



## Low-cost irrigation water for arsenic removal in north Chile

*Prof. Cáceres L, Chile*

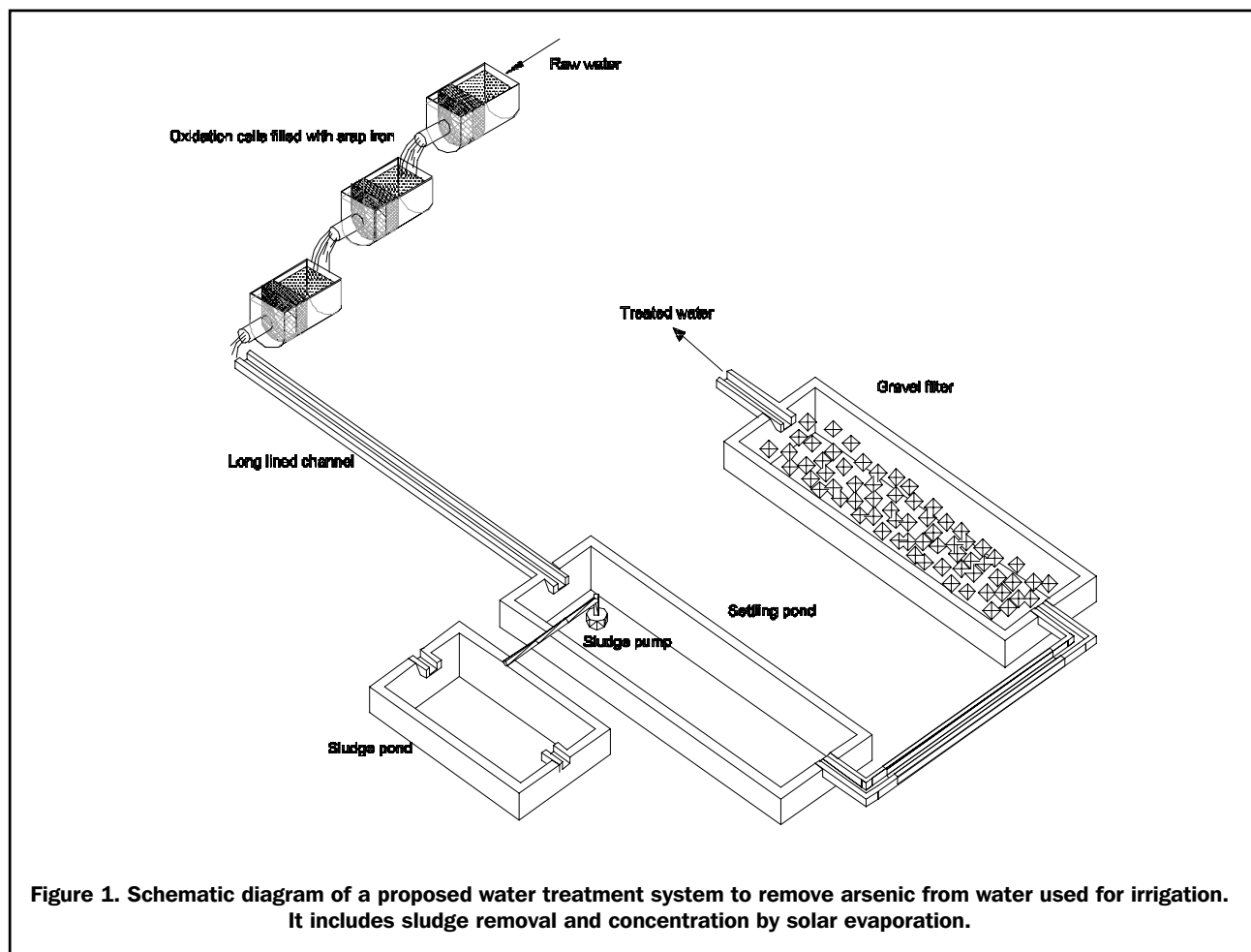
URBAN LIFE AND agriculture in the North of Chile one of the most arid places in the world are affected by high concentrations of arsenic in water supplies (Alonso et al, 1992). Historically protective measures against this problem have evolved toward a widespread potable water treatment only in large communities leaving distant villages exposed to high concentration of arsenic in potable water. On the agricultural side crops cultivated with high concentration of this contaminant in the region, constitutes a direct route of arsenic exposure for which no countermeasures still exists.

