*Second Edition*

# Handbook on Drinking Water Treatment Technologies

Government of India
Ministry of Drinking Water and Sanitation
New Delhi

Prepared by
National Environmental Engineering Research Institute
(CSIR-NEERI), Nagpur

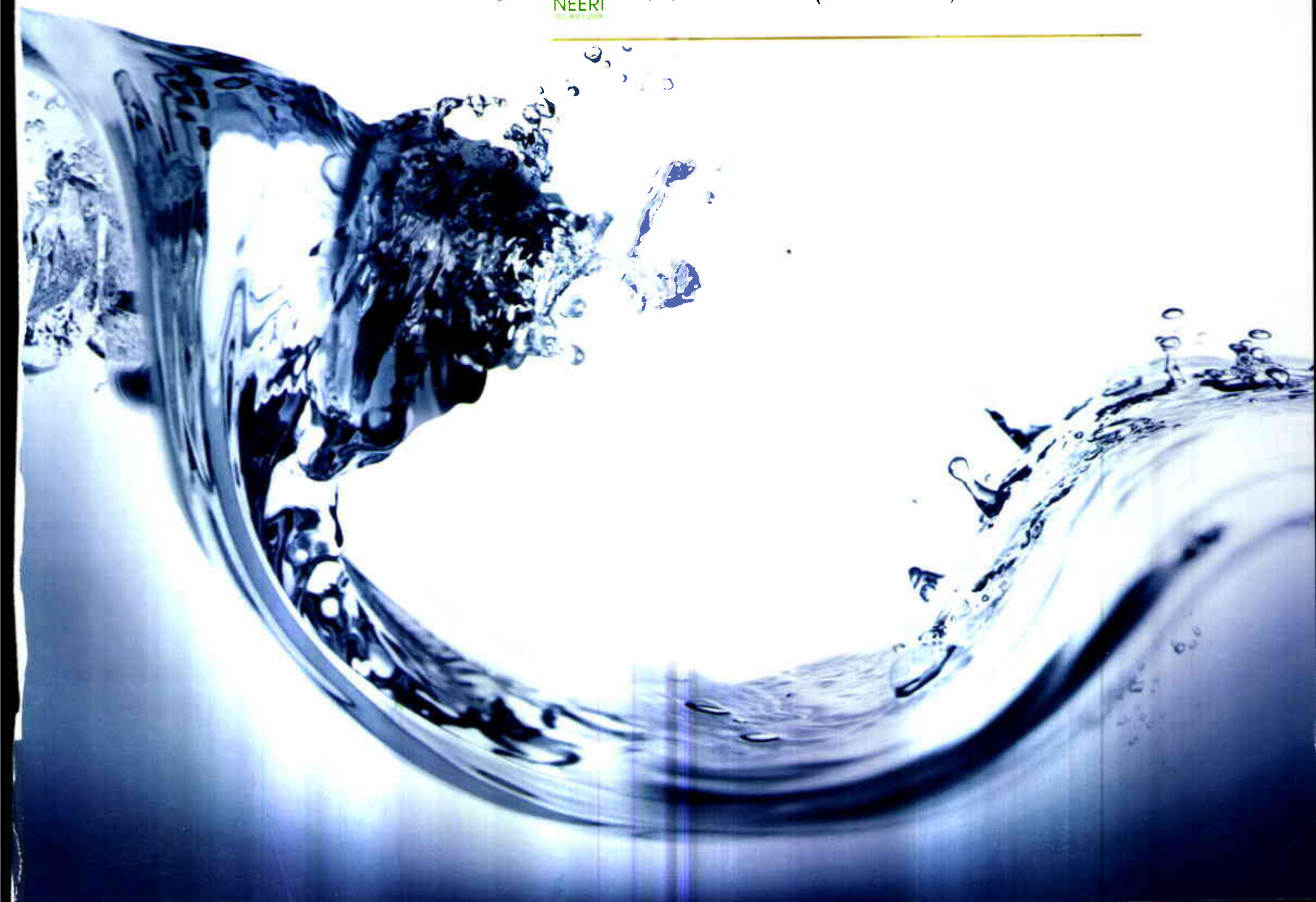
FEBRUARY
2013

*Second Edition*

# Handbook on Drinking Water Treatment Technologies

Government of India
Ministry of Drinking Water and Sanitation (MDWS)
New Delhi

National Environmental Engineering
Research Institute (CSIR-NEERI)



राज्य मंत्री (स्वतंत्र प्रभार)
पेयजल एवं स्वच्छता
भारत सरकार
नई दिल्ली

सत्यमेव जयते

MINISTER OF STATE (INDEPENDENT CHARGE)
FOR DRINKING WATER & SANITATION
GOVERNMENT OF INDIA
NEW DELHI

**भरतसिंह सोलंकी**
**Bharatsinh Solanki**

# Message

The mandate of the Ministry of Drinking Water and Sanitation and the State Departments dealing with rural drinking water supply is to provide safe and uncontaminated drinking water to the rural people in adequate quantity.

Quality of drinking water is a cause of major concern in our villages. There is rising awareness and demand from rural areas that safe water adhering to national standards be provided at least for drinking and cooking. Many parts of the country are affected by contamination of arsenic and fluoride, the most hazardous in terms of health impact. In addition many other chemical contaminants like iron, salinity uranium, pesticides are to be tackled.

I congratulate the scientists of CSIR-NEERI and officers of my Ministry for bringing out such a useful reference document. I would like to suggest that all stakeholders working in the drinking water sector refer to this document and use it appropriately for providing safe drinking water to our rural people.

(Bharatsinh Solanki)

New Delhi

1st February 2013

**पंकज जैन,** आई.ए.एस.
**PANKAJ JAIN** I.A.S.

सत्यमेव जयते

**सचिव**
**भारत सरकार**
**पेयजल एवं स्वच्छता मंत्रालय**
**Secretary**
**Government of India**
**Ministry of Drinking Water and Sanitation**
247, 'A' Wing, Nirman Bhawan, New Delhi-110108
Tel. : 23061207, 23061245 Fax : 23062715
E-mail : secydws@nic.in
Website : www.ddws.nic.in

# Foreword

Though drinking water is a State subject, the Central Government assists the States technically and financially in providing safe drinking water in adequate quantity through the centrally sponsored National Rural Drinking Water Programme (NRDWP). Under this programme, upto 67% of funds allocated to States could be utilized for tackling drinking water quality problems including installation of stand-alone community based water treatment units.

The national strategy is to provide safe drinking water to quality-affected areas from safe drinking water sources, even if they are distant, as the sustainable solution. However, commissioning of big project takes 2-3 years of time and requires large investments and people cannot be expected to continue drinking contaminated water. Therefore, water treatment units mentioned in the Handbook would be a useful short-term solution to provide good quality drinking water to the people of our country.

This second edition of the Handbook on Drinking Water Treatment Technologies is an enlarged version with addition of technological options for treatment of heavy metals like Chromium and Uranium in drinking water sources. A major addition in this second edition that will be of practical use in applying the technologies found in the Handbook, is a Comparative statement of treatment technologies available for the major contaminants. This Statement gives a comparative picture of the scientific, technical, operational, financial and other aspects of each technology, It would help decision makers to zero-in on the most appropriate technology for their requirements.

I expect that all public health engineers, civil and environmental engineers, chemical, mechanical and electrical engineers, chemists, policy planners and all other stakeholders dealing with drinking water quality related issues will greatly benefit by referring to this Handbook.

(Pankaj Jain)

New Delhi,

1st February 2013.

***T.M. Vijay Bhaskar,*** *I.A.S.*
**Joint Secretary**
टी.एम. विजय भास्कर,आई.ए.एस.
संयुक्त सचिव

सत्यमेव जयते

भारत सरकार
पेयजल एवं स्वच्छता मंत्रालय
राजीव गांधी राष्ट्रीय पेयजल मिशन
**Government of India**
**Ministry of Drinking Water and Sanitation**
**Rajiv Gandhi National Drinking Water Mission**

# Message and Acknowledgments

This Ministry had requested CSIR-NEERI, Nagpur to prepare a Handbook of Drinking Water Treatment Technologies for use by State Rural Water Supply Departments and rural water supply engineers at all levels, NGOs, scientists and other stakeholders. The need for such a Handbook was felt for many reasons. Increasing awareness about contamination of drinking water sources, increasing demand for safe drinking water, better testing and reporting of contamination of drinking water sources, focus on water quality affected habitations under Bharat Nirman and separate allocation of funds under National Rural Drinking Water Programme (NRDWP).

Responding to the request made by this Ministry, CSIR-NEERI had prepared a very exhaustive and attractive Handbook. This was well received by all States and others working in the sector. Based on the feed-back received and further developments, CSIR-NEERI was requested to prepare a second edition by including new emerging contaminants like uranium etc. CSIR-NEERI was also requested to prepare a comparative statement of treatment technologies to help take informed decisions on the type of technologies and treatment products for use in rural water supply programme.

In this regard, I extend my gratitude to Dr. S.R. Wate, Director, CSIR-NEERI, Nagpur who has led a team of experts to develop this useful reference manual. I am also grateful to Dr. Pawan Labhasetwar, Mr. Prashant Pal, Mr. Sandeep Namaware, Mr. Deepak Deshpande and Mrs. Vandana Cinthray of CSIR-NEERI for their technical inputs, and editorial support provided by Professor Vandana Bhagdikar, Head, Department of English, Mahila Mahavidyalay, Nagpur. Last but not the least, I acknowledge the contribution of Shri D. Rajasekhar, Deputy Adviser (WQ) and Dr. Brajesh Shrivastave, Consultant (WQ) who have been substantially involved in preparation of the Handbook.

