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Latest Technologies for Arsenic Removal in Drinking Water

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Abstract Arsenic contamination in drinking water is an issue worldwide, which have caused massive impacts on human health. Various countries have reported to have high amount of arsenic in their drinking water i.e. Canada, United States, Chile, Bolivia, El Salvador, Nicaragua, Slovenia, Mexico, Bangladesh, India and others. People in rural areas rely on ground water for drinking purposes so removing arsenic from ground water is a significant challenge. In case of drinking water treatment where the requirement is to reduce few parts per billion the technologies have various limitation and prospects. This paper reviews latest technologies of arsenic treatment (coagulation, sorptive process, adsorption, oxidation, membrane process, biological process, emerging techniques). The technologies should meet basic technical criteria for its implication, the biggest challenge is to apply these technologies in setting where arsenic is high in amount and saving the community by promoting safe drinking water.

Keywords arsenic, removal technologies, emerging techniques, safe drinking water

1. Introduction

Arsenic contamination is a worldwide problem, its toxicity has no effective medicine or treatment but by drinking arsenic free water the symptoms could be much less or removed totally [1]. Various countries have reported to have high amount of arsenic in their drinking water *i.e.* Canada, United States, Chile, Bolivia, El Salvador, Nicaragua [2], Slovenia [3], Mexico [2,6], Bangladesh and India [4-5,7]. The groundwater contamination of arsenic occurs by natural processes such as human activities and weathering of minerals which contains arsenic [8,11]. Inorganic arsenic is usually present in natural water. There are two primary forms of arsenic *i.e.* Arsenate [As (V)] and Arsenite [As (III)], found in soil and natural water [8, 14, 17]. Arsenite is the most abundant form and can make up 90% of total arsenic content in groundwater [9]. In 21st century science have developed so far, so does the technologies there are some latest techniques for arsenic treatment; sorption process, adsorption, coagulation, oxidation, precipitation, cementation, ion exchange, membrane process, biological process and emerging technologies [1-25]. There are almost 14 technologies worldwide for the removal of arsenic with efficiency varying from 70 % to 99% [2]. Drinking arsenic enriched for a long period of time usually results in adverse and severe health impacts such as dermal problems, skin cancer, bladder cancer, kidneys and lungs damage, and blood vessels of legs and feet, diabetes, high blood pressure and reproductive disorders [15]. The World Health Organization (WHO) in 1993 established a standard value 10 µg/l for arsenic in water [5, 12, 17-18]. In under developed countries the source of water in rural areas are ponds ,tube wells, rain water, deeps wells, these sources are associated with various health effects [19, 21]. Human exposure to arsenic can take place through three phenomena inhalation ingestion and dermal adsorption. However ingestion is most seen phenomena in terms of exposure [20]. This paper is a short review of technologies that are attended to update the development among the removal of arsenic in drinking water, limitation, prospects and understanding of these technologies.

2. Coagulation

For removal of arsenic from drinking water coagulation technology is effective and it is used from 1970 [1-2, 4].

2.1. Electrocoagulation

Electrocoagulation is latest technology used for the removal of arsenate and arsenite from the drinking water. The experiments were done in laboratory to evaluate the efficiency of three different electrodes such as iron, titanium and aluminum. Electrocoagulation can remove the As(III) easily from the sample. During electrocoagulation As(III) oxidized to As(V) and metal hydroxides which generated might use for adsorption of arsenic[8-10]. Electrocoagulation is effective technology when it uses the iron electrodes because it has more capacity to remove the arsenic. By different parameters the ECFe efficiency for removal of arsenic can be influenced and these parameters such as intensity, pH, amount of arsenic and other ions like bicarbonate, silicate, phosphate, sulphate, chloride, organic matter and nitrate. It was found that if pH7 and intensities low then removal of arsenic from drinking water was found better [9-10].

