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# Arsenic Removal by Dissolved Air Flotation

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**Abstract:** In the present research Arsenic removal by Dissolved Air Flotation (DAF) has been studied in pilot scale. Polyaluminium chloride is best coagulant for arsenic removal is primary turbidity of 10 NTU and coagulant concentration of 40 mg $L^{-1}$ and saturation Pressure of 4.5 atmosphere. Survey of flocculation time, flotation time and saturation pressure on arsenic removal by dissolved air flotation has shown that their effect on arsenic removal is identical (same). Arsenic has been removed about 99% by this method.

**Key words:** Drinking water, Arsenic, dissolved air flotation, coagulant, polyaluminium chloride

## INTRODUCTION

Arsenic (As) is a ubiquitous element present in various compounds throughout the earth's crust. Contamination of the environment with arsenic from both natural and anthropogenic sources is widespread, occurs in many parts of the world and may be regarded as a global issue (Zaw and Emett, 2002).

Water is one of the major means of transport of arsenic in the environment (Viraraghavan *et al.*, 1999). Industrial effluents are a major source of arsenic to the environment (Edwards, 1994).

From many countries, incidents of arsenic contamination have been reported. Recently, major ground water contamination problems have been reported from Bangladesh, West Bengal, India, inner Mongolia and Taiwan and some south American countries.

More than 100 million people are reported to be at risk. The US Environmental Protection Agency (EPA) ha recently announced the reduction of permissible values of arsenic in drinking water from 50 to 10 μg $L^{-1}$ in the light of recent epidemiological evidence to support the carcinogenic nature of the ingested arsenic and its connection with liver, lung and kidney diseases and other dermal effects (Krishna *et al.*, 2001).

Arsenic occurs in both inorganic and organic forms in natural waters. Inorganic arsenic may be present in the form at oxidation states of arsenate [As(V)] and arsenite [As(III)]. The dominant arsenic species is a function of pH and redox potential (Cheng *et al.*, 1994).

Inoxygenated waters, As(V) is dominant, existing in anionic forms of either $H_2AsO_4^-$, $HAsO_4^{2-}$ or $AsO_4^{3-}$ over the pH range typically encountered in water treatment (pH 5-12) (Edwards, 1994; Wang *et al.*, 2002).

$HasO_4^{2-}$ predominates from pH 7 to 11.5, indicating that this is the from most likely to occur in surface water supplies. At pH<7, $H_2AsO_4^-$ dominates (Cheng *et al.*, 1994).

The most common treatment technologies for removing As from drinking water are conventional coagulation and filtration, lime softening and Iron removal, which are well-suited for large scale treatment plants (Wang *et al.*, 2002; Chen *et al.*, 2002).

One disadvantage of these methods is the large quantities of wasts that may be generated, which can make processing and Disposal costly (Wang *et al.*, 2002).

Dissolved Air Flotation (DAF) was first applied in the dressing of ores as well as in the process industry at the end of 19th century. Dissolved Air flotation was introduced into water treatment in the 1920s. DAF is used in water and wastewater treatment for purification of water by taking particles away from water as effectively as possible (Kiuru, 2001). In which Air bubbles are released in the flotation tank by dissolving air under pressure into the raw water and then lowering the pressure by release of the water to atmospheric pressure through needle valves placed in the flotation tank. Because of the high pressures used, small bubbles with a mean diameter of 40 μm (range 10-100) are produced (Edzwald *et al.*, 1992).

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DAF is currently receiving much attention as an effective process for solid-liquid separation in water technology. In drinking water treatment it has been applied successfully in combination with flocculation for the removal of algae and humic substances (Klute *et al*., 1995) and the high color and low turbidity from water (Reali *et al*., 2001; Malley *et al*., 1991).

Tessele *et al*. (1998) began to remove Hg, As, Se ions of gold cyanide Leaching solution by DAF.