I am sure the Handbook will be very useful to practicising engineers, chemists, policy makers and all stakeholders working in the water and sanitation sector.

While in some cases the names of products and companies have been mentioned in the Handbook, it should be borne in mind that there may be other such products by other companies. States and other agencies can use this Handbook as the first step in further identifying the most appropriate technologies / products for their requirements and follow relevant State rules / procedures in in any procurement.

Mention of any products and / or companies in the Handbook should not be considered as a recommendation by this Ministry of such a product and / or company.

TMVijaybhaskar
**(T.M. Vijay Bhaskar)**

New Delhi
5th February, 2013

ग्रामीण क्षेत्रों में
पेयजल स्थायित्व एवं सम्पूर्ण स्वच्छता

**Sustainable Drinking Water and**
**Sanitation for all in Rural Areas**

Paryavaran Bhawan, 9th Floor, CGO Complex, Lodhi Road, New Delhi-110003
Tel. : 24361043 Fax : 24364113 E-mail : jstm@nic.in

सी.एस.आई.आर. – राष्ट्रीय पर्यावरण अभियांत्रिकी अनुसंधान संस्थान
**CSIR - National Environmental Engineering Research Institute**
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद् / **Council of Scientific & Industrial Research**)
नीरी
NEERI
ISO 9001 : 2008

**डॉ. सतीश आर. वटे**
निदेशक
**Dr. Satish R. Wate**
Director

# *Preface*

Access to clean water is an important social, economic and environmental issues. Drinking water quality which has direct impact on health due to microbial or chemical contamination needs to be improved through appropriate treatment technologies. Though microbiological contamination is of serious concerns in India, source protection and improving microbiological quality through physical and chemical treatment methods are well established. Rural Water Supply. Agencies are attempting to identify suitable technologies to deal with chemical contaminants of health importance particularly fluoride, arsenic, nitrate and iron. There is also a demand for technologies for reduction of total dissolved solids by these agencies.

With a view to disseminate technical information about drinking water treatment technologies, Ministry of Drinking Water and Sanitation, Government of India, released Handbook on Drinking Water Treatment Technologies in November, 2011. This Handbook was prepared by National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur as a desk study by accessing information on drinking water treatment technologies, interacting with rural private agencies and running query on Water Portal.

Since technology development is a dynamic process and sustained R&D efforts lead to update and or addition of new technologies. Ministry of Drinking Water and Sanitation, Government of India, entrusted National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur to update the Handbook on "Drinking Water Treatment Technologies". Second Version of the Handbook includes two more chapter on chromium and uranium removal from water in addition to updating has ten chapters incorporating drinking water treatment technologies for improvement in microbiological quality and removal of fluoride, arsenic, iron, nitrate, total dissolved solids, chromium and uranium.

This Handbook will be useful reference tool for various stakeholders such as engineers, chemists, public health and water resources professionals, entrepreneurs and sociologists.

**(S.R. Wate)**
Director
CSIR-NEERI, Nagpur

नेहरू मार्ग, नागपुर – 440 020 भारत –Nehru Marg, Nagpur - 440 020 INDIA
**Ph (O) :** 91-712-2249999 **Fax :** 2249900 **Ph ® :** 2220226 **Email :** director@neeri.res.in **URL :** www.neeri.res.in
सतत विकास की ओर / Towards Sustainable Development

# CONTRIBUTING AUTHORS

**NEERI (CSIR), Nagpur**

Dr. Pawan Labhasetwar

Dr. Srimanth Kagne

Er. Subhash Andey

Dr. Nitin Labhsetwar

Dr. Gajanan Khadse

Mr. Prakash Patni

Ms. Rupali Rakhunde

Ms. Poonam Gwala

Ms. Kalpana Korat

Mr. Piyush Mahore

Dr. Satish R. Wate, Director

**Ministry of Drinking Water and Sanitation**, New Delhi

Er. D. Rajasekhar

# CONTENTS

# LIST OF ACRONYMS

| | |
|---|---|
| AA | Activated Alumina |
| AIIH&PH | All India Institute of Hygiene and Public Health |
| ARU | Arsenic Removal Unit |
| ARUBA | Arsenic Removal Using Bottom Ash |
| BAC | Biological Activated Carbon |
| BARC | Bhaba Atomic Research Centre |
| BC | Brick Chips |
| BCSIR | Bangladesh Council of Scientific and Industrial Research |
| BEC | Bengal Engineering College |
| BLAC | Balaji Industries and Agricultures Castings |
| BTU | Bucket Treatment Unit |
| BUET | Bangladesh University of Engineering and Technology |
| C / P | Coagulation / Precipitation |
| CASP | Community Aid & Sponsored Programme |
| CCT | Compact Carbon Trap |
| CEESD | Centre for Energy, Environment and Sustainable Development |
| CFA | Cerium-Iron Adsorbent |
| CGCRI | Central Glass and Ceramic Research Institute |
| CMERI | Central Mechanical Engineering Research Institute |
| CMFRI | Central Mining and Fuel Research Institute |
| COM | Composite Iron Matrix |
| CRS | Coarse River Sand |
| DALY | Disability Adjusted Life Year |
| DO | Dissolved Oxygen |
| DOC | Dissolved Organic Carbon |
| DOD | Department of Ocean Development |
| DOG | Dissolved Oxygen Generation |
| DPDs | Disinfection Byproducts |
| DST | Department of Science and Technology |

| | |
|---|---|
| ECAR | Electro-Chemical Arsenic Remediation |
| ED | Electrodialysis |
| EDR | Electrodialysis Reversal |
| EVOH | Ethylene-vinyl Alcohol Copolymer |
| GAC | Grannular Activated Carbon |
| GFH | Granular Ferric Hydroxide |
| Hb | Momoglobin |
| HWTS | Household Water Treatment and Safe Storage |
| ICOH | Inter-Country Centre for Oral Health |
| IDE | International Development Enterprises |
| IEC | Information, Education and Communication |
| IGCRT | Institute of Glass and Ceramic Research and Testing |
| IGRAC | International Groundwater Resources Assessment Centre |
| IMMT | Institute of Minerals and Materials Technology |
| IOCS | Iron Oxide Coated Sand |
| Knust | Kwame Nkrumah University of Science and Technology |
| LTTD | Low Temperature Thermal Desalination |
| MCL | Maximum Contaminant Level |
| MDWS | Ministry of Drinking Water and Sanitation |
| MED | Multiple Effect Distillation |
| MEE | Multi-Effect Evaporation |
| MetHb | Methemoglobin |
| MF | Microfiltration |
| MSF | Multistage Flash |
| MVC | Mechanical Vapour Compression |
| NEERI | National Environmental Engineering Research Institute |
| NF | Nano-filtration |
| NIOT | National Institute of Ocean Technology |
| NMRL-DRDO | Naval Materials Research Laboratory – Defence Research and Development Organisation |

| | |
|---|---|
| NOM | Natural Organic Matter |
| O&M | Operation and Maintenance |
| OCETA | Ontario Center for Environmental Technology Advancement |
| PET | Polyethylene Terephtalate |
| PLC | Programmable Logic Controller |
| PPP | Public-Private Partnershisp |
| RKM | Rama Krishna Mission |
| RO | Reverse Osmosis |
| SCSS | Silty Clay Sediment Series |
| SDC | Swiss Agency for Development and Cooperation |
| SEC | Solar Energy Centre |
| SEUF | Socio-Economic Unit Foundation |
| SODIS | Solar Water Disinfection |
| SOES | School of Environmental Studies |
| SORAS | Solar Oxidation and Removal of Arsenic |
| TDS | Total Dissolved Solids |
| TERI | The Energy and Resources Institute |
| THMs | Trihalomethanes |
| TNO | The Netherlands Organisation of Applied Scientific Research |
| TVC | Thermal Vapour Compression |
| UF | Ultrafiltration |
| VC | Vapour Compression |
| VCD | Vapour Compression Desalination |
| VTE | Verticle Tube Evaporators |
| WC | Wood Charcoal |
| WHO | World Health Organization |
| WRC | Western Regional Centre |

# 1.0 Introduction

## 1.1 Preamble

The rural population of India comprises more than 700 million people residing in about 1.42 million habitations spread over various hydrological and hydrogeological regions. Provision of safe drinking water sources to large population having different physical, socio-cultural and economic background is a difficult task. There are about 35 lakhs informed public drinking water sources in the country. Considering many uninformed and/or private sources, the total number of drinking water sources in rural India may likely to exceed 60 lakhs. It is estimated that about 37.7 million persons in India are affected by waterborne diseases, 1.5 million children die of diarrhoea and 73 million working days are lost due to waterborne disease annually. The resulting economic burden is estimated at $600 million a year. It is estimated that 66 million Indians are at risk due to excess fluoride and 10 million due to excess arsenic in groundwater. In all, 195,813 habitations in the country are affected by poor water quality which is likely to increase further as results of water quality monitoring and surveillance are being made available.

