

NOVEL MATERIALS FOR ARSENIC REMEDIATION

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ABSTRACT

This paper reports the application of two novel materials, Spherical Activated Carbon (SAC) and Processed Iron Waste (PIW), along with the existing materials, hematite and Granular Activated Carbon (GAC), for the removal of sodium arsenate and mixture of arsenic (III) and arsenic (V) from water. Results of static adsorption studies carried out in the laboratory have shown higher efficiency (almost hundred percent removal of arsenic from water) of SAC and PIW compared to hematite and GAC. Effect of various parameters such as adsorbent dose, contact time and initial arsenic concentration is presented. These studies will prove beneficial in the development of treatment technology (plant / filter) for arsenic-contaminated ground water.

INTRODUCTION

Arsenic contamination in ground water is the most widely discussed problem for scientists at present since various parts of the world are severely affected by this deadly poison (Pearce in *New Scientist*, August, 2003). It is more prevalent in the lower Gangetic plains, especially in Bangladesh and West Bengal, India (Chakraborti *et al.* 2003). Arsenic is a known human carcinogen which, if consumed beyond permissible limit, can prove fatal (Adams *et al.* 1990). It causes skin manifestations called Arsenicosis. Several other manifestations such as melanosis, keratosis, leukomelanosis, hyperkeratosis, conjunctivitis, bronchitis and skin cancer also result from arsenic toxicity. Arsenic is predominantly present in water in inorganic as well as organic forms. Inorganic arsenic, which is considered more toxic than organic arsenic, includes arsenic existing in two different oxidation states, (III) and (V). As (III) is about four

times more toxic than As (V) (Winship, 1984; Ellenhorn, 1988; Fuortes, 1988 and Gorby, 1988).

Various treatment technologies are being developed worldwide (Pierce *et al.* 1982; Lackovic and co-workers, 2000). During last decade, water remediation, with respect to removal of arsenic, has gained impetus (Alauddin, 2000; Farrell *et al.* 2001; Su *et al.* 2001), however, a user friendly and cheaper technology remains in question and the present work is an effort in the same direction.

This paper discusses comparative efficiency of activated carbon (GAC and SAC), hematite and processed iron waste (PIW) for the removal of arsenic from water.

MATERIALS AND METHODS

Coconut-based Granular Activated Carbon (GAC) of varying surface area (1000, 1150 and 1300 m²/g)

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and Spherical Activated Carbon (SAC) have been obtained from M/s Active Carbon, Hyderabad, India, and M/s Krehan, USA, respectively. Processed iron waste (PIW), which is a waste material generated by steel industries, is supplied by Tata Wire Ltd., Mumbai.

Static adsorption isotherm studies for aqueous sodium arsenate (As+5) and a mixture sodium arsenate and sodium arsenite (in the ratio of 1:1) are carried out separately using 50 ml solution, with doses of materials varying from 5g/L - 80 g/L, in stoppered glass bottles. All the materials are thoroughly washed with Milli-Q grade water and dried to constant weight at 120°C before using them for any study. Contents are then shaken for 24 hrs on a thermostatic shaker maintained at 30 ± 1°C. The solutions are allowed to settle and then filtered through Whatman filter paper No.1. Arsenic concentration before and after removal is determined as per ASTM method (ASTM: D 2972, 1988) using GBC-HG-3000 atomic absorption spectrophotometer (AAS).

Concentration of different metal ions in these materials is determined using Phillips X-ray fluorescence (XRF) at Durgapur Steel Plant and surface area measurement was carried out using Micromeritics ASAP 2010 Surface Analyzer at CEES.

