

REMOVAL OF ARSENIC FROM CONTAMINATED WATER: REVIEW

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Abstract: *Arsenic contamination in water, especially groundwater, has been recognized as a major problem of catastrophic proportions. As the world population increases, one of the most fundamental resources for human survival, clean water, is decreasing. The rising demands for water often cannot be met by surface water supplies. This has led to increased dependence on groundwater resources in many parts of the world. Arsenic is present in the earth's crust, the consequences of groundwater development often include over drafting, land subsidence. Arsenic can be easily solubilized in groundwaters depending on pH, redox conditions, temperature, and solution composition and hence it is present in ground water in some arsenic affected areas. Arsenic in drinking water beyond limit can do harm to human health and the use of ground water unfit for human consumption in those areas. Anthropogenic sources of arsenic include industrial processes (in particular, mining and smelting), ash residues from power plants, pesticide and fertilizer applications, wood preservatives, inorganic arsenical pesticides and herbicides industrial and municipal waste, and sewage sludge. In this paper, a broad overview of the available technologies for arsenic removal has been presented on the basis of literature survey. The main treatment methods included coagulation-sedimentation, adsorption separation, ion exchange, membrane technique, which have both advantages and disadvantages. It concluded that the selection of treatment process should be site specific and prevailing conditions and no process can serve the purpose under diverse conditions as each technology has its own limitations.*

I. INTRODUCTION

Arsenic (atomic number 33, atomic weight 74.9; specific gravity 5.73, melting point 817°C (at 28 atm), boiling point 613°C and vapor pressure 1mm Hg at 372°C.) is a silver-grey brittle crystalline solid. Arsenic exists in the -3, 0, +3 and +5 oxidation states [6,8]. Two forms are common in natural waters: arsenite (AsO_3^{3-}) and arsenate (AsO_4^{3-}), referred to as arsenic (III) and arsenic(V)[3,5,8]. Arsenic contaminants present in our drinking water supply may be from natural (geogenic) and/or anthropogenic sources. Naturally arsenic is present in the earth's crust as the 20th most abundant element, it is typically associated with igneous and sedimentary rocks in an inorganic form, such as arsenopyrite and Anthropogenic sources of arsenic include industrial processes (in particular, mining and smelting), ash residues from power plants, pesticide and fertilizer applications, wood preservatives, inorganic arsenical

pesticides and herbicides industrial and municipal waste, and sewage sludge[6]. However, the main cause of groundwater contamination is geogenic. The World Health Organization (WHO) had recommended a maximum contaminant level (MCL) of arsenic in drinking water of 10 ppb [3, 11,12]. The acute toxicity of arsenic at high concentrations has been known about for centuries. It was only relatively recently that a strong adverse effect on health was discovered to be associated with long-term exposure to even very low arsenic concentrations. Drinking water is now recognized as the major source of human intake of arsenic in its most toxic (inorganic) forms. The presence of arsenic, even at high concentrations, is not accompanied by any change in taste, odor or visible appearance of water. The presence of arsenic in drinking water is therefore difficult to detect without complex analytical techniques. The effects of arsenic are serious and ultimately life-threatening. Arsenic in drinking water is a global problem affecting countries on all five continents. The most serious damage to health has taken place in Bangladesh and West Bengal, India[12]. Several treatment technologies have been adopted to remove arsenic from drinking water under both laboratory and field conditions. Technologies should provide communities with a sustainable, continuous, affordable, safe water supply in all cases and also technologies should not have an undue adverse effect on the environment. Technologies meeting these technical criteria can be evaluated under several socioeconomic criteria. First, the systems must be economically feasible.

II. METHODS FOR ARSENIC REMOVAL

Most of arsenic present in the nature water is in inorganic forms. The most common valence states of arsenic, As(V) or arsenate is more prevalent in aerobic surface waters and As(III) or arsenite is more likely to occur in anaerobic ground waters. As(V) includes H_3AsO_4 , H_2AsO_4^- , HAsO_4^{2-} , AsO_4^{3-} in which the negatively charged arsenate accounts for more and As(III) includes H_3AsO_3 , H_2AsO_3^- , in which the uncharged H_3AsO_3 accounts for more [2]. Knowledge of the speciation of arsenic i.e. the repartition of the different species as a function of pH, is fundamental to understand the removal process. In the typical pH range of natural waters, arsenate ions are present as H_2AsO_4^- , HAsO_4^{2-} and AsO_4^{3-} and arsenite is found mostly as the uncharged species H_3AsO_3 , which is shown in the following figures.