Attempts are being made to monitor water quality of drinking water sources and it is observed that sources having chemical and microbiological contamination are gradually increasing. However, there are sparse estimates of unsafe sources and temporal variability in level of contamination further complicates the problem. Ministry of Drinking Water and Sanitation (MDWS), Government of India are proposing implementation of Uniform Drinking Water Quality Monitoring protocol which will ensure water quality monitoring of all the drinking water sources every year. This protocol will lead to monitoring of all the sources periodically and may result in identifying sources having microbiological contamination. Though microbiological contamination is of serious concerns in India, source protection and improving microbiological quality through physical and chemical treatment methods are well established. Rural Water Supply Agencies are attempting to identify suitable technologies to deal with chemical contaminants of health importance particular fluoride, arsenic, nitrate and iron. Moreover, there is demand for technologies for reduction of total dissolved solids by these agencies.

Rural India largely depends on ground water to meet drinking water demand. While quantity, access, equity and variability in availability of water are of concerns, water quality is also emerging as major challenge in India. Rapid industrialisation, increasing urbanisation and rampant irrigation are leading to water quality problems. Water quality is affected by both geogenic and anthropogenic sources. While geogenic and anthropogenic sources contribute to chemical contaminants; improper handling and management of sewage, greywater, human and animal excreta; improper collection, storage and handling of drinking water and poor hygiene are the major factors for microbial contamination.

Many people in rural India do not have access to safe sources of water. Moreover, those having access to safe sources of water, contamination of water during transport and in the household presents a significant health risk. Chemical contaminants of geogenic and anthropogenic nature are also significantly increasing in India. Use of sustainable technologies for community and household water treatment and storage is likely to have direct beneficial health effects.

There is conclusive evidence that simple, low-cost and sustainable treatment technologies at the household and community level are capable of dramatically improving the microbial quality of household stored water and reducing the attendant risks of water borne diseases. Similarly, more and more numbers of drinking water sources in India are identified having chemical contamination particularly arsenic, fluoride, nitrate and iron. Many different water collection and storage systems and strategies have been developed, described and evaluated on the basis of various criteria for household and community use in developed and developing countries. A variety of physical and chemical treatment technologies to improve the microbial and chemical quality of water are available and many have been tested and implemented to varying extents in India. There is significant research work being undertaken in India to develop water treatment technologies and some of these systems are tested under controlled conditions in the laboratory and implemented in the field to evaluate their ability to produce drinking water of acceptable quality and to maintain this quality during storage and use.

However, sustainability of technology is a major concern in India and it is observed that successful operation of technologies is dependent on site conditions. Awareness, education, socio-cultural acceptance, behavioural aspects and community dynamism affect achieving sustainability and affordability in the provision of safe water. It is also observed that some of the successful water treatment and storage systems are accompanied by efforts to address these considerations.

This Guidance Manual is prepared as per the requirements of Ministry of Drinking Water and Sanitation (MDWS), Government of India having following objectives:

## 1.2 Objectives

- Identification of existing drinking water treatment technologies in India and other countries with a feasibility of application in India
- Data and information collection on various drinking water treatment technologies with tentative cost estimates
- Suggestive O&M protocol, community mobilization and capacity building protocol and reject management protocol for every treatment technology
- Synthesis of technologies

## 1.3 Approach in preparing the Guidance Manual

The Guidance Manual is prepared as a desk study by accessing information on drinking water treatment technologies, interacting with rural water supply agencies, contacting Departments such as Department of Science and Technology (DST), requesting academic, research institutions and private agencies and running query on Water Portal. Extensive literature search was undertaken on available water treatment techniques and more emphasis was given to technologies implemented in the field than mere tested in the laboratory. Inputs received from these agencies were synthesized and checked for authenticity and subsequently included in the Manual. Similarly, information available from DST on two major programmes namely WAR for water and Water Technology Initiatives was also used for inclusion in the Manual. However, it is found that though numerous attempts are made in the laboratory based research, successful and sustainable application of these technologies in the field are extremely limited. Moreover, drinking water treatment technologies from private entrepreneurs/ organizations are mostly related to point-of-use application with geographical extent limited to urban and peri-urban areas.

The target audience for this Guidance Manual is intended to be engineers, chemists, public health and water resources professionals having knowledge and experience about the fundamentals of drinking water related health sciences and water engineering technology. The Manual is not intended to be a comprehensive document to help the audience to completely design water treatment system or to have detailed cost estimate and engineering design. It is desired that this Manual provides a scientifically sound and supportable basis for identifying, accepting and promoting community and household water treatment and storage systems. The inclusion of technologies in the Guidance Manual does not justify the fact that these technologies are evaluated by NEERI/MDWS and it will not be responsibility of these organizations if some of the technologies listed in document do not achieve the targeted objectives. Content of this document are solely accounted to those of the authors/suppliers and developers of these technologies, who are also responsible for any errors, omissions or other deficiencies that these technologies may contain.

The objective of this Manual is to critically review the various candidate technologies and systems for providing microbiologically and chemically improved water and to present appropriate technologies based on their technical description, implementation potential, replication possibility and performance criteria.

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 2.0 Water Treatment – Improvement in Microbiological Quality

## 2.1 Water treatment

Water treatment particularly to treat chemical contaminants should be the last alternative and be practiced if possibility of identifying safe water source is remote. However, various rural water supply agencies struggle to identify sustainable and accessible safe water source in villages particularly affected with chemical contaminants such as fluoride and arsenic. In rural perspective, advance and complex water treatment technologies might not be viable option. Water treatment technologies should be simple, easy to operate and maintain, affordable, should not require external source and utilise local resources. Identifying technology meeting afore referred criteria is extremely difficult, however, academic and research institutions are developing and simplifying already available technologies. Use of traditional methods for water treatment should be explored; however, these methods should be verified and practiced in pilot basis to justify their utility.

Water treatment is undertaken at the household or/and at the community level. It is observed that community ownership, socio-cultural issues and awareness and togetherness among community are major factors for successful implementation, operation and maintenance of community based water treatment plants. There are several instances of successful community based water treatment plant operations if community contribution in terms of financial and labour inputs is ensured.

### 2.1.1 Community based water treatment

In India and other parts of the world, community based treatment plants are installed to provide safe water at centralised locations. These plants cater to a number of families and are regulated either by the government or private agencies and community. It is required by rural water supply agencies to provide safe water to the community and it is preferred to install centralised plants. Community based plants are required and may work efficiently if household treatment options are not viable and not preferred by community and water supply agencies. In India, rural water supply agencies only remain responsible to provide safe water up to source of water and they prefer to have community based water treatment plants. Though community based plants are viable options and preferred by the agencies, household water collection, handling, treatment and storage provide additional public health benefits. Therefore, household water treatment is also included in this manual in addition to community based water treatment plants.

#### 2.1.1.1 Conventional water treatment: coagulation, flocculation and filtration

Many water treatment plants use a combination of coagulation, sedimentation, filtration and disinfection to provide clean and safe drinking water to the public. Worldwide, a combination of coagulation, sedimentation and filtration is the most widely applied water treatment technology, and has been used since the early 20th century.

**a) Coagulation**

The coagulation process involves adding iron or aluminium salts, such as aluminium sulphate, ferric sulphate, ferric chloride or polymers, to the water. These chemicals are called coagulants, and have a positive charge. The positive charge of the coagulant neutralizes the negative charge of dissolved and suspended particles in the water. When this reaction occurs, the particles bind together, or coagulates (sometimes this process is called as flocculation). The larger particles, or floc, are heavy and quickly settle to the bottom. This settling process is called sedimentation. Figure 2.1 illustrates the basic reactions and processes that occur during coagulation.

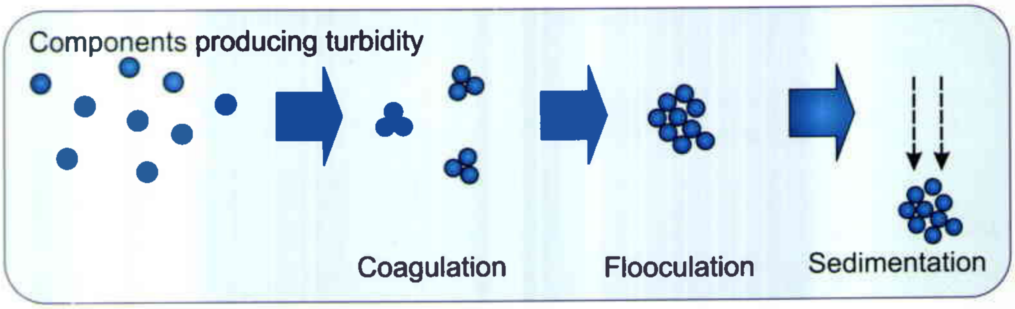


**Figure 2.1 :** Basic reactions and processes during coagulation

**b) Process of coagulation, flocculation and sedimentation**

Table 2.1 presents the length of time that is required for particles of different sizes to settle through the water.

**Table 2.1 :** Settling Time for Particles of Various Diameters

| Diameter of Particle | Type of Particle | Settling time through 1 m of water |
|---|---|---|
| 10mm | Gravel | 1 seconds |
| 1mm | Sand | 10 seconds |
| 0.1mm | Fine Sand | 2 minutes |
| 10 micron | Protozoa, Algae, Clay | 2 hours |
| 1 micron | Bacteria, Algae | 8 days |
| 0.1 micron | Viruses, Colloids | 2 years |
| 10 nm | Viruses, Colloids | 20 years |
| 1 nm | Viruses, Colloids | 200 years |

In a water treatment facility, the coagulant is added to the water and it is rapidly mixed, so that the coagulant is circulated throughout the water. The coagulated water is moved to a settling tank. In a settling tank, or clarifier, the heavy particles settle to the bottom and are removed, and the water moves on to the filtration step of the treatment process.

