Iron oxide waste to clean arsenic-contaminated water

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ABSTRACT Serious cases of arsenic (As) toxicity of people by drinking water have led to the development of water purification methods. For instance, arsenic can be removed from water by adsorption on natural iron oxides. The use of iron oxide from waste could decrease the cost and recycle iron. Here, we studied arsenic removal from contaminated water using iron oxide wastes from a pickling unit of a steel plant. This iron oxide was reduced to magnetic iron oxide in a fluidised bed reactor. We tested arsenic removal from As-spiked solutions and from contaminated waters from West Bengal. Results showed more than 95% arsenic removal within 10 min. The arsenic concentration of contaminated waters was decreased from 0.010–0.018 to 0.002–0.008 mg/L. We also found that the occurrence of Ca^{+}, Ma^{++}, SO_4^{2-} and PO_4^{3-} decreased arsenic adsorption. Iron oxide waste is therefore a new low-cost and effective arsenic adsorbent to clean water.

INTRODUCTION & OBJECTIVE

- Arsenic contamination in ground water identified as global problem.
- About 6 million people in West Bengal (India) and 25 million population in Bangladesh are affected by As-contaminated ground water (Chakraborti et al. 2002)
- Consumption of As-contaminated water found linked to heart related deceases (Moon et al. 2013)
- Acceptable limit of arsenic in drinking water according to BIS and WHO is 0.01 mg/L.

Serious manifestations of arsenic toxicity

Natural and synthetic iron oxide based filtering media are good adsorbents to clean arsenic-contaminated ground water

IRON OXIDE WASTEs can be considered better due to zero production cost and environmental-friendly recycling

Iron oxide based adsorbent	Initial [As], mgAs(V)/L	pH	Arsenic removal/ loading capacity Q^m (mgAs/g)	Reference
Natural ore (Haematite)	1.0	3-10	0.204	Guo et al. 2007
Natural ore (Haematite)	0-30	6.5	0.40	Zhang et al. 2004
Nanocrystalline magnetite	1-100	7.9	0.214	Bujnakova et al. 2013
Commercial haematite	0.1-0.5	6.0	0.411	Mamindy-Panjany et al. 2009
Commercial goethite	0.1-0.5	6.0	1.219	Mamindy-Panjany et al. 2009
Commercial magnetite	0.1-0.5	6.0	0.852	Mamindy-Panjany et al. 2009
Natural haematite	0.075-75	7.3	0.82	Gimenez et al. 2007
Natural magnetite	0.075-75	6.5	0.253	Gimenez et al. 2007
Natural goethite	0.075-75	7.5	0.45	Gimenez et al. 2007
Goethite rich ore	0.17-0.98	6.5	0.294	Behera et al. 2012

OBJECTIVE: Physico-chemical characterisation and utilization of iron oxide waste for studies on treatment of arsenic-contaminated ground water.

EXPERIMENTAL METHODS

- The iron oxide waste (Haematite) was converted to magnetic iron oxide (Magnetite) by controlled reduction in fluidized bed reactor using CNG as reductant. Characterisation carried out for chemical analysis, phase identification by XRD, morphological analysis by SEM, determination of particle size, surface area, pH_{pzc} and magnetic susceptibility.
- Batch sorption studies were carried out by mixing $As^{(V)}$ (0.2 mg/L) spiked 100 mL water with iron oxide waste (1.0 g/L) in a flask and shaking for 1h at pH 7. Each parameter was varied to evaluate As(V) removal properties of iron oxide wastes. The resultant arsenic was determined by Hydride Generation-AAS method. Real ground water from West Bengal was also tested to remove arsenic.