Research done by Zouboulis *et al*. (1995) on removal of dilute cadmium solution by flocculation showed that cadmium in optimum condition of pH 10-11 had been removed 100% (Zouboulis and Matis, 1995).

Park *et al*. (2002) did research about simultaneous removal of cadmium and turbidity. Maximum simultaneous removal of cadmium and turbidity was, respectively 80 and 19%.

Some of available technologies for arsenic removal can not meet existing arsenic standards. Available technologies removing arsenic with high efficiency (98%) require (need) a competent operator and cost of consuming chemical is high-underdeveloped and developing countries often have issue of high arsenic concentration and those may not have necessary fiscal and scientific ability for using of these technologies.

Investigation about arsenic removal up to now, was often on available or acceptable technologies for small systems.

DAF is a nearly new technology that is used widespread. DAF has high advantages for treatment of cold areas water and waters with high algae and low turbidity and provided remove arsenic with high efficiency will belong to technologies removing arsenic as well as water treatment and in fact a treatment unit will do conventional and advanced treatment investigation done (on) DAF was often on improvement of design parameters, saturation conditions and factors affecting in floatation. No investigation is done on arsenic removal by DAF up to now. The arsenic removal by DAF method and determination of effect of factors effecting in flotation on arsenic removal was purpose of present research.

## MATERIALS AND METHODS

This investigation has been done in Health College of Isfahan Medical in 2005 year. In all stages, distilled waters were used to carefully control experimental conditions. Optimum conditions were determined by jar test. Required turbidity was provided by kaolin powder. Sodium bicarbonate was used for providing alkalinity about 100 mg $L^{-1}$ $CaCO_3$ in distilled water. pH in desirable range was adjusted by use of 0.1N HCl and sodium hydroxide. In jar test, Variables of primary turbidity, pH, concentration and kind of coagulant were examined.

Speed of 380 revolution per minutes for 2 min was used for coagulation and speed of 30 revolution per

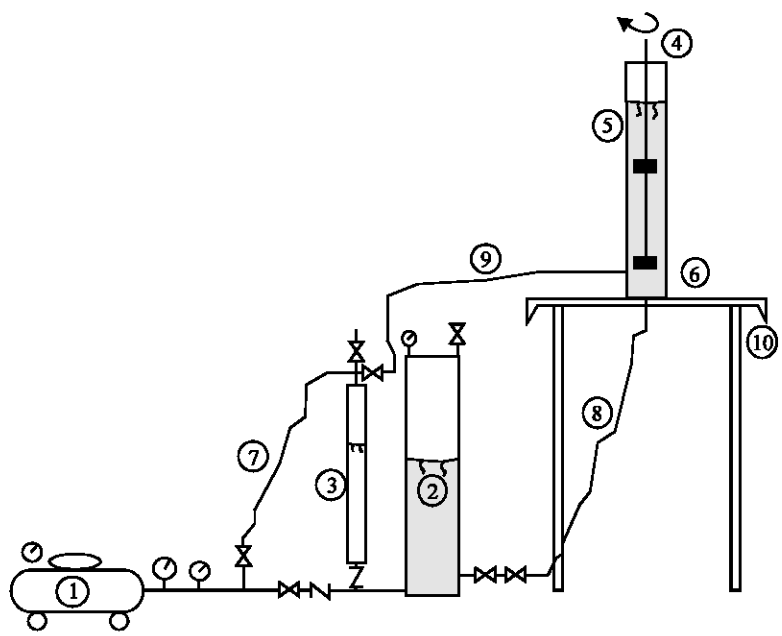


Fig.1: Schematic diagram of DAF pilot. 1: Air compressor, 2: 4-inch metal cylinder, 3: 1/5-inch metal cylinder, 4: Mixer, 5: 2/5-inch plexiglass pipe, 6: Sampling value, 7: Air hose, 8: Exiting hose from saturation cylinder to flotation cylinder, 9: Recycling hose, 10: Bench

minutes for 20 min was used for flocculation. In final, flocs were allowed for 30 min to settle. Sample was taken from 1 cm under water and turbidity and pH were measured. Turbidity was measured by unite Tps-wp-89 and pH was measured by pH meter model GG 110.