Coagulation can successfully remove a large amount of organic compounds, including some dissolved organic material, which is referred to as Natural Organic Matter (NOM) or Dissolved Organic Carbon (DOC). Coagulation can also remove suspended particles, including inorganic precipitates, such as iron hydroxides. A large amount of DOC can give water an unpleasant taste and odour, as well as a brown discolouration. While coagulation can remove particles and some dissolved matter, the water may still contain pathogens. Coagulation and sedimentation can only remove between 27 and 84 percent of viruses and between 32 and 87 percent of bacteria. Usually, the pathogens that are removed from the water are removed because they are attached to the dissolved substances that are removed by coagulation.

As coagulation does not remove all of the viruses and bacteria in the water, it cannot produce safe drinking water. It is, however, an important primary step in the water treatment process, because coagulation removes many of the particles, such as dissolved organic carbon, that make water difficult to disinfect. Because coagulation removes some of the dissolved substances, less chlorine must be added to disinfect the water. A water treatment plant can save money by using less chlorine, and the water will be safer, because trihalomethanes (THMs) are harmful by-product that results from the reaction of chlorine with NOM.

With accurate dosages and proper application, the residuals of the added chemicals generally do not pose a problem. Residuals are the by-products that remain in the water after substances are added and reactions occur while treating water. The particular residuals depend on the coagulant that is used. If ferric sulphate is used, iron and sulphate are added to the water. If ferric chloride is used, iron and chloride are added. And if aluminium sulphate is used, aluminium and sulphate are added. The majority of water treatment plants use aluminium sulphate as the coagulation chemical. Generally, water treatment facilities have the coagulation process set up so that the coagulant chemicals are removed with the floc.

### c) Filtration

The next step in a conventional water treatment system is filtration, which removes particulate matter from water by forcing the water to pass through porous media. The filtration system consists of filters with varying sizes of pores, and is often made up of sand, gravel and charcoal.

There are two basic types of sand filtration; slow sand filtration and rapid sand filtration. Slow sand filtration is a biological process, because it uses bacteria to treat the water. The bacteria establish a community on the top layer of sand and clean the water as it passes through, by digesting the contaminants in the water. The layer of microbes is called a schumtzdecke (or biofilm), and requires cleaning every couple of months, when it gets too thick and the flow rate declines. After the schumtzdecke is removed, the bacteria must be allowed several days to re-establish a community before filtering can resume. Slow sand filtration systems have been used for many years. However, slow sand filtration systems require large areas of land to operate, because the flow rate of the water is between 0.1 and 0.3 m3 per hour. Due to the land area that is required and the down-time for cleaning, rapid sand filters, which were developed in the early 20th century, are much more prevalent today.

Rapid sand filtration is a physical process that removes suspended solids from the water. Rapid sand filtration is much more common than flow sand filtration, because rapid sand filters have fairly high flow rates and require relatively little space to operate. In fact, during rapid sand filtration, the water flows at a rate up to 20 $m^3$ per hour. The filters are generally cleaned twice per day with backwashing filters and are put back into operation immediately.

The particles that are removed from the water during filtration depend upon the size of filters that are used. Slow sand filtration removes bacteria, protozoa and viruses, and produces essentially clean water, though it is still advisable to also use a disinfectant. Rapid sand filtration removes suspended particles, which may have bacteria attached, but in general does not remove bacteria, protozoa, or viruses. In water treatment plants, filtration removes a large number of contaminants, but still requires disinfection to produce drinking water that is safe. Though rapid sand filtration cannot effectively remove bacteria and viruses, it is an important step in the water treatment process. Like coagulation, filtration can remove the suspended and dissolved matter so that disinfection is more successful with a reduced amount of chlorine.

## 2.1.2 Household Water Treatment

Treating water at the household level has been shown to be one of the most effective and cost-effective means of preventing waterborne disease in development and emergency settings. Promoting household water treatment and safe storage (HWTS) helps vulnerable populations to take charge of their own water security by providing them with the knowledge and tools to treat their own drinking water.

While household water treatment offers superior health gains, the economic advantages over conventional improvements in water supplies are equally compelling. The cost of implementing water quality interventions varies as per Table 2.2:

**Table 2.2 :** Cost of Water Quality Interventions

| | Water treatment Method | Cost/person/year |
|---|---|---|
| 1. | Solar Disinfection | US$0.63 |
| 2. | Chlorination | US$0.66 |
| 3. | Ceramic Filters | US$3.03 |
| 4. | Combined Flocculation/Disinfection | US$4.95 |
| 5. | Installing & Maintaining Wells, borehole and Communal Tap Stands in Africa | US$1.88 |

(Clasen 2007)

The combination of lower cost and higher effectiveness renders household-based chlorination the most cost effective of water quality interventions to prevent diarrhoea, with a cost effectiveness ratio in Africa of US$53 per disability-adjusted life year (DALY) averted, compared to US$123 for conventional source-based interventions.

When health cost savings are included in the analysis, implementing low-cost HWTS interventions actually result in net savings to the public sector; in other words, the intervention more than pays for itself (Clasen 2007). A recent WHO-sponsored analysis also concluded that household-based chlorination was among the most cost-beneficial options yielding high returns on every dollar invested mainly from lower health care costs but also increased productivity and value of school attendance (Hutton 2007). Finally, there is considerable evidence that the target population is willing and able to pay for some or all of the cost of household based water treatment products (Ashraf 2006), leveraging public sector and donor funding and allowing it to be more focused on the base of the economic pyramid. In summary, (i) the up-front cost of providing low-cost household water treatment is about half that of conventional source-based interventions, (ii) most or all of that cost can be borne directly by the beneficiary, not the public sector, and (iii) the public sector will nevertheless recover more than the full cost of implementation from reduced health costs for disease treatment.

## 2.2 Microbial Contamination

### 2.2.1 Treatment Technologies to Improve Microbiological Quality of Drinking Water

It is observed that even if water source is properly maintained and water is disinfected prior to distribution in small community, contamination during distribution and at household is a definite possibility due to various reasons. Treatment technologies to improve microbial quality of drinking water (will be referred as disinfection) are mainly available at household level and chlorination is preferred choice for disinfection for community water supply. There exists several technologies for treatment of household water and many such technologies are widely used in different parts of the world including India. These treatment technologies include a number of physical and chemical methods. The physical methods include settling, filtering particularly through cloth, boiling, heating (fuel and solar) and UV disinfection with lamps. The chemical methods include coagulation-flocculation and precipitation, adsorption, ion exchange and chemical disinfection particularly by using chlorine.

These technologies for providing microbiologically (particularly bacteria) safe drinking water appear to be affordable, simple and sustainable in rural context. Among technologies and systems currently available, the following appear to be having definite potential for development, implementation and dissemination:

- Boiling
- Solar disinfection by the combined action of heat and UV radiation
- UV disinfection with lamps
- Chlorination
- Combined systems of chemical coagulation-filtration and chlorine disinfection.

In India, it is observed that drinking water if collected from surface water sources and in certain instances from groundwater contains high turbidity. It is more complex to treat water to make it bacteriologically safe if turbidity is high. This is because potential of microbial reductions in presence of particles are reduced or prevented as it reduces access to target microbes or otherwise protect them from inactivation by other mechanisms. Turbidity causing particles present in water reduces the disinfection efficiency of chlorine and other chemical disinfectants as these particles physically shield microbes from action.

Pre-treatment technologies for removal of turbidity (suspended matter) from water suitable for such applications potentially include:

- Settling or plain sedimentation
- Fibre, cloth or membrane filters
- Granular media filters and
- Slow sand filter.

## 2.2.2 Water Treatment Methods

### 2.2.2.1 Physical Methods

Physical and chemical methods for disinfection or improving microbiological water quality are summarized in Tables 2.3 and 2.4 respectively. These methods are listed along with categorizations (listed as high, medium and low) of their availability and practicality, technical difficulty, cost and microbial efficacy (WHO, 2002).

These methods for disinfection are known hence they are not described in detail in the Manual and details can be obtained from the document "Managing Water in the Home: Accelerated Health Gains from Improved Water Supply" (WHO, 2002). There are various filter materials available and considered to be effective in improving water quality in households and presented in Table 2.5.

