similar design, replacing rusted Iron nails with Charcoal. Charcoal adsorbs the

Arsenic in water and the precipitates get trapped within the sand allowing the Arsenic free water [13]. This present work studied the removal efficiency of these two sand filters when operated individually and jointly.

The main objectives of this project are to portray the performance of Sand Filters with respect to Arsenic removal efficiency and contact time, its impact on the chemical composition of treated water.

Arsenic poisoning has been a wide range problem all over the world. Several health issues are caused with the consumption of Arsenic contaminated water. The people of West Bengal (India) & Bangladesh are at highest risk of arsenic poisoning. The consequences of Arsenic poisoning may be acute or chronic. After, about two years of As exposure the Chronic effects will occur, whereas the acute effects will occur when exposed to overdose. The common effects are muscle pain and weakness, diarrhea and stomach pain, in extreme cases will cause death or coma. Whereas the chronic impacts are hypo pigment and hyper pigment within the skin. It will cause keratosis, toughening of skin in feet and hands that may cause skin lesions. [14] It additionally causes loss of hair [15]. According to American National Academy of Sciences Arsenic causes bladder cancer, lung cancer, urinary organ cancer, skin cancer, liver cancer, damages heart, nervous system and blood vessels. It may also cause procreative issues and genetic defects.

MATERIALS AND METHODS

Sand filter design and amendment

The treatment of groundwater contaminated with Arsenic (As) by using Sand filters was conducted at JNTUA College of Engineering Anantapur, Andhra Pradesh, India. The analysis was done on the groundwater before and after the filtration process for duration of one month in laboratory. The major focus was established on the feasibility of using Charcoal as an adsorbent material (bio sorbent) to remove Arsenic from groundwater. In addition to charcoal, one more adsorbent material i.e. rusted Iron nails were also taken for the study. Performances of both the adsorbent materials were individually studied and finally compared with each other. For this study, column filters were designed and prepared with a plastic water bottle as a filter column and filled with gravel, brick chips, coarse and fine sand in it. These entire filter media are arranged one above the other with certain thicknesses. For these experiments synthetic sample (i.e. ground water contaminated with Arsenic (As) was prepared at laboratory) could pass through both the filters individually and regular studies were conducted for 1, 3, 5, 10, 15 and 30 days.

Sand Filter media preparation and construction

Here the adsorbents used were Charcoal, Iron nails, Coarse sand, fine sand, Brick chips & Gravel. The filter media was first sieved for regular size distribution and later fully washed and dried to remove the clay, organic matter, grit, etc. trapped with sand and gravel. With the dried materials the sand filter is prepared in a bottle as shown in the figure-5. The filter consists of the following design: bottom-most 4 cm thick gravel layer (12-15mm dia.), 2 cm medium sized Brick Chips (6 mm dia.), 2 to 3 cm sand with an effective size (D_{10}) of 0.18 to 0.22mm and (D_{60}) of 0.60–0.90mm and the uniformity coefficient (D_{60}/D_{10}) was 3.5 to 4.0 mm, 5 cm of 500g Charcoal (6mm), followed by 5 cm of top coarse and fine sand layer (0.2-0.9mm) for maintaining equal water distribution. Two Sand Filters T1 and T2 were thus prepared created with altering the adsorbent media i.e. 1 kg Rusty Iron Nails of 5cm length replacing the Charcoal as Adsorbent shown in figure 1(a) & 1(b) respectively. Different Adsorbents of filter media layers in different set of treatments were ready within the middle of the sand column of the Sand Filters. These treatments were maintained with controlling of removal efficiency of Arsenic within the sand filters. The materials like gravel and sand were washed properly to remove the clay particles, organic content and different materials [2].

