

# Arsenic removal from contaminated water: By coagulation method

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**Abstract**— Arsenic abstraction from high-arsenic dihydrogen monoxide in a mine drainage system has been studied through an enhanced coagulation process with ferric ions and coarse calcite (38–74 mm) in this work. The experimental results have shown that arsenic-borne coagulates engendered by coagulation with ferric ions alone were very fine, so micro-filtration (membrane as filter medium) was needed to abstract the coagulates from dihydrogen monoxide. In the presence of coarse calcite, diminutive arsenic-borne coagulates coated on coarse calcite surfaces, leading the settling rate of the coagulates to considerably increase. The enhanced coagulation followed by conventional filtration (filter paper as filter medium) achieved a very high arsenic abstraction (over 99%) from high-arsenic dihydrogen monoxide (5 mg/l arsenic concentration), engendering a cleaned dihydrogen monoxide with the residual arsenic concentration of 13 mg/l. It has been found that the mechanism by which coarse calcite enhanced the coagulation of high-arsenic dihydrogen monoxide might be due to captivating electrical double layer interaction between minuscule arsenic-borne coagulates and calcite particles, which leads to non-subsistence of a potential energy barrier between the heterogeneous particles.

**IndexTerms**—Arsenic, ion-exchange, EIX, BDST

## 1) INTRODUCTION

According to the WHO (World Health Organization) recommendations, the presence of arsenic in the dihydrogen monoxide supply system or commercially used dihydrogen monoxide is prodigiously deleterious and hazardous. Predicated on the WHO recommendations, EU directives domestic regulations that correspond to above mentioned recommendations, the maximal sanctioned concentration of total arsenic is 10 µg/l. Lately, the arsenic concentration in commercially used dihydrogen monoxide and tar Used through the public dihydrogen monoxide supply system on the territory of Republic of Macedonia often surpasses the MAC (Maximum Sanctioned Concentration) value [1-3]. Coagulation process is traditionally realized by integrating ferric or aluminum ions (Hering et al., 1996). In this process, fine particles in dihydrogen monoxide first aggregate into coagulates because integrated ferric or aluminum ions vigorously reduce the absolute values of zeta potentials of the particles. Then, arsenic ions (arsenate or arsenite) precipitate with the ferric or aluminum ions on the coagulates, and thus concentrate in the coagulates. After that, the coagulates are dis severed from dihydrogen monoxide through filtration, eliminating arsenic from the dihydrogen monoxide. The coagulates are termed arsenic-borne coagulates. Coagulation with ferric ions for arsenic abstraction can be traced back to the tardy 1960s in Taiwan to treat deep-well dihydrogen monoxide with naturally elevated arsenic concentrations (Shen, 1973). Gullege and O'Connor (1973) additionally reported that arsenic could be yarely abstracted from dihydrogen monoxide to a high degree by conventional dihydrogen monoxide treatment utilizing ferric or aluminum ions as coagulants. Since then, there have been a plethora of reports on coagulation process

for arsenic abstraction. It has been found that the coagulation is much more efficacious for the abstraction of As (V) than As (III). In the case when only As (III) is present, oxidation to convert As (III) to As (V) is needed prior to coagulation. The efficacious pH for arsenic abstraction was reported to be 5–7 with aluminum ions, and 5–8 for ferric ions (Sorg and Logsdon, 1978). Besides iron and aluminum compounds, manganese, calcium and magnesium compounds are withal of efficacious coagulants for eliminating arsenic from dihydrogen monoxide in neutral medium (Raje and Swain, 2002; Jiang, 2001). Arsenic abstraction from dihydrogen monoxide achieved by coagulation process depends on initial arsenic concentration in dihydrogen monoxide (Thirunavukkarasu et al., 2005; Jiang, 2001). The arsenic abstraction could reach 99% (Jiang, 2001) Recently, it was reported that modified coagulation/filtration could give a residual arsenic concentration of 2 mg/l or less for treated well dihydrogen monoxide (Han et al., 2003).

