



REVIEW ON TREATMENT OF ARSENIC (III) AND ARSENIC (V)

¹Ashish Kumar

¹Undergraduate Student

¹Department of Chemical Engineering, BIT Sindri

Abstract: Arsenic is a normally occurring nephrotoxic metal in natural systems. It is a human carcinogen in water over a wide range of pH values, having harmful effects on human health and environment, even at low concentration. It occurs through a combination of natural processes and human activities. Inorganic As(V) and As(III) are identified to be more toxic than its organic forms. The arsenic is build up through intake of food or contaminated potable water. The largest population in danger is in East Pakistan followed by Asian nation (West Bengal). There is no effective treatment for arsenic toxicity. A great deal of analysis over recent decades has been done to lower the concentration of arsenic in beverage and still there's a necessity to develop low price viable techniques. Existing major arsenic separation technologies such as oxidization, adsorption, precipitation, coagulation and membrane separation. This paper presents the review of current standing of analysis within the space of arsenic removal from contaminated water and comparison of all technologies out there with additional stress on the adsorption. Adsorption has become one of the most commonly used processes. The objective is to do brief study about the removal of arsenic from water by the process of adsorption. The cost of adsorbents developed depends on treatments conditions, availability, processing etc. Cost may vary when the adsorbents are made in developed countries, developing countries and underdeveloped countries. However there are scopes in demonstrating evaluation costs at the industrial scale.

Index Terms - Arsenic, Adsorption, Activated carbon, Low cost adsorbents, Arsenic removal

I. INTRODUCTION

Arsenic is 20th most abundant element on the earth crust, 14th in seawater and 12th in human body. It has been used in medicines. It has been used in various fields such as agriculture, livestock, industry and metallurgy. [1] It is a silver coloured crystalline solid with an atomic weight of 74.9 and specific gravity; 5.73. Arsenic is mobilized by natural weathering reactions, biological activity, geochemical reactions and volcanic emissions. Arsenic exists in the -3, 0, +3 and +5 oxidation states [2]. Arsenic occurs in both inorganic and organic compounds and its toxicity is strongly related to its chemical form. Arsenic is a ubiquitous element found in the atmosphere, soils and rocks, natural waters and organisms. It occurs through a combination of natural processes and human activities. Inorganic As(V) and As(III) are identified to be more toxic than its organic forms. The arsenic is build up through intake of food or contaminated potable water.

The researchers, who are involved in arsenic removal for many years, looked into the presently available technologies that have been used for the removal of arsenic from water. To remove arsenic from water, several technologies have been used, including precipitation [3], electro coagulation, adsorption and ion exchange. Adsorption has become one of the most commonly used processes. The objective is to do brief study about the removal of arsenic from water by the process of adsorption.

1.1 Application of Arsenic

It is better to use the removed Arsenic rather than disposing it; because its disposal may create other environmental problems. It can be extracted and further used in various fields such as:

Agriculture- For nutritional supplements for chickens. Mono-sodium methyl arsenate and disodium methyl arsenate are used as insecticides.

Medical use- Arsphenamine is used to treat syphilis and arsenic trioxides-for treatment of cancer.

Alloys- Alloying with lead (used in car batteries) to reduce dezincification by adding arsenic. Gallium arsenide is used as semiconductor material (LASER diodes).

Other uses- Copper aceto-arsenate is used as a green pigment (colouring agent) in sweets. For bronzing: Up to 2% of arsenic is used for manufacture of bullets and shots. It is also used in optical glass and glass manufacturing.

Military- Lewisite ($\text{ClCH}=\text{CHAsCl}_2$) is used as chemical weapon.

