

Analytical study on the removal of arsenic species and its compound by applying magnetic field

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Abstract- Arsenic (As), one of most toxic contaminants found in water, is well known to have adverse effects, such as skin cancer, on human health. The consumption of arsenic contaminated water has led to human health crises in many countries such as Bangladesh, China, and even the western United States. The new Environmental Protection Agency(EPA) standard for arsenic in drinking water is 10 [µg/L], and many smaller drinking water treatment plants are in need of additional treatment to achieve this standard. Recently, many researchers have been trying to find cost-effective filtration for the many small-scale water systems or individual ground wells that are used in most arsenic endemic areas. The present analytical study discloses a very efficient, low-cost approach for the removal of arsenic species and compounds [III {Na₂AsO₃} and V {Na₃AsO₄}] from drinking water. The Innovation consists of a Sequence of separation chambers which houses multiple conical structures in succession such that outer surface of each conical magnetic field structure has got permanent NdFeB magnets are used as the Conical Shapes in a special pattern (to enhance the magnetic field & ensure the separation of arsenic and deposition in a string structure(specialized) . When Arsenic contaminated drinking water is passed through the sequence of separation through the magnetic chamber the Arsenic particles get repelled and adhere to the surface of the space between conical structures and surrounding area. The concentration of Arsenic decreases by about 98-99% after water is passed through the device. The devices offers the advantage of being online separation device, thus enabling Arsenic removal during water flow through pipeline, without need for holding tank. No electricity is needed for its operation. In addition, there is zero wastage of water and no consumables are needed

INTRODUCTION

1. Arsenic is a natural component of the earth's crust and is widely distributed throughout the environment in the air, water and land. It is highly toxic in its inorganic form. Arsenic element exists as oxides in the soil, sediments and water in many parts of the world and originates from both natural and anthropogenic activities. There are four chemical oxidation states for Arsenic (-3, +3, 0, and +5) in Nature.¹The most common Arsenic compounds that naturally occur are arsenite (H₃AsO₃ – As(III)) and arsenate (HAsO₄²⁻ – As(V)). As(V) is the predominant species present under oxidizing conditions and exists as oxyanions of Arsenic acid (H₃AsO₄, H₂AsO₄⁻, HAsO₄²⁻ and AsO₄³⁻), while As(III) exists as arsenious acid (H₃AsO₃, H₂AsO₃⁻, HAsO₃²⁻) under mildly reducing conditions. Arsenic compounds have been recognized as group 1 carcinogens by the International Agency for Research on Cancer (IARC). Arsenic can release into the aquatic environments by natural processes such as dissolution of minerals by weathering, microbial activity, and complexation with natural organic materials.—On the other hand, anthropogenic activities, including industrial mining and metallurgical industries, combustion of fossil fuels, use of

Arsenic pesticides, herbicides, and crop desiccants, can result in Arsenic contamination in soils and surface water

• The geochemical cycles of Arsenic in Nature

Arsenic enters into groundwater in the form of As (III) and As(V) through many ways such as industrial activities, weathering of rocks, volcanic emissions, biological activities and geochemical reactions. Arsenic exists in the natural pH range of groundwater primarily as an oxyanion of H₃AsO₃ that is neutral in charge. Owing to the deficiency of potable water sources, the Arsenic contaminated groundwater (including geothermal water) was used for developing or underdeveloped world without treatment, which led to many adverse health conditions in the local population.

Harmful effects of Arsenic on Human Health - Inorganic

Arsenic is a confirmed carcinogen and is the most significant chemical contaminant in drinking water globally. Arsenic can also occur in an organic form. Inorganic Arsenic compounds (such as those found in water) are highly toxic while organic Arsenic compounds (such as those found in seafood) are less harmful to health.

Acute effects- The immediate symptoms of acute Arsenic poisoning include vomiting, abdominal pain and diarrhoea. These are followed by numbness and tingling of the extremities, muscle cramping and death, in extreme cases.