3. Sorptive Techniques

There are several sorption techniques which help to remove arsenic from water. Some of these are activated alumina, activated carbon, ion exchange, iron and manganese coated sand, activated bauxite, titanium oxide and many natural and synthetic media [1]. The efficiency of all of the sorptive media depends on use of oxidizing agent [4]. Media saturation takes place on different time because of different contaminants and components. Saturation means the efficiency of removal of impurities [1].

3.1. Activated Alumina

It is effective medium for arsenic removal. This technique is effective for treating water with high dissolved solid content [14]. Its efficiency is greater than 95% and it is mostly occurs under acidic conditions. Alumina surface is protonated [9]. When water passes through alumina surface the impurities like arsenic adsorbed on the surface. After that column becomes saturated first at upstream zone later at downstream zone and finally it is completely saturated [1].

3.2. Iron coated sand

This method was tested on a small scale unit for the removal of arsenic from drinking water. It depends upon how much contaminant water has according to which media amount used. Such as 25 mg/g of iron content of iron coated sand and 300 mg/L of arsenic in raw water was filtered through iron coated sand becomes essentially arsenic free [1].

4. Adsorption

Solutes are separated from solvent in adsorption method. Solutes adsorb on the surface of the adsorbent and its concentration become reduces in the solvent [2, 6, 7, 12, 13, 15] .Absorbents or sorptive media such as activated alumina and carbon is well established for the treatment of drinking water [7,12, 22].

4.1. Coagulation Adsorption

In coagulation adsorption, coagulants are added then aggregation of those solid particles which present in the water that consist of arsenic occur because the ions show in hydrolyzed species form in colloidal particles hard layers. With hydrolyzed species that appear in stern layers, water arsenate ions form aluminum arsenate or ferric arsenate and then on coagulates they adsorb [2, 6, 20, 24].

4.2. Ion Exchange Adsorption

Different solid materials have strong attraction for dissolved arsenic and these materials such as aluminum hydroxide and iron. From drinking water arsenic can easily remove by the adsorption of arsenic on the surface of the solid materials. In ion exchange, through dissolved ion the reversible displacement occurs of an ion that will adsorb on the surface of the solid materials. The process of adsorption usually based on the adsorbent [6, 16]. Those adsorbents which have such structure that has pores then it will be more effective because the ratio of surface area-to-volume is big. For arsenic removal from water different natural and artificial adsorbents are used such as activated carbon, activated alumina, resins of polymer, sandy soils, ferric hydroxides, hematite, silica gel loaded with lanthanum and coral limestone loaded with metal etc. In adsorption process, oxides of iron have more affinity for arsenic adsorption from drinking water. pH parameter, occurrence of other ions like chloride and pretreatment process of adsorbent may affect the adsorption process. In drinking water the adsorbents which are used for arsenic are also minerals of iron oxide such as magnate, siderite limonite, goethite, ferrihydrite and hematite [6, 23].

5. Oxidation

Oxidation process is also used for arsenic removal from drinking water to make its removal easy the arsenite is oxidized to arsenate. Ozone, chlorine and potassium permanganate may be utilized. Copper oxide, ultraviolet radiation and copper oxide make possible the As^{+3} oxidation such as catalytic oxidation. Reaction time is the main issue in this process. The oxidation of arsenic through atmospheric oxygen is usually slow and for the completion of arsenic it can require weeks. But the oxidation with the help of chemicals can be less time taking [1-2, 4, 20, 22, 24-25].

5.1. Passive Sedimentation

Water is stored for long time in passive sedimentation so that oxygen of water can be exchange from the atmospheric air. By plain sedimentation the reduction of arsenic usually based on the precipitating iron that is present in the water and the quality of water. The removal of arsenic can be increase in the tube wells water by the occurrence of iron and high alkalinity in it [1].

5.2. *In-situ* oxidation

In situ oxidation process, the water is taken out from a tube well and allowing it to oxygenate by the oxygen that is present in the air. The water which has oxygenated is flow back into the same tube well which consists of arsenic and the iron also. Then iron hydroxide covering take place on particles of sand around the tube well sieve. When water is extracted again from the well then the concentration of arsenic as well as iron will be low it is more suitable in places where the source of water is tube well or deep wells and others [1, 4, 20].