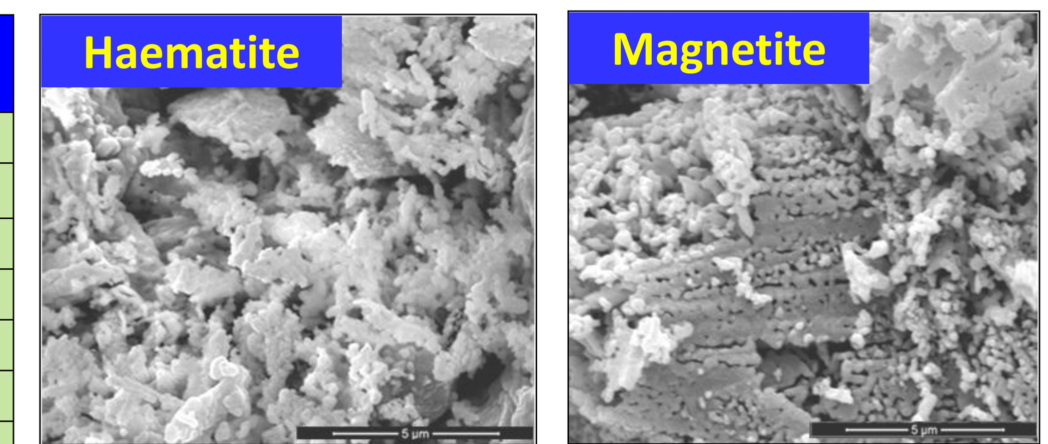
RESULTS

Physico-chemical properties of iron oxide waste

Chemical analysis and other properties

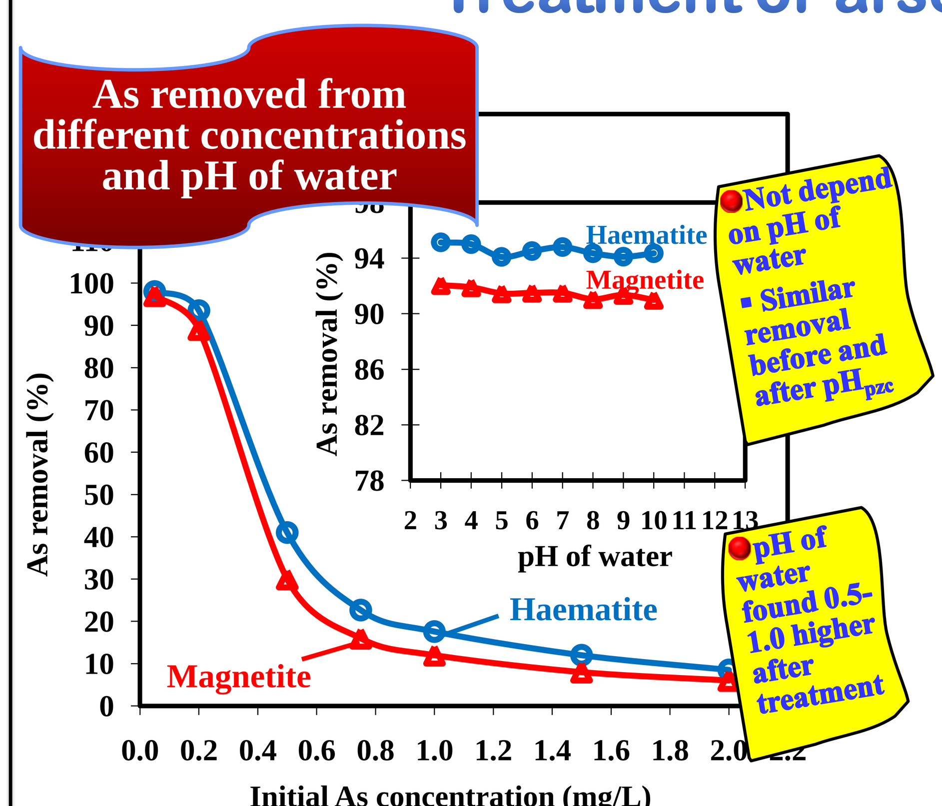
Constituent/ property	Haematite	Magnetite
Fe (total)	69.94%	71.49 %
Fe_2O_3	98.16%	37.64 %
FeO	0.22%	14.70 %
Fe_3O_4	0.91%	60.89 %
Surface area	3.18 m^2/g	2.38 m^2/g
Particle size	27.04 µm	36.77 µm
pH_{pzc}	8.25	7.95
Specific magnetization	1.48 emu/g	86.79 emu/g
Major phases (XRD)	Fe_2O_3	Fe_2O_3 and Fe_3O_4

Morphology under SEM (Scale bar: 5 µm)



Both haematite and magnetite types of iron oxide wastes exhibit dendritic structures, sometimes forming mesh with numerous irregular voids. Note the fusion of particles in magnetite is higher than haematite; might be due to fluidization at high temperature during preparation.