**Table 2.3 :** Physical Methods for Water Treatment at the Household Level

| Method | Availability and Practicality | Technical Difficulty | Costa | Microbial Efficacyb |
|---|---|---|---|---|
| Boiling or heating | Varies[c] | Low-Moderate | Varies[c] | High |
| Exposure to Sunlight (SODIS) | High | Low-Moderate | Low | Moderate |
| UV Irradiation (lamps) | Varies[d] | Low-moderate | Moderate-high[d] | High |
| Plain Sedimentation | High | Low | Low | Low |
| Filtratione | Varies[e] | Low-Moderate | Varies[e] | Varies[f] |
| Aeration | Moderate | Low | Low | Low[g] |

a Categories for annual household cost estimates in US dollars are less than $10 for low, >$10-100 for moderate and >$100 for high.

b Categories for microbial efficacy are based on estimated order-of-magnitude or log10 reductions of waterborne microbes by the treatment technology. The categories are <1 $\log_{10}$ (<90%) is low, 1 to 2 $\log_{10}$ (90-99%) is moderate and >2 $\log_{10}$ (>90% is high).

c Depends on heating method as well as availability and cost of fuels, which range from low to high.

d Depends on availability of and type of lamps, housings, availability and cost of electricity, as well as operation and maintenance needs (pumps and system cleaning methods)

e Different filtration technologies are available. Some (e.g., membrane filtration) are recommended for emergency water treatment). Practicality, availability, cost and microbial efficacy depend on the filter medium and its availability: granular, ceramic, fabric, etc.

f Depends on pore size and other properties of the filter medium, which vary widely. Some are highly efficient (>> 99% or >> 2 $\log_{10}$) for microbial removals.

g Aeration (oxygenation) may have synergistic effects with other water treatments, such as solar disinfection with sunlight or with other processes that may oxidize molecular oxygen.

### a) Boiling or Heating

Boiling is the oldest and most commonly practiced household water treatment/disinfection method since decades. It is also one of the widely recommended methods both for water treatment in developing countries and to provide safe drinking water in emergency situations across the world. Boiling the water in a container over hot plate or any other heating device and at 100°C/212°F for 15-20 minutes disinfects it. Boiling water is an effective method of treatment as no important water-borne diseases are caused by heat resisting organisms. This technique may be used effectively after a flood or when a main water pipe bursts as an emergency aid.

### b) Exposure to Sunlight (SODIS)

Solar Water Disinfection (SODIS) is an ideal method for treating water for drinking mostly in developing countries. It is a simple water treatment method which uses solar radiation (UV-A light and temperature) to destroy pathogenic bacteria and viruses present in water. Its efficiency to kill protozoa is dependent on water temperature reached during solar exposure and on the climatic and weather conditions. Microbiologically contaminated water is filled into clear PET bottles and exposed to full sunlight for 6 hours or more depending on weather and climatic conditions. Very turbid water with a turbidity of more than 30 NTU cannot be used for SODIS. Imp ortant points to be considered for applying SODIS method are given below:

#### Material, Colour and Shape of the Bottle

Use of (Polyethylene terephtalate) PET bottles in the application of the SODIS method because they are light in weight and do not break. Moreover, they can also be obtained easily in many regions of the world. However, even glass bottles or special bags can be used. Generally, bottles or containers used for SODIS method must be transparent and colourless and also should not exceed a depth of 10 cm.

#### Turbidity

If the water is very turbid, the effectiveness of the method is reduced. The turbidity of water should be around 30 NTU so that this method can be applied successfully.

#### Cloudiness

It is well known that cloudiness affects the strength of solar radiation this in turn also affects the effectiveness of the method.

### Rain

It does not work satisfactorily during lengthy periods of rain. On these days, collecting rain water is recommended. However, it should be properly treated and disinfected before drinking.

### Preventing Recontamination

The treated water should be kept in the same bottle and drunk directly from it, or poured into a cup or glass immediately before it is drunk. In this way, it is possible to prevent the treated water from becoming contaminated again.

### c) Ultraviolet Irradiation (lamps)

The use of ultraviolet light is an attempt to mimic the nature. Sunlight destroys some bacteria in the natural purification of water. Exposing water to ultraviolet light destroys pathogens. It uses a UV light source (lamp) which is generally enclosed in a protective transparent sleeve usually made up of quartz. The lamp is mounted such that water passing through a flow chamber is continuously exposed to the UV light rays. When harmful microbes present in water are exposed to the UV rays, their nucleic acid absorbs the UV energy, which then scrambles the DNA structure of the microbes so that cell is rendered sterile and can no longer reproduce. The cell is now considered to be dead and is no longer a health threat. UV treatment is an excellent choice to eliminate harmful microbes/biological contamination from household drinking water, whether it is from municipal water or untreated private water system like well, lake water etc. hence, it should always be combined with other forms of filtration like Granular Activated Carbon (GAC) / carbon black, reverse osmosis etc., in order to reduce other chemical contaminants like heavy metals, chlorine, VOCs etc.

### d) Plain Sedimentation or Settling

The microbial quality of water sometimes can be improved by holding or storing it without mixing long enough, for larger particles to settle by gravity. Storing water for few hours will allow settling of large, dense particles, such as inorganic sands and silts, large microbes and any other microbes associated with larger, denser particles. However, extended settling times for 1-2 days or more will be required for comparatively large sized microorganism. Therefore, microbial reductions by plain sedimentation or gravity settling are often low and inconsistent. Overall reductions of viruses and bacteria by sedimentation rarely exceed 90%, but reductions of helminth ova and some protozoans can exceed 90%, especially with longer storage times of 1-2 days. The settled water can then be carefully removed without disturbing the settled particles.

Sedimentation of household water can be done in simple storage vessels, such as pots and buckets. Care must be taken to avoid disturbing the sedimented particles when recovering the supernatant water by decanting or other methods. Typically, at least two containers are needed to settle water: one to act as the settling vessel and another to be the recipient of the supernatant water after the settling period. Water also can be settled in larger bulk storage systems, such as cisterns, basins and tanks. Regard less of the sedimentation vessel, it is essential that solids are removed and the vessel cleaned on a regular basis. Hence, plain sedimentation or gravity settling of highly turbid water for household use is recommended as a pre-treatment for systems that disinfect water with solar radiation, chlorine or other chemical disinfectants. Furthermore, sedimentation of particles improves the aesthetic qualities of the water and thereby increases its acceptance by consumers. Pre-treatment of turbid household water by sedimentation is recommended because is easy to perform and requires a minimum of materials or skill.

### e) Filtration

Filtration is another widely used technology that removes particles and some microbes from water. There are various types of filter media and filtration processes for treatment of water. The practicality, ease of use, availability, accessibility and affordability of these filtration media and methods vary widely and often depend on local factors. The effectiveness of these filtration methods in reducing microbes also varies widely, depending on the type of microbe and the type and quality of the filtration media or system.

- Granular media, rapid rate depth filter
- Slow sand filter
- Vegetable and animal derived depth filters
- Fabric, paper, membrane, canvas, etc. filter
- Ceramic and other porous cast filters
- Septum and body feed filters

**Table 2.4 :** Filters and Filtration Media for Treatment of Household Water

| Type of Filtration | Media | Availability | Ease of Use | Effectiveness (Comments) | Cost |
|---|---|---|---|---|---|
| Granular media, rapid rate depth filter | Sand, gravel, diatomaceous earth, coal, other minerals | High | Easy to Moderate | Moderate* (depends on microbe size and pre-treatment) | Low to moderate |
| Vegetable and animal derived depth filters | Coal, sponge, charcoal, cotton, etc. | Medium to high | Moderate to Difficult | Moderate* | Low to moderate |
| Fabric, paper, membrane, canvas, etc. filter | Cloth, other woven fabric, synthetic polymers, wick siphons | Varies: some low; others high | Easy to moderate | Varies from high to low (with pore size and composition) | Varies: low for natural; high for synthetics |
| Ceramic and other porous cast filters | Clay, other minerals | Varies: high- low, with materials availability and fabrication skill | Moderate. Must be physically cleaned on a regular basis to prevent clogging and biofilm growth | Varies from high to low (with pore size and ceramic filter quality) | Moderate to high |
| Septum and body feed filters | Diatomaceous earth, other fine media | Varies | Moderate to difficult; dry media a respiratory hazard | Moderate | Varies |

* Moderate typically means 90-99% reductions of larger pathogens (helminth ova and larger protozoans) and solids-associated pathogens, but low (<90%) reductions of viruses and free bacteria, assuming no pre-treatment. With pre-treatment (typically coagulation), pathogen reductions are typically >99% (high).

### 2.2.2.2 Chemical or Physico-Chemical Methods

Chemical disinfectants are chemical substances, which are used to kill or deactivate pathogenic microorganisms. Some of the chemicals which have disinfection properties include chlorine and chlorine compounds, hydrogen peroxide, ozone, etc. Till date, there is no perfect disinfectant. However, certain features of the disinfectant should be considered while choosing the most suitable disinfectant.

- Ability of the disinfectant to penetrate and destroy infectious agents under normal operating conditions.

- Lack of features that could be harmful to people and the environment
- Safe and easy handling, shipping and storage
- Absence of toxic residuals such as cancer-causing compounds, after disinfection
- Affordable capital and operation and maintenance (O&M) costs.