5.3. Solar Oxidation

The solar oxidation common method is SORAS, the process includes arsenic oxidation in transparent bottles. In the existence of other oxidants such as O2, oxidation process of arsenite can be catalyzed with the help of UV radiation [1].

6. Membrane Techniques

Membrane techniques are applicable for all types of heavy metals in water especially arsenic treatment. Membrane techniques include reverse osmosis, nano-filtration and electro-dialysis. In these processes water is allowed to pass through special filter media that retain the impurities present in water physically. Water treated by this method removes free suspended solids and arsenic in pentavalent form [1]. In recent years nanofiltration technique is so developed that now they are less expensive and operate at low pressures but capable of efficient rejection of both arsenate and arsenite. [4]. Removing arsenic from groundwater areas where no manufacturing infrastructure and no electricity supply available remains significant challenge. For arsenic mediation magnetite nanocrystals have been proven useful. It can be synthesized by thermal decomposition method [19].

6.1. Nano-filtration and Reverse Osmosis

Applied reverse osmosis and nano-filtration process for arsenic removal from water is done by applying low pressure by bicycle pump. Under conditions of low recovery and low pressure range, nano-filtration membrane process coupled with bicycle pump [1]. Water containing higher arsenite requires ore oxidation for reduction [17]. Reverse osmosis coupled with bicycle pump for operating and removal of arsenic from drinking water because of its arsenite rejection [1]. Arsenic removal is indepent of solutes and pH. The use of this membrane when water contains excessive quantity of organic material. Nanofiltration have efficiency of 90% while by reverse osmosis it can be 91% - 98% of penta arsenic [As(∨)] in high pressure reactor and 77% - 87% in low reactors. Removal of As (III) gives efficiency of 63% - 70% in high pressure system and 12% -35% in low pressure systems [2]. Advantages of these membranes are low water recovery rate of about 10% - 20% so they need to operate at high pressure and high operating cost [3].

7. Precipitation

The phenomenon of precipitation and co-precipitation are responsible for the transfer of arsenic from dissolved phase to its solid phase. Arsenic in dissolved form is transformed into a solid having low solubility and thus removed by the process of filtration and sedimentation [2, 20]. For example the dissolved arsenic forms a solid mineral of low-solubility *i.e.* calcium arsenate. This solid then can be removed with the help of processes like sedimentation or filtration. When coagulants are get mixed form flocs while other dissolved compounds like arsenic can remain insoluble and ultimately form solids, this phenomenon is called co precipitation [24, 20]. These solids may become suspended and require proper removal by suitable processes such as solid/liquid separation processes that are usually coagulation and filtration [4].

7.1. Lime Precipitation

It is basically used to decrease the concentrations of arsenic from a higher level *i.e.* hundreds of mg/L to a moderate level (*e.g.*, 1 to 5 mg/L). After precipitation solids are removed by clarification and filtration. Though, a further process is mandatory to maintain the arsenic concentrations less than drinking water standards [22].

8. Cementation

Cementation is the best recommended and proper method used for arsenic removal from drinking water. In the process of cementation, reaction temperature is very important because it has a great effect on the efficiency of cementation. Temperature also influences the rate controlling mechanisms of this process. Surface reactions of cementation are controlled by low temperature which ranges from 30-45 °C while higher temperatures control ranges from 45-50 °C control the diffusion of this process. Ammonium citrate also affects the efficiency of cementation [23].