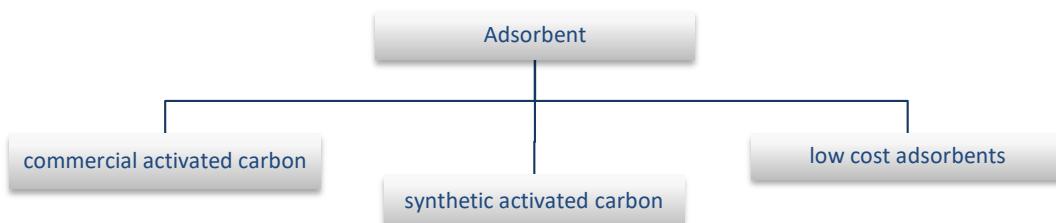
1.2 Main Arsenic Removal Technologies

METHODS	ADVANTAGES	DISADVANTAGES
Major oxidation/precipitation technologies		
<ul style="list-style-type: none"> • Air oxidation • Chemical oxidation 	<p>Relatively simple, low cost but slow process; <i>in situ</i> arsenic removal; also oxidizes other inorganic and organic constituents in water.</p> <p>Oxidizes other impurities and kills microbes; relatively simple and rapid process; minimum residual mass.</p>	<p>Mainly removes arsenic (V) and accelerates the oxidation process.</p> <p>Efficient control of the pH and oxidation step is needed.</p>
Coagulation/electro-coagulation/co precipitation		
<ul style="list-style-type: none"> • Alum coagulation • Iron coagulation • Lime softening 	<p>Durable powder chemicals are available; relatively low capital cost and simple in operation; effective over a wide range of pH.</p> <p>Common chemicals are available; more efficient than alum coagulation on weight basis.</p> <p>Chemicals are available commercially.</p>	<p>Produces toxic sludges; low removal of arsenic; pre-oxidation may be required.</p> <p>Medium removal of As (III); Sedimentation and filtration needed.</p> <p>Re-adjustment of pH is required.</p>
Major sorption and ion-exchange technologies		
<ul style="list-style-type: none"> • Adsorption • Activated alumina/carbon • Iron coated sand • Ion-exchange resin 	<p>Simple in operation, cost effective, Availability of in-situ preparation of adsorbent, easily regenerated if required, effective removal of arsenic.</p> <p>Relatively well known and commercially available.</p> <p>Cheap; no regeneration is required; remove both As (III) and As (V).</p> <p>Well-defined medium and capacity; pH independent; exclusive ion specific resin to remove arsenic.</p>	<p>Needs replacement after 4 to 5 regeneration.</p> <p>Not standardized; produces toxic solid waste.</p> <p>High cost medium; high-tech operation and maintenance; regeneration creates a sludge disposal problem; As(III) is difficult to remove; life of resins</p>
Major membrane technologies		
<ul style="list-style-type: none"> • Nano-filtration • Reverse osmosis • Electro-dialysis 	<p>Well-defined and high-removal efficiency.</p> <p>No toxic solid waste is produced.</p> <p>Capable of removal of other contaminants.</p>	<p>Very high-capital and running cost, pre-conditioning; high water rejection.</p> <p>High tech operation and maintenance.</p> <p>Toxic wastewater produced.</p>

II. METHODOLOGY

2.1 Arsenic Removal by Adsorption

In this review paper, adsorbents are broadly divided into three classes: (1) commercial activated carbon (2) synthetic activated carbons and (3) low-cost adsorbents.



2.1.1 Commercial activated carbon

Rodrigues reviewed the assembly and characterization of activated charcoal from several carbons containing sources. Recently, the science and technology of charcoal production is reviewed. The process of charcoal production includes: discontinuous (commonly known as batch type), continuous and semi-continuous. Recent studies are done on the above processes. Traditional charcoal production is mostly characterised by discontinuous production systems, however, continuous and semi-continuous production systems sometimes end in higher yield and productivity. Typically, in such systems, gas burners are used to generate heat and power battery of kilns, providing the drying and heating of the material, reducing the quantity of labor, saving fuel, and reducing emissions. [4]

Commercial activated carbons are basically used for the removal of As (III), As (V) adsorption from water. The removal of arsenic from liquid solutions by sorption onto activated charcoal has been researched by various authors. [5]

C Feng, C Aldrich established that pH scale adjustment alone can control arsenic sorption and bearing from activated charcoal. Batch adsorption tests on isotherms were conducted at 25 °C. The study shows that process waters from gold cyanide leaching are difficult, exhibiting high ionic strength and complicated chemistry, which may probably influence the arsenic sorption by competitive effects. A huge arsenic activity capability (2860 mg/g) was obtained on this coal-derived industrial carbon. Some activated carbons inseminated with golden silver and copper were additionally used for arsenic correction [6]. Yuwei and Tingting studied sorption of As (III) and As (V) on activated carbon versus pH and temperature. The capability of As (III) on carbon was constant at hydrogen ion concentration 0.16–3.5. However, As (V) exhibited a most sorption at pH 2.35 over the pH range of 0.86–6.33. The investigation of arsenic sorption mechanics was conducted with initial concentration of 30 mg/L at 25°C. [7]

Three activated carbons with completely different ash contents were studied for Arsenic adsorption: coconut shell carbon with 3% ash, peat-based extruded carbon with 5% ash and a coal-based carbon with 5–6% ash. A lot of As (V) was removed from water using carbon with high ash content. Carbon pretreatment with Cu (II) improved arsenic removal capability. [8] Liangjie Dong studied the removal of arsenic from water based on the iron coated pottery granules (IGPC). The sorption characteristics of Arsenic on the ICPG were studied under equilibrium and dynamic conditions. The IGPC media have been tested in column filter configurations for measuring efficiency of arsenic removal. This study shows that maximum adsorbent capacity of iron coated pottery granules from the Langmuir isotherm is very closer to that of nanoscale zerovalent. [9]