Long-term effects- The first symptoms of long-term exposure to high levels of inorganic Arsenic (for example, through drinking-water and food) are usually observed in the skin, and include pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (**hyperkeratosis**). These occur after a minimum exposure of approximately five years and may be a precursor to skin cancer. In addition to skin cancer, **long-term exposure to Arsenic may also cause cancers of the bladder and lungs**. The International Agency for Research on Cancer (IARC) has classified Arsenic and Arsenic compounds as carcinogenic to humans, and has stated that Arsenic in drinking water is carcinogenic to humans. Other adverse health effects that may be associated with long-term ingestion of inorganic Arsenic **include developmental effects, diabetes, pulmonary disease, and cardiovascular disease**. Arsenic-induced myocardial infarction, in particular, can be a significant cause of excess mortality. In China (Province of Taiwan), Arsenic exposure has been linked to **“Blackfoot disease”, which is a severe disease of blood vessels leading to gangrene**. This disease has not been observed in other parts of the world however, and it is possible that malnutrition contributes to its development. Arsenic is also associated with **adverse pregnancy outcomes and infant mortality**, with impacts on child health, and exposure in utero and in early childhood has been linked to increases in mortality in young adults due to multiple cancers, lung disease, heart attacks, and kidney failure. Numerous studies have demonstrated negative impacts of Arsenic exposure on cognitive development, intelligence, and memory.

Safe Levels of Arsenic in groundwater as per WHO - Arsenic contamination of groundwater is widespread and there are a number of regions where Arsenic contamination of drinking water is significant. It is now recognized that at least 140 million people in 50 countries have been drinking water containing Arsenic at levels above the **WHO provisional guideline value of 10 µg/L**. Arsenic in Bangladesh has attracted much attention since recognition in the 1990s of its wide occurrence in well water in that country. Since this time, significant progress has since been made and the number of people exposed to Arsenic exceeding the Bangladesh drinking-water quality standard has decreased by approximately 40%. Despite these efforts, it was estimated that **in 2012 about 19 million and 39 million people in Bangladesh were still exposed to Arsenic concentrations above the national standard of 50 µg/L and the WHO**

provisional guideline value of 10 µg/L respectively. In a highly affected area of Bangladesh, 21.4% of all deaths in the area were attributed to Arsenic levels above 10 µg/L in drinking water. A similar dose-response function has been found in other parts of Bangladesh, and these results have been combined with national survey data to estimate an annual death toll of nearly 43,000. The US National Research Council has noted that as many as 1 in 100 additional cancer deaths could be expected from a lifetime exposure to drinking water containing 50 µg/L. The symptoms and signs caused by long-term elevated exposure to inorganic Arsenic differ between individuals, population groups and geographical areas. Thus, there is no universal definition of the disease caused by Arsenic. This complicates the assessment of the burden on health of Arsenic. Similarly, there is no method to distinguish cases of cancer caused by Arsenic from cancers induced by other factors. As a result, there is no reliable estimate of the magnitude of the problem worldwide. In 2010, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) re-evaluated the effects of Arsenic on human health, considering new data. JECFA concluded that regions of the world **where concentrations of inorganic Arsenic in drinking water exceed 50–100 µg/L, there is some evidence of adverse effects**. In other areas, where Arsenic concentrations in water are elevated (10–50 µg/L), JECFA concluded that while there is a possibility of adverse effects, these would be at a low incidence that would be difficult to detect in epidemiological studies.

• **Magnetic properties formation of arsenic species and its compounds**

Arsenic – Arsenic is a Chemical element with the symbol (As) and atomic number 33. Arsenic occurs in many minerals, usually in combination with sulfur and metal, but also as pure elemental crystal. Arsenic is a metalloid it has various allotropes, only the grey form that has a metallic appearance.