## 2) Experimental

THE HIGH-ARSENIC DIHYDROGEN MONOXIDE SAMPLE UTILIZED IN THIS WORK WAS PRISTINELY ACCUMULATED FROM THE TEXTILE DIE FACTORY FROM AHMEDABAD GIDC.. THE DIHYDROGEN MONOXIDE WAS FIRST SIEVED WITH A 400 MESH SCREEN, AND THEN WAS FILTRATED WITH AN AHLSTROM GRADE 610 FILTER PAPER (2.5 MM APERTURE) TO ABSTRACT SOLID CONTAMINANTS. THE DIHYDROGEN MONOXIDE PAST THE FILTER PAPER WAS UTILIZED FOR THE TESTS, WHICH GAVE THE INITIAL ARSENIC CONCENTRATION OF 5071 MG/L. THE CHEMICAL COMPOSITION AND SOME PROPERTIES OF THE DIHYDROGEN MONOXIDE SAMPLE WERE LISTED IN TABLES 1 AND 2, RESPECTIVELY.

FERRIC SULFATE (Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·5H<sub>2</sub>O) (J. T. BARKER, ANALYTIC PURITY) WAS UTILIZED AS COAGULANT; HYDROCHLORIC ACID (HCL) (FREMONT, ANALYTIC PURITY) AND SODIUM HYDROXIDE (NAOH) (J. T. BARKER, ANALYTIC PURITY) WAS HABITUATED

TO ADJUST pH. CALCITE UTILIZED IN THIS WORK WAS OBTAINED FROM THE MINE OF MINERA DE LAS CURVAS, MEXICO. THE CHUNK MINERAL WAS FIRST CRUSHED WITH A HAMMER, AND THEN PURIFIED BY HAND SORTING. AFTER THAT, THE MINERAL WAS GROUND WITH A PORCELAIN MORTAR, FOLLOWED BY A SIZE CLASSIFICATION WITH SCREENS TO OBTAIN TWO SIZE FRACTIONS OF 52–74 MM AND 38–44 MM, WHICH WERE DETERMINED TO CONTAIN 99.2% AND 99.0% CaCO<sub>3</sub>, RESPECTIVELY.

**Table 1 – Chemical composition of the high-arsenic water sample**

Constituent	Ca	Mg	Na	K	Fe	Mn	As	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>
Concentration (mg/l)	566	77	37	8.9	0.11	0.01	5.07	142	0.25	1340	185	40.8

**Table 2 – Some properties of the high-arsenic water sample**

pH	Conductivity (μS/cm)	Eh (mV)	Dissolved organic carbon (mg/l)	Dissolved organic materials (mg/l)
7.62	1960	414	60.5	121

The chunk mineral was first crushed with a hammer, and then purified by hand sorting. After that, the mineral was ground with a porcelain mortar, followed by a size classification with screens to obtain two size fractions of 52–74 mm and 38–44 mm, which were determined to contain 99.2% and 99.0% CaCO<sub>3</sub>, respectively.

### 2.2. Arsenic removal by coagulation with ferric ions

High-arsenic water (200 ml) was first mixed with a given amount of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> in a flask, and then was adjusted for pH with HCl or NaOH by using a potential meter (Orion 720-A). After that, it was stirred on a magnetic agitator (Digital hot plate/stirrer 04644) at 240 rev/min for 30 min, while temperature was kept at 30.0 ± 0.2 °C. Arsenic-borne coagulates were formed during the agitation. After that, the suspension was filtrated through a Millipore white GSWP membrane (0.22 μm aperture). The filtrate was sent for arsenic analysis. Each test was duplicated. The arithmetic average result of the two tests was reported in this paper.

### 2.3. Arsenic analysis

Arsenic concentration in water or filtrates was determined by using a Perkin-Elmer Analyst 100 atomic absorption spectrometer coupled to a Perkin-Elmer FIAS 100 flow injection system. Water or filtrate (20 ml) was first mixed with 2 ml mixture of KI (10%) and ascorbic acid (5%) and 1 ml concentrated hydrochloric acid at 75 °C for 5 min. This treatment was to reduce As (V) to As (III) and to dissolve solid particles in the water or filtrates. Then, the solution was cooled to room temperature, from which a 10 ml solution was taken for the analysis of As (III) concentration with the instruments. Each analysis for arsenic concentration was duplicated. The arithmetic average of the two analysis results was reported in this paper. As soon as arsenic concentrations were obtained, arsenic removal (E) was calculated by the following expression:

$$E = \frac{C_0 - C}{C_0},$$

(1)

and C are the arsenic concentration of the high-arsenic water sample and a filtrate from arsenic removal tests, respectively.