**Determination of best coagulant for arsenic removal by use of optimum condition provided from jar test:** Concentrations of 50, 100 and 200 μg $L^{-1}$ arsenic in optimum conditions provided from jar test were tested in DAF system in order to choose best coagulant. This test was done in coagulation and flocculation conditions similar to jar test. Only difference was this fact that in lieu of sedimentation, flotation for 10 min and saturation pressure of 4.5 atmosphere were used.

**Effect of flocculation time, flotation time and saturation pressure on arsenic removal:** Effect of flocculation time, flotation time and saturation pressure on arsenic removal was determined by change of these variables. DAF system consist of a 6 cm plexiglass cylinder with height of 75 cm and volume of 2 L and a pressure tank for saturating water with air and a compressor for providing this saturation pressure. After flocculation with opening of needle valve attached to pressure tank, water saturated with air arrived in cylinder through beneath. needle valve was closed after spending of time needed for flotation.

It is necessary for beginning of flotation that a given volume of distilled water was already poured in pressure tank and saturated with air. Samples were taken from 3.5 cm beneath water by value (Fig. 1). Aluminium and arsenic were measured according to standard method book (APHA, 1992).

## RESULTS AND DISCUSSION

Optimum conditions resulting from jar test with variables of primary turbidity (10-80 NTU), pH (5.5, 6, 6.5, 7 and 7.5), concentration (5, 10, 20, 30 and 40 mg $L^{-1}$) and coagulants (Ferric chloride, Aluminium sulphate, polyaluminium chloride) are illustrated in Table 1.

Effect of optimum conditions (Table 1) on arsenic removal (concentrations of 50, 100 and 200 μg $L^{-1}$) shows that polyaluminium chloride is best coagulant for arsenic removal and aluminium sulphate places in next rank.

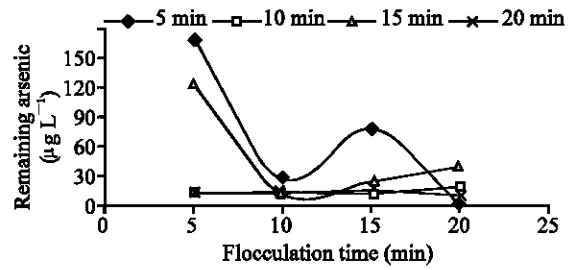


Fig. 2: Remaining arsenic in different flocculation, flotation times, saturation pressure 3 atm

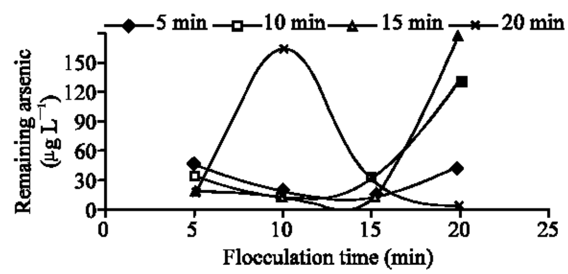


Fig. 3: Remaining arsenic in different flocculation, flotation times, saturation pressure 3.5 atm

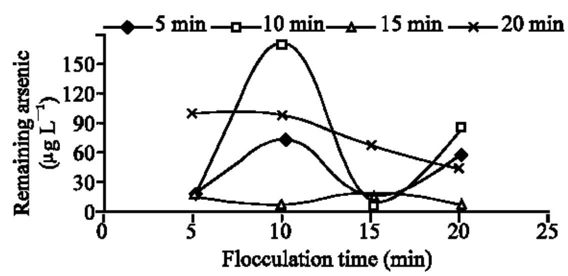


Fig. 4: Remaining arsenic in different flocculation, flotation times, saturation pressure 4 atm.

Arsenic concentration of 200 μg $L^{-1}$ was efficiently removed by DAF. Conditions under which, arsenic was removed by DAF are described in Table 2.

