

# Role of Wooden Charcoal in Indigenous Household Iron Filters used in Assam (India)

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**Abstract:** Ground water, the major source of drinking water in rural and semi-urban areas of Assam (India), contains an excessive amount of iron (1 to 10 mg/L). In order to reduce the amount of iron from water, people use household iron filter units – indigenously developed using wooden charcoal as one of the filter media. The present work evaluates role of wooden charcoal in reducing the dissolved iron. The experiments were carried out at a fixed pH of 5.5 and zero DO levels. Batch kinetic studies indicated rapid Fe(II) uptake in the first 40 min. and yielded a rate constant of  $0.0136 \text{ min}^{-1}$ . The adsorption process seemed to be governed by diffusion within the pores of wooden charcoal and the mechanism of Fe(II) removal appeared to be complex. The Fe(II) adsorption data fitted into Langmuir isotherm ( $R^2 = 0.9952$ ) indicating favourable adsorption process. The breakthrough column studies with 5 and 10 cm bed depths yielded 66 and 82 number of bed volumes respectively of treated water containing Fe(II) concentration  $\leq 0.3 \text{ mg/L}$  at a fixed flow rate of  $1.4 \text{ mL/min}$ . Overall wooden charcoal seemed to have good potential for Fe(II) removal from the water.

**Key words:** Potable water, iron removal, wooden charcoal, adsorption.

## Introduction

The ground water is the major source for domestic water needs of people living in rural and semi-urban areas of Assam – a northeastern state of India. However, it contains high concentrations of dissolved iron (1 to 10 mg/L or above) (MOWR, 2004), much higher than the permissible limit of  $0.3 \text{ mg/L}$  for drinking water (WHO, 1993). Though water with high iron contents has not been reported for adverse health impacts but it imparts unpleasant colour to water and stains clothes and utensils (Sawyer et al., 2003). Iron removal has been a subject of intensive research for the last couple of decades in developing countries including India. This has yielded many different designs and configurations of iron removal units to be used/applied at community levels (Chibi, 1995; Ahamad, 2005). But surprisingly, none of these

community level units has found application in Assam. Instead, rural and semi-urban population of Assam uses indigenous household iron filter units developed solely based on experiences gained over past few generations. One of the most popular units is made of reinforced cement concrete (RCC) pipes as shown in Figure 1. It is fabricated using two circular RCC pipes (60 cm internal diameter and a height of 60 cm), placed one over the other giving a total height of 120 cm. The top RCC pipe holds the filter media (up to a depth of 50 cm) while the bottom one stores the filtered water. The filtering medium usually comprises three different materials available locally and is placed in layers in the top RCC pipe: river sand (top layer), wooden charcoal (middle layer) and gravel (bottom layer). At the interface of sand and charcoal layers, nylon net with fine openings is provided to protect sand from getting washed into charcoal medium. Upon continuous use, charcoal gets exhausted needing replacement with new stocks while sand and

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## Nomenclature

$a$	: Langmuir isotherm constant
$b$	: Langmuir isotherm constant
BAC	: Breakthrough adsorption capacity
$C_o$	: Influent adsorbate concentration
$C_e$	: Equilibrium adsorbate concentration
DO	: Dissolved oxygen
EDX	: Energy dispersive X-ray
$K_{ad}$	: Adsorption rate constant
$K_p$	: Intraparticle diffusion rate constant
$q_e$	: Binding capacity at equilibrium
$q$	: Binding capacity at any time
$Q$	: Flow rate
$r$	: Dimensionless equilibrium parameter
SEM	: Scanning electron microscopy
$V_B$	: Breakthrough throughput volume



**Figure 1: A typical indigenous iron filter unit used in Assam.**

gravel are re-used after washing and drying. Wooden charcoal is believed to be the main component responsible for iron removal. Even though, indigenous iron filter units are in use for past few generations, very limited scientific studies have been carried out to understand the role of wooden charcoal in removal of dissolved iron from the ground water. The present work is an attempt in this direction.