2.1.2 Production of commercial activated charcoal

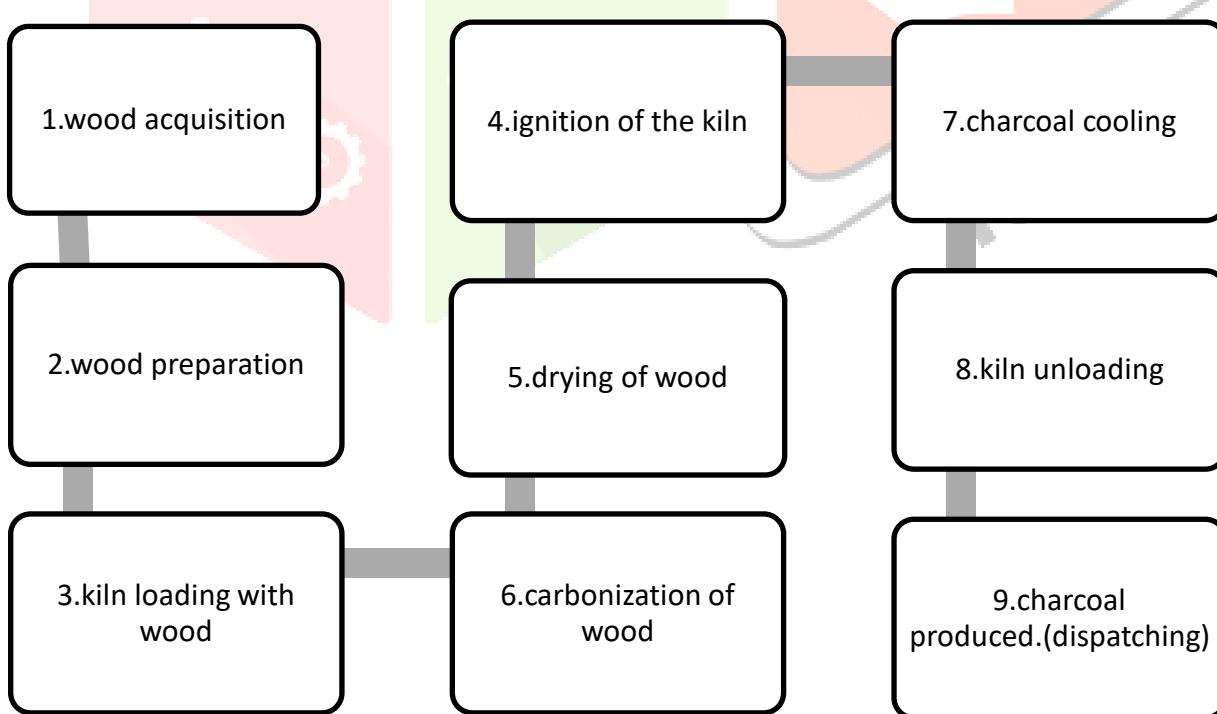


FIG 1: PRODUCTION OF ACTIVATED CHARCOAL.

As shown in **FIG1:** Production of charcoal involves nine stages. The first stage is acquisition of wood which can be obtained from planted forest for charcoal production or plant extraction.

The second stage is wood preparation. The wood is stored in open for 120 days to reduce its humidity. The woods are cut in the sizes of 1-1.4m according to the kiln's size.

The third stage is loading kiln with wood. Loading determines how well the kiln fires. The pieces of wood should always be placed vertically, where the carbonization temperatures are higher.

The next step is igniting the kiln. During this process, the exhaust openings have to remain open. This opening help in smoke and dust exhaustion and control of oxygen input and it also effects temperature and rate of heating.

The next step is drying of the wood. This is done to reduce water content (moisture) initially present in it. The higher the water content of the wood the more time it will take to evaporate.

The sixth step is carbonization of wood; its internal degradation takes place. To regulate the carbonization process, it is very important to control the input of oxygen; so that the chemical reactions and physical phenomena that result in the concentration of carbon can occur, forming the charcoal.

Oxygen input control in the kiln is usually carried out empirically by most charcoal producers in developing countries, assessing the smoke's colour. In this system, the kiln operator causes wood combustion through the top holes of the kiln. Initially, the smoke coming out through these holes is white and damp; when it darkens, the holes are closed. The smoke will then begin to emerge from lower-level holes (the kiln has several orifices arranged radially and axially, forming layers of equidistant holes), and when it becomes blue—indicating that carbonization is taking place at the level of that row of holes—the row is closed.

This is repeated for the other lower rows of holes, until reaching the one in the bottom part of the kiln. When the volume of smoke at this level becomes lower and it assumes the same blue coloration (transparent blue), these holes are sealed. Thus, after the final carbonization temperature is reached and after being kept at this temperature for a predetermined time span, the cooling step begins. To this end, the kiln is sealed to prevent the entry of oxygen during the cooling cycle.

In traditional kilns, the “barrela” sealing technique is employed after the closing of all holes. This technique consists in the application of a mixture of clay and water on the external walls of the kiln. In most kilns, the cooling is slow, occurring naturally (natural convection), and after several days, the kiln reaches a temperature below 40°C, acceptable for manual manipulation of the charcoal by humans. After the charcoal has cooled, the next step is the unloading of the kiln. The kiln is opened, and the charcoal is removed.

Finally, the charcoal is packed and dispatched. An increased production of residue occurs during these two stages (kiln unloading; packing and dispatching), mainly due to mechanization and the fact that charcoal produced in this way usually has low density and high friability. The main stages of charcoal production concern the process of carbonization. The characteristics of the wood, the control of the carbonization process, and the employed technology directly influence the yield and quality of the produced charcoal.

2.1.2 Synthetic activated carbon

Activated carbons are created by carbonization using slow substrate heating within the absence of air below 600 °C. This removes volatiles. Treatment with oxidizing agents (steam, CO₂, or oxygen) at elevated temperature completes the activation of the reaction [10]. A favourable position of synthetic initiation is the lower temperature required. Chemical activation gives higher worldwide yields.

Activated carbon are mainly synthesized and used for the removal of arsenic from waste water. The three different types of carbon specimens used in their experiment as sorbents were arc-carbon, char-carbon and a commercial carbon. The result shows that the commercial carbon did not perform well with respect to arsenic removal from aqueous solution. The result of their experiment shows that the uptake of arsenic by carbons is dependent upon the form of arsenic present in solution, the type of adsorbent and the metal concentration. Usually, the use of highly oxidized carbon is preferred because it results in greater As (III) and As (V) uptake. The result of the experiment also shows that free ash is the good adsorbent for arsenic (V) removal while the inherent ash content of the carbon samples have no influence on the metal uptake [11]. Tanjina Nur developed iron-containing granular activated carbon adsorbents (As-GAC) for arsenic removal from drinking water. Granular activated carbon (GAC) was a support for ferric ions that were inseminated using liquid metallic element chloride (FeCl₂) followed by NaClO chemical oxidation.