All the reagents used are of AR quality and only Milli-Q grade water is used for solution preparation

Table 1 Physical and chemical characteristics of materials

S.No.	Material	pH (in water)	pH (in As soln)	Fe (%)	Al (%)	Mn (%)	Si (%)	Surface area (BET) m ² /g
1.	GAC-50	9.5	9.8	trace	trace	trace	trace	1020
2.	GAC-60	9.7	10	trace	trace	trace	trace	1117
3.	GAC-70	10.2	10.5	trace	trace	trace	trace	1264
4.	Hematite	7.0	7.2	62.6	1.8	-	1.3	42
5.	PIW	8.5	8.8	99.2	nd	0.42	0.15	-
6.	SAC	7.5	7.8	nd	nd	nd	0.12	1200

GAC: Granular Activated Carbon; PIW: Processed Iron Waste; SAC: Spherical Activated Carbon; nd: not detected

Table 2. Freundlich Constants for different materials used in the study

S.No	Material	Freundlich Constants for As(V)		Freundlich Constants for Mixture of As (V) & As (III)	
		n	K	n	K
1.	GAC-50	-0.02406	1.00E+125	211.47	-0.014572161
2.	GAC-60	-0.006094	1e+494	240.85	-0.01279656
3.	GAC-70	-0.039041	8.71E+76	211.47	-0.014572161
4.	SAC	0.412456	0.309	0.989	0.957854406
5.	Hematite	2.2041	8.054	0.864	1.517450683
6.	PIW	1.035411	9.528	1.384	3.039513678

and washings.

RESULTS AND DISCUSSION

Characterization

Scanning Electron Microscope (SEM) technique is used to determine the surface characteristics of these materials. Micrographs of GAC, SAC and PIW [Figs. 1 (a), (b) & (c)] show their morphology.

Values of physical and chemical parameters for all materials used, as given in Table 1, clearly indicate iron richness of PIW and a very high surface area of GACs and SAC, the two key factors that play important role in arsenic removal.

Effect of Dose

The dose of GACs, SAC, hematite and PIW has been varied from 5g/L to 80g/L, keeping the other parameters, viz., adsorption time and initial arsenic concentration constant at 24 hrs. and 1ppm, respectively, to carry out isotherm studies as per the method described in experimental section. Efficiency of the different materials being investigated for removal of arsenic follow the sequence

PIW>SAC>Hematite >GAC

irrespective of whether arsenic exists as arsenic (V) or as a mixture of As (V) and As (III). Maximum removal (final arsenic concentration <10ppb) is

