EWCE 331
Water Supply Engineering

Lecture 9

Instructor

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Lecture outline

Water Treatment Methods

Topics	References
• **Advanced water treatment for heavy metal removal** ✓ **Arsenic removal**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Removal of Arsenic

- There are several methods available for removal of arsenic from water in large conventional treatment plants.

- The most commonly used technologies include –
  - ✓ oxidation,
  - ✓ co-precipitation and adsorption onto coagulated flocs,
  - ✓ lime treatment,
  - ✓ adsorption onto sorptive media,
  - ✓ ion exchange resin and
  - ✓ membrane techniques

Removal of Arsenic – **Oxidation**

- Arsenic is present in groundwater in Arsenite [As(III)] and Arsenate [As (V)] forms in different proportions.
- Most treatment methods are effective in removing arsenic in As (V) form and hence include an oxidation step as pre-treatment to convert As(III) to As (V) .
- Arsenite can be oxidized by oxygen, ozone, free chlorine, hypochlorite, permanganate, hydrogen peroxide.

Removal of Arsenic – **Oxidation**

- Atmospheric oxygen, hypochloride and permanganate are commonly used for oxidation in developing countries.

$$H_3AsO_4 + \tfrac{1}{2}O_2 = H_2AsO_4^- + 2H^+ \quad (1)$$

$$H_3AsO_4 + HClO = HAsO_4^{--} + Cl^- + 3H^+ \quad (2)$$

$$3\,H_3AsO_4 + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O \quad (3)$$

Note: H_3AsO_4: Arsenic Acid
$H_2AsO_4^-$: Dihydrogen Aesenate
$HAsO_4^{--}$: Hydrogen Aesenate

- Air oxidation of arsenic is very slow and can take weeks for oxidation.
- Chemicals like chlorine and permanganate can rapidly oxidize arsenite to arsenate under wide range of conditions.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Water treatment with coagulants such as aluminium alum, $Al_2(SO_4)_3.18H_2O$, ferric chloride , $FeCl_3$ and ferric sulfate $Fe_2(SO_4)_3.7H_2O$ are effective in removing arsenic from water.

- Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH.

- In both cases pentavalent arsenic can be more effectively removed than trivalent arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- In the coagulation-flocculation process aluminium sulfate, or ferric chloride, or ferric sulfate is added and dissolved in water under efficient stirring for one to few minutes.
- Aluminium or ferric hydroxide micro-flocs are formed rapidly.
- During this flocculation process all kinds of micro-particles and negatively charged ions are attached to the flocs by electrostatic attachment.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Arsenic is also adsorbed onto coagualted flocs.

- As trivalent arsenic occurs in non-ionized form, it is not subject to significant removal.
- Oxidation of As(III) to As(V) is thus required as a pretreatment for efficient removal.

- This can be achieved by addition of bleaching powder (chlorine) or potassium permanganate as shown in Equations 2 and 3.

$$H_3AsO_4 + HClO = HAsO_4^{--} + Cl^- + 3H^+ \quad (2)$$

$$3\,H_3AsO_4 + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O \quad (3)$$

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The possible chemical equations of alum coagulation are as follows:

Alum dissolution:

$$Al_2(SO_4)_3.18H_2O = 2Al^{+++} + 3SO_4^{++} + 18H_2O \quad (4)$$

Aluminium precipitation(acidic):

$$2Al^{+++} + 6H_2O = 2Al(OH)_3 + 6H^+ \quad (5)$$

Co-precipitation (Non-stoichiometric, non-defined product):

$$H_2AsO_4^- + Al(OH)_3 = \text{Al-As (complex)} + \text{Other Products} \quad (6)$$

- Arsenic adsorbed on aluminiun hydroxide focs as Al-As complex is removed by sedimentation.

- Filtration may be required to ensure complete removal of all flocs.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Similar reactions take place during the coagulation – precipitation process using ferric chloride and ferric sulfate.
- Fe-As complex is formed as the end product, which is removed by sedimentation and filtration.
- Arsenic removal is dependent on pH.
- In alum coagulation, the removal is most effective in the pH range 7.2 -7.5.
- In iron coagulation, efficient removal is achieved in a wider pH range usually between 6.0 and 8.5.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India.