Variables of flocculation time (20-50 min), flotation time (5-20 min) and saturation pressure (3-4.5 atmosphere) on arsenic removal in optimum condition was evaluated according to Table 2 and Fig. 2-5.

Table 1: Optimum conditions resulting from jar test

| | Optimum condition in low turbidity | | | Optimum condition in high turbidity | | |
|---|---|---|---|---|---|---|
| Coagulant | Turbidity NTU | Concentration mg $L^{-1}$ | pH | Turbidity NTU | Concentration mg $L^{-1}$ | pH |
| Ferric chloride | 10 | 20 | 5.5 | 80 | 30 | 6.5 |
| Aluminium sulphate | 10 | 10 | 7 | 40 | 20 | 6 |
| Polyaluminium chloride | 10 | 40 | 7 | 70 | 40 | 7 |

Table 2: The most optimum conditions for arsenic removal by polyaluminium chloride ( PAC )

| Primary turbidity, NTU | Primary arsenic concentration (mg $L^{-1}$) | Concentration of PAC (mg $L^{-1}$) | pH | Percent of removal |
|---|---|---|---|---|
| 10 | 200 | 40 | 7 | 99.4 |

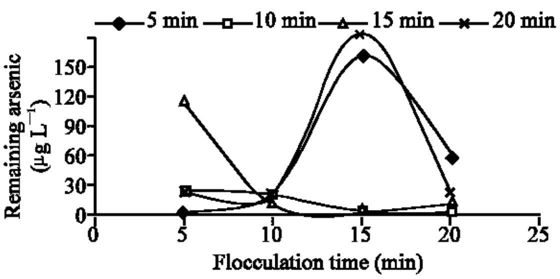


Fig. 5: Remaining arsenic in different flocculation, flotation times, saturation pressure 4.5 atm

## DISCUSSION

Studies done by Chen *et al.* (2002) showed in conventional treatment methods, coagulation by iron salts as compared to aluminium salts, can lead to better results. Difference in results perhaps be due to difference of treatment mechanism between conventional and DAF processes of course, coagulation and flocculation requirements are tow identical process but in conventional methods (processes) due to need to floc settlement, rough and heavy floc should be formed, but in DAF method pinpoint flocs are required. In DAF method, ferric chloride and aluuminium sulphate could remove arsenic 91 and 96%, respectively. perhaps, other reason for more arsenic removal by polyaluminium chloride is it's polymerized nature. It is necessary to study more on diameter of flocs formed by coagulants and determine amount of zeta potential reduction on molar basis by these coagulants in time of consumption..

Also, differences of polymerized coagulants and simple coagulants on arsenic removal should be investigated.

This study showed that polyaluminium chloride in pH = 7 is best coagulants for arsenic removal in optimum conditions resulting from jar test that can remove about 99.4% arsenic that in comparison with other two coagulant has more efficiency in arsenic removal.

More recent studies by researches from the water research center in England showed that use of coagulants, including polyaluminium chloride, effectively removed color, turbidity and alge (Malley *et al.*, 1991).

Results of this study showed that flotation time can be very effective on level of remaining arsenic in water. Studies showed that optimum flotation time is 5-15 min (Malley *et al.*, 1991).

Table 3: Average remaining aluminium level for arsenic removal in saturation pressure of 3-4.5 atm

| | Flocculation time (min) | | | |
|---|---|---|---|---|
| Flotation time (min) | 5 | 10 | 15 | 20 |
| 5-20 | 1.44 | 2.25 | 1.03 | 0.93 |

Figure 2 show that is saturation pressure of 3-4.5 atm, arsenic remaining shows different behavior in flotation period. It is observed that arsenic has not been reduced or increased lineally with increase of flocculation period and charts have had a zigzag form.