**Table 2.5 :** Chemical or Physico-Chemical Methods for Water Treatment at the Household Level

| Method | Availability and Practicality | Technical Difficulty | Cost[a] | Microbial Efficacy[b] |
|---|---|---|---|---|
| Coagulation-Flocculation or Precipitation | Moderate | Moderate | Varies | Varies[c] |
| Adsorption (charcoal, carbon, clay, etc.) | High to moderate | Low to moderate | Varies | Varies with adsorbent[d] |
| Ion exchange | Low to Moderate | Moderate to high | Usually High | Low or moderate |
| Chlorination | High to Moderate | Low to Moderate | Moderate | High |
| Ozonation | Low | High | High | High |
| Chlorine Dioxide | Low | Varies[e] | High | High |
| Iodination (elemental, salt or resin) | Low | Moderate to High | High | High |
| Acid or base treatment with citrus juice, hydroxide salts, etc. | High | Low | Varies | Varies |
| Silver or Copper | High | Low | Low | Low |
| Combined systems : chemical coagulation-flocculation, filtration, chemical disinfection | Low to Moderate | Moderate to High | High | High |

a Categories for annual household cost estimates in US dollars are less than \$10 for low, >\$10-100 for moderate and >\$100 for high.

b Categories for microbial efficacy are based on estimated order-of-magnitude or log10 reductions of waterborne microbes by the treatment technology. The categories are <1 $\log_{10}$ (<90%) is low, 1 to 2 $\log_{10}$ (90-99%) is moderate and >2 $\log_{10}$ (>90% is high).

c Varies with coagulant, dose, mixing and settling conditions and pH range

d Microbial adsorption efficiency is low for charcoal and carbon and high for some clays

e On-site generation of gas is difficult but chemical production by acidifying chlorate or chlorite is simple if measuring devices and instructions are provided.

**Table 2.6 :** Filters and Filtration Media for Treatment of Household Water Characteristics, Advantages and Disadvantage

| Type of Filtration | Media | Availability | Ease of Use | Effectiveness (comments) | Cost |
|---|---|---|---|---|---|
| Granular media, rapid rate depth filter | Sand, gravel, diatomaceous earth, coal, other minerals | High | Easy to Moderate | Moderate* (depends on microbe size and pre-treatment) | Low to moderate |

| Type of Filtration | Media | Availability | Ease of Use | Effectiveness (comments) | Cost |
|---|---|---|---|---|---|
| Slow sand filter | Sand | High | Easy to moderate (community use) | High** in principle but often low in practice | Low to moderate |
| Vegetable and animal derived depth filters | Coal, sponge, charcoal, cotton, etc. | Medium to high | Moderate to Difficult | Moderate* | Low to moderate |
| Fabric, paper, membrane, canvas, etc. filter | Cloth, other woven fabric, synthetic polymers, wick siphons | Varies: some low; others high | Easy to moderate | Varies from high to low (with pore size and composition) | Varies: low for natural; high for synthetics |
| Ceramic and other porous cast filters | Clay, other minerals | Varies: high-low, with materials availability and fabrication skill | Moderate. Must be physically cleaned on a regular basis to prevent clogging and biofilm growth | Varies from high to low (with pore size and ceramic filter quality) | Moderate to high |
| Septum and body feed filters | Diatomaceous earth, other fine media | Varies | Moderate to difficult; dry media a respiratory hazard | Moderate | Varies |

* Moderate typically means 90-99% reductions of larger pathogens (helminth ova and larger protozoans) and solids-associated pathogens, but low (<90%) reductions of viruses and free bacteria, assuming no pre-treatment. With pre-treatment (typically coagulation), pathogen reductions are typically >99% (high)

** High pathogen reduction means >99%

## 2.3 Disinfection

### 2.3.1 Chlorine

Chlorine is one of the most versatile chemicals used in water treatment/disinfection. Chlorine can be applied for the deactivation of most microorganisms (excluding protozoa which are resistant to chlorine) and it is relatively cheap. When chlorine reacts with water it forms hypochlorous acid which then undergoes dissociation to form hypochlorite ion. The distribution of chlorine into hypochlorous and hypochlorite ion is pH dependent. Hypochlorous acid is a stronger disinfectant than hypochlorite ion and therefore a lower pH is preferred for disinfection with chlorine. The chlorine attacks bacterial cells and the protein coat of viruses, hence effectively killing both bacteria and viruses. Chlorination, while highly effective at inactivating pathogens, produces several potential harmful by-products.

The influencing factors to be considered in chlorination process are the following:

- Chlorine concentration
- Contact time
- pH
- Temperature and
- Interfering substances

### 2.3.2 Chloramines

Chloramines are typically used along with chlorine as a part of the drinking water treatment process. Chloramines are most commonly formed when ammonia is added to chlorine treated water. Different types of chloramines that are produced while treating water are monochloramine, dichloramine, trichloramine and organic chloramines but most of them are formed at much lower levels than monochloramine. So, among them monochloramine is the most effective disinfectant. It reacts directly with amino acids in the bacterial DNA. During deactivation of microorganisms, chloramines destroy the shell which protects a virus. When the pH value is 7 or higher, monochloramine is the most abundant chloramines. The pH value does not interfere with the effectiveness of chloramines. Chloramines provide long-lasting protection as they do not break down quickly in water pipes. The most typical purpose of chloramines is to protect water quality as it moves through pipes.

### 2.3.3 Chlorine Dioxide

Chlorine dioxide ($ClO_2$) is another chlorine derivative which is an unstable, potentially explosive gas. Therefore, it must be generated at the point of application. Chlorine dioxide can be used both as a disinfectant and oxidizing agent for drinking water treatment. Chlorine dioxide is the only biocide that is a molecular free radical which disinfects through oxidation. The need arose when it was discovered that chlorine and similar products formed some dangerous DPD's (Disinfection by-products) like THM (trihalomethanes).

### 2.3.4 Hypochlorites

Sodium hypochlorite and calcium hypochlorite both are chlorine derivatives that are formed by the reaction of chlorine with hydroxides. The application of hypochlorites to water systems produces the hypochlorite ion and hypochlorous acid, just as the application of chlorine. Both the hypochlorites can be effectively used for water purification. They are used on large scale for surface purification, bleaching, odour removal and water disinfection. In general, the stability of hypochlorite solutions are adversely affected by heat, light, pH and metal contamination. All hypochlorites are somewhat harmful to skin and must be handled carefully. Corrosion-resistant materials should be used for storing and dispensing.

### 2.3.5 Electrochlorinators

On-site Hypochlorite generation and the electrolysis process of salt to produce Sodium Hypochlorite for drinking water purification are internationally accepted practices. In Electrochlorination Process, common salt (Equivalent to IS797 Grade II) is dissolved in water to prepare brine solution. This solution is passed across electrodes and low voltage direct current is applied and as a result of this a diluted 0.6 to 0.8% sodium hypochlorite solution is generated. Electrochlorinators are being increasingly used for online chlorination in water treatment plant and for booster chlorinators during piped water supply.

The direct current, passing through the brine flowing in the electrolyzer, where the sodium chloride is completely dissociated into the ions $Na^+$ and $Cl^-$. The complete process is complex but the final result is well represented by the following formula:

$$NaCl + H_2O + \text{energy} \rightarrow NaOCl + H_2$$

Thus generated solution contains 0.7% to 1% chlorine as <1% hypochlorite is classified as a non-hazardous chemical. The only byproduct hydrogen is safely vented into the atmosphere. Electrochloriator is preferred water disinfection/antifouling option as compared to gaseous chlorine, commercial hypochlorite and bleaching powder considering safety, economy and convenience.

Details of available electrochloriators are provided in Annexure I.

### 2.3.6 Hydrogen Peroxide

Among other applications, hydrogen peroxide is also used for the disinfection of water. Hydrogen peroxide is a strong oxidizer. It is more powerful than chlorine($Cl_2$), chlorine dioxide ($ClO_2$) and potassium permanganate ($KMnO_4$). It is used to control biological growth, to add oxygen, to remove chlorine residues and to oxidize sulphides, sulphites, metals and other easily oxidized materials. The efficiency of hydrogen peroxide is greatly influenced by pH, temperature, peroxide concentration and reaction time. Hydrogen peroxide reacts very fast and then disintegrates into water and oxygen, without the formation of by-products which in turn increases the amount of dissolved oxygen (DO) in water.

Peroxides such as hydrogen peroxide ($H_2O_2$), perborate, peroxiphosphate and persulphate are good disinfectants and oxidisers. In general, these can adequately remove micro-organisms. However, these peroxides are very unstable. Recently, advanced oxidation processes involve combination of hydrogen peroxide with ozone (perozone) or ultraviolet light which is a new development in the field of hydrogen peroxide disinfection. The use of these methods is increasing rapidly worldwide for groundwater treatment, drinking water and industrial process water treatment.

### 2.3.7 Copper-Silver Ionization Method

Since mid 1980's, Copper-silver ionization method has continued to evolve into the revolutionary technology that it is today. In the method, electrically charged copper ions ($Cu^{2+}$) in the water search for particles of opposite polarity, such as bacteria, viruses and fungi. Positively charged copper ions form electrostatic compounds with negatively charged cell walls of microorganisms. These compounds disturb cell wall permeability and cause nutrient uptake to fail. Copper ions penetrate the cell wall and as a result they will create an entrance for silver ions ($Ag^{+}$). These penetrate the core of the microorganism. Silver ions bond to various parts of the cell, such as the DNA and RNA, cellular proteins and respiratory enzymes, causing all life support systems in the cell to be immobilized. As a result, there is no more cellular growth or cell division; causing bacteria to no longer multiply and eventually die out. The ions remain active until they are absorbed by a microorganism.

## 2.4 Protection, Collection and Storage of Water in Community and Households

Protection of water sources, hygienic collection and storage of water are important factors in the provision of safe household water. There are several studies in the world and India which had clearly demonstrated vulnerable water sources, inadequate storage conditions and vulnerable water storage containers contributing to increased microbial contamination and decreased microbial quality compared to either source waters or water stored in improved vessels. There are various risk factors which contribute to contamination of sources and stored water households which otherwise should remain safe. In case of sources and households, these risk factors can easily be identified using sanitary surveillance. These risk factors vary for type of source e.g. for groundwater source attached to hand pump, risk factors may include breakage of platform, choking of drainage channel, accumulated water around handpump etc. Higher levels of microbial contamination are normally associated with storage vessels having wide openings, vulnerability to access of hands, cups and dippers that can carry faecal contamination, and lack of a narrow opening for dispensing water.