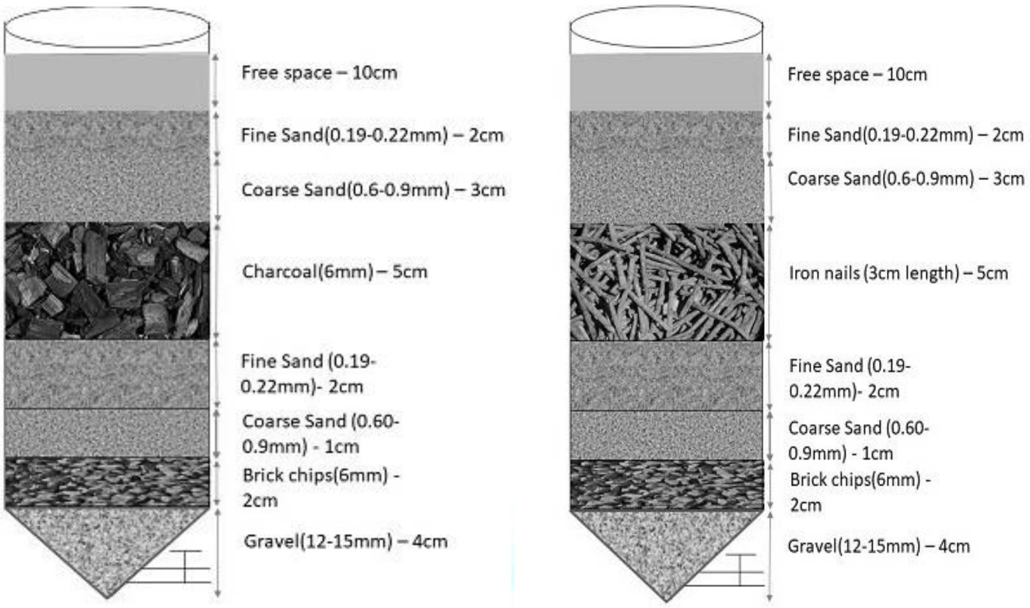

Fig.1: *(a)-CharcoalSand filter (T1), 1(b)- Iron nails Sand filter (T2)*

Preparation & Treatment of synthetic Arsenic contaminated groundwater

Arsenic contaminated groundwater was prepared with varying concentrations from 2mg/L,3mg/L and 4mg/L from Arsenic stock solution by using Sodium Arsenate (Na_3AsO_4). The contaminated water was passed through every Sand filter. The filter adsorbs the Arsenic content from the water when passed through it. When the treatment of arsenic water run on each treatment systems T1 and T2, the quality of water was lab tested for residual Arsenic content. This process of treatment and testing was continued for 30 days. The samples were collected at different intervals of time 0,1,3,5,10,15,30 days for the test. The Sand filters efficiency is compared with one another Filter systems.

Analytical methods

Arsenic within the raw and treated samples was measured by UV-Spectrophotometer at 228 nm. The values of pH scale were determined for pre and post water samples using calibrated pH meter. For samples each pre and post filtration from the sand filters area unit measured for the Arsenic absorbance present in the samples which may be calculated for the effective Arsenic removal efficiency.

RESULTS AND DISCUSSION

Effect of Arsenic Removal in Charcoal Sand Filter

In this Charcoal is used as the filter media in the Sand Filter and adsorption of arsenic is determined by the percentage removal of arsenic obtained in the sample solutions collecting at different period of contact time with the adsorbent. The effect of contact time can be explored from the extent of adsorption in the filter. Three different concentrations (2mg/L, 3mg/L & 4mg/L) of arsenic contaminated ground water is passed through the filters and sample collections are taken at a certain interval i.e., at 1, 3, 5, 10, 15 & 30 days respectively. These experiments were carried out at room temperature. Sand filter bed acts like automatic device for the removal of particles by adsorbing the tiny particles from the turbid raw groundwater. The sand layer has an effective sand diameter of 0.5 to 1.0 mm with a void gap of 0.1 mm that is to trap the particles and bacteria of size less than 0.01mm and less than 0.001mm.

In this Filter treatment, it was noticed that the Charcoal filter recorded the removal of Arsenic ranging between 90 and 96% for the period of 30 days as shown in the Table 20. And it is the maximum Arsenic removal percentage recorded. It is also noticed that with the increase in the concentration of Arsenic, the removal efficiency decreases. This is due to the fact of decrease in the contact time as shown below Fig 2. However, it shows the maximum Arsenic (As) removal over period of 30. It was observed that, the rate of removal of arsenic becomes slow in later stages as the arsenic reaches to its saturation point. The final Arsenic concentration varies significantly after 30 days from the beginning of adsorption. This makes it obvious that the equilibrium cannot be achieved post 30 days.