“Z”	33
Group	15 (pnictogens)
Period	IV
Block	P
Element category	Metalloid
Electronic configuration	[Ar] 3d10 4s2 4p3
E- per shell	2,8,18,15
Electronegativity	2.18
Atomic radius	119 PM
Ionization energy	1-947.0Kj/Mol

Table: A :1 Atomic Properties of Arsenic [As]

In addition, Arsenic element occurs in oxidized form in the soil, sediments and water in and originates from both

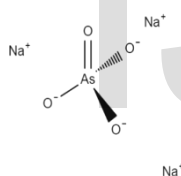
natural and anthropogenic activities. There are four chemical oxidation states for arsenic (-3, +3, 0, and +5) in Nature. The most common arsenic compounds that

Name	Oxidation State	Formula	pKa1	pKa2	pKa3
Arsenite	As(III)	H ₃ AsO ₃	9.1	12.1	13.4
Arsenate	As(V)	H ₃ AsO ₄	2.19	6.7	11.2

naturally occurs are Arsenite (H₃AsO₃ – As(III)) and Arsenate (HAsO₄²⁻ – As(V)). As(V) is the predominant species present under oxidizing conditions and exists as oxyanions of Arsenic acid (H₃AsO₄, H₂AsO₄⁻, HAsO₄²⁻ and AsO₄³⁻).

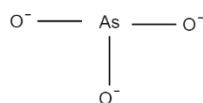
Sodium Arsenate Formation – {Na₃AsO₄}

Atomic number of Sodium atoms have 11e⁻ to attain inert gas electronic configuration [1s² 2s² 2p⁶] [Na] loose {e⁺¹} electron. Therefore, Sodium Has +1 charge {Na⁺¹}, Arsenate Have -3 Anion (AsO₄⁻³) When [Na⁺¹] cations combined with Arsenate {-3} Ions through the ionic Bond, the compound Sodium Arsenate Formed [Na₃AsO₄].



The compound obtained by neutralizing Arsenic Acid [H₃AsO₄]. [H₃AsO₄ + 3NaOH → Na₃AsO₄ + 3H₂O], The salt (as its dodecahydrate) is isomorphous with disodium phosphate. While, As (III) exists as arsenious acid (H₃AsO₃, H₂AsO₃⁻, HAsO₃²⁻) under mildly reducing conditions.

Sodium Arsenite Formation: [Na₂AsO₃] - Similarly, Atomic number of Sodium atoms have 11 e⁻ to attain inert gas electronic configuration [1s² 2s² 2p⁶] Sodium loose {e⁺¹} electron. Therefore, Sodium Has +1 charge {Na⁺¹}, Arsenite Have -2 Anion (AsO₃⁻²). Na⁺¹ cations combined with Arsenite -2 Ions through the Ionic Bond the compound Sodium Arsenite formed [Na₂AsO₃].



Arsenic species are always pH dependent. Arsenite can be oxidized to arsenate at high pH, and arsenate can be reduced to Arsenite at low pH. Generally, groundwater contains

Arsenite under anaerobic condition (Feenstra & Erkel, 2007). The form of the arsenic present influences removal efficiency. When present in water, As (III) and As(V) are in ionized or neutral forms, depending on the water pH. The pKa values of Arsenite and arsenate are listed in Table 3.1. As(III) is about 60 times more toxic than As(V), and the mobility of Arsenic (III) is more than that of Arsenic (V) because the probability of adsorption of neutral Arsenic (III) to a mineral surface is less than Arsenic (V).

Table 3.1: Dissociation constants (pKa) of arsenite and arsenate acids (Mohan & Pittman, 2007). Based on these values, in the natural water pH range from 5.5 to 8.5, the dominant form of arsenite is the protonated neutral molecule (H₃AsO₃), while the dominant form of arsenate is the dissociated ionic form (H₂AsO₄⁻). Figures 3.1 and 3.2 show arsenite and arsenate dissociation as a function of pH.