Carbons produced by brown coal steam activation were best suited among 13 tested activated carbons for iron impregnation and arsenic removal. [12]

The productivity of As (V) adsorption by activated carbon (AC) created from oat bodies. The result of this research clearly indicates that the adsorption amounts of As (V) by activated carbon were less affected by the initial pH values lower than 8. Capacity of absorption is decreased from 3.09 to 1.57 of arsenic per gram when the initial pH gets increased from 5 to 8. Langmuir and Freundlich isotherms are considered to be the two most functions for describing adsorption. The research proves that activated carbon (AC) derived from oat hulls has considerable potential for the adsorption of As (V) [13].

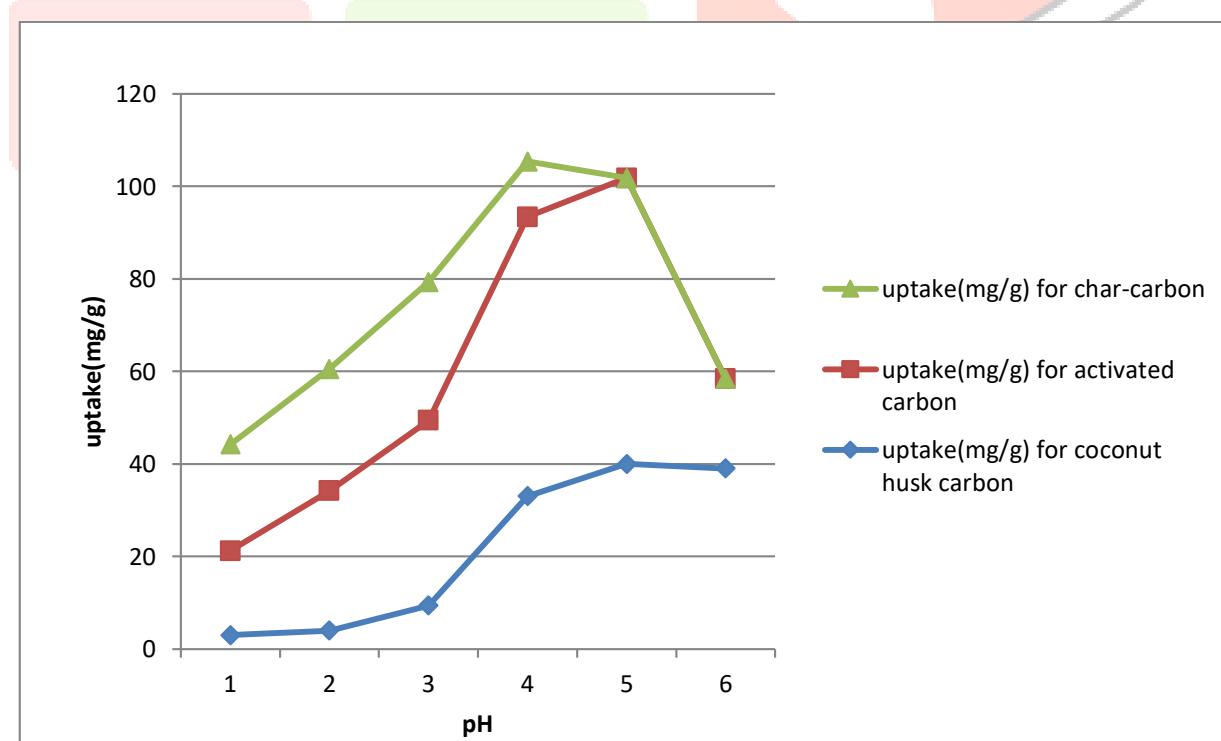
Daus et al. [14] reviewed As(III) and As(V) adsorption onto five different adsorbents [granular activated carbon (AC), zirconium-loaded activated carbon (Zr-AC), a sorption medium with the tradename ‘Absorptionsmittel 3’ (AM3), granulated iron hydroxide (GIH) and zero-valent iron (Fe0)]. To obtain the assessment of the performance of the various adsorbents, batch experiments were carried out. The dynamics of the sorption processes of arsenic onto the varied materials have to be compelled to indicate their efficiency and behaviour.

As (V) removal by an iron oxide-impregnated activated charcoal was sculpted by Vaughan and Reed using the surface complexation model (SCM) approach. The result of this research shows that As (V) removal by iron oxide impregnated activated carbon (FeAC) was because of the impregnated Fe oxide, not the base carbon material and was a powerful function of pH [15].

Activated carbon was pretreated with iron-salt solutions to improve arsenic sorption As (III) action onto amorphous iron oxyhydroxide, iron ore and magnetic iron-ore and found that surface complexation reduced As (V) mobility at near neutral pH conditions. In soil, arsenic sorption has been found to extend with increasing Fe(OH)_3 concentrations [16]. The salt type and concentration, pH, and treatment time were examined to enhance removal capacity. A 10-fold capacity increase was finally achieved versus the untreated activated carbon. Metal ions were adsorbable and arsenic removal was increased by salt (arsenate) complex formation. The carbon type and the pH were the major factor that decides the removal of As (V) from water. Modified saw-dust carbons were used for adsorption of As (III) chemical treatment, such as acid modification, is frequently utilized to prepare biochar with special functional groups and improved adsorption capacity [17].