## Experimental

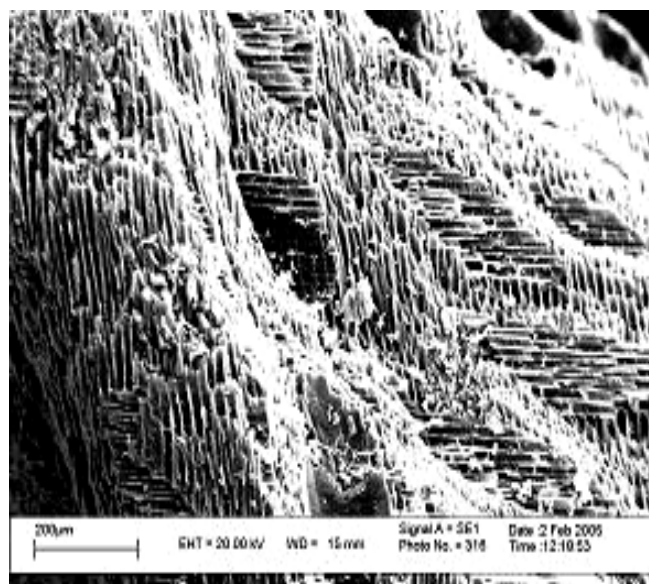
### Wooden Charcoal

The wooden charcoal used in household iron filter units was prepared indigenously using woods procured from

hilltops located in and around Amingaon village situated at a distance of 1 km from IIT Guwahati campus on the north bank of River Brahmaputra. The procured woods were cut into small pieces, dried in sun and burnt partially in air (not to ashes), and then cooled and washed with surface water (possibly river water) resulting in individual charcoal pieces of 2.5 cm × 1.5 cm × 1.5 cm to 4 cm × 2.5 cm × 1.5 cm, which are readily sold in local village market. The wooden charcoal used in the present study was obtained from Amingaon, which was further processed into smaller sizes, washed with distilled water and dried at 105 °C in a drying hot air oven. The dried wooden charcoal was sieved as per IS:2720 and its relevant characteristics are presented in Table 1. A specimen of processed charcoal was subjected to SEM analysis, which indicated porous structure with large surface area (Figure 2) while EDX analysis indicated absence of iron from the surface of charcoal. Processed charcoal particles passing through 425 mm sieve but retaining on 300 mm sieve (with average size of 363 mm) were selected for this study.

**Table 1: Characteristics of processed charcoal**

<i>Characteristics</i>	<i>Processed Charcoal</i>
Bulk density	289.84 kg/m <sup>3</sup>
Moisture content	9.88%
Ash content	7.68%
Particle size range	4.74 mm to 75 μm
BET surface area	30.083 m <sup>2</sup> /g
Coefficient of uniformity	28.75
Coefficient of curvature	5.43



**Figure 2: Micrograph of wooden charcoal particle showing porous structure.**

### Solubility of Fe(II) with Change in pH and DO Levels

The iron in the dissolved form, Fe(II), is expected to change to insoluble form, Fe(III), with change in pH and/or dissolved oxygen (DO) levels. Experiments were designed to assess solubility of Fe(II) in pH range of 2 to 12. Analytical grade ferrous sulfate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ) was used to prepare a Fe(II) stock solution of 200  $\mu\text{g/mL}$ . The required volume of stock solution was taken in a 100 mL specimen tube, added with appropriate amounts of acid (0.2N  $\text{HNO}_3$ ) or lime solution for adjusting desired pH (Rao and Rekha, 2004). The volume was made up to 100 mL with distilled water to give a final Fe(II) concentration of 10 mg/L. The contents in specimen tubes were mixed thoroughly with manual shaking in an end-over-end type motion ( $\approx 40\text{--}50$  rpm) for 5–8 min. and then allowed to stand for 20 min. at room temperature ( $29 \pm 1$  °C). Fe(II) remaining in the solution was estimated using phenanthroline method as per Standard Methods (APHA, 1998). All the experiments were conducted in triplicate.

The solubility of Fe(II) in the presence of DO was assessed separately at room temperature ( $29 \pm 1$  °C). 10–12 L of distilled water was taken in a plastic bucket and pH was initially adjusted to 5.5 with 0.2N  $\text{HNO}_3$ . Initial DO level was estimated (APHA, 1998) and then brought down to zero by adding slightly more than the stoichiometric requirement of sodium sulfite ( $\text{Na}_2\text{SO}_3$ ). The required amount of stock Fe(II) solution was added and the liquid volume was made up to 15 L to achieve a final Fe(II) concentration of 5 mg/L. The aeration was carried out with an air pump. Variation in pH was observed with increase in DO level, which was controlled using a buffer prepared with acetic acid and sodium acetate (1 mL of 0.2M acetic acid and 9 mL of 0.2M sodium acetate mixed to give 10 mL of buffer solution) (Jeffery et al., 1996). Samples were drawn at regular intervals for estimation of Fe(II) and DO. This experiment was conducted in duplicate.