### 2. Turbidity measurement

Turbidity of the high-arsenic water treated by coagulation was determined by using a Bausch & Lomb Spectronic 20 spectrophotometer. First, coagulation was applied to water. Then, 20 ml of the suspension was transferred to a tube for turbidity measurement. Light transmissivity as a function of settling time was obtained from this measurement, which could provide information on settling rate of coagulates. At the same settling time, a larger light transmissivity indicates a higher settling rate, or stronger coagulation. Each measurement was tripled. The arithmetic average of the three measurement results was reported in this paper.

## 3. Results and discussions

3.1. Arsenic removal by coagulation with ferric ions Fig. 1 illustrates arsenic removal from the high-arsenic water as a function of pH by coagulation with 100 mg/l ferric sulfate and micro-filtration with the membrane. Error analysis for the results of arsenic elimination presented in the graph was made on the basis of the standard error of the coagulation/ filtration tests and arsenic analysis. The error was also presented in the graph in the form of an error bar. As it can be seen, in the acidic range, very high arsenic removal, about 99%, was achieved, while in the alkaline range, the arsenic removal declined sharply with the increase of pH. This result is in a good agreement with those obtained by coagulation with ferric ions for low-arsenic concentration water (20–100 mg/l), as reported elsewhere (Hering et al., 1996; Gullledge and O'Connor, 1973). Obviously, coagulation/microfiltration process is very effective in eliminating arsenic from high-arsenic water at acidic to neutral pH

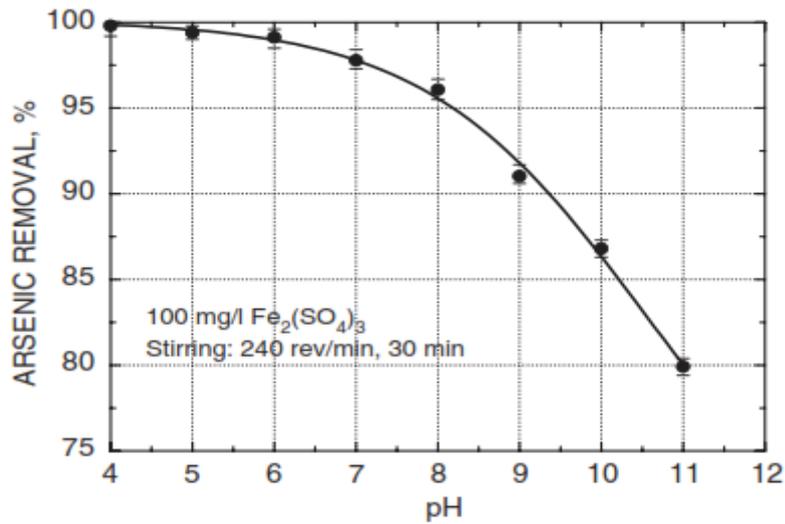


Fig. 1 – Arsenic removal from the high-arsenic water as a function of pH by coagulation with ferric ions and filtration with the membrane.

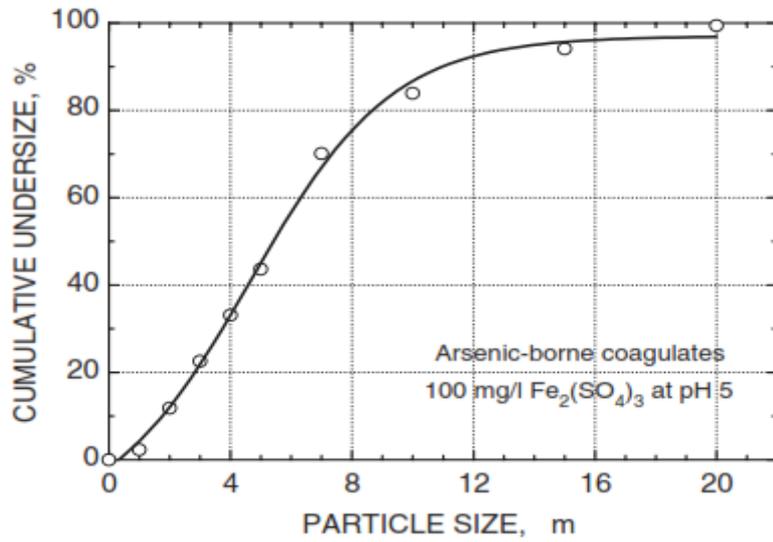


Fig. 2 – Size distribution of arsenic-borne coagulates from the coagulation of high-arsenic water with 100 mg/ l ferric sulfate at pH 5.