G.N Manju [18] prepared a coconut husk carbon (CHC) by carbonizing one part of coconut husk with 1.8 parts by weight of sulfuric acid (18 M) at 150 °C for 24 h. The turn material (CHC) was water washed to get rid of acid and dried at 105 °C. The CHC (10 g) was mixed with 100 ml of 100 mol/L copper solution. The mixture was agitated for 24 h at 30°C and filtered. The filtrate’s pH scale was 6.5. The resulting copper-impregnated coconut husk carbon (CuCHC) was water washed until the filtrate was copper free. Optimum As (III) adsorption conditions on this copper-impregnated activated carbon were established. Most adsorption capability occurred at pH 12.0. Capability increased going from 30 to 60°C. Spent adsorbent was regenerated using 30 minutes H_2O_2 in 0.5M HNO_3 .

The comparison between most commonly used synthetic activated carbons (as an adsorbent) are made according to the data documented in the research papers. This shows the behaviour of the adsorbents (char-carbon, activated carbon, and coconut husk carbon) at varying pH and concentration. (GRAPH 1)



GRAPH 1: COMPARISON BETWEEN THE BEHAVIOUR OF SYNTHETIC ACTIVATED CARBONS

2.1.3 Low cost adsorbents

2.1.3.1 Agricultural byproducts

Agricultural byproducts such as rice husks were used for the removal of arsenic. Maximum adsorption occurred at 0.01 mol/L of HNO_3 , HCl , H_2SO_4 or HClO_4 using 1.0 g of adsorbent for 5.97×10^{-3} mol/L of arsenic for 5 min. With increase in temperature the uptake of arsenic increases. The one-pot pyrolytic treatment of the lingo-cellulose rich rice husk yielded five different time-based IPMN variants having a disordered graphitic carbon-rich matrix which was permeated by Fe_3O_4 nanoparticles and carbon nanotube like fibrillary conduits, as seen through The micro structural assessment. [19]

Untreated rice husk was used for liquid arsenic remediation. Complete removal (using rice husk columns) of each As (III) and As (V) was achieved under the subsequent conditions: initial As concentration, 100 $\mu\text{g}/\text{L}$; rice husk quantity, 6 g; average particle size, 780 and 510 μm ; rate of flow, 6.7 and 1.7 ml/min ; and a pH of 6.5 and 6.0, respectively. Desorption (71–96%) was additionally achieved with 1 M of KOH. Zahra Shamsollahi reviewed the adsorption of different organic pollutants, heavy metals and dyes by rice husk as a bio-based adsorbent. [20]

2.1.3.2 Industrial byproducts

Chars and coals are considered to be very useful in wastewater treatment. Peat chars [21] and bio chars [22] are gathering attention of many researchers in this field. This acts as a substituent for activated carbons. It has many advantages such as it is locally available and is inexpensive as compared to the preparation process of activated carbon. Biochar by-products from were investigated as adsorbents for the removal of the As^{3+} , Cd^{2+} , Pb^{2+} from water. Oak bark, pine bark, oak wood, and pine wood chars were obtained from fast pyrolysis at 400 and 450 $^{\circ}\text{C}$ in an auger-fed reactor and characterized. Adsorption studies were performed at different temperatures, pHs and solid to liquid ratios in the batch mode. Maximum adsorption occurred over a pH range of 3–4 for arsenic. The equilibrium data were modelled with the help of Langmuir and Freundlich equations. Overall, the data were well fitted with both the models, with a slight advantage for Langmuir model.[31]

Steel plants generate an oversized volume of granular furnace slag. It's being employed as filler or in the production of slag cement. Recently, it was converted

Into an efficient and economical scavenger and utilised for the remediation of liquid arsenic . Zhang and Itoh [23] synthesized an adsorbent for liquid arsenic removal by loading iron (III) oxide onto liquefied municipal solid waste incinerator slag. The simultaneous generation of amorphous hydrated oxide sol and a silicon oxide sol in place eventually led to the formation of Fe–Si surface complexes that tightly bonded the iron oxide to the slag. For comparison, amorphous hydrous oxide was also prepared. Loading of iron oxide on the slag enhanced the area of iron (III) oxide loaded melted slag (IOLMS) by 68 compared to FeOOH , which might be attributed to the porous structure shaped in IOLMS throughout the synthesis method. This adsorbent effectively removed both arsenate and arsenite, exhibiting removal capacities for As (V) and As (III) 2.5 and 3 times of those of amorphous Hydrous oxide.

Zhang and Itoh [24] additionally Used photo catalytic oxidation of arsenite and removal using slag iron Oxide – TiO_2 adsorbent. The reaction of arsenite was fast, but the adsorption of the generated arsenate was slow. A concentration of 100 mg/L arsenite was modify to arsenate within 3 hr in the presence of adsorbent and under UV-light, however the reaction rate was some 1/3rd of the photo catalyzed reaction.