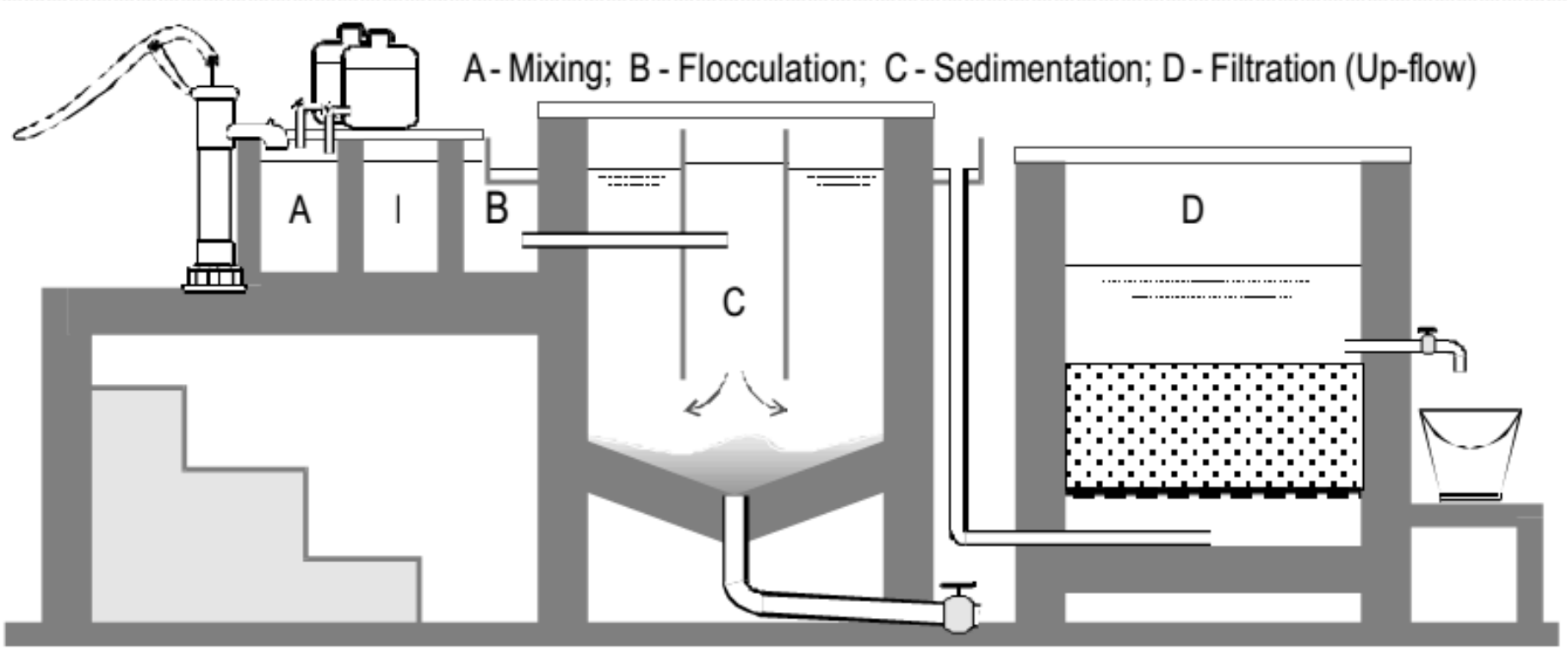


Fig 1: Arsenic removal plants attached to tubewell (designed and constructed in India)

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The arsenic removal plant attached to hand tubewell as shown in Figure 1 has been found effective in removing 90 percent arsenic from tubewell water having initial arsenic concentration of 300 mg/L.

- The treatment process involves in the As removal plant (Figure 1) –
  ✓addition of sodium hypochloride (NaOCl) and alum in diluted form,
  ✓mixing,
  ✓flocculation,
  ✓sedimentation and
  ✓up flow filtration ------ in a compact unit.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Bucket Treatment Unit

- The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes.

- These units are based on chemical doses of 200 mg/L aluminum sulfate and 2 mg/L of potassium permanganate supplied in crushed powder form.

- The units were reported to have very good performance in arsenic removal in both field and laboratory conditions.

- In many cases of rapid assessment, the units under rural operating conditions fails to remove arsenic to the desired level of 0.05 mg/L in Bangladesh.

Removal of Arsenic – Co-Precipitation and Adsorption

Bucket Treatment Unit

- Poor performance in rapid assessment is due to –
  - ✓ Poor mixing
  - ✓ Variable water quality (specially pH) of groundwater in different locations of Bangladesh