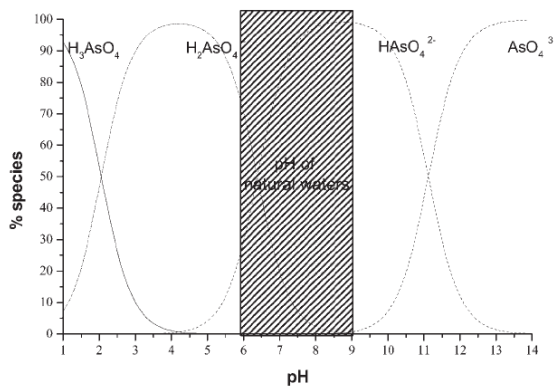


Figure 1: As(V) species repartition as function of pH [4].

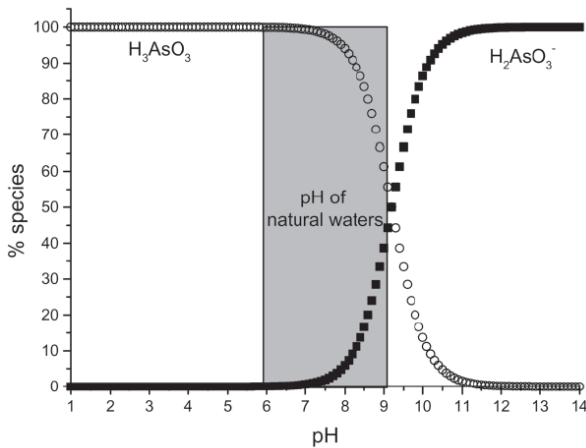


Figure 2: As(III) species repartition as function of pH [4].

Removal efficiencies for As(III) are poor compared to removal As(V) by any of the technologies evaluated due to the negative charge on As(V) and hence the technologies under review perform most effectively when treating arsenic in the form of As(V). If not so then As (III) may be converted through pre-oxidation to As(V). Data on oxidants indicate that chlorine, ferric chloride, potassium permanganate, ozone and hydrogen peroxide are effective in oxidizing As(III) to As(V). Pre-oxidation with chlorine may create undesirable concentrations of disinfection byproducts. Ozone and hydrogen peroxide should oxidize As(III) to As(V), but no data are available on performance [5].

Table 1: Showing performance and limitations of arsenic oxidants[13].

Performances and limitations of arsenic oxidants.

Oxidants	Performances and Limitations of Arsenic Oxidants
Ozone (O ₃)	Ozone may be the most satisfactory for pre-oxidation to convert As (III) to As(V) in water with the requirement to reduce disinfectant byproducts. Limitations are probably fewer on the use of ozone as a pre-oxidant for arsenic than when O ₃ is used after filtration as a primary disinfectant. Assimilable Organic Carbon (AOC) formation is ameliorated by coagulation/filtration treatment downstream, and oxidation of bromide, though still possible is much less likely during pre-oxidation because the development of a significant ozone residual is not necessarily required. Ozone pre-oxidation before nanofiltration could present problem if the AOC that is formed has a low molecular weight and passes through the membrane.
Hydrogen peroxide (H ₂ O ₂)	Hydrogen peroxide oxidation was effective but limited by reactions with calcium hydroxide. After oxidation, the resulting arsenate waste was effectively stabilized using ferric sulfate.
Chlorine (Cl)	Chlorine is a good oxidant for As(III), but application must come early in the treatment train when disinfectant byproduct precursor concentration is high and there is a danger of producing large concentrations of disinfectant byproducts.
Permanganate	Permanganate may work better than chlorine, however, no sufficient information on the permanganate demand for arsenic oxidation relative to the demand exerted by other substances.