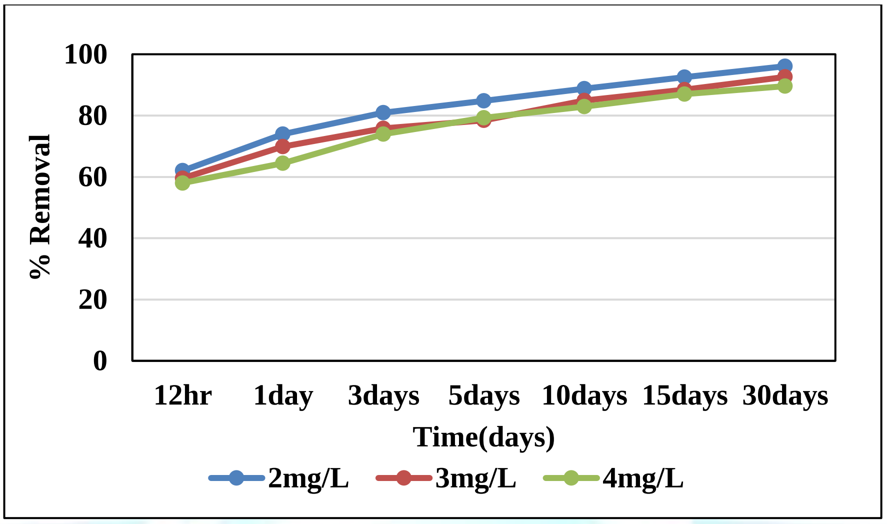

***Fig.2**: % Removal of Arsenic content in Charcoal sand filter at different Concentrations*

Effect of Arsenic Removal in Iron nails Sand Filter

In this Iron nails is used as the filter media in the Sand Filter and adsorption of arsenic is determined by the percentage removal of arsenic obtained in the sample solutions collecting at different period of contact time with the adsorbent. The effect of contact time can be explored from the amount of adsorption in the filter. Three different concentrations (2mg/L, 3mg/L & 4mg/L) of arsenic contaminated ground water is passed through the filters and sample collections are taken at a certain interval i.e., at 1, 3, 5, 10, 15 & 30 days respectively. The Iron nails Sand Filter system contains 5 cm depth of Iron nails as filter media. This treatment system was analyzed to check the efficiency of Arsenic removal. The percentage of removal for every concentration was logged as 82%, 83% & 85% respectively after 30 days.

It's evident from the Fig. 3 that Iron nails filter has the less efficiency as compared with Charcoal Filter and removed arsenic between 80 and 85% up to 30 days with little fluctuations. A decrease in the removal efficiency was observed over a time period, because the SF becomes clogged with arsenic and other particles. It was observed that, the rate of removal of arsenic becomes slow in later stages as the arsenic reaches to its saturation point. All these treatment systems with Iron nails recorded with a constant removal of 300 μg/L, when the increase in the dose up to 750 μg/L Arsenic (As). Later a sudden fall in the percentage of Arsenic removal occur. This reflects that the equilibrium cannot be realized post 30 days.

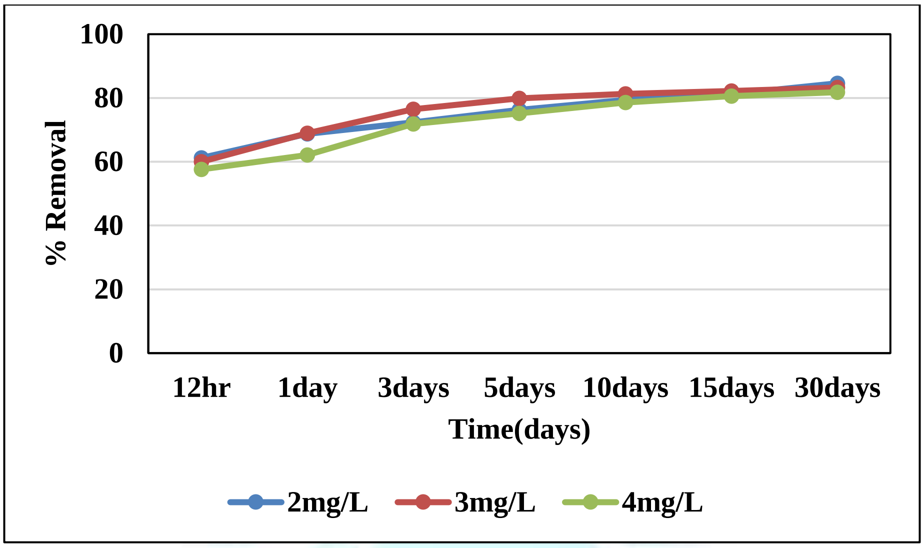

Fig.3: Removal % of Arsenic in Iron nails in sand filter at different Concentrations

Batch adsorption results

Effect of Arsenic Concentration

Concentration of Arsenic increases in the water, the removal percentage of arsenic decreases in the both filters. For the concentration of 2mg/L with totally different filter media the adsorption of arsenic ion varies from 62% to 96%. For 3mg/L concentration, the adsorption of arsenic varies from 60% to 93% and for the 4mg/L concentration adsorption of arsenic varies from 58% to 90% in both the filters. The maximum % removal of arsenic is obtained after 30 days is about 96% for 2mg/L concentration in Charcoal Sand Filter. The % removal of arsenic obtained at different concentrations of both treatment systems are shown in the Table 1 and is calculated from equation1

$$\% \text{ removal} = (C_i - C_f) * 100 / C_i \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, C_i= *initial concentration of the sample*

C_f=*final Concentration of the sample*

Table 1.*percentage Removal of Arsenic in both Treatments at different Concentrations*