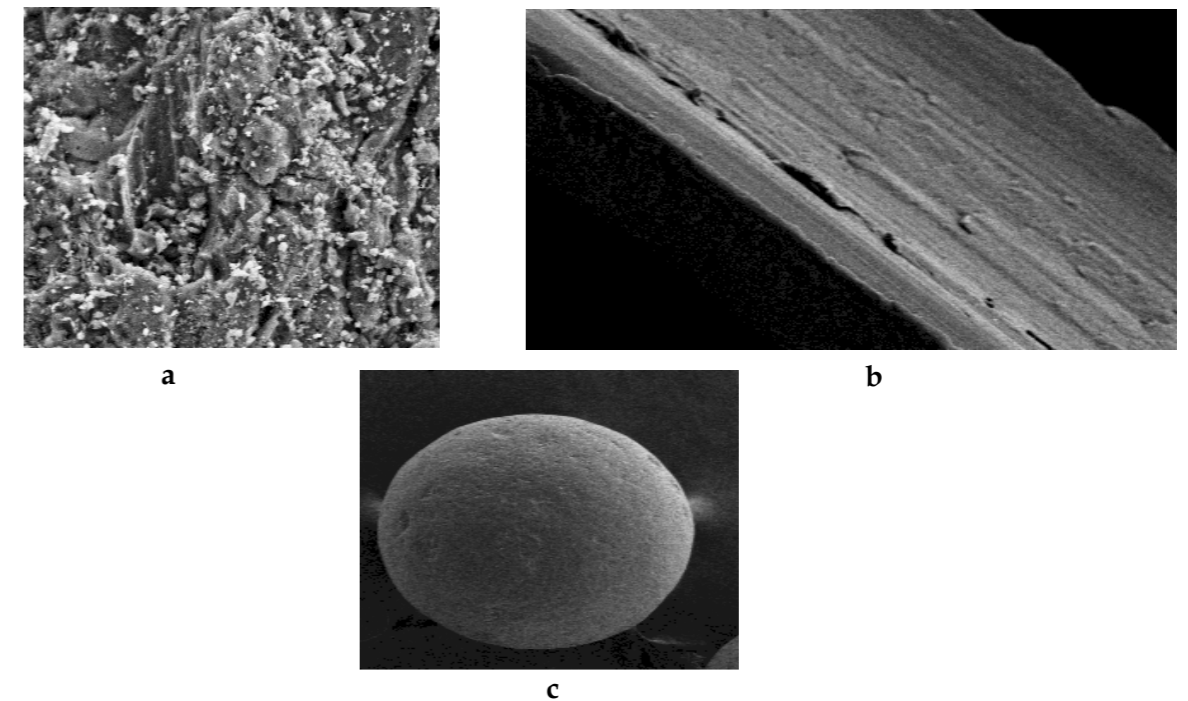


Fig.1. SEM Micrographs: (a) GAC at Mag.:500, (b) PIW at Mag.:500, (c) SAC at Mag.:100

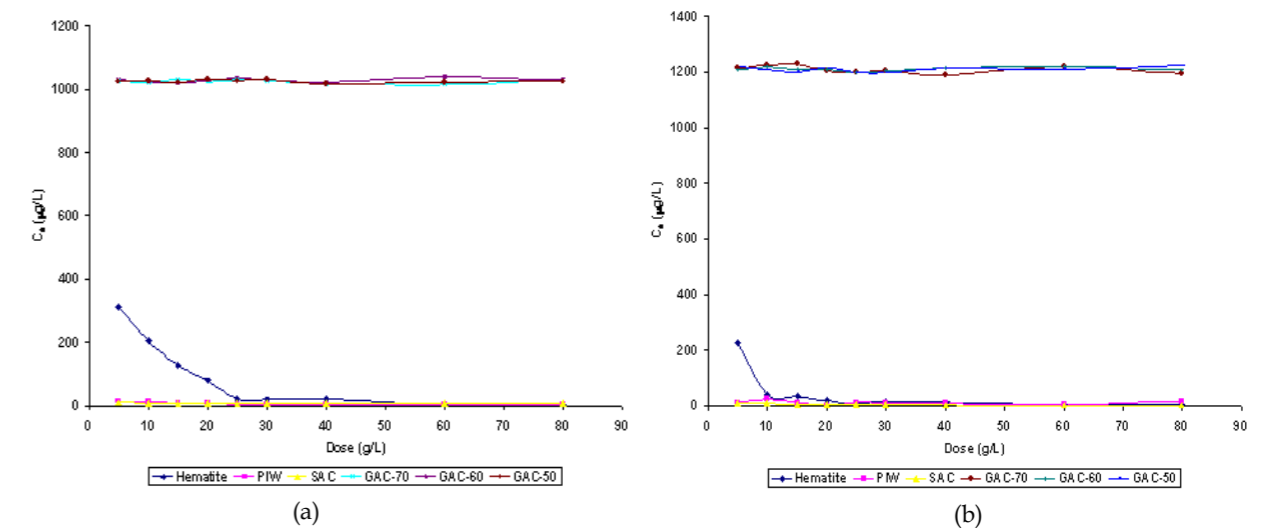


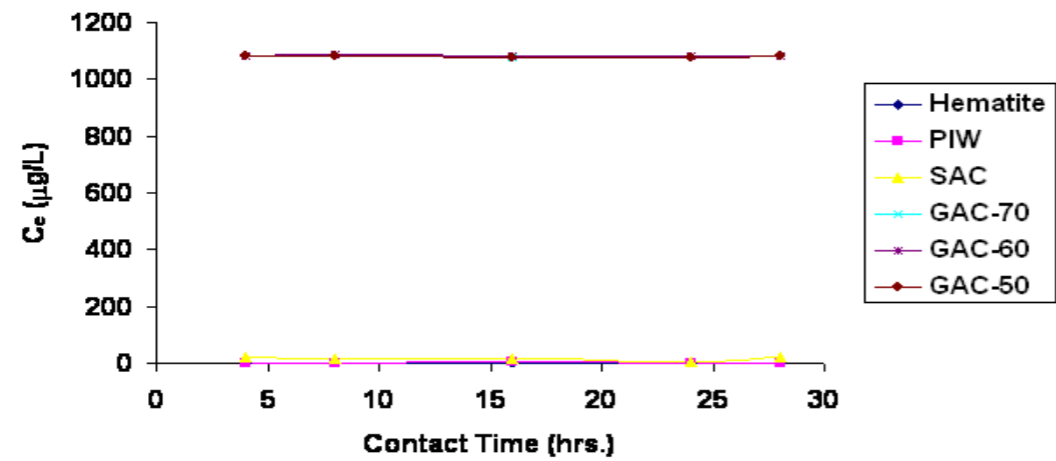
Fig. 2 Effect of Dose (a) Sodium arsenate aqueous solution ; (b) 1:1 :: Sodium arsenite : Sodium arsenate aqueous solution