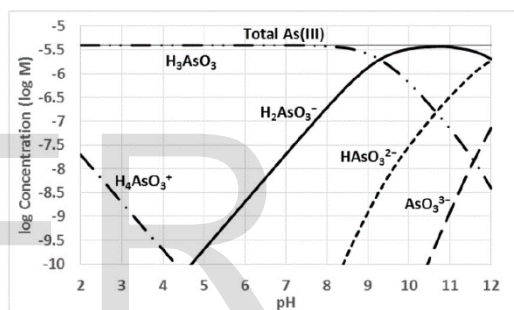


Figure 3.1: Soluble species of arsenic (III) with change in pH. The arsenic concentration was 4x10⁻⁶ M. The figure was reproduced with the author’s approval: (Heffron, 2015).

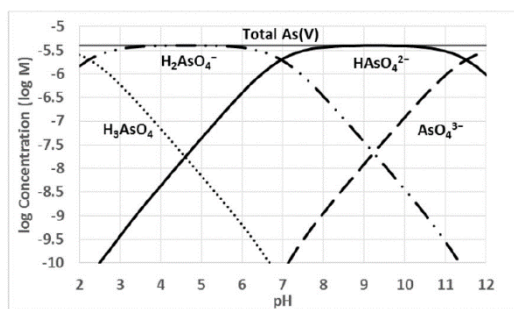


Figure 3.2: Soluble species of arsenic (V) with change in pH. The arsenic concentration was 4x10⁻⁶ M. The figure was reproduced with the author’s approval: (Heffron, 2015).

The dissociated arsenate species present in the range of common groundwater pH values can be removed by applying strong Magnetic Field [Repulsion effect]. Removal of Arsenic compounds (III & V) by the magnet field detailed below here.

• Magnetic Behavior of Arsenic Compounds] Sodium Arsenate & Arsenite[

Element	Electron	Proton
Na	11	11
As	33	33
O	8	8

Table: Number of Sub Atomic Particle {Involved in Sodium Arsenate and Arsenite Compound.

Chemical Analogy.

The magnetic property of a substance can be determined by examining its electron sum

2. If the 'e – sum = Even, [The magnetic Property of a Compound /Element Diamagnetic].
 3. If the 'e – sum = Odd, [The magnetic property of a Compound/ Element Paramagnetic].
1. Calculating Electron sum of [Na₃AsO₄ & Na₂AsO₃] Compounds , There for the Compound Sodium Arsenate contain (Na₃AsO₄)

That for The compound consist three element Sodium Arsenic Oxygen, In the Compound the Sodium, loose [1 e⁻] & Arsenic Atom gain [1e⁻] electrons of Sodium atom are transferred permanently to Arsenic atom, from the electrostatic attraction between oppositely charged **ions** in a [Na₃AsO₄] compound. **Covalent bonding** occurs when the electron are shared among oxygen and Arsenic atom will covalently **bond** with Oxygen. Atom.

Calculative Analogy-

After this reactivity Sodium Arsenate Completed [Na₃AsO₄] the electron sum of the Compound -

$$Na_3 = 3 [No. of Atom] \times 1 [e^-] = 3 [Total Sum of e^-]$$

$$As = 1 [No. of Atmos] \times 5 = 5 [Total e - in compound]$$

$$4o = 4 [No. of Atom] \times 6 [No. of e^-] = 24 \\ = 32 [e^-]$$

Condition - 'e – sum = even(Diamagnetic)
'e – sum = odd (Paramagnetic)

Conclusion- Therefore [32] is divisible by 2. Hence, the above value can be considered as Even Number.

$$'e - sum = even(Diamagnetic)$$

$$'e - sum = odd (Paramagnetic)$$

There for, Na₃AsO₄ is complete Diamagnetic Compound of Arsenic.

1. Calculating Electron sum of [Na₃AsO₄ & Na₂AsO₃] Compounds. There for the Compound Sodium Arsenite contain [Na₂AsO₃] That for The compound consist three element Sodium Arsenic Oxygen, in the Compound the Sodium, loose [1 e⁻] & Arsenic Atom gain [1 e⁻] electrons. Sodium atom are transferred permanently to Arsenic atom, from the electrostatic attraction between oppositely charged **ions** in [Na₂AsO₃] compound. **Covalent bonding** occurs when the electron are shared among oxygen and Arsenic atom will covalently **bond** with Oxygen atom.