Time(days)	2mg/L		3mg/L		4mg/L	
	%R of As in Charcoal	%R of As in Iron nails	%R of As in Charcoal	%R of As in Iron nails	%R of As in Charcoal	%R of As in Iron nails
Initial(12hrs)	62	61.2	59.56	60	58	57.6
1	74	68.75	69.9	68.9	64.47	62.15
3	80.95	72.35	75.86	76.43	74	71.9
5	84.85	76.25	78.4	79.86	79.25	75.17
10	88.75	79.4	84.93	81.3	82.92	78.6
15	92.55	81.2	88.46	82.23	86.97	80.55
30	96.1	84.6	92.6	83.26	89.6	81.8

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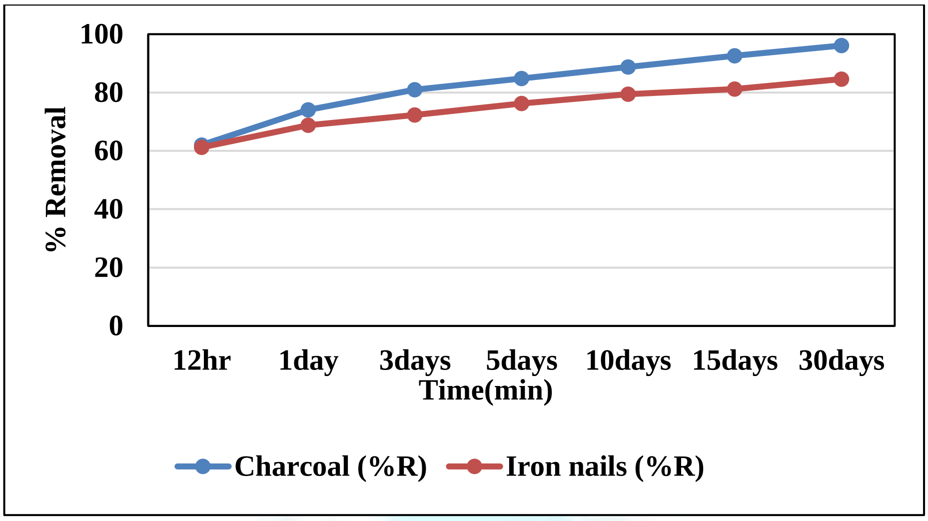