Treatment of arsenic-spiked water

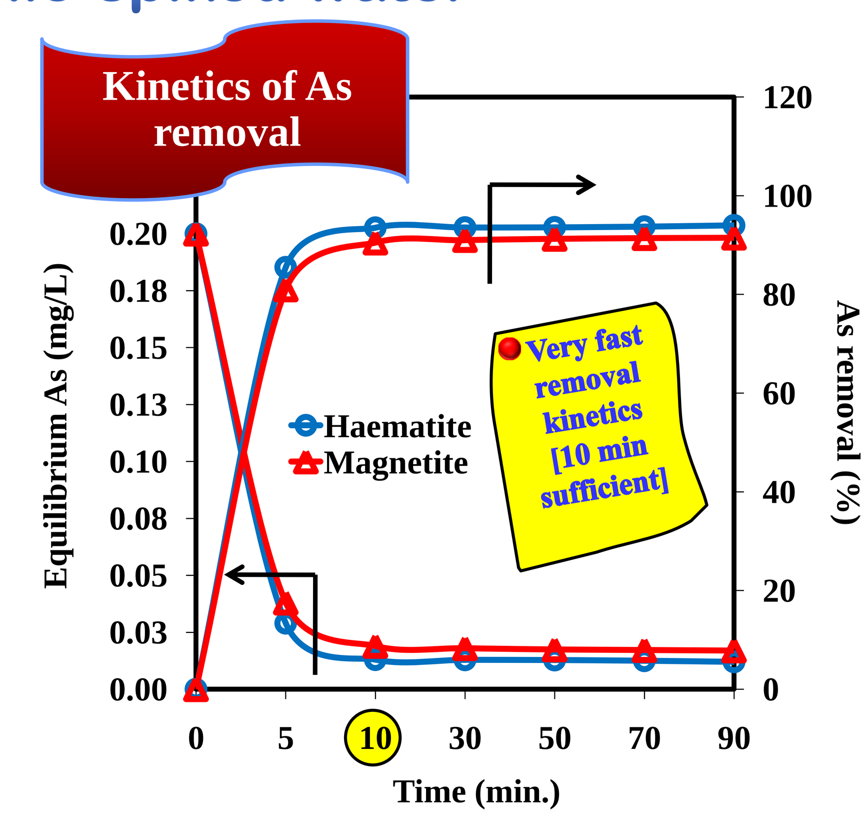


Non-dependence on pH, significant removal even after pH_{pzc} and increased pH of water after treatment support Ligand-Exchange mechanism for arsenic removal by iron oxide waste.

Arsenic anions exchanged with ^-OH groups at surface

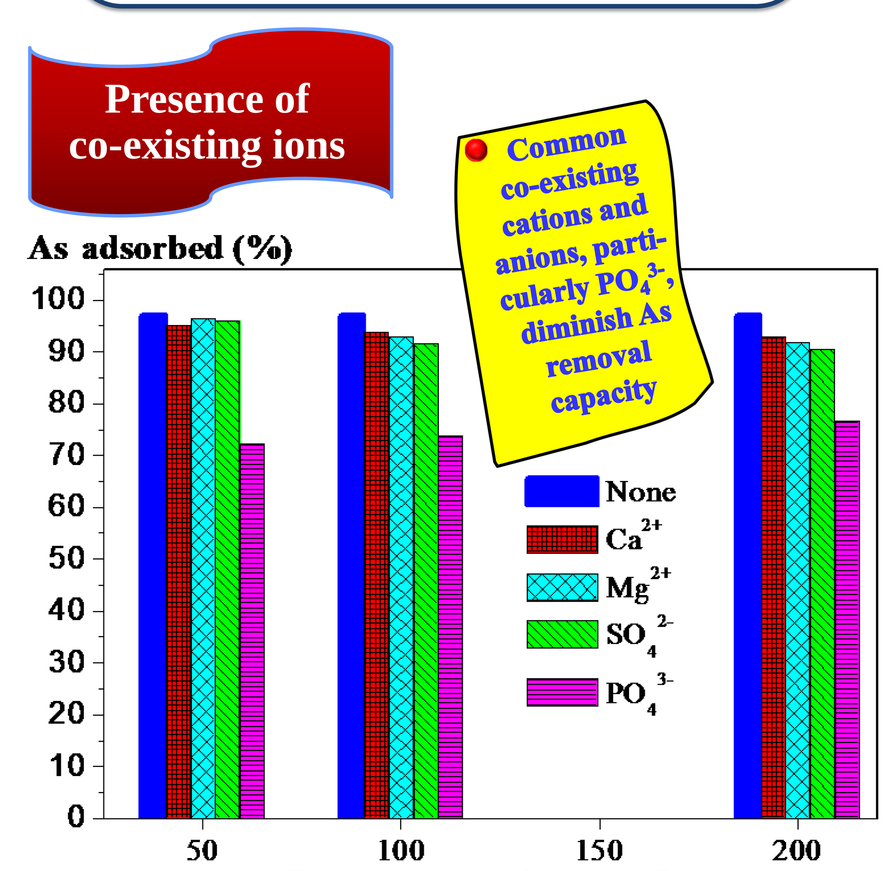
$S\text{---}OH + H^+ + HAsO_4^{2-} \rightarrow S\text{---}HAsO_4^{2-} + H_2O$

$S\text{---}OH + 2H^+ + HAsO_4^{2-} \rightarrow S\text{---}H_2AsO_4^{2-} + H_2O$



Water spiked with 0.2 mg/L As cleaned within 10 min, meeting to BIS and WHO acceptable limit for drinking water.