Combustion of coal produces a huge amount of by-product fly ash, the disposal of the fly ash requires large amount of water. Indeed, fly ash can also used as a adsorbent. Results show that iron oxide-coated sand may be utilized as an adsorbent for reducing As(III) concentrations to less than 24 $\mu\text{g}/\text{l}$ (with 20 g/l adsorbent dose and initial arsenic concentration of 400 $\mu\text{g}/\text{l}$) in drinking water for use in small systems or home treatment units within the developing areas of the world.[25]

Drinking water residuals are also evaluated for the removal of arsenic from wastewater. Drinking water treatment residuals (WTRs) were evaluated for their ability to absorb both As (V) and As (III). Two WTRs were used in this study: one was Al-based, and the other was Fe-based. The study shows that WTRs are low cost adsorbents for removal of arsenic. [26]

In the pH range of 2–8, a low cost ferruginous magnesium ore (FMO) were used for the removal of both As (III) and As (V) without any pre-treatment. Adsorption capacity is enhanced by the presence of some cationic groups (Ni^{2+} , Co^{2+} , Mg^{2+}) present in ferruginous manganese ore. [27]

2.1.3.3 Red mud

Red mud is the waste product formed during the production of alumina when bauxite ore is subjected to caustic leaching. Red mud is a waste material formed during the production of alumina when bauxite ore is subjected to caustic leaching. Bayer process plant generate about 1–2 tonnes of red mud per ton of alumina produced. Red mud is only about 25% iron oxide and contains similar amounts of alumina and silica along with smaller amounts of natural components such as titanium oxide, and soluble components. The As (III) adsorption was exothermic, whereas As (V) adsorption was endothermic.

Heat and acid treatments on red mud increased its adsorption capacity.[29] Arsenic adsorption on acid and heat treated red mud is also pH-dependent, with an optimum range of 5.8–7.5 for As(III) and 1.8–3.5 for As(V). Isotherms were used to obtain thermodynamic properties. Adsorption followed first order kinetics and fit the Langmuir isotherm well. The As(III) adsorption was exothermic, whereas As(V) adsorption was endothermic.

2.1.3.4 Biomass

Various properties of biomass have been reviewed. Micro-fungi have been recognized as very popular adsorbents for heavy metal ion removal from aqueous solutions. A few studies are reported on the removal of anionic metals including arsenic by fungal organisms. Kamala et al.[30] experiment proves the ability of *Garcinia cambogia*, (commonly known as Malabar tamarind) an indigenous plant found in many parts of India, to remove trivalent arsenic from solution. The As(III) removal capacity of fresh and immobilized *G. cambogia* biomass was estimated.

As(III) uptake was not greatly affected by pH with optimal bio-sorption occurred at around pH 6–8. Common ions such as Ca^{2+} and Mg^{2+} did not inhibit As(III) removal at concentrations up to 100 mg/L, but 100 mg/L of Fe(II) caused a noticeable drop in the extent of As(III) removal. Immobilized biomass columns were recycled five times.

2.1.3.5 Soil sediments

Aquifer materials from mining areas were tested for groundwater arsenic removal. Quartz, feldspar, calcite, chlorite, and magnetite/hematite were all present in the aquifer material. A maximum of 80% arsenite was adsorbed. The adsorption isotherm at pH 7 indicated saturation of surface sites at high solute concentrations.

As (III) and As(V) adsorption and mobility on an oxisol, and its main mineral constituents was investigated by Ladeira and Ciminelli.[33] Goethite in this soil was the most efficient arsenic adsorbent, retaining 12.4 mg/g of As(V) and 7.5 mg/g of As(III). Gibbsite also adsorbed considerable As (4.6 mg/g of As (V) and 3.3 mg/g of As (III)). Adsorption on kaolinite was negligible (<0.23 mg/g for As (V) and As(III)). Arsenic desorption varied with the arsenic oxidation state, the adsorbents and the leaching solutions.

I. RESULTS AND DISCUSSION

The interaction between solute and surface complicate the study of adsorption in multi-component systems. Solute–solute competition happens at the active sorption sites. Solid–liquid part equilibrium can emerge with a distinct capability for single metal ions and a replacement set of isotherms once competitive ions are present.

ADSORBENT	pH	CONCENTRATION/ RANGE	TEMPERATURE (°C)	MODEL USED TO CALCULATE ADSORPTION CAPACITY	REFERENCES
Iron oxide coated sand	7.5	100–800 $\mu\text{g/L}$	27±2	Langmuir	[25]
Iron oxide uncoated sand	7.5	100–800 $\mu\text{g/L}$	27±2	Langmuir	[25]
Seawater-neutralized red mud	7.3	0.80–32.00 Mm	30	Langmuir	[28]
Red mud	7.25 for As(III); 3.50 for As(V)	33.37–400.4 $\mu\text{mol/L}$	25	Langmuir	[29]
Activated carbon (AC) produced from oat hulls	5.0	25–200 $\mu\text{g/L}$	24	Langmuir	[13]
Zirconium-loaded activated carbon (Zr-AC)	8–9	5–100 mg/L	25	Column capacity	[14]
Coconut husk carbon	12.0	50–600 mg/L	30	Langmuir	[18]

Coconut shell carbon with 3% ash	5.0	0–200 mg/L	25	Langmuir	[5]
Peat-based extruded carbon with 5% ash	5.0	0–200 mg/L	25	Langmuir	[5]
Coal-based carbon with 5–6% ash	5.0	0–200 mg/L	25	Langmuir	[5]
Pine wood char	3.5	10–100 ug/L	25	Langmuir	[31]
Oak wood char	3.5	10–100 ug/L	25	Langmuir	[31]
Oak bark char	3.5	10–100 ug/L	25	Langmuir	[31]
Pine bark char	3.5	10–100 ug/L	25	Langmuir	[31]
Char carbon	2.0-3.0	157–737 for As(V) and 193–992 for As(III)	25	Langmuir	[11]
Activated carbon	6.4–7.5	157–737 for As(V) and 193–992 for As(III)	25	Langmuir	[11]
Oxisol	5.5	10–1000 mg/L	25	Langmuir	[33]
Gibbsite	5.5	10–1000 mg/L	25	Langmuir	[33]
Goethite	5.5	10–1000 mg/L	25	Langmuir	[33]
Kaolinite	5.5	10–1000 mg/L	25	Langmuir	[33]
Fresh biomass	6.0	50–2500 mg/L	30	Langmuir	[30]
Immobilized biomass	6.0	50–2500 mg/L	30	Langmuir	[30]

TABLE-1 BRIEF STUDY OF VARIOUS ADSORBENTS.