### Batch Kinetic Studies

Approximately 800 mL distilled water was taken in a 1 L plastic beaker and pH adjusted to 5.5 with 0.2N  $\text{HNO}_3$ . The DO level was made to zero by adding appropriate amounts of  $\text{Na}_2\text{SO}_3$ . The required amount of stock Fe(II) solution was added in the beaker and the liquid volume was made upto 1 L to give a Fe(II) concentration of 10 mg/L. 5 g of selected wooden charcoal particles were then added to the beaker and continuous stirring was carried out at room temperature

( $29 \pm 1$  °C) by a speed controlled mechanical stirrer (Maximum speed 4000 rpm). The speed was regulated for uniform mixing of charcoal particles in the liquid without formation of strong vortex. Samples were withdrawn at shorter intervals of 5 min. for the first 30 min. and then at 10 min. intervals and analyzed for Fe(II) remaining in the solution.

### Batch Equilibrium Adsorption Studies

Five mL Fe(II) stock solution was taken in a 100 mL specimen tube, 50 mL of distilled water was added and then pH was adjusted to 5.5 with 0.2N  $\text{HNO}_3$ . The volume was made upto 100 mL with distilled water to give final Fe(II) concentration of 10 mg/L. Required amounts of wooden charcoal particles (0.2 to 0.7 g) were added and then mixed thoroughly with manual shaking in an end-over-end type motion ( $\approx 40\text{--}50$  rpm) for 60 min. at room temperature ( $22 \pm 1$  °C). Samples were then allowed to stand for 10 min., filtered through ordinary Whatman filter paper and analyzed for Fe(II) remaining in the solution. Experiments were carried out in triplicate.

### Breakthrough Column Studies

The experimental set-up was prepared using 10 mm internal diameter glass columns (Figure 3). Two different bed depths (5 and 10 cm) of selected wooden charcoal particles and a fixed flow rate ( $Q = 1.4$  mL/min) were used to develop breakthrough profiles. The columns were operated continuously at room temperature (20–25 °C) in down-flow mode using a multi-channel peristaltic pump. The synthetic Fe(II) sample water of 5 mg/L was

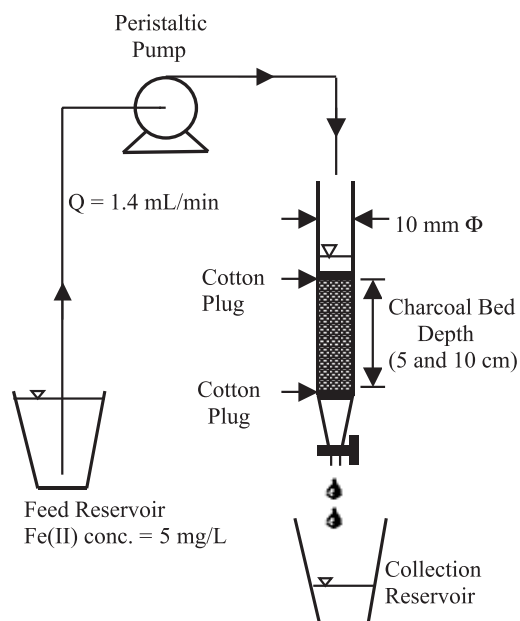


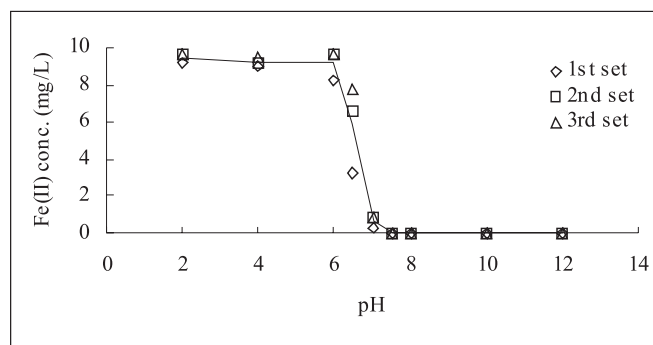
Figure 3: Experimental set-up for column studies.

prepared in adequate volume using distilled water with zero DO level and pH adjusted to 5.5. Samples from the column were collected at regular intervals till the bed exhausted or yielded effluent with 90% of initial Fe(II) concentration. All column studies were carried out in duplicate.