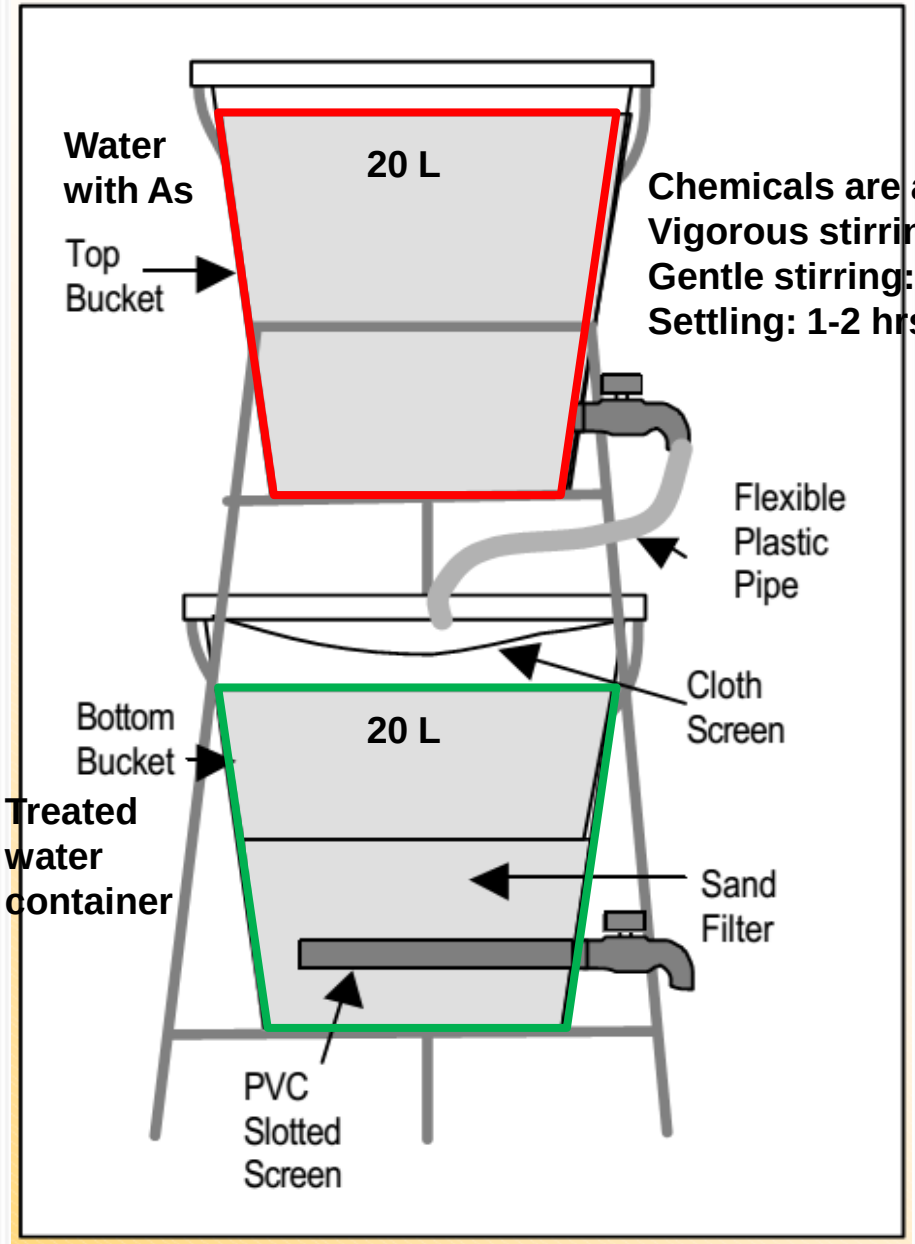


Fig 2: Bucket treatment unit

Removal of Arsenic – **Co-Precipitation and Adsorption**

Steven Institute Technology

- Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested.

- The sand bed used for filtration is quickly clogged by flocs and requires washing atleast twice a week.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Steven Institute Technology