All of the technologies for arsenic removal rely on a few

basic chemical processes, most common methods used for arsenic removal are elaborated here:

Precipitation processes: Precipitation processes involving coagulation/ filtration have been studied extensively for the removal of arsenic from water. Adsorption co-precipitation with hydrolyzing metals such as Al³⁺ and Fe³⁺ is the most commonly used treatment technique for removing arsenic from water. The precipitate formed after coagulation or in situ oxidation of iron and manganese present in water could be removed by sedimentation followed by rapid sand filtration or direct filtration or microfiltration. Coagulation with iron and aluminum salts and lime softening has been considered the most effective treatment process for removing arsenic from water to meet the interim primary drinking water regulations standard. Oxidation of As(III) to As(V) and removal using one of the processes described above has been recommended (USEPA 2000a & b). Atmospheric oxygen, hypochlorite and permanganate are commonly used for oxidation of As(III) to As(V). However, oxidation with air (atmospheric oxygen) is very slow. The effectiveness of this technology is less likely than other treatments to be reduced by characteristics and contaminants other than arsenic. It is also capable of treating water characteristics or contaminants other than arsenic, such as hardness or heavy metals. Systems using this technology generally require skilled operators, for this reason, precipitation/co-precipitation is more cost-effective at large scale where labour costs are spread over a larger quantity of treated water. The As is removed in the formation of the insoluble compounds Al(AsO₄) or Fe(AsO₄) [12].

Sorption Technology: Sorption is a common word used for both adsorption and absorption. Some materials with big specific surface area and high surface energy which have strong adsorption ability can separate and remove the contaminant to purify water in the process of adsorption. This adsorption action may be chemistry effect such as surface chemistry coordination or complex or physical effect such as static-electric attraction. Adsorption is one of the most effective methods to remove the arsenic in the water; the common adsorbents included activated alumina, activated carbon, function resin and metal oxide, etc. [2]. Adsorption involves the use of granular adsorptive media for the selective removal of arsenic from water with or without pH adjustment and with or without spent media regeneration. Several granular adsorptive filter media have shown high effectiveness in arsenic removal from water. These include activated alumina, activated carbon, iron oxide coated or based filter media including some commercial media like Aqua-Bind MP, ArsenX, Bayoxide E33 ferric oxide, Granular Ferrichydroxide (GFH), MEDIA G2, manganese greensand etc. These technologies are consistently capable of removing arsenic to below the required standard level (USEPA 2002). The effectiveness of adsorption for arsenic treatment is more likely than precipitation processes to be affected by characteristics and contaminants other than arsenic. Small capacity systems using these technologies tend to have lower operating and

maintenance costs and require less operator expertise. Adsorption and ion exchange therefore tend to be used more often when arsenic is the only contaminant to be treated, for relatively smaller systems, and as an auxiliary process for treating effluent from larger systems[12]. Several adsorptive media like activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, silicon oxide and many natural and synthetic media have been reported to remove arsenic from water. The efficiency of adsorptive media depends on the use of oxidizing agents as aids to provoke the adsorption of arsenic on the media[10].

Activated Alumina:

Activated alumina (Al_2O_3) has a good adsorptive surface, in the range of 200-300 m^2/g . The large surface area gives the material a very large area for adsorption of arsenic. When water passes through a packed column of activated alumina, the impurities including arsenic present in water are adsorbed on the surfaces of activated alumina grains. Eventually, the column becomes saturated, first at its upper zone and later downstream towards the bottom end, and finally the column gets totally saturated. Regeneration of saturated alumina is carried out by exposing the medium to 4% caustic soda (NaOH) either in batch or by flow through the column resulting in highly arsenic contaminated caustic wastewater. Arsenic removal by activated alumina is controlled by pH and the arsenic content of water. The efficiency drops as the point of zero charge is approached and at pH 8.2 where the surface is negatively charged, the removal capacities are only 2-5% of the capacity at optimal pH. Some examples of activated alumina based adsorptive media are: the "BUET Activated Alumina", the "Alcan Enhanced Activated Alumina" and the "Apyron Arsenic Treatment Unit"[10].