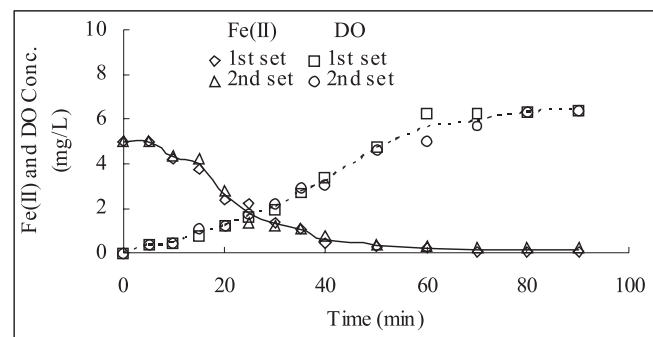
## Results and Discussion

### Solubility of Fe(II) with Change in pH and DO Levels

The variation in Fe(II) remaining in solution with pH is presented in Figure 4. Almost all the iron came out of the solution phase at pH > 7, whereas it remained in soluble form at pH < 6. Therefore, further experiments were conducted at a fixed pH of 5.5 to ensure availability of iron in dissolved form. DO levels seemed to have marked effect on the solubility of Fe(II) as shown in Figure 5. This effect was visible at DO levels > 1 mg/L. When the DO level reached a steady value of 6 mg/L, the Fe(II) decreased to the lowest level. Therefore, experiments related with kinetics, equilibrium and column studies were carried out at a fixed pH of 5.5 with zero DO levels to ensure availability of iron in Fe(II) form.



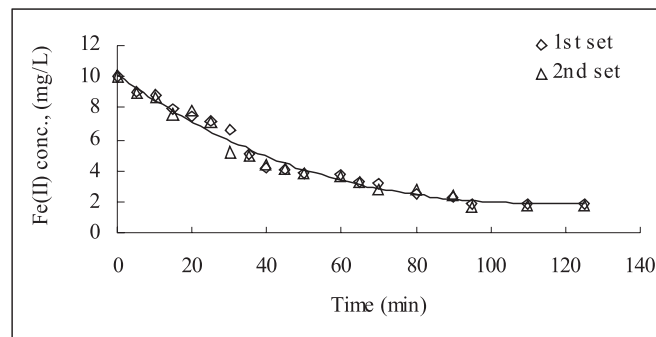
**Figure 4: Solubility of Fe(II) with pH [initial Fe(II) = 10 mg/L, temp = 29±1 °C].**



**Figure 5: Variation in Fe(II) conc. with DO levels at pH 5.5 [initial Fe(II) = 5 mg/L, temp = 29±1 °C].**

### Batch Kinetic Studies

The variation in Fe(II) concentration with time is presented in Figure 6. The uptake of Fe(II) was observed to be rapid in the first 40 min. and it declined towards



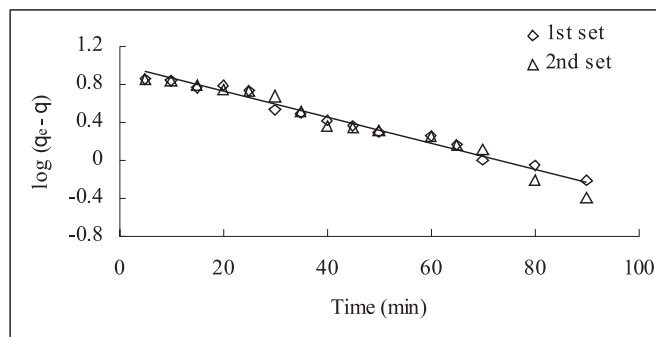
**Figure 6: Variation in Fe(II) conc. with time [initial Fe (II) = 10 mg/L, charcoal weight = 5 g, DO = 0 mg/L, temp = 29±1 °C].**