After this reactivity Sodium Arsenite Completed [Na₂AsO₃] the electron sum of the Compound -

$$"2Na" = 2 [No. of Atom] \times 1 [e^-] = 2 [Total Sum of e^-]$$

$$As = 1 [No. of Atmos] \times 3 [Total e - in compound] = 5$$

$$3o = 3 [No. of Atom] \times 6 [No. of e^-] = 18 \\ = 23 [e^-]$$

Condition - 'e – sum = even(Diamagnetic)
'e – sum = odd (Paramagnetic)

There for ["25"] is not divisible by 2. Hence, it can be considered as odd Number.

$$'e - sum = even(Diamagnetic)$$

$$'e - sum = odd (Paramagnetic)$$

There for, Na₂AsO₃ is complete Paramagnetic Compound of Arsenic.

Conclusion –

Arsenic species are always pH dependent. Aarsenite can be oxidized to Arsenate at higher pH, and Arsenate can be reduced to Arsenite at lower pH. Hence, most of the Arsenic compound is found in Arsenate form on the surface because of oxidation and Arsenite will be converted to Arsenate form and gains diamagnetic property removed by applying strong magnetic field (in suitable structure of [conical higher magnetic field.]

- **Illustrative analysis magnetic field formation and arsenic separation** - Removal of an arsenic species and its compounds by applying the strong magnetic field]through repulsion; diamagnetism[In this removal system the Magnetic behavior)diamagnetism were used for the removal of the Arsenic)as well other magnetic behavior consisting impurities.(from Ground water. Therefore, the

need of special; type of structure for the magnetic field formation and Separation Structure also required Neodymium magnet)NdFeB – 50 grades(are the type of permanent magnets applied strongest magnetic field.

Experimental conclusion-

Experimentally observed- that Magnetic Field Line (NdFeB): require special structures contains three conical shapes covered with the NdFeB Magnets Contaminated water came from the [1] and get contact with the [3 C1] its c contain higher Magnetic field [2 UMF] due to the Arsenic repelled to the opposite direction. In the opposite direction [7] ([7] it control the flow of water and focused to the point of the [3c1]. Therefore the particles of Arsenic not prevent to go opposite direction as well as from [8] to any other direction therefore experimentally it proved that's Arsenic move with the flow of water and get contact with [3 C2] [UMF. There is also higher magnetic field on this area the [DMF C1] also behave, in between two field [DMF C1-UMF C2] the particles get Stuck [5] [Trapped]; because in this area [3C1 & 3C2] applied equal magnetic field on the particles of the contaminants (As) and [3C1] also provide the protective structure for the flow protection of contaminants particles, the same happen with the [3C2 DMF] and [3C3 UMF]. In the this Arsenic Filtration Unit don't required more number of [CHMF] (Conical Higher Magnetic Field) Structure, In the Second Trapping zone [4] the arsenic species and its compounds completely removed from the water by the magnetic filtration (the order of separation in decreasing order, the contaminants is decrease when it comes in the contact of [C1] [C2] [C3].

Condition: If object / Particles contain Diamagnetic behavior it repel to opposite direction of the magnetic field but if applied the magnetic field from the both sided then the particle/ object is stuck/ Trapped in the mid. e.g.: - Arsenic move with the flow of water and get contact with [3 C2] [UMF] there is also higher magnetic field on this area the [DMF C1] also behave, in between two field [DMF C1-UMF C2] the particles get Stuck [5] [Trapped] because in this area [3C1 & 3C2] applied equal magnetic field on the particles of the contaminants and [3C1] also provide the protective structure for the flow protection of contaminants particles ; if the contaminants contain Ferromagnetic or Paramagnetic (Behavior) compound then it attracted in in

the structure, the Ferromagnetic or Paramagnetic (Behavior) compound removed from the water by the magnetic filtration (the order of filtration in decreasing order, the contaminants is decrease when it comes in the contact of separation structure. On the other hand if contaminant contain paramagnetic (behavior) compound then it's attracted in the same order (stated above).

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