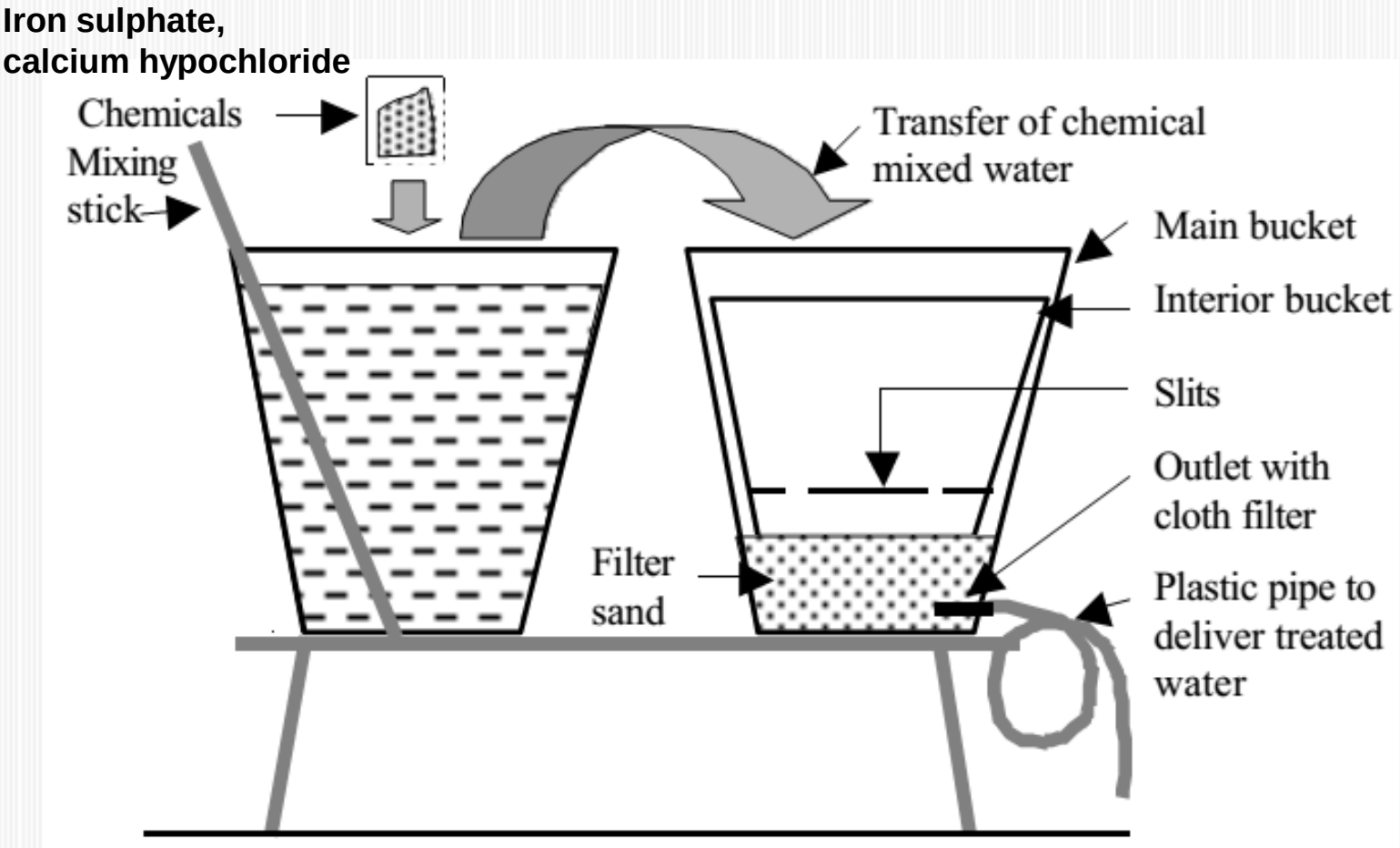


Fig 3: Steven Institute Technology

Removal of Arsenic – **Co-Precipitation and Adsorption**

Steven Institute Technology

- This technology also uses two buckets –
  - ✓one to mix chemicals (iron sulphate and calcium hypochloride) supplied in packets and
  - ✓ the other to separate flocs by the processes of sedimentation and filtration.

- The second bucket has a second inner bucket with slits on the sides as shown in Figure 3 to help sedimentation and keeping the filter sand bed in place.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The use of naturally occurring iron precipitates in ground water in Bangladesh is a promising method of removing arsenic by adsorption.

- Although no good correlation between concentrations of iron and arsenic has been derived, iron and arsenic have been found to co-exist in ground water.

- Most of the tubewell water samples satisfying Bangladesh Drinking Water Standard for Iron (1 mg/L) also satisfy the standard for Arsenic (0.05 mg/L).

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The iron precipitates $[Fe(OH)_3]$ formed by oxidation of dissolved iron $[Fe(OH)_2]$ present in groundwater, have the affinity for the adsorption of arsenic.

- Only aeration and sedimentation of tubewell water rich in dissolved iron has been found to remove arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The Iron Removal Plants (IRPs) in Bangladesh constructed on the principles of aeration, sedimentation and filtration in a small units have been found to remove arsenic without any added chemicals.

- The conventional community type IRPs, depending on the operating principles, more or less work as Arsenic Removal Plants (ARPs) as well.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Sorptive Filtration Media

- Several sorptive media have been reported to remove arsenic from water.

- These are activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, and many natural and synthetic media.

- The efficiency of all some sorptive media depend on the use of oxidizing agent as aids to sorption of arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Sorptive Filtration Media - Activated Alumina

- Activated alumia, (Al_2O_3) having good sorptive surface is an effective medium for arsenic removal.

- 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 upstream zone and later the saturated zone moves downstream towards the bottom end and finally the column get totally saturated.

- Then the media requires to be regenerated.

Removal of Arsenic

Other Methods of Arsenic Removal

- Ion Exchange
- Membrane Filtration
- Nano Filtration
- Reverse Osmosis
- Microbial process