achieved by PIW followed by SAC and an adsorbent dose of 5.0 g/L has been found optimum for this removal (Fig. 2 a & b). This is very much in concurrence with the previous studies carried out for As (III) (Goel *et al.* 2003). This behavior is further confirmed by values of Freundlich constants, K and n, given in Table 2 and calculated using following equation (Sivasankari and co-workers, 2002).

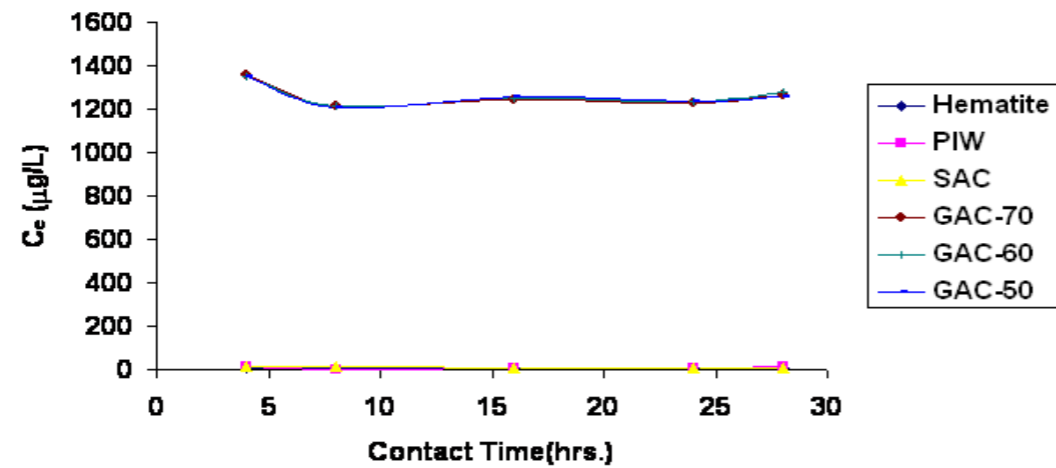
$x/m = KCe^{1/n}$
where, x/m is the amount adsorbed per unit mass of the adsorbent,

Ce is the equilibrium concentration of the adsorbate in the solution, K is the adsorption capacity, and n is the affinity of the adsorbent for the adsorbate.