Arsenic adsorption onto precipitated ferric hydroxide and floc separation, is the process under current use to remove arsenic from potable water in the North of Chile. The limited profits of local agriculture is a severe restriction to use this process to remove arsenic from irrigation water whose total cost is 1,5 US\$/m<sup>3</sup>.

Recently, new projects and ideas have emerged in the region as a result of an increasing degree of public awareness. In this work a low-cost water treatment system for arsenic removal based on its adsorption over corroding iron is discussed as a solution for a safe development of agricultural activities.

### Arsenic in crops

Arsenic uptake by crops from contaminated irrigation water has been demonstrated (Seremi de Agricultura, 1999). On a basis of a continuous consumption, arsenic in crops represent a health risk for the population, and water treatment is the only measure to prevent this health hazard.



**Figure 1. Schematic diagram of a proposed water treatment system to remove arsenic from water used for irrigation. It includes sludge removal and concentration by solar evaporation.**

**Table 1. Factors considered in the design of arsenic removal from irrigation water.**

Factor	Effect characterization	Action (s) to enhance o inhibit its effect	Expected result
Iron oxidation rate	Is the most important factor affecting As removal by adsorption.	<ul style="list-style-type: none"> <li>Maximize dissolved oxygen and iron interface</li> </ul>	Provide enough iron oxidation products for arsenic removal
Dissolved oxygen in water	Responsible for iron oxidation.	<ul style="list-style-type: none"> <li>Promote natural mixing or turbulence of water in contact wit iron.</li> </ul>	Maximize concentration of dissolved oxygen in water
Oxidation products build up in the vicinity of iron-water interface.	<ul style="list-style-type: none"> <li>Oxygen must be present at water- iron interface in order to oxidize water.</li> <li>Diffusion of oxygen to the water-iron interface is inhibited by iron oxidation products built-up, resulting in an decrease of the oxidation rate</li> <li>Oxidation products: <b>a) Colloidal iron.</b> Washed away by circulating water. <b>b) Iron hydroxide flocs.</b> Free floating low density particles. Have the tendency to settle on internal voids of scrap iron. <b>c) Attached oxidized iron film.</b> This is a minor fraction. It can produce an attached protective film.</li> </ul>	<ul style="list-style-type: none"> <li>Induce random turbulence in water in contact with scrap iron (Take advantage of natural falls).</li> <li>Rust removal from iron surface by injecting periodic pulses of acid. No need to remove washed acid.</li> </ul>	<ul style="list-style-type: none"> <li>Maintain a constant iron oxidation rate.</li> <li>Maximize scrap iron use.</li> <li>Arsenic removal is improved at lower pH values (up to 6.5)</li> </ul>
Colloidal iron in water	<ul style="list-style-type: none"> <li>Particles do not settle.</li> <li>Colloids will change with time. They tend to form agglomerates (flocs).</li> <li>Colloidal destabilization is favored in the presence of porous media</li> </ul>	<ul style="list-style-type: none"> <li>Allows free flowing of water in open channels.</li> <li>Use detention ponds and settling tanks.</li> <li>Use low cost rapid sand filter (for soil with iron deficiency no need to filter)</li> </ul>	Destabilize colloidal iron and remove suspended solid.
Local irrigation water distribution network	<ul style="list-style-type: none"> <li>Characterization of local water distribution network.</li> <li>Operating procedures for water management in current use.</li> </ul>	<ul style="list-style-type: none"> <li>Use removable deposits for scrap iron in channels.</li> <li>Take advantage of existing natural falls.</li> <li>"Reactor installed as far upstream as possible" to promote colloidal destabilization.</li> <li>Irrigation water distribution channels should be lined.</li> </ul>	Cheap design according to local conditions
Sludge disposal	<ul style="list-style-type: none"> <li>Arsenic laden sludge should be disposed according to environmental regulations.</li> </ul>	<ul style="list-style-type: none"> <li>Concentrate sludge as much as possible, ideally by using solar energy.</li> </ul>	Sludge disposal according to local environmental regulations.
Public acceptance of the water treatment process to remove arsenic.	<ul style="list-style-type: none"> <li>Cheap local availability of scrap iron and acid.</li> <li>Process supervisor with an adequate level of training.</li> <li>Proper institutional arrangements to ensure continuity of the applied technology.</li> </ul>	<ul style="list-style-type: none"> <li>Selected farmers should be trained.</li> <li>Scrap iron and acid can be supplied by nearby manufacture companies (i.e., Mining, etc.)</li> </ul>	<ul style="list-style-type: none"> <li>Ensure a constant supply of raw materials</li> <li>Ensure and adequate process control operation</li> </ul>