equilibrium. The adsorption rate constant ( $K_{ad}$ ) was determined from the following first order rate expression (Gupta et al., 1988):

$$\log (q_e - q) = \log (q_e) - \frac{K_{ad}}{2.303} t \quad (1)$$

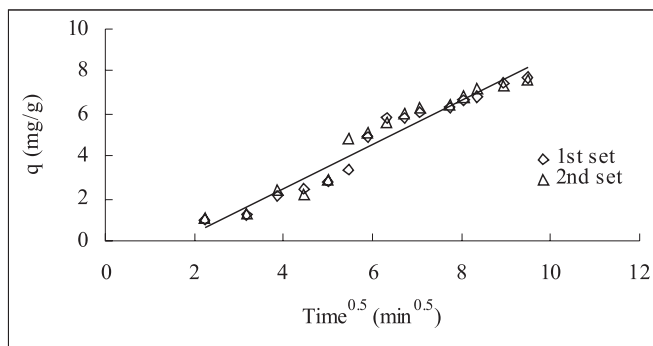
where  $q_e$  and  $q$  (both in mg/g) are the amount of Fe(II) adsorbed per unit mass of wooden charcoal at equilibrium and at time  $t$  respectively and  $K_{ad}$  is the rate constant ( $\text{min}^{-1}$ ). The slope of the linear plot of  $\log (q_e - q)$  versus  $t$  (Figure 7) yielded  $K_{ad}$  value as  $0.0136 \text{ min}^{-1}$ . Besides adsorption taking place on the outer surface of wooden charcoal, there is also a possibility of transport of Fe(II) ions from the solution to the pores of the wooden charcoal. This possibility was tested in terms of a graphical relationship between amount of Fe(II) adsorbed ( $q$ ) and square root of time ( $t$ ) as represented by (Gupta et al., 1988):

$$q = K_p t^{1/2} \quad (2)$$



**Figure 7: Linear plot of Fe(II) adsorption on wooden charcoal at pH 5.5.**

where  $K_p$  ( $\text{mg g}^{-1} \text{min}^{-1/2}$ ) is the intraparticle diffusion rate constant. The plot of  $q$  versus  $t^{0.5}$  yielded a linear correlation as shown in Figure 8 giving  $K_p$  value of  $1.037 \text{ mg g}^{-1} \text{min}^{-1/2}$ . The linear plot suggests that adsorption is governed by diffusion within the pores of the adsorbent. Since the linear plot does not pass through the origin, Fe(II) removal mechanism seems to be complexed one and both the surface adsorption as well as intraparticle diffusion might contribute to the rate-determining step.



**Figure 8: Intraparticle mass transfer curve for Fe(II) adsorption on wooden charcoal at pH 5.5.**

### Batch Equilibrium Adsorption Studies

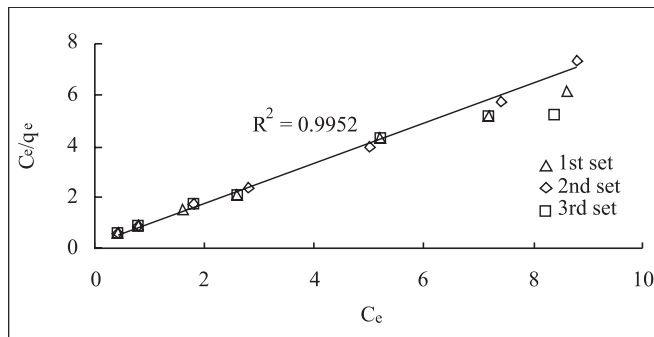
The distribution of Fe(II) between the liquid phase and the solid phase is a measure of the position of equilibrium in the adsorption process and can be expressed by Langmuir isotherm—a rational model which is valid for monolayer sorption onto a surface with a finite number of identical site. The model is represented by:

$$q_e = \frac{abC_e}{1 + bC_e} \quad (3)$$

with its linearized form as:

$$\frac{C_e}{q_e} = \frac{1}{ab} + \frac{C_e}{a} \quad (4)$$

where  $a$  is the maximum amount of Fe(II) per unit weight of wooden charcoal to form a complete monolayer on the surface and  $b$  is a constant related to the affinity of the binding sites. The equilibrium data fitted into the linearized form of the model ( $R^2 = 0.9952$ ) as presented in Figure 9 with model parameters— $a$  and  $b$  obtained as  $1.293 \text{ mg/g}$  and  $3.258 \text{ L/mg}$  respectively. The calculated binding capacity of wooden charcoal for Fe(II) equilibrium concentration of  $0.3 \text{ mg/L}$  is  $0.639 \text{ mg/g}$ . In order to predict the efficiency of the adsorption process, the dimensionless equilibrium parameter ( $r$ ) was determined by using the following relation