Changes of remaining arsenic in water is due to changes of floc conditions in terms of size, stability and electrical charge interaction between bubble and floc. There is universal agreement and experimental evidence that tow conditions are necessary for favorable flotation: (1) charge neutralization of the particle and (2) production of hydrophobic particles (Edzwald, 1995).

Tuky analysis of data showed that effect of saturation pressure, floatation time, flocculation time on arsenic removal is identical (equal).

It's concluded that effect of parameters effecting on flotation i.e., flotation. coagulation and flocculation length and saturation pressure (AWWA, 1990; HDR, 2001) on each other in some circumstance in such a way that lead to formation of floc with diameter floc -30 μm (Edzwald *et al.*, 1992) as well as neutralization and hydrophobication of particle charge that there by conditions for optimal floc-bubble attachment are provided. It should be noted that arsenic concentration increase has led to arsenic removal improvement and remaining of less arsenic in water i.e., (that is) arsenic ion in water improves conditions for arsenic removal. perhaps this improvement that arsenic ion itself has is due to this fact.

Involved in floc-buble attachment and will lead to attachment stability.

Stability between particles and bubble can be effected by floc-particle electrical charge interaction and hydrophilic effect resulting from water binded on particle surface (Malley *et al.*, 1991).

This study showed that only in flocculation times of 10 and 15 min in all flotation times, pattern of remained arsenic is identical.

Studies stated that best flocculation times are 5-10 min (Edzwald *et al.*, 1999) , 5 + 15 min (HDR, 2001) and even 5 min (Bunker *et al.*, 1995).

This study showed that best flocculation time in different flotation times are 5-20 min in saturation pressure of 3 atm (Fig. 2), 5-15 min in saturation pressure of 3.5 atm (Fig. 3), 5-20 min in saturation pressure of 4-5 atm (Fig. 5). Malley and Edzwald concluded that flocculation time dose not considerably effect on DAF performance (Malley *et al.*, 1991).

This study shows that best flotation time for remaining less level of arsenic is 10 and 20 min in saturation pressure of 3 atm and 5, 10 and 15 min in saturation pressure of 3.5 atm and 15 min in 4 atm and 10, 15 min in 4-5 atm (Fig. 2-5).

This study showed that saturation pressure of 4 atm is most critical pressure for arsenic removal from water (Fig. 4) because of it's high effect on remaining arsenic during flotation times.

Small bubbles are formed in higher pressures and pressures more than 5 atm have less effect on particle size (Edzwald, 1995). Malley and Edzwald have reported that provided bubbles volume be more than particles volume, DAF efficiency increases (Malley *et al*., 1991).

This research showed that in saturation pressures of 3 and 4.5 atm respectively flocculation times of 5 and 15 min in saturation pressures of 3.5-4 atm, respectively flocculation times of 10 and 20 min are effect in arsenic removal. In general, DAF method could remove arsenic as much as 99%.

Earlier studies in experimentals comparing DAF with Conventional Gravity Settings (CGS) , measurement also indicated that the amount of residual dissolved aluminium is independent of solid-liquid separation.

DAF and CGS produce comparable levels of residual dissolved coagulant (Malley *et al*., 1991) which support the finding of this study.

Literature have noted that increase of flocculation time from 12 to 16 min in DAF can, reduce remaining concentration up to gravity settings water treatment. Studies in 1983 showed that treatment of surface water by alum remaining alumimium level of 2.57 mg $L^{-1}$ (AWWA, 1990). Average remaining aluminium level in DAF during arsenic removal is explained in Table 2.

Table 3 shows that during of arsenic removal by polyaluminium chloride, with increase of flocculation time from 5 min to 20 min, remaining aluminium level is reduced about 35%.

## CONCLUSIONS

The removal of Arsenic from distilled water was studied by Dissolved Air Flotation (DAF) at the laboratory scale.

DAF experiments showed that when polyaluminium chloride was used to remove arsenic, it achieved 99% arsenic removal. this research indicates that DAF can be operative with flocculation times 5 to 20 min in different saturation pressure and showed that the remaining aluminium level is high.

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