9. Biological Processes

In some other processes of arsenic removal, bacterial activity acts as catalyst to remove the arsenic from water [2]. Biological process involves two mechanisms in which arsenate are reduced into arsenite. In the first mechanism, cells are detoxified. In the second mechanism, bacterial cell breathe arsenic which is also known as respiratory arsenate reductase for obtaining metabolic energy. In this process As(V) act as an electron acceptor [12]. Phytoremediation is like chemical arsenic removal in which biomass of fungal and plants are utilized as adsorbent. This biomass is more efficient adsorbent as compared to activated carbon and others resins used in the treatment of water. So phytoremediation has greater efficiency of arsenic removal from water [24]. Biofiltration is also very beneficial process for the removal of pollutants from water. This process removes the pollutants like arsenic, iron and manganese through microorganisms. The efficiency of biofilter for arsenic removal is 98.2%. Bacteria e.g. Pseudomonas or Alcaligenes are utilized in biofilter as arsenic oxidizing bacteria. In Phytofiltration, arsenic is accumulated in aquatic plants and eliminated from water. For example greater amount of asenic is found in *Azolla caroliniana*, *Ranunculus trichophyllus*, *Callitriche stagnalis* etc. plant species [12].

10. Emerging Technologies

In last few years, removal of arsenic technologies have been developing and improving. Different application emerged in 21^{st} century that works on same or combined techniques.

10.1. Hydrotalcite

The use hydrotalcite made from clay material is used for the removal of Arsenite and Arsenate from drinking water.Three different solution are formed NO_3-HT (slurry), CO_3-HT (slurry) and Cl-HT (solid). Adsorption of As (III) takes place by these three solutions. At the end the samples prepared is passed through membrane filter [18].

10.2. Nano-Materials

Nano-materials are playing essential roles in the development of novel arsenic treatment process. Magnetite nanocrystals have proven to be useful in arsenic remediation and could be synthesized by thermal decomposition method [19].

10.3. Point-of Use (POU) treatment systems

Household level arsenic removal systems are a new level arsenic removal at small scale which works are based upon adsorptive filtration (which uses an Alcan enhanced activated alumina, Aypron Arsenic Treatment Unit, BUET activated alumina filter, Read-F Arsenic Removal Unit and many other) or coagulation (Garnet Filter and etc.), ion exchange treatment or combination of coagulation and adsorption. Some also includes oxidation step for efficient removal of As(III). READ-F, Alcan, Sidko (a granular hydroxide filter system) and Sono are the approved and reliable technologies [1, 20, 25].

10.4. Hydrometallurgical Arsenic Removal Processes

These processes are used to remove some of the insoluble inorganic arsenic and insoluble product that is obtained is basically a disposal material. precipitation in the form of arsenic (III) sulfide, ferric arsenate or calcium arsenate are the common methods, but all these insoluble products are usually unstable in certain conditions; that is why it is not suitable to dispose them off directly as it may produce leachate having considerable amounts of arsenic. There are certain forms of calcium arsenates that are capable of being precipitated from the solutions of arsenic (V) by the addition of lime to higher pH. Some of the complex compounds like the apatite structured calcium phosphate-arsenate has lower solubility and is more stable after its disposal. Lead (II) chloro-arsenate is one of the best insoluble compounds that is known at present [23].

10.5. Arsenic Filter

Adsorption technique is used in arsenic filter, a bed of ferric hydroxide is formed in which arsenic is adsorbed, rapidly. Exfoliation takes place of particles of arsenic ferric hydroxide from the iron nails, as for new surfaces are created providing new surfaces; additional arsenic adsorption capacity. Kanchan Arsenic Filter (KAF) works under the principle of two proven water treatment techniques i.e. adsorption one ferric hydroxide andslow sand filtration for microbial removal [21]. There are other arsenic filters present as well worldwide. Indigenious Filter that use indigenous materials as absorbent, the application of this includes Sono 3-Kolshi Filter, Garnet Home-made Filter, Char Filter, Shafi Filter, Adarsha Filter and etc. Cartridge filters contains sportive media or ion-exchange resins e.g. Chiyoda Arsenic Removal Unit in Japan, Coolmart Water Purifier in Korea [1].

11. Conclusion

Arsenic removal from the drinking water have become a need to improve the current conditions of polluted drinking water which is causing havoc in the world. A reliable and comparative analytical capability must be developed in order to obtain reliable results in the studies of arsenic removal in drinking water. These technologies found effective and safe for arsenic removal from drinking water, wider implementation of these technologies to avoid arsenic problem should be addressed so that ingestion of polluted water could be avoided.

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