The listed adsorbents in **Table1** are studied in compressive manner. On the basis of their adsorption capacity, the major adsorbents are documented. Due to lack of consistency in literature data, it is very difficult to directly compare their adsorption capacities. Adsorption capacities were studied at varying temperatures and pHs. The adsorbents were used for the treatment of wastewater, drinking water wastewater from industries/factories, groundwater etc. Some sorption capacities are documented in batch mode and others in column mode. In batch experiment the adsorption capacities were calculated by Langmuir isotherm or the Freundlich isotherm. Some adsorbents with very high sorption capacities were chosen and shown in a bar diagram (**Figure2**) and (**Figure 3**)

FOR ADSORPTION OF ARSENIC(III)

Nos.	Adsorbent	Adsorption capacity (in mg/g)
1	Iron oxide uncoated sand	0.006
2	Red mud	0.663
3	Coconut husk carbon	146.3
4	Fresh biomass	128.1
5	Pine wood char	0.0012
6	Oak wood char	0.006
7	Oak bark char	0.0074
8	Pine bark char	12
9	Char carbon	89
10	Activated carbon	29.9
11	Immobilized biomass	704.1

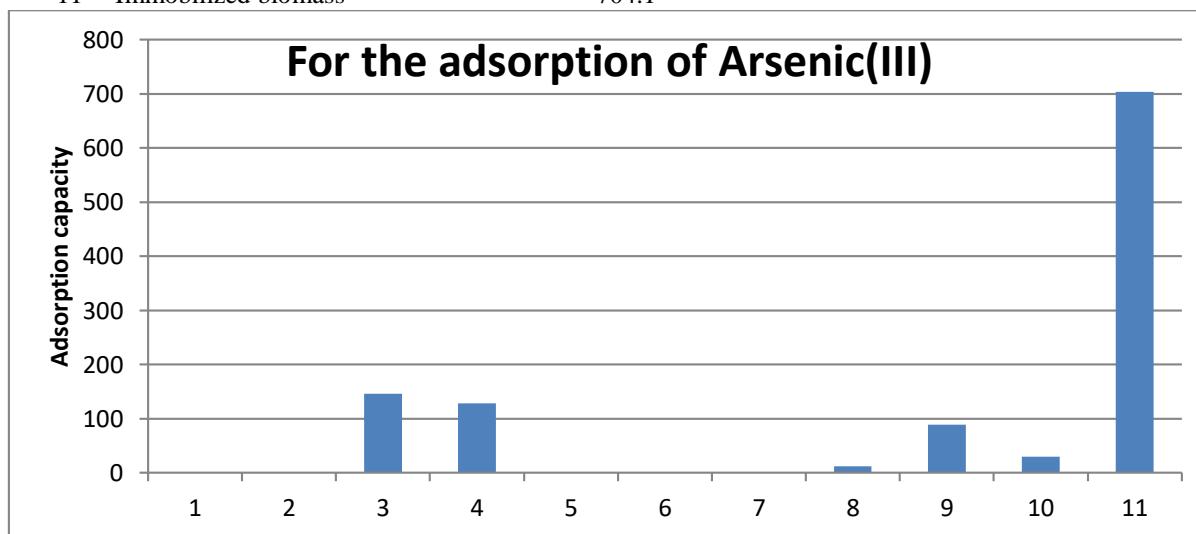


FIG 2 COMPARITIVE EVALUATION AMONG BEST ADSORBENT FOR REMOVAL OF Ar(III)

FOR ADSORPTION OF ARSENIC(V)

Nos.	Adsorbent	Adsorbent capacity (in mg/g)
1	Seawater-neutralized red mud	1.081
2	Red mud	0.514
3	Activated carbon(AC) produced from oat hulls	3.08
4	Zirconium-loaded activated carbon (Zr-AC)	2.8
5	Coconut shell carbon with 3% ash	2.4
6	Peat-based extruded carbon with 5% ash	4.9
7	Coal-based carbon with 5-6% ash	4.09
8	Char carbon	34.46
9	Activated carbon	30.48