Higher values of n in case of PIW and hematite

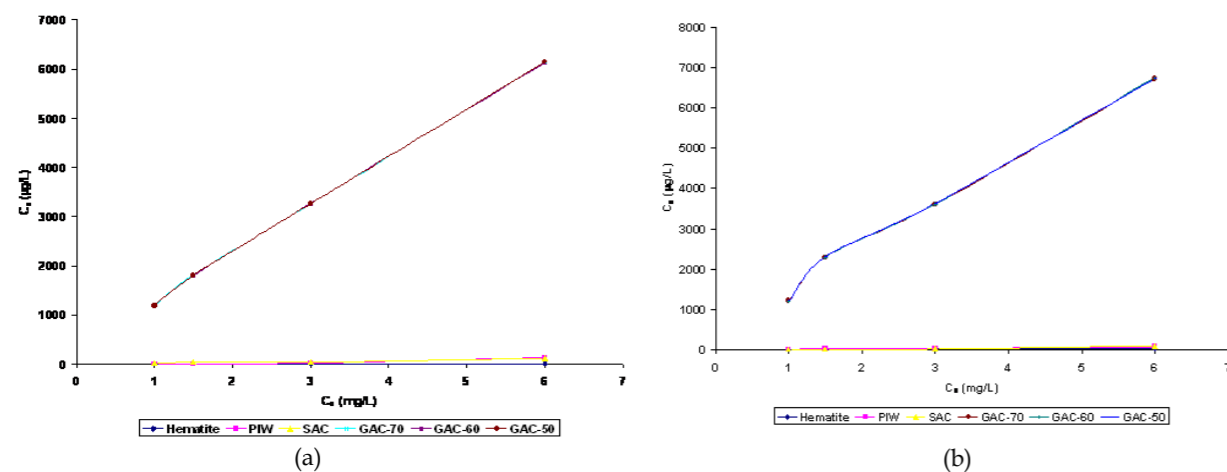


(a)

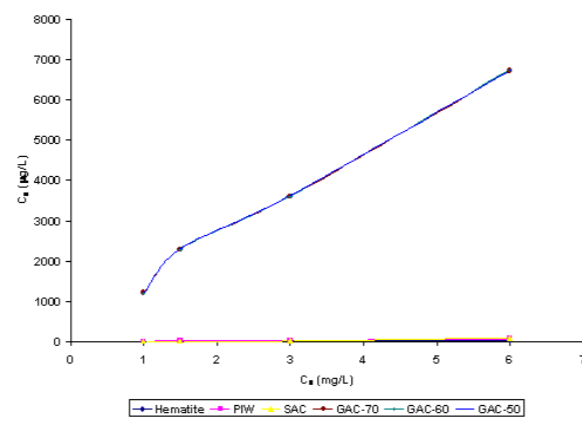


(b)

Fig. 3 Effect of Contact Time (a) Sodium arsenate aqueous solution
(b) 1:1 :: Sodium arsenite : Sodium arsenate aqueous solution

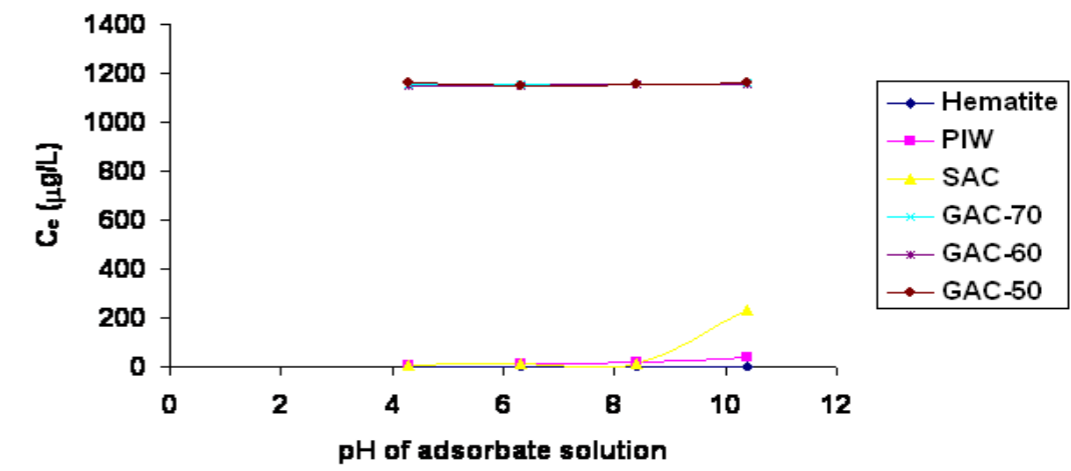


(a)