Metal (hydrogen) oxide:

Iron oxide with high surface energy and surface area has strong adsorption capability with respect to many inorganic ions and organic matters. Lots of literatures have reported that heavy metal ions and organic contaminants can be removed by iron (hydrogen) oxide. Several iron oxides remove arsenic effectively such as amorphous hydrous ferric oxide, crystalline hydrous ferric oxide (ferrihydrite), hematite, magnetite and goethite. The iron hydroxide and its polymer with high adsorption and fast kinetics which have the biggest capability of adsorption were the most effective. However, some shortcomings with iron hydroxide still exist, for example, some anions have an adverse influence on the arsenic removal such as SO_4^{2-} , Cl^- , F^- , PO_4^{3-} and SiO_3^{2-} . The latter two have relatively stronger impact than the former three. In addition, the arsenic removal was influenced by pH markedly. The removal efficiency decreased quickly as pH is over 8.5. Arsenate removal is much better than arsenite by iron hydroxide. Also iron hydroxide had poor adsorption to arsenite. Lakshminathiraj et al (2006) combined the advantages of Mn and Fe, synthesized a suitable adsorbent, Mn-substituted iron oxyhydroxide (MIOH), which could remove both arsenite and arsenate from aqueous solutions with considerable efficiency [8].

Activated Carbon:

Activated carbon (AC) has been extensively used for the removal of organic contaminants in water. Results regarding arsenic removal are quite controversial but most of them show that activated carbon can remove As(V) but not As(III). However, As(V) uptake capacities were low, reaching 20 mg/g on granular activated carbon. The performance of activated carbon depends on its chemical composition. It has been demonstrated that a fly ash content of activated carbon was a critical parameter in arsenate removal. In another study, As(V) sorption was correlated to Activated Carbon zeta potential values but fly ash content was not consistent with As(V) removal. As(III) was removed significantly only at high initial concentration (700 mg/L), which was explained by an oxidation from As(III) to As(V) by the oxygenated functional groups present at the surface of the sorbent. Furthermore, Jubinka and Rajakovic demonstrated that activated carbon did not remove As(III) in the pH range of 2-10[4]. Chemically treated activated carbon exhibits high adsorption capacity for arsenic. The factors (such as solution pH, carbon type and carbon pretreatment and elution of the arsenic from loaded carbon) that affect the mechanism of the adsorption of arsenic species on activated carbons. It is found that As(V) is more effectively removed from solution by using activated carbon with high ash content and pre-treatment of the carbon with Cu(II) solutions improves its arsenic removal capacity. In these studies, commercially available activated carbons were used. The use of commercial activated carbon is not suitable for developing countries because of its high cost [13].

Strong Base Anion (SBA) Exchange Resin:

Strong base anion (SBA) exchange resins have quaternary ammonium groups connected to the polymer matrix and differ by the nature of the group attached to the nitrogen. They can be classified in two classes: type I resins with three methyl groups connected to the nitrogen and type II with two methyl and one ethanolamine group. Anion exchange resins have more affinity for divalent anions than monovalent anions, therefore, $HAsO_4^{2-}$ will be preferentially adsorbed over $H_2AsO_4^-$. Thus, according to the speciation diagram reported in Fig.1, arsenate removal is expected to increase between pH 6 and 9. On the other hand, due to its weak dissociation constant, As(III) cannot be removed. A pre-oxidation step is necessary to treat an arsenite solution with ion exchange technology[4].

Metal-Loaded Polymers:

Metal-loaded polymers were described four decades ago by Helfferich to separate ligands of different coordination. These materials have been used only recently for the treatment of water contaminated with toxic anions like arsenic, selenite, or fluoride. Another domain of application is analytical chemistry, where these sorbents are used to pre-concentrate very dilute solutions of arsenic before analysis. One attractive feature of these polymers is that most of the time, they overcome interferences with chloride and sulfate ions generally observed with strong anion exchange resins. Due to the strong interaction between the metal bound onto the polymer and arsenic, uptake capacities can also be