Different types of water collection and storage containers with respect to their advantages and limitations for safe storage and use of household water are described in detail (Mintz et al., 1995; Reiff et al., 1995; USA CDC, 2001) and major findings and recommendations are presented in Table 2.7.

**Table 2.7 :** Advantages and Disadvantages of Alternative Household Water Storage Vessels

| Type of Vessel | Protected opening for filling and cleaning | Size of volume | Material / cleanability / composition compatible with use | Protected dispenser (Spigot, spout, etc.) | Shape / weight / portability |
|---|---|---|---|---|---|
| Pot, jug or Um | Varies; some yes, some no | Varies; usually 4-40 L | Varies / Varies / Varies | No, often; Yes, some | Varies / Varies / Moderate-High |
| Cooking Pot | Yes (lid) No (no lid) | Varies; usually 4-40 L | Plastic or Metal / High / Varies | No | Cylindrical / Varies / Moderate-High |
| Gourd (Calabash) | Yes | Varies, usually 1-10 liters | Plant fruit / moderate / moderate | Yes, usually | Globular or elliptical, with a curved neck |
| Flexible Bags, Flagons, etc. | Yes | Varies, typically 1-10 L | Animal hide or bladder, canvas, rubber, plastic, etc. / Varies / Varies | Yes | Elliptical, oval of rectangular / Light / High |
| Storage Drum or Barrel | No | Varies, often 200 L (55 gal.) | Metal / Moderate / High | No | Cylindrical / Heavy / Low |
| Cistern or Basin | No, typically | Varies, often large (>200 L) | Varies: concrete, metal, clay / Low-moderate / High | Often No | Cylindrical; Rectangular / Heavy / Low |
| Plastic Beverage Bottle | Yes, if cap is available | Usually 1- 2 L | Plastic / High-Moderate / Varies by type of plastic and use conditions | Yes, narrow mouth | Cylindrical / Light / High |
| Jerry Can | Yes | Usually 1- 2 L | Metal; Plastic / Medium / varies | Yes, narrow mouth | Rectangular / Light / High |
| CDC Vessel | Yes | 20 L | Plastic / High / High for chlorination Treatment, low for solar Treatment | Yes, spigot | Rectangular / Light / High |
| Oxfam Vessel[a] | Yes | 14 L | Plastic / High / High for chlorination Treatment, low for solar Treatment | Yes, spigot | Cylindrical / Light / High |

[a] Oxfam vessel is used primarily for emergency water storage and delivery. But vessels of similar size and shape have been used for household water collection and storage worldwide.

## References:

1. Ashraf N, Berry J, Shapiro J (2006). Can Higher Prices Stimulate Product Use? Evidence from a Field Experiment on Chlorin in Zambia. Presentation at the Berkeley Water Center Workshop on water sanitation and hygiene, Berkeley, California, November 6, 2006
2. Bajpai S., Nano-Technology for Safe Water Benefitting Bottom of the Pyramid Department of Science & Technology
3. CDC (2001). Safe Water Systems for the Developing World: A Handbook for immplementing Household-Based Water Treatment and Safe Storage Programs. Atlanta, GA, USA: Centers for Disease Control and Prevention. (downloaded from http://www.cdc.gov/safewater/manual/sws_manual.pdf)
4. Clasen T, Haller L, Walker D, Bartram J, Cairncross S (2007). Cost-effectiveness analysis of water quality interventions for preventing diarrhoeal disease in developing countries. J. Water & Health 5(4):599-608
5. Hutton G, Haller L, Bartram J (2007). Global cost-benefit analysis of water supply and sanitation interventions.
6. http://cdn.changemakers.com/sites/default/files/Jal%20tara%20water%20filter.pdf
7. Mintz, E.D., F.M. Reiff, et al. (1995). "Safe Water Treatment and Storage in the Home: A Practical new strategy to prevent waterborne disease." Journal of the American Medical Association 273(12):948-953.
8. MIT, 2011, Water: Low Cost Water Purifiers, Technology review India
9. Murugan K., Revathi J., Hebalkar N.and Rao T.N., Nano silver coated ceramic filter candles for disinfectant water filter applications
10. Nanotechnology developments in India – a status report, 2009, The International Development Research Centre, Canada,[Part of project: Capability, Governance and Nanotechnology Developments: a focus on India]
11. Reiff, F. M., M. Roses, et al. (1995) "Low-Cost Safe Water for the World: A practical interim solution." Journal of Public Health Policy 17(4): 389-408.
12. Vijaya Lakshmi K., Nagrath K., Jha A., 2001. Access to Safe Water: Approaches for Nanotechnology Benefits to Reach the Bottom of the Pyramid. Project report to UK DFID, May 2011. Development Alternatives Group, New Delhi.
13. WHO (2002), Managing Water in the Home: Accelerated Health Gains from Improved Water Supply, Geneva: World Health Organization.

### Table 2.8 : Comparative Statement of Technologies available for Disinfection of Water

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENCEE CHLOR Generator | NAGPUR AQUATECH (P) LTD.Works (Nagpur) | Chlorination by electrolysis of salt water | -- | -- | -- | -- | Community | -- | -- | -- | -- | -- | -- | -- | Effective technology for disinfection |
| SOLAR MAC® Electrochlorinators | De Nora India | Chlorination by electrolysis of salt water | various sites in Goa | -- | -- | -- | Community | -- | -- | No | 3000 liters/hr | -- | No | No | successful for disinfection of water on field |
| SEACLOR Mac® Batch/continuous Model | De Nora India | Chlorination by electrolysis of salt water | Tested in field | -- | -- | -- |  | -- | -- | -- | -- | -- | -- | -- | successful for disinfection |
| Smart Electrochlorinator 200 (SE200) | PATH, USA | Chlorination by electrolysis of salt water | Tested in field | -- | -- | -- | Community | -- | Rs 5500 for 200 liter capacity | No | -- | Rs 0.0027/lit | No | No | Disinfection without affecting taste and odor |
| Florichlor (AGIL power control system) | AGIL power control system | Disinfection by hypochlorite ions | Field Tested | -- | -- | -- | -- | -- | -- | -- | -- | -- | No | No | Fully automated |
| PERFECT CHLORO SYSTEM | PERFECT CHLORO SYSTEM, Chennai | Disinfection by hypochlorite ions | Field Tested | -- | -- | -- | Community | -- | -- | -- | 500000 lit/hr | -- | -- | No | Suitable for treatment of large quantity of water |
| Compact Electrochlorinator | Pristine Water, Delhi | Disinfection by sodium hypochlorite | Field Tested | -- | -- | -- | Community | -- | -- | Yes | 7500 lit/hr | -- | -- | No | All accessories integrated into single unit |
| Batch Process Electrochlorinator | Pristine Water, Delhi | Disinfection by sodium hypochlorite | Field Tested | -- | -- | -- | Community | -- | Rs 47000 | Yes | 3125-50000 lit/hr | -- | -- | No | produces Liquid Chlorine from common salt as per requirement |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/ hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar Electrochlorinator | Pristine Water, Delhi | Disinfection by sodium hypochlorite | Field Tested | -- | -- | -- | Community | -- | -- | No | 7500 lit/ hr | -- | -- | No | produces Liquid Chlorine from common salt and Solar power |
| Automatic Electro-chlorinators | Pristine Water, Delhi | Disinfection by sodium hypochlorite | Field Tested | -- | -- | -- | Community | -- | -- | Yes | -- | -- | -- | No | This is a wall mounted compact model with automatic control |
| Hydrogen peroxide | -- | Oxidation | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Puritech (Nanosilver coated Ceramic Candles) | ARCI, Hyderabad & SBP Aquatech Pvt. Ltd. | disinfection by nano silver coated ceramic | Field Tested | -- | -- | -- | Domestic | -- | -- | No | -- | -- | No | No | Nanosilver based candle used for disinfection |
| TATA Swach | Tata Consultancy Services (TCS) | Disinfection by silver nano particles | Field Tested | -- | -- | -- | Domestic | -- | -- | No | -- | Rs 0.10 | No | No | Bulb is capable of purifying 3,000 litres of water without clogging or losing effectiveness |
| Jal-TARA Water filter-A | Development Alternatives, Delhi | Slow sand filtration | Field Tested | -- | 25-100 MPN per 100 ml | Nil | Community | -- | -- | No | 3000 lit/ day | -- | No | No | Removes turbidity, Bacteria, Excessive Iron |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEERI-Zar | NEERI, Nagpur | Disinfection by oxidation and sand filtration | Field Tested | -- | -- | -- | Community | -- | -- | No | 10 lit/hr | -- | No | No | Useful to provide safe potable water in emergency situations like flood |
| UV System | SF Products, Mumbai | Disinfection by UV rays | -- | -- | -- | -- | Domestic | Yes |  | Yes | 500 to 50000 lit/hr | -- | No | No | Retains natural properties of water after disinfection |
| KENT UV water purifier | Kent Health Care Products | UV Disinfection | -- | -- | -- | -- | Domestic | -- | -- | Yes | 60 lit/hr | -- | -- | -- | Suitable for low TDS water |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 3.0 Fluoride Removal Technologies

## 3.1 Preamble

Fluoride as a groundwater contaminant is a worldwide problem. According to estimates of UNESCO (internet source, status January 2007) more than 200 million rely on groundwater for drinking with fluoride concentrations higher than the present World Health Organization (WHO) guideline value (1.5 mg/L). The source of this contamination is natural depending on climate, rock type and geochemical conditions that are favourable to the release of fluoride from aquifer rocks. Arid regions are particularly affected. In addition, an estimated 26 to 62 million people are reported to be affected with dental, skeletal and/or non-skeletal fluorosis in India, the extent of fluoride contamination of water varying from 1.0 to 48.0 mg/l. A WHO study estimates a Disability Affected Life Years (DALY) value due to skeletal fluorosis to be 17 per 1000 population in India. It may be concluded, therefore, that the ability to treat fluoride-contaminated drinking water is essential. Fluoride in groundwater is increasing in India in alarming rate as exploitation of groundwater is increasing.