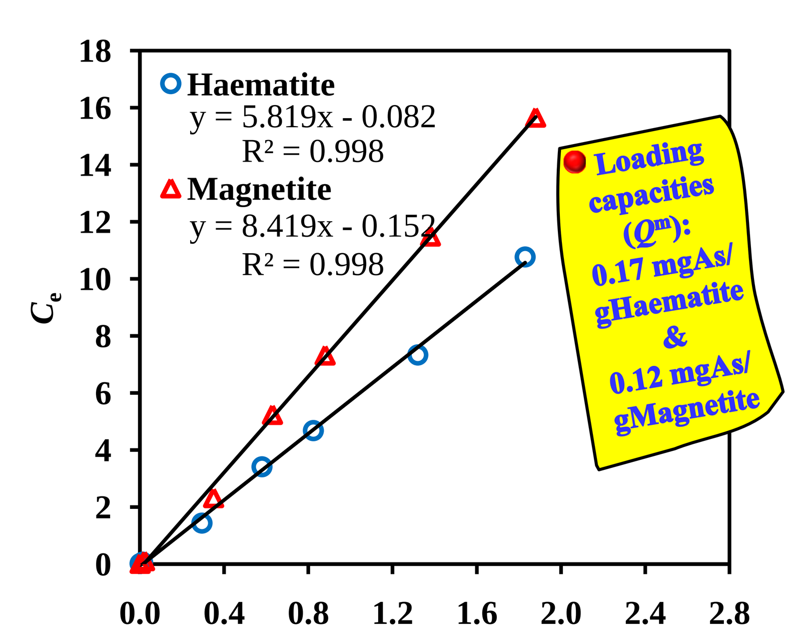
Fast kinetics is very suitable for point-of-use treatment of arsenic contaminated water in continuous columns/filter candles loaded with iron oxide waste.



Adsorption isotherm/ As loading capacity

Langmuir model

$$\frac{C_e}{q_e} = \frac{1}{bQ^m} + \frac{C_e}{Q^m}$$



Real ground water treatment

Ground water collected from Block-Chakda, District-Nadia, West Bengal (India) treated using both types of Iron oxide wastes

Ground water collected from the hand pumps

As-contaminated ground water

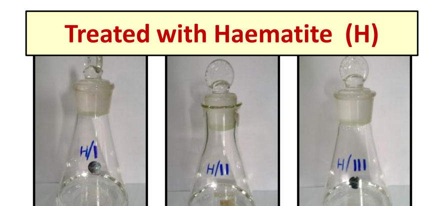
Arsenic level	I	II	III
	0.010 mg/L	0.017 mg/L	0.018 mg/L

Mixing with IRON OXIDE WASTE (1g/L)

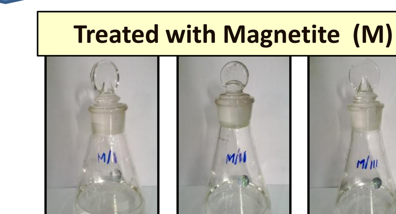
Haematite (H) Magnetite (M)

Shaking for 1 h in water bath shaker

Treated with Haematite (H)



Treated with Magnetite (M)



Arsenic level	H-I	H-II	H-III	M-I	M-II	M-III
	0.002 mg/L	0.005 mg/L	0.008 mg/L	0.003 mg/L	0.0065 mg/L	0.0087 mg/L

Clean ground water suitable for drinking

CONCLUSION

- Both iron oxide wastes exhibited fast uptake of arsenic. Initial arsenic level of 0.2 mg/L was brought down to BIS and WHO specification for drinking water, within 10 min contact time. Arsenic removal efficiency was found to be unaffected by pH of water.
- Arsenic-contaminated ground water obtained from Nadia district, West Bengal was successfully cleaned (As level <0.01 mg/L) making suitable for drinking purpose, using both the adsorbents.
- Advantages of iron oxide waste as adsorbent are: (a) It is a by-product of industrial process and no chemical routs for synthesis are needed, (b) no secondary pollutants are produced during preparation, (c) simple and rapid separation of As-loaded magnetite from the treated solutions can be achieved via external magnetic field and (d) it recycles iron oxide. This makes the iron oxide waste (haematite and magnetite) environmentally very friendly sorbents.

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Acknowledgements:
Director, CSIR-National Metallurgical Laboratory, Jamshedpur and Tata Steel, Jamshedpur.

NMD-ATM 12-15 November 2015, College of Engineering, Pune

Theme symposium - Sustainability: Remanufacturing, Refurbishing & Recycling