increased. The most interesting property may be the possibility to remove both As(III) and As(V). Operating pH conditions can also be less restricted than with SBA because arsenic species do not have to be negatively charged to be removed. However, sorbent has to be carefully designed to avoid any release of the metal in solution and adversely affect the quality of water. Metal-loaded polymers are usually prepared by passing a metal ion solution at a given concentration and pH through a packed column of resins in a down flow or up flow mode. With this method, the operator has control of the pH and concentration of the feed solution. pH is one of the most important parameter to study because it affects both the nature of arsenic species in solution and the surface of the adsorbent. Whenever possible, buffers should be avoided as they can interfere with Sorption Technologies for Removal of Arsenic in Water. Some of metal loaded polymers are: Fe(III)-Resins, Cu(II)-Resins, Zr(IV)-Resins, La(III)-Resins, Ce(IV)-Resins etc. [4]. Most of the work on metal-loaded polymers has been done with Fe(III) but these sorbents have limitations for drinking water treatment due to their low operating pH for As(V) removal and a low affinity for As(III). Zr(IV)-loaded chelating resins are promising because they are selective and have a high affinity for arsenite ions at neutral pH [4].

Granular Ferric Hydroxide:

Granular ferric hydroxide is also used for the adsorptive removal of arsenate, arsenite and phosphate from water. Granular ferric hydroxide reactors are fixed bed absorbers operate like a conventional filter with a downward flow of water. The water containing high dissolved iron and suspended matters should be aerated and filtered through a gravel/sand bed as a pretreatment to avoid clogging of the adsorption bed [10].

Hydrous Cerium Oxide:

Hydrous cerium oxide is also a good adsorbent. Laboratory test and field testing of the materials at several sites showed that the adsorbent is highly efficient in removing arsenic from groundwater [10].

Iron Coated Sand and Brick Chips:

Iron coated sand and iron coated brick chips are effective in removing both As(III) and As(V). The "Shapla arsenic filter (Shapla arsenic filter has been developed and tested widely use in Bangladesh. This is flow through system in which arsenic contaminated water flows through a bucket containing active arsenic removal material prepared by a specialized chemical treatment of ordinary brick particles to incorporate activated iron oxide in the brick particles)" and "Surokka Arsenic Filter (The Surokka filter is a house hold arsenic filter made out of local components and materials. The filter operates on the properties of locally available iron containing yellow sands to absorb arsenic from ground water. The water flows through the filter at a predetermined rate so that almost 100% removal of As(III) and As (IV) is obtained. The operation of the filter is very simple, just pouring water to the container containing 20 kg active material and collecting water in a receiver)" are example of a household arsenic removal filter based on iron coated brick chips developed and promoted by the International Development Enterprises (IDE). The brick

chips are treated with ferrous sulphate solution for iron coating. The water collected from contaminated tube wells passes through the filter media placed in earthen container having a drainage system underneath. The Na₂CO₃-rich water may be used for leaching of arsenic from As loaded brick chips/sands.

Membrane filtration: Membrane processes can remove arsenic through filtration, electric repulsion, and adsorption of arsenic-bearing compounds. The effectiveness of microfiltration and ultrafiltration as a technique for arsenic removal is highly dependent on the size distribution of arsenic bearing particles in the source water. Nano-filtration membranes are capable of removing significant portions of the dissolved arsenic compounds in natural waters. Reverse Osmosis (RO) is a technology proven through several bench- and pilot-scale studies, and is very effective in removing dissolved constituents. Since arsenic in groundwater is typically 80- 90% dissolved, RO is a suitable technology for arsenic removal in groundwater. Membrane filtration is effective in removing both As(III) and As(V) species. However, efficiency in removing As(V) is higher than for As(III). The effectiveness of membrane filtration for arsenic removal is sensitive to a variety of untreated water contaminants and characteristics. It also produces a larger volume of residuals and tends to be more expensive than other arsenic treatment technologies. It is therefore used less frequently than precipitation/ co-precipitation, adsorption, and ion exchange (USEPA 2002).