Fig.4: *Removal of Arsenic % at 2mg/L concentration*

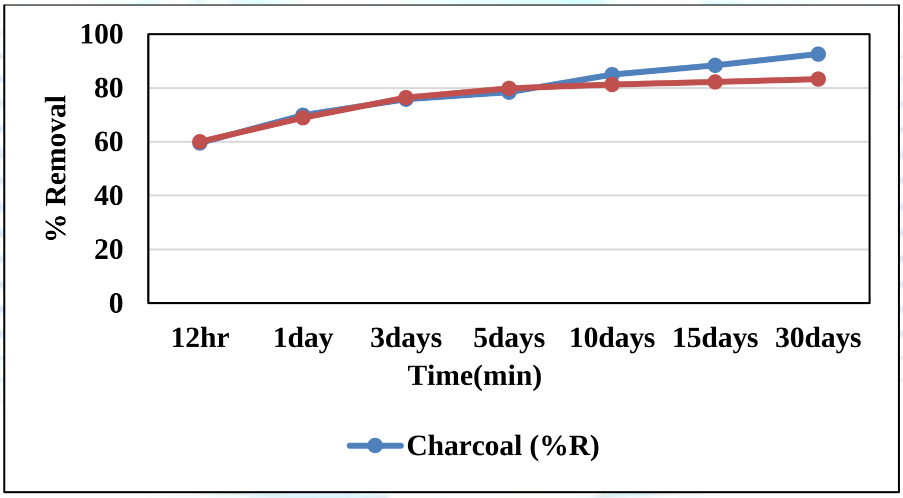

Fig.5: *Removal of Arsenic % at 3mg/L concentration*

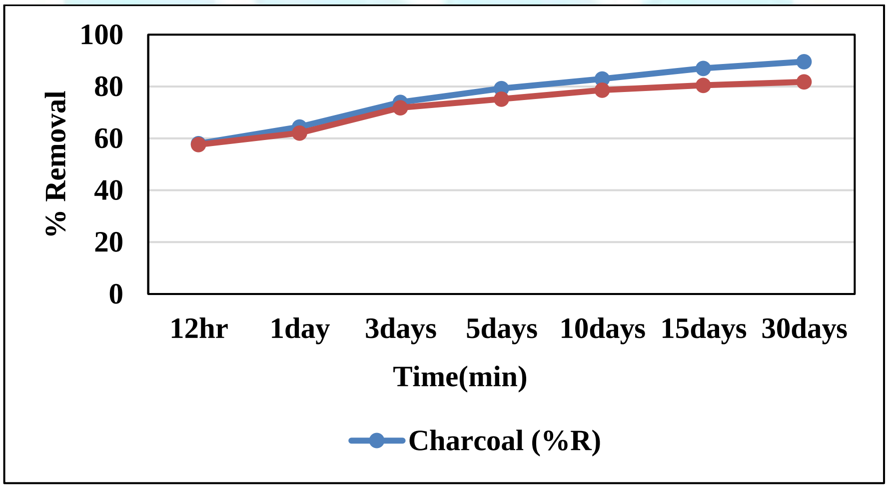

Fig.6: *Removal of Arsenic % at 4mg/L concentration*

Kinetics of Arsenic adsorption

Sand Filters of both treatments are selected with respect to effective removal of arsenic efficiency at 2mg/L concentration for kinetic studies. The analysis thru using data for pseudo 1st order and 2nd order equations are presented graphically for both filters made known from Figures. These graphs represent the adsorption of arsenic in both Charcoal and Iron nails Filters and the obtained linear equation graphs confirm the adsorption mechanism.

Adsorption Kinetic models for Charcoal:

It was observed that for first order equation the graph plot between the ln(qe-qt) to the time. The plotting of graph between q/qt to the time for the 2nd order equation. The regression value in 1st order curve also makes sure more linearity than to the 2nd one. Thus, it is concluded that 'pseudo 1st order' is the best fitting kinetic model in the first treatment i.e. Charcoal filter.

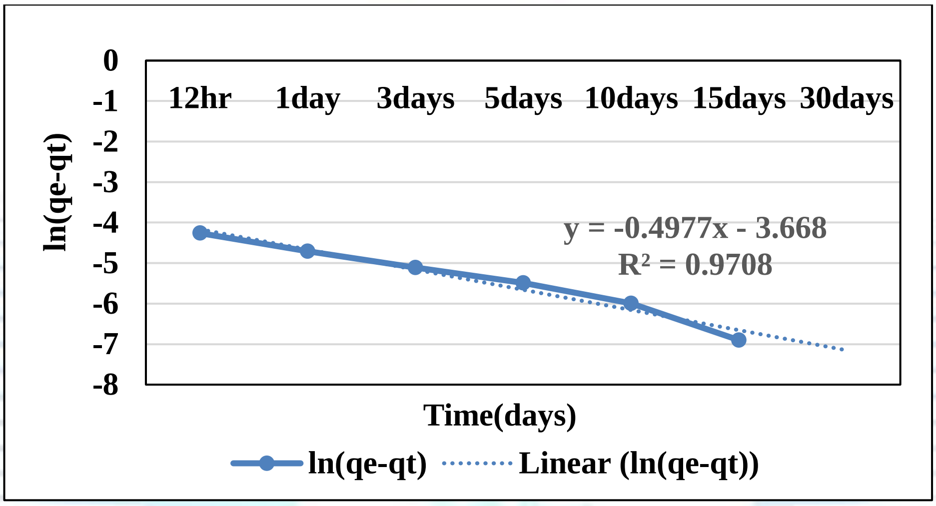

***Fig.7:** Pseudo-first order curve at 2mg/L(Charcoal)*

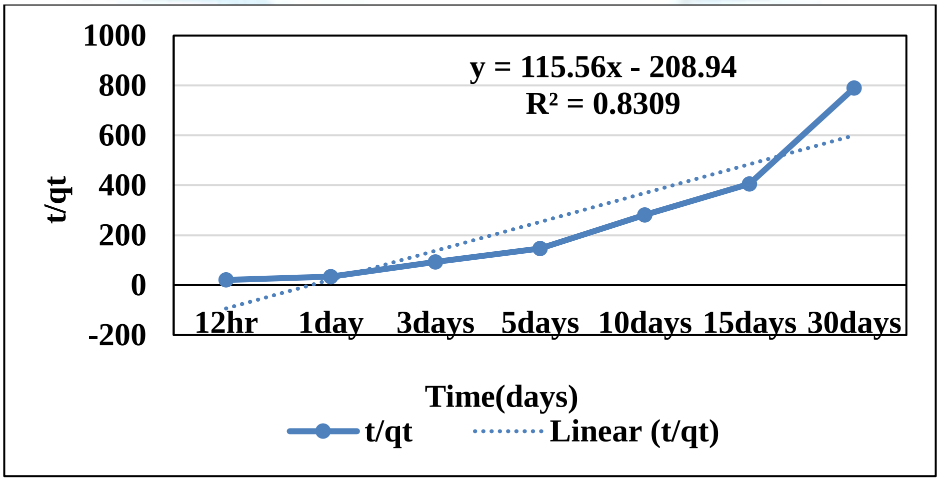

***Fig.8:**Pseudo-second order curve at 2mg/L(Charcoal)*

Adsorption Kinetic models for Iron nails:

It was noticed that for 1st order equation the graph plot between the ln(qe-qt) to the time. The graph plot between q/qt to the time is for the second order equation. The regression value in 1st order curve also makes sure more linearity than to the 2nd one. Thus, it decides that pseudo 1st order curve is the finest fitting kinetic model in the second treatment i.e. Iron nails filter.