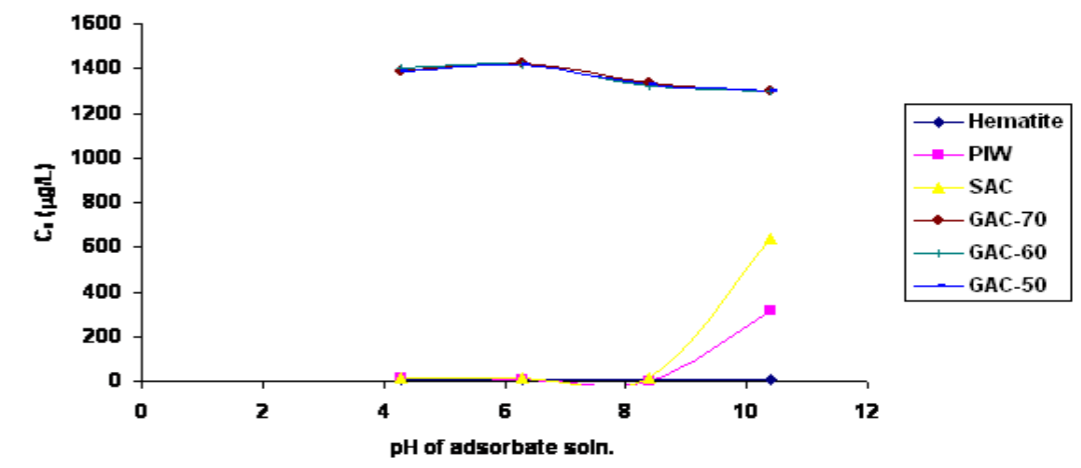


(b)

Fig. 4 Effect of Initial Arsenic Concentration (a) Sodium arsenate aqueous solution
(b) 1:1 :: Sodium arsenite : Sodium arsenate aqueous solution



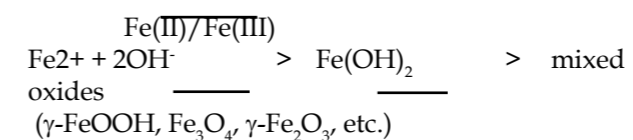
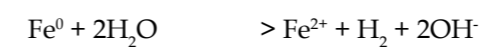
(a)



(b)

Fig. 5 Effect of pH (a) Sodium arsenate aqueous solution (b) 1:1 :: Sodium arsenite : Sodium arsenate aqueous solution

definitely show a very good affinity of materials for arsenic compared to SAC. However SAC has given more adsorption efficiency compared to hematite as it follows simple physical adsorption (Bansal and co-workers, 1988) while PIW and hematite both follow a path of co-precipitation followed by adsorption on iron oxy-hydroxide as per the probable mechanism given below:



Sodium salts of As (V) and As (III) get ionized in water medium. The arsenate and arsenite ions are removed as co-precipitants (as FeAsO_4 and FeAsO_3)

followed by adsorption onto ferric oxyhydroxide solids (Su *et al.* 1997).

The fact that GACs do not have much adsorption efficiency for arsenic in spite of possessing very high surface area further confirms the chemisorption and co-precipitation mechanism for removal of arsenic by PIW, SAC and hematite.

Effect of Contact Time

Results of experiments carried out for contact time optimization, by varying the adsorption time from 2 hrs. to 28 hrs. and keeping other parameters constant, indicate that 2 hrs. of contact time is sufficient for the effective removal of Arsenic (Fig. 3a & b).

Effect of Initial Concentration of Arsenic

This study involves variation of initial concentration

of arsenic from 1ppm to 6 ppm keeping the other two adsorption parameters constant at their optimized values. From the corresponding adsorption isotherms (Fig. 4 a & b) it can be deduced that with an adsorbent dose of 15.0g/L and a contact time of 2 hrs., the desired removal can be achieved only up to 2 ppm initial concentration, the adsorbent efficiency decreasing thereafter for the aforesaid dose and contact time.

Effect of pH

Effect of pH on the removal of arsenic has been studied by carrying out experiments by changing the pH of arsenic solution between 4 to 11. As can be seen from the fig.5 a & b, change in pH does not effect arsenic removal efficiency of PIW and Hematite while it declines after pH 8 incase of SAC.

CONCLUSION

The novel materials, PIW and SAC used in the present work, have been proved quite efficient for the removal of arsenic from water and, thus, can be successfully utilized in the development of water treatment technologies for arsenic remediation.

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