**Figure 9: Equilibrium result showing Langmuir isotherm fit [initial Fe(II) =  $10 \text{ mg/L}$ , pH = 5.5, temp =  $22 \pm 1^\circ \text{C}$ ].**

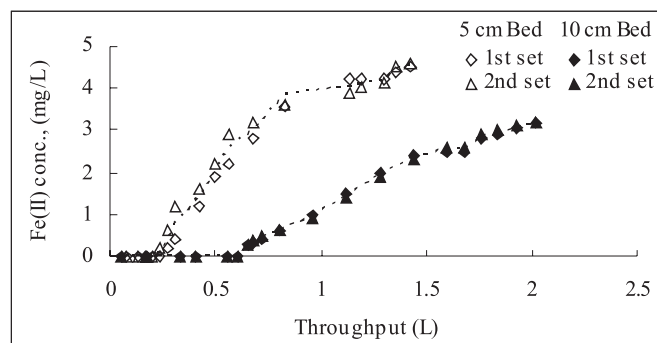
(Namasivayam and Yamuna, 1995):

$$r = \frac{1}{1 + bC_0} \quad (5)$$

where  $C_0$  is the initial Fe(II) concentration. Value of  $r < 1$  represents favourable adsorption conditions. The  $r$ -value for the initial Fe(II) concentration of  $10 \text{ mg/L}$  was found to be  $0.03$ , which indicated a favourable adsorption process.

### Breakthrough Column Studies

The results of breakthrough column studies are presented in Figure 10. The breakthrough profiles were used to obtain breakthrough throughput volumes ( $V_B$ ) at  $0.3 \text{ mg/L}$  Fe(II) concentration, which is presented in Table 2. It was evident that with increase in bed depths from  $5 \text{ cm}$  to  $10 \text{ cm}$ ,  $V_B$  increased from  $260 \text{ mL}$  to  $650 \text{ mL}$  with consequent increase in the breakthrough adsorption capacity (BAC) from  $0.778 \text{ mg/g}$  to  $1.203 \text{ mg/g}$ . The number of bed volumes treated by  $5$  and  $10 \text{ cm}$  bed depths of wooden charcoal for effluent Fe(II) concentration  $\leq 0.3 \text{ mg/L}$  were  $66$  and  $82$  respectively at the fixed flow rate of  $1.4 \text{ mL/min}$ .



**Figure 10: Breakthrough profile with 5 and  $10 \text{ cm}$  bed depth columns.**

**Table 2: Summary of continuous column studies**

<i>Flow rate (mL/min)</i>	<i>Bed Depth (cm)</i>	<i>V<sub>B</sub> (mL)</i>	<i>BAC (mg/g)</i>
1.4	5	260	0.778
	10	650	1.203

### Conclusions

The solubility of Fe(II) is observed to be significantly affected by the pH and DO levels. The Fe(II) comes out of solution at pH>7 and DO>1 mg/L. Batch kinetic studies indicate rapid uptake in the first 40 min. with an adsorption rate constant of 0.0136 min<sup>-1</sup>. The adsorption process seems to be governed by diffusion within the pores of wooden charcoal and the mechanism of Fe(II) removal on wooden charcoal is appeared to be complex. Equilibrium adsorption studies data fitted into Langmuir isotherm ( $R^2 = 0.9952$ ) and the calculated binding capacity at equilibrium Fe(II) concentration of 0.3 mg/L is 0.639 mg/g. The continuous column studies with 5 and 10 cm bed depths yield 66 and 82 number of bed volumes respectively of treated water with Fe(II) concentration  $\leq 0.3$  mg/L at the fixed flow rates 1.4 mL/min. Overall, wooden charcoal seems to have good potential for Fe(II) removal.

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