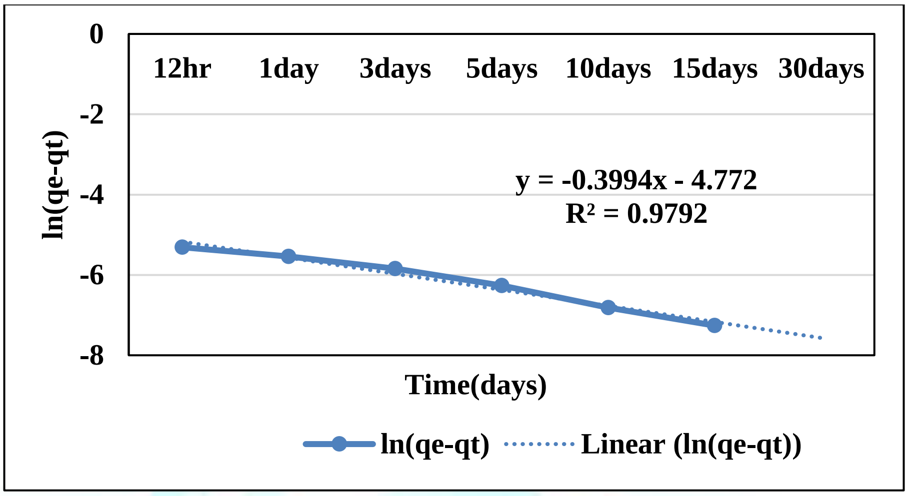

***Fig.9:** Pseudo-first order curve at 2mg/L (Iron nails)*

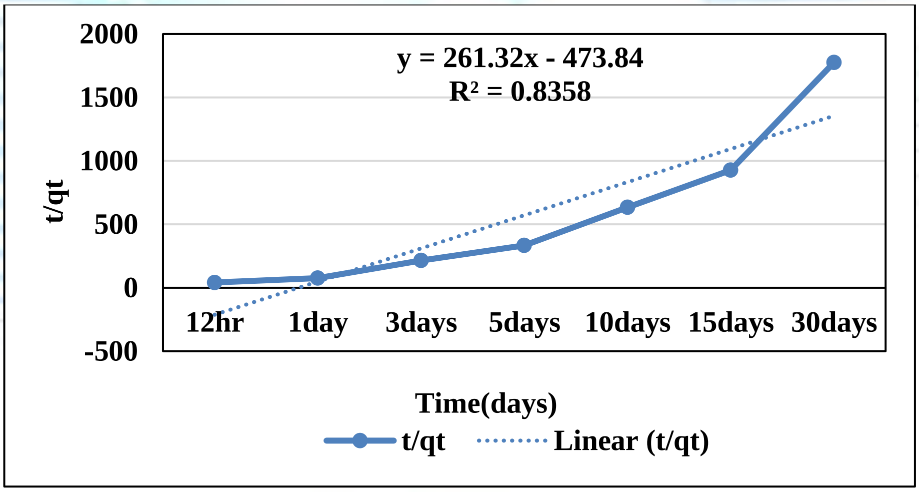

***Fig.10:** Pseudo-second order curve at 2mg/L (Iron nails)*

Adsorption Isotherms

This study shows the Arsenic adsorption up to 96% in charcoal Filter and 85% in Iron nails filter with the initial concentration of adsorbate as 2mg/L with adsorbent quantities of 500g/L and 1000g/L. The difference was due to the huge difference in adsorbates. Charcoal Filter bed of 5 cm thickness offers more area of surface for arsenic to adsorb. For this case, the graph plotted between Cf&Cf/qe was utilized to get the value of intercept 1/k1 and the slope 1/k1 or qmax. The value of intercept k1 is the adsorption capability of the adsorbent; slope a1/k1 shows the result of concentration on the capacity of adsorption and denotes the intensity of adsorption.
In this modelthe equation2. involved is shown below.

$$\frac{c_f}{q_e} = c_f * \frac{a_l}{k_l} + \frac{1}{k_l} \qquad \text{.....................} (2)$$

A curve c_f/q_evs. c_f is plotted, slope gives the a_l/k_l value and the intercept gives the k_l value

Langmuir isotherm model
The essential feature of the Langmuir isotherm isfrequentlystated in terms of a dimensionless constant 'separation factor' (R_L) shown by the following equation3.

$$R_L = \frac{1}{(1+a_L c_0)} \qquad \text{............................ (3)}$$

R_L values within the range 0< R_L<1 indicate favorable adsorption. In this study, R_L value of arsenic for the Iron nails obtained as 0.068 is more than the value obtained in the charcoal filter i.e. 0.034, indicates favorable adsorption of Iron nails than the charcoal filter.