### Process description

Formation of ferric ions from natural metallic iron corrosion is the key feature of this process. Scrap iron immersed in a continuous flow of water is oxidized in the presence of dissolved oxygen leading to the formation of rust and Fe(OH)<sub>3</sub> which are efficient arsenic adsorbents. Under a joint project between Technical University of Berlin in Germany and University of Antofagasta in Chile different reactor arrangements have been tested for arsenic removal. From them open horizontal reactors have been considered to treat irrigation water. Design factors and practical aspects affecting the process are indicated in table 1. A section having at least 10° slope at the irrigation channel is selected to install iron oxidation cells which consists in plastic or rubber compartments filled with scrap iron. To avoid clogging with deposited rust during operation scrap iron should have large and homogeneous voids. Rust removal is favored by flow-induced mixing when water falls between iron compartments. The number of iron compartment depends on water quality, iron oxidation rate and arsenic content on water.

### Design parameters

The four most important parameters are, arsenic concentration, iron oxidation rate, superficial area of the scrap iron and water flow.

#### Arsenic concentration and iron oxidation rate

The concentration of oxidized iron required to remove a given concentration of arsenic in water should exceed a limiting value. This is expressed in terms of a limiting arsenic to ferric iron load (L<sub>AF</sub>). Therefore the minimum value for iron oxidation rate should be:

$$-R_{Fe} = C_{AS}Q/ L_{AF}$$

Where:

R<sub>FE</sub>: Oxidation rate of metallic iron (mg s<sup>-1</sup>)

C<sub>AS</sub>: Arsenic concentration (mg l<sup>-1</sup>)

Q : Water flow (l s<sup>-1</sup>)

L<sub>AF</sub>: Arsenic to ferric iron load : (g As g<sup>-1</sup> Fe)

For a conventional water treatment to remove arsenic in the North of Chile, L<sub>AF</sub> is around 0.05 (Karcher et al, 1999).