Biological removal processes: In the present study, an alternative technology for the removal of both trivalent and pentavalent arsenic species was examined based on the established biological iron oxidation from groundwater. Iron oxidation can be catalyzed by several microorganisms, which are indigenous in most groundwater, such as *Gallionella ferruginea* and *Leptothrix ochracea*. Arsenic can be removed by direct adsorption or co-precipitation on the preformed biogenic iron oxides, whereas there was an indication of As(III) oxidation by iron oxidizing bacteria, leading to improved overall removal efficiency. The objective of the present research was to study the mechanism of As(III) removal during biological iron oxidation, as well as to establish the optimum conditions for efficient arsenic (III and V) removal, in order to meet the new standard of 10 mg/L. Furthermore, investigations using living, dead or resting cells have been performed, in order to obtain additional information regarding the role of bacteria and the mechanism of trivalent arsenic removal. In addition, the removal of pentavalent arsenic has been examined, in order to obtain an integrated view on the applicability of this technology in groundwater treatment, when both inorganic forms of arsenic are present. It is considered as an innovative treatment approach, which can be summarized under the term "biological adsorptive filtration". The removal of arsenic was examined simultaneously to biological iron oxidation. The treatment process was based on a fixed-bed up flow filtration unit. A schematic diagram of experimental set-up is shown in Fig. 3. The apparatus consisted of a (Plexiglas)

column, which was filled with appropriate filtration media (polystyrene beads). The indigenous microorganisms after 3 months of operation have been deposited and accumulated in the filtration column. The oxidation of iron resulted in the formation of a biofilm. In particular, *Gallionella ferruginea* forms stalks and *Leptothrix ochracea* sheaths, when present in an oxidizing environment rich in ferrous iron. It is proposed that the formation of stalks and sheaths may serve as a protective mechanism against the increasing reducing capacity of ferrous iron as it becomes unstable in an environment that becomes oxidized. By this way these bacteria accumulate in the filtration media and grow by obtaining their energy either by the oxidation of ferrous iron (*Gallionella*) or by consumption of organic matter (*Leptothrix*) [7].

Figure 3: Schematic representation of biological oxidation and filtration unit [7].

- (1) Continuous flow of contaminated groundwater,
- (2) arsenic stock solution,
- (3) peristaltic (feeding) pump,
- (4) influent sampling vessel,
- (5) air injection,
- (6) aeration column,
- (7) filtration column and
- (8) effluent.

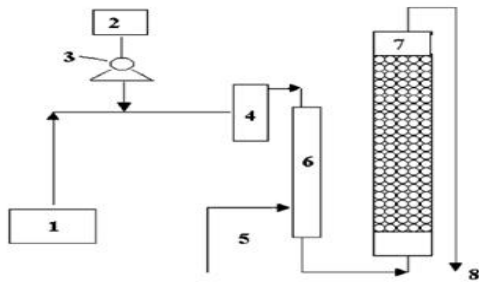


Fig. 1. Schematic representation of biological oxidation and filtration unit. (1) Continuous flow of contaminated groundwater, (2) arsenic stock solution, (3) peristaltic (feeding) pump, (4) influent sampling vessel, (5) air injection, (6) aeration column, (7) filtration column and (8) effluent. *Column characteristics:* active height: 1m, inner diameter: 68 mm, surface area: 0.0036 m², bed volume: 3.6 L, total bed porosity: 0.37, bead diameter 3–4mm.

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Table 2: Efficiency of conventional arsenic removal techniques[11].

Technology	Chemical reagent	Efficiency (%)	Efficiency (%)	Initial conditions
Adsorption	Activated carbon	80-90	>90	pH 6-8
		30-40	>90	pH 2-4
Oxidation	Potassium dichromate	<30	80-90	pH 6-8
		<30	80-90	pH 6-8
Filtration	Polystyrene beads	<30	80-90	pH 6-8
		<30	80-90	pH 6-8

Emerging Physico-Chemical Technologies:

The conventional technologies for arsenic removal referred above are fairly well documented, although some of the systems have only come into prominence in recent decades. Nowadays, extensive research has been conducted towards identifying new technologies for arsenic removal. These focus particularly on low-cost systems that can be applied to small water

supply systems, in order to increase efficiency and improve the cost-benefit balance of arsenic removal. Technology research has also focused on the improvement of existing conventional technologies such as adsorption, by modifying or using novel adsorbent materials, or by introducing new chemical oxidation processes. Most of these technologies rely on the oxidation of arsenite followed by filtration through a porous material, where arsenic is removed through adsorption and co-precipitation. TiO₂ immobilization, on a PET (poly ethylene terephthalate) surface, combined with co-precipitation of arsenic on iron (III) hydroxides (oxides), could be an efficient way for total inorganic arsenic removal from waters. Because of their very strong affinity for arsenic, iron compounds are used by many removal systems. This is also the case for the application implemented and described in the case study presented below. Recent research work was developed to find a suitable iron (II) to arsenic ratio in water to reduce arsenic to 5 ppb (or lower) through slow sand filtration. It was found that a ratio of 40:1 was necessary to ensure the desired arsenic concentration in the treated effluent [11].