Table.2:*Langmuir adsorption isotherm model constants and correlation coefficients*

Langmuir Isotherm					
Filter Media	**a1**	**k1**	**k1/a1**	**R_L**	**R^2**
Charcoal	1.418	0.032	0.023	0.034	0.9796
Iron nails	0.684	0.068	0.099	0.068	0.9637

Freundlich isotherm model

$$lnq_t = \frac{1}{n} * lnc_f + lnk_f \qquad \text{................................ (4)}$$

A curve is plotted by ln (q_t) Vs ln (c_f), the '1/n' value represents slope and lnK_f is the intercept value.

It is observed that in both filters both isotherm curves fit well with the adsorption system as their R^2. Langmuir equation is closer to 1.000 than that of' Freundlich equation' for the given isotherm data to be fit. Consequently, the Langmuir model signifies the better exp. data based on values of 'regression coefficient' obtained.

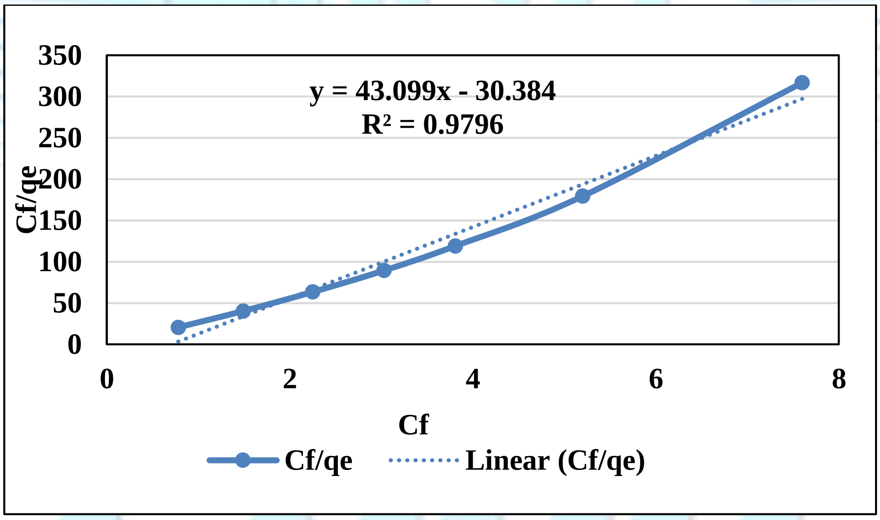

Fig.11:*Langmuir Isotherm at 2mg/L (Charcoal)*

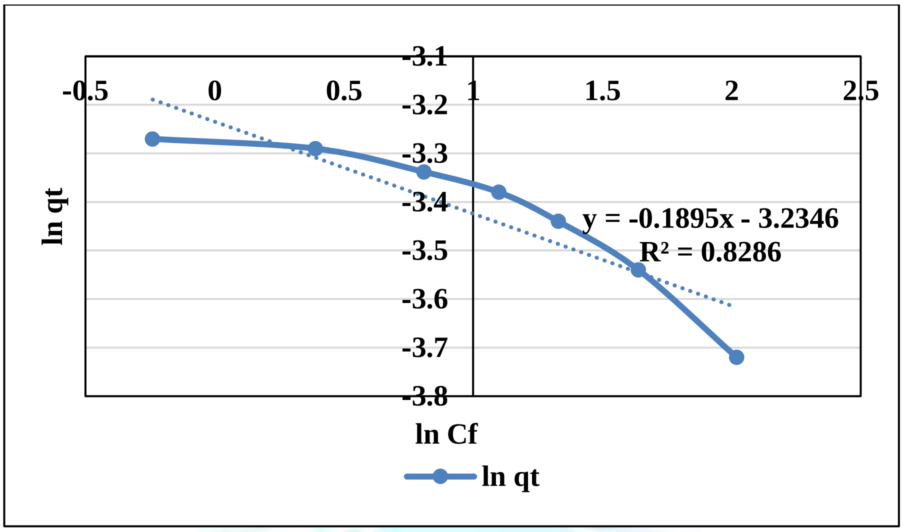

Fig.12:Freundlich Isotherm at 2mg/L (Charcoal)

Table.3:*Adsorption isotherm model constants and correlation coefficients for Charcoal filter*