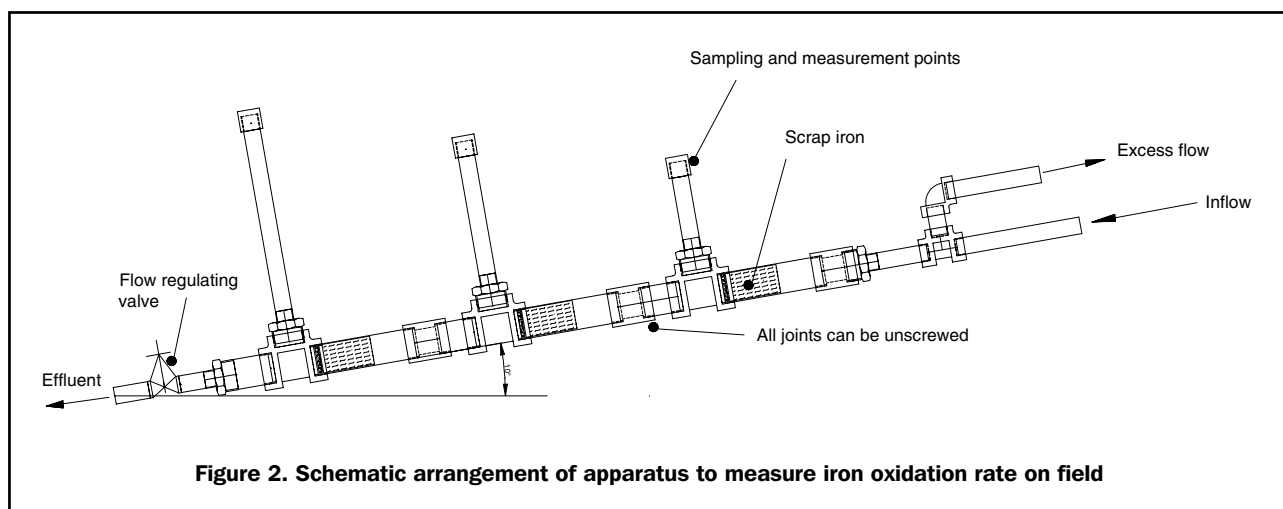


Figure 2. Schematic arrangement of apparatus to measure iron oxidation rate on field

The precise value of  $L_{AF}$  for a given field condition can be found experimentally. In general iron oxidation rate shows a complex dependency on many variables related to water quality, iron surface, dissolved oxygen, etc. Therefore, for a given situation, a reliable design should be based upon on-site iron oxidation rate measurements. The apparatus we propose for such determination is shown in Figure 2.

The system consists of a column having scrap iron compartments with sampling points designed to measure dissolved oxygen. The column fixed on a selected site is fed with an adjusted raw water flow. After an equilibrium time estimated in three hours is reached, reading and sampling are taken. The procedure is repeated with different flows. Iron oxidation rate calculation procedures is given elsewhere (Meenken, 2000). By using this system a value of iron corrosion rate of  $2600 \text{ (mg Fe m}^{-2} \text{ h}^{-1}\text{)}$  was measured at Lasana's river, one of the agricultural locations in the North of Chile under an hydraulic load of  $3.06 \text{ (m h}^{-1}\text{)}$  and  $60 \text{ g}$  of iron wool having an specific area of  $0.0027 \text{ (m}^2\text{g}^{-1}\text{)}$ . Arsenic concentration in raw water being  $0.18 \text{ mg l}^{-1}$  was immediately reduced to  $0.10 \text{ mg l}^{-1}$  (unfiltered). After filtering arsenic concentration was reduced to  $0.001 \text{ mg l}^{-1}$ .

### Water treatment example

For Lasana's conditions of  $40 \text{ l s}^{-1}$ ,  $0.18 \text{ mg l}^{-1}$  of As and initial iron corrosion rate of  $2600 \text{ (mg Fe m}^{-2} \text{ h}^{-1}\text{)}$  a proposed water treatment plant consists of: 60 scrap iron cells of 20 Kg each one, one settling pond lined with 1 mm high density PVC of  $1,700 \text{ m}^2$  surface and 1 m deep, two solar evaporation ponds  $4000 \text{ m}^2$  surface and 0.5 m deep each one. Iron consumption is estimated in  $15 \text{ kg day}^{-1}$ . Replacement and cleaning of 1 and 6 cells/day respectively is necessary. Cleaning include removal, water washing to remove loose rust and acid washing to remove attached rust to the iron

surface. Total operating cost is  $1.5 \text{ UScents m}^{-3}$ . This includes 2 employees, scrap iron and concentrated acid consumption of 15 and  $0.5 \text{ kg day}^{-1}$  respectively and  $1$  energy consumption equivalent to  $2 \text{ Kw day}$ .

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PROF. CÁCERES L., Instituto del Desierto, Universidad de Antofagasta, Avenida Angamos 601, Antofagasta, Chile Tel. 56-55-637207, Fax 56-55-637207 and PROF. DR JEKEL M. and KARSCHUNSKA K., Department of Water Quality Control, Technical University of Berlin, Straße des 17. Juni 13510623, Berlin, Germany Tel: 49 - 30 - 314 22 562, Fax: 49- 30 - 314 23 850

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