Alternative Technologies: Some alternative safe water options applied in West Bengal and Bangladesh include clay filters, deep tube wells, dug wells, surface and rainwater harvesting and solar distillation. Solar distillation techniques use the sun's energy to evaporate water, which is then re-condensed. This process of evaporation and re-condensation separates all chemicals, including arsenic, from the water. The SORAS (Solar Oxidation and Removal of Arsenic) process has been used in the rural Andes regions in Latin America. It is based on the adsorption of As(V) onto iron oxides and hydroxides using UV radiation and the addition of citrate as a catalyst for the formation of oxidizing radicals that allow the conversion of arsenite to arsenate. In this context, the combination of solar oxidation with one of the conventional adsorption processes might be a pertinent development towards yet another promissory alternative to arsenic removal. The goal would be to optimize the SORAS process by incorporating complementary conventional techniques, thereby increasing its reliability. To that effect, it was proposed that a UV radiation measurement cell be programmed so that the water to treat is automatically re-routed to a chemical oxidation process, whenever the available UV radiation is less than that required for arsenite oxidation. This alternative technology appears as particularly suitable for small and medium-size water supply systems. By integrating a solar radiation (renewable energy source) oxidation technology with conventional reactive filtration or adsorption processes, it is also aiming for the reduction of arsenic removal costs[11].

III. SLUDGE DISPOSAL

All the arsenic treatment technologies ultimately concentrate arsenic in sorption media, sludge or liquid media and indiscriminate disposal of these may lead to environmental pollution. Hence, environmentally safe disposal of sludge, saturated media and liquid wastes rich in arsenic is of high concern. Experiments were conducted to assess transformation of arsenic from aqueous solutions in the presence of cow dung. Some studies suggested that bio-chemical (e.g., bio-methylation) process in the presence of fresh cow-dung may lead to significant reduction of arsenic from arsenic rich treatment wastes. Another option would be to blend the arsenic contaminated material into stable waste or engineering materials such as glass, bricks, concrete or cement blocks. However, there is also possibility of air pollution or water pollution downstream of kilns burning bricks containing arsenic contaminated sludge due to volatilization of arsenic during burning at high temperature [10].

IV. CONCLUSION

To remove arsenic from wastewaters, the most commonly used technologies are adsorption onto activated alumina, and precipitation or adsorption by metal oxides, predominantly Fe(III) and membranes. These technologies for removal of arsenic from wastewaters are most suited to dealing with relatively low concentrations of arsenic, i.e. the low $\mu\text{g/l}$ level. However, the technique of precipitation, generally using Fe (III) or lime softening is suited to higher concentrations, normally at the low mg/l levels. Adsorption is a method that has been an important method used in arsenic removal. Most studies are focused on the type of adsorbent medium and the economics of their regeneration. Membrane technology, especially Nano filtration, becomes a promising method in arsenic removal and is also widely considered as the methods that can be used to meet regulations for lowered arsenic concentrations in drinking water. Also the biotic oxidation of iron by the microorganisms is found to be a promising technology for effective removal of arsenic from groundwater. During this process, iron oxides were deposited in the filter medium, along with the microorganisms, which offer a favorable environment for arsenic to be adsorbed and removed from the aqueous streams. This technology offers several advantages towards the conventional physicochemical treatment processes, applied in the removal of arsenic. It avoids the use of chemical reagents for the oxidation of trivalent arsenic; therefore, it is more economical and environment friendly. Other alternative methods also studied for their feasibility in replacing the current available methods. Future needs on arsenic removal technology should take into consideration of reducing the treatment cost, simplifying the operational complexity of the technology and disposal of arsenic bearing treatment residual.

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