Langmuir Isotherm	**a_l**	**k_l**	**k_l/a_l**	**R_L**	**R^2**
	1.418	0.032	0.023	0.034	0.9796
Freundlich Isotherm	**k_f**	**(1/n)**	**R^2**		
	3.23	-0.189	0.8286		

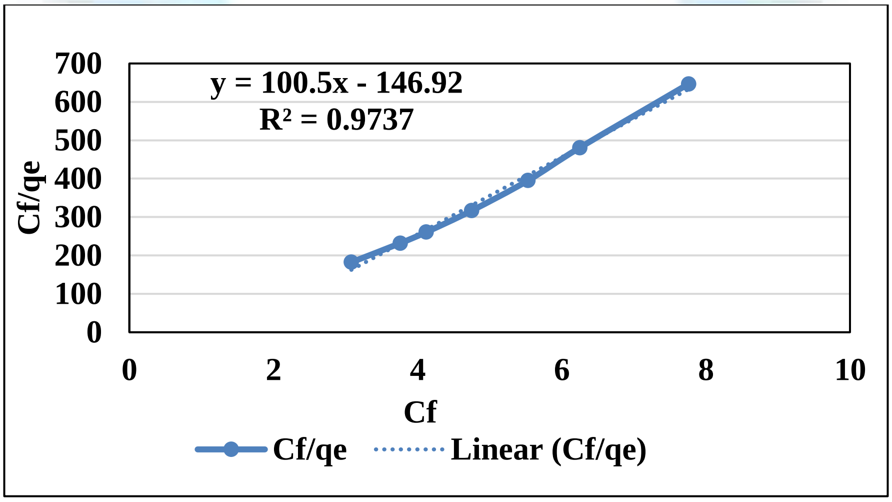

Fig.13:Langmuir Isotherm at 2mg/L (Iron nails)

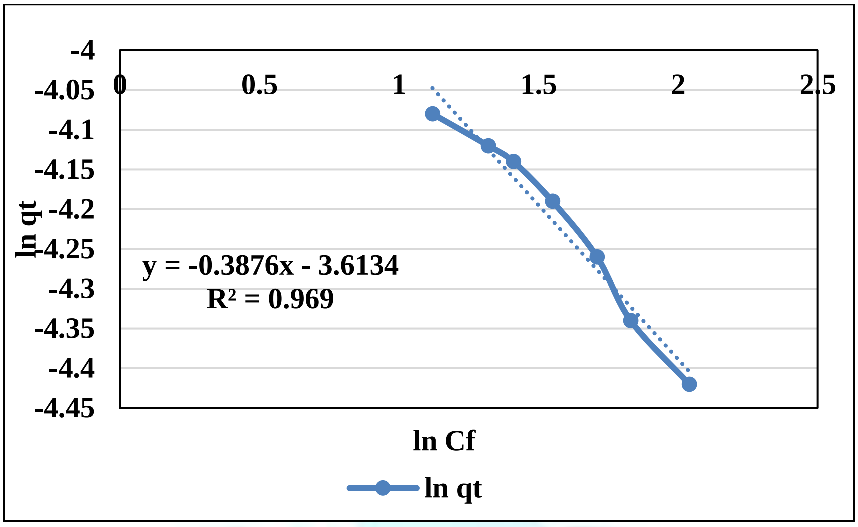

Fig.14:*Freundlich Isotherm at 2mg/L (Iron nails)*

Table.4: *Adsorption isotherm model constants and correlation coefficients for Iron nails filter*

Langmuir Isotherm	a_l	k_l	k_l/a_l
	0.684	0.0068	0.0099
Freundlich Isotherm	k_f	**(1/n)**	R^2
	3.61	-0.38	0.969

CONCLUSIONS

From this whole study it can be concluded that the Sand filter with Charcoal was a sensible decentralized treatment option for groundwater. As it's a cost-effective treatment method, it can be widely used at household level. The Sand Filter with a layer of Charcoal for a depth of 5 cm given more than 95% of Arsenic removal efficiencies throughout the period of experimental studies (30 days). Whereas the sand filter with Iron nails given less than 85% of Arsenic removal efficiency, which is less than the one with charcoal filter. It was observed that the sand filter with charcoal adsorb most of the Arsenic of a concentration 1.9 mg, whereas the sand filter with Iron nails adsorb the Arsenic Concentration up to 1.3 mg. In adsorption kinetics, R2 value of pseudo-first-order model is high as compared to the pseudo 2nd order model in both Filters. Thus, it states that pseudo 1st order is the best fitting kinetic model among both. In adsorption isotherms model, R2 value of Langmuir isotherm model is high when compared with Freundlich isotherm model (i.e. R2 value is closer to 1.000) in both Filters. Thus, it states that Langmuir isotherm model is best fitting model as it describes monolayer adsorption in both Charcoal and Iron nails Filters.

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