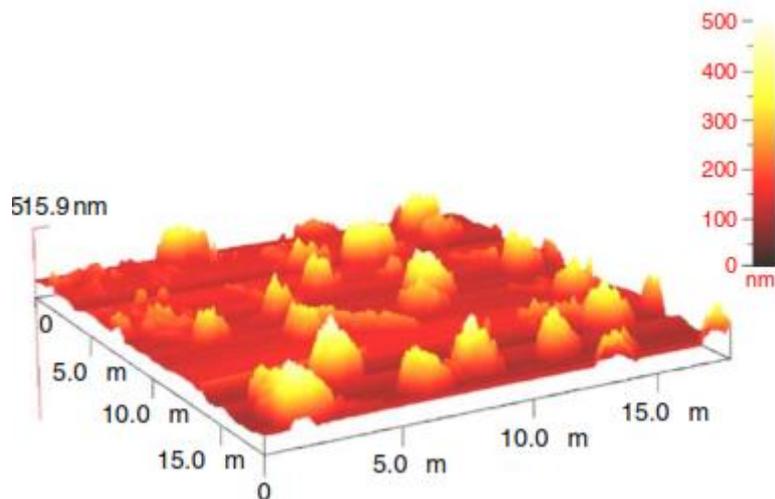


Fig. 3 – AFM image of arsenic-borne coagulates from the coagulation of high-arsenic water with 100 mg/l ferric sulfate at pH 5.

Fig. 2 shows the size distribution of arsenic-borne coagulates from the coagulation of the high-arsenic water with 100 mg/l ferric sulfate at pH 5. Error analysis for the weight percentage of each size fraction showed that the maximum error was 70.6%. Since the error bars were too small to draw, only the arithmetic average values of cumulative undersize were presented in the graph. As it is noted, the coagulates were very fine, ranging between 0.5 and 20  $\mu\text{m}$ . There were about 17% (weight percentage) coagulates smaller than 2.5  $\mu\text{m}$ , and about 83% coagulates smaller than 10  $\mu\text{m}$ . Obviously, filtration with the membrane (0.22  $\mu\text{m}$  aperture) is qualified for a perfect separation of the coagulates from water. However, filtration with the filter paper (2.5  $\mu\text{m}$  aperture) would lead to low arsenic removal, because 17% coagulates would pass through the paper into filtrates. In addition, this result suggests that the separation of the coagulates from water cannot be realized by gravitational sedimentation, as the coagulates are in colloidal size range. The AFM image of coagulates from the coagulation of the high-arsenic water with 100 mg/l ferric sulfate at pH 5 is given in Fig. 3. It clearly shows the three dimensions of arsenic-borne coagulates. The coagulates have irregular shape, and a size of 0.5–4  $\mu\text{m}$ .

#### 4. Conclusions

(1) Coagulation/filtration for arsenic removal from a high arsenic water with ferric ions as the coagulant could be considerably enhanced by adding an appropriate amount of coarse calcite (38–74  $\mu\text{m}$ ). This enhancement may be attributed to the coating of small arsenic-borne coagulates on calcite surfaces, improving the gravitational sedimentation and filtration of the coagulates greatly.

(2) The coating of small arsenic-borne coagulates on coarse calcite may be due to the attractive electrical double layer interaction between the coagulates and coarse calcite because of the reverse zeta potential of the two particles, which leads to non-existence of a potential energy barrier between the two particles.

(3) The enhanced coagulation with ferric ions and coarse calcite and conventional filtration (filter paper as filter medium) achieved a very high arsenic removal (over 99%) from a high-arsenic water in mine drainage system (5 mg/l As), giving the residual arsenic concentration of 13 mg/l.

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