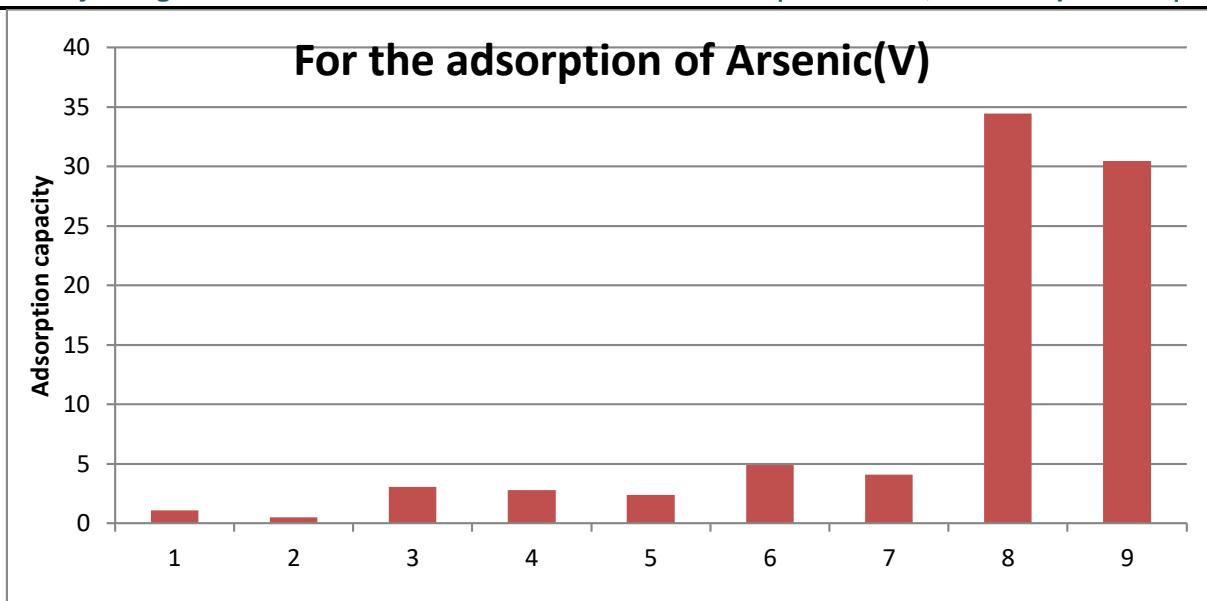


FIG 3 COMPARITIVE EVALUATION AMONG BEST ADSORBENT FOR REMOVAL OF Ar (V)

Some low cost adsorbents that are developed from agriculture wastes and industrial wastes have outstanding adsorption capacities.

Out of all the adsorbents compared in this review paper immobilized biomass offers outstanding performance for adsorption of Arsenic(III) and char carbon for Arsenic(V).

3.1 Arsenic desorption/sorbent regeneration

Once the sorbent becomes exhausted, the metals must be recovered and the sorbent regenerated. Desorption and sorbent regeneration is a critical consideration and contributor to process costs and metal(s) recovery in a concentrated form. A successful desorption process must restore the sorbent close to its initial properties for effective reuse. Desorption can be improved by gaining insight into the metal sorption mechanism. In most of the arsenic sorption studies discussed earlier, desorption/regeneration was not discussed. Very few desorption studies were found in literature. Furthermore, once arsenic is recovered in the concentrated form, the problem of how to dispose of this concentrated arsenic product must be addressed. This is a difficult task. Few attempts have been made in the literature to address the handling of concentrated arsenic wastes. Various disposal options and their advantages and disadvantages were reviewed by Leist et al. The methods frequently used for other metals and organics include combustion or recovery and purification for resale. These options are not feasible for arsenic due to the following reasons. Leist et al. [32]

1. Incineration is not practically feasible because arsenic oxides are volatile and can easily escape.
2. Recovery and purification of arsenic is not cost effective because arsenic has limited markets.

One attractive option for treating arsenic concentrates is encapsulation through solidification/stabilization followed by disposal of treated wastes in secure landfills. Solidification/stabilization transforms potentially hazardous liquid/solid wastes into less hazardous or non-hazardous solids before entombing these solids in secure landfills.

3.2 COST EVALUATION

The cost of adsorbents developed depends on treatments conditions, availability, processing etc. Cost may vary when the adsorbents are made in developed countries, developing countries and underdeveloped countries. Batch experiments are described in many papers. Batch adsorption isotherm cannot predict the dynamic performance. However it is difficult to compare different adsorbents due to inconsistency in the data presentation. However there are scopes in demonstrating evaluation costs at the industrial scale.

I. CONCLUSION

Adsorption is a very useful method for controlling arsenic pollution in water. Activated carbon was studied briefly for arsenic removal. However, it only removes few milligrams of metal ions per gram of activated carbon. Thus, use of activated carbon is expensive. Therefore, there is an urgent need for low-cost adsorbents, exhibiting superior adsorption capacities and also available locally. Activated alumina is very efficient and can be regenerated in situ to extend the useful life. However, sorption efficiency is highest only at low pH.

The removal efficiency of ion exchange resins are independent of water pH and the adsorbent and can also be regenerated in situ. However, sulphates, nitrates or dissolved solids reduce adsorption efficiency.

Clays, silica, sand, etc. are in fact low-cost adsorbents (and substrates). They are available worldwide. These can also be regenerated in situ. Unfortunately, they have lower adsorption efficiency than most of the other adsorbents.

Iron or iron compounds are the most widely used adsorbents, having higher removal efficiency at lower cost. However, their adsorption efficiency is highest only at low pH and they are not regenerable. Most of the commercially available adsorbents are designed for application only within specific pH ranges.

Selection of a suitable sorbent media to supply arsenic free drinking water depends on (1) the range of initial arsenic concentrations, (2) other elements and their concentration in water, (3) optimization of adsorbent dose, (4) filtration of treated water, (5) adjustment of pH in water, (6) post treatment difficulties, (7) handling of waste and (8) proper operation and maintenance.

Adsorbent selection is a complex decision. The choice depends on the oxidation state of arsenic and the many other factors mentioned above. Hence the criteria for best technology should include high removal efficiency, affordability, general geographic applicability, and compatibility with other water treatment processes, process transferability and process reliability.

This review would be helpful in initial screening of various sorbent media for setting up the treatment plants for removal of arsenic at the community level/ household levels.

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