## 3.2 Health Impacts of Fluoride

The excessive intake of fluoride causes fluorosis, a disease affecting the multiple tissues, organs and systems in the body. An individual exposed to excessive fluoride intake may suffer from dental fluorosis, non-skeletal manifestations, skeletal fluorosis, or a combination of afore referred diseases.

The excess fluoride intake may cause dental fluorosis in which mottling of teeth occurs particularly in young children during the age of tooth calcification which alters the structure and appearance of the enamei, producing opacity and brown colouration of the permanent teeth and increases with increase in fluoride content of water. Excessive intake of fluoride can also result in skeletal fluorosis and other skeletal abnormalities which have been observed normally with consumption of water containing more than 3.0 mg/L fluoride.

### 3.2.1 Dental Fluorosis

In dental fluorosis, the enamel loses its luster and shining and attains progressive discoloration. The discoloration of the teeth is in progression from white-yellow to brown-black and may be in streaks with horizontal orientation as, during development, new layers of the matrix are added horizontally. The discoloration is normally away from the gums on the enamel surfaces and can never be removed as it becomes an integral part of the tooth matrix. Dental fluorosis is rated as mild, moderate and severe depending on coverage of the crown and depends on the amount of fluoride ingested during the age of formation of the teeth. The commonly affected teeth are central incisors, lateral incisors and molars of the permanent dentition involving both inner and outer surfaces. The teeth affected by fluorosis being poorly calcified, loses enamel under the normal masticatory stresses. Tooth enamel has no regenerative capacity and once lost is lost forever exposing the dentin.

### 3.2.2 Skeletal Fluorosis

Skeletal fluorosis escapes diagnosis until the advanced stage. The changes in bones are revealed in radiographs when an excessive quantity of fluoride is deposited in the skeleton. The ill-effects of skeletal fluorosis are prominently detected in neck, spine, knee, pelvic and shoulder joints. Fluorosis also affects joints of hands and legs.

Manifestation of skeletal fluorosis can be seen in children as well as adults depending upon the fluoride intake. The usual complaints are pain in neck, back and joints. Rigidity begins in regions where cancellous bones predominate. It is well recorded that cancellous bone accumulates more fluoride compared to cortical bone.

With increase in severity of skeletal fluorosis, acute pain is associated with rigidity and restricted movement of cervical and lumber spine, knee and pelvic joints as well as shoulder joints. In severe cases of fluorosis, there is complete rigidity of the joints resulting in stiff spine described as "bamboo spine", and immobile knee, pelvic and shoulder joints. Crippling deformity is associated with rigidity of joints and includes kyphosis, scoliosis, and flexion deformity of knee joints, paraplegia and quadriplegia. In patients with paralysis, it begins with vague pain in the back. Symptoms develop due to pressure caused by osteophytess (bony outgrowth)/ narrowing of intervertebral foreman and increase in size of the vertebrae or narrowing of the spinal canal, can lead to paralysis.

### 3.2.3 Non-Skeletal Fluorosis

Fluoride when consumed in excess can cause several ailments, besides skeletal and dental fluorosis, which are called non-skeletal fluorosis:

- **Neurological :** Nervousness, depression, tingling sensation of fingers and toes, excessive thirst and tendency to urinate more frequently
- **Muscular :** Muscle weakness, stiffness, pain in muscle and loss of muscle power
- **Allergic :** Very painful skin rashes, which are perivascular inflammation prevalent in women and children, pinkish red or non-persistent oval shaped bluish-red spots on the skin.
- **Gastro-intestinal :** Acute abdominal pain, diarrhea, constipation, blood in stool, bloated feelings (gas), tenderness in stomach, feeling of nausea (flu-like symptoms) and mouth sores
- **Urinary tract :** Urine may be less in volume, red in colour and passed with itching sensation.
- **Headache :** This kind of fluorosis is often overlooked due to misconception that fluoride affects only bone and teeth.

## 3.3 Techniques for Removal of Fluoride from Water

Defluoridation of drinking water is the only practicable option to overcome the problem of excessive fluoride in drinking water, where alternate source is not available. During the years following the discovery of fluoride as the cause of fluorosis, extensive research has been done on various methods for removal of fluoride from water and wastewater. While a number of technologies, based on adsorption and ion exchange in filter systems, coagulation and precipitation and membrane filtration processes have been developed and tested, sustainable implementation has rarely been achieved in rural communities. There is routine use of activated alumina in industrialised countries, where technical know-how and funds for frequent filter regeneration are available. In rural communities failure is due to a combination of factors including a lack of technical support and material supply, costs, lack of maintenance and monitoring but also to deterioration in water quality as a result of treatment. There are several defluoridation processes that have been tested globally. The common methods used for the removal of fluoride from drinking water are divided in the following categories:

- Adsorption and Ion-Exchange
- Coagulation and Precipitation
- Membrane Filtration Processes

## 3.3.1 Adsorption and Ion-exchange

Adsorption processes involve the passage of water through a contact bed where fluoride is removed by ion exchange or surface chemical reaction with the solid bed matrix. After a period of operation, a saturated column must be refilled or regenerated. The adsorbents commonly used for fluoride removal include activated alumina, carbon, bone charcoal and synthetic ion exchange resins. The adsorption behaviour of fluoride by various adsorbents varies significantly, depending on the bonding between fluoride species and active sites on the surface of the specific adsorbent.

### 3.3.1.1 Activated Alumina

Activated alumina is a granular, highly porous material consisting essentially of aluminum trihydrate. It is widely used as a commercial desiccant in many gas drying processes. Fluoride removal capacity of alumina is reported between 4 and 15 mg/g. Experience from the field, however, shows that the removal capacity is often about 1 mg/g. Thus, there seems to be a large difference in the degree of "activation" of alumina products. One of the explanations may be due to variation in pH. The capacity of alumina is highly dependent on pH and the optimum pH is about 5. Hence, pH of the solution should be between 5.0 and 6.0. At pH > 7, silicate and hydroxide affects the exchange capacity of activated alumina and at pH less than 5, activated alumina gets dissolved in water leading to loss of adsorbing media.

Several research results indicated that the presence of $Al^{3+}$, $La^{3+}$, and $Y^{3+}$ ions on the surface of adsorbents can increase the selectivity and extent of fluoride removal in aqueous solutions. An initial concentration of 5 mg/L was effectively brought down to 1.4 mg/L before regeneration and to 0.5 mg/L on regeneration with 2N HCl. The bed was regenerated with a solution of 2% NaOH, 5% NaCl and 2N HCl. The removal capacity of the medium was found to be about 800 mg of fluoride per litre of alumina. Also the filter alum was used to regenerate activated alumina bed. Many modifications in process were suggested by subsequent workers. Batch adsorption data showed very little removal at pH 11.0 and optimum removal at pH 5.0. Hence raw water pH and regenerated bed pH need to be adjusted accordingly. The ability of activated alumina to remove fluoride depends on factors as hardness, silica and boron, etc., if present in water will interfere with fluoride removal and reduce the efficiency of the system.

The use of activated alumina in a continuous flow fluidized system is an economical and efficient method for defluoridating water supplies. This process can reduce the fluoride levels down to 0.1 mg/L. The operational, control and maintenance problems, mainly clogging of bed, may be averted in this method.

### 3.3.1.2 Bone char

Bone charcoal is the oldest known water defluoridation agent. It was used in USA in the 1940s through to the 1960s, when bone charcoal was commercially widely available because of its large scale use in the sugar industry. Studies were conducted to investigate the effect of some of the variables viz. sorbent mass input rate, sorbate flow-rate, initial sorbate concentration on the removal of fluoride by adsorption on fishbone charcoal in a moving media adsorption system. Studies of water defluoridation using fishbone charcoal are indicated that fluoride removal was the function of pH and time. The process is pH dependent with good results only at pH 3.0 or less. Therefore, the use of this material is expensive due to need of pH adjustment. The process was reportedly one of the ion exchange in which carbonate radical of the apatite comprising bone, $Ca(PO_4)_6.CaCO_3$, was replaced by fluoride to form an insoluble fluorapatite. Bone char produced by carbonizing bone at temperature of 1100-1600°C had superior qualities than those of unprocessed bone and hence replaced bone as defluoridating agent. The fluoride removal capacity of the product is 1000 mg/L. Common sorption defluridation units are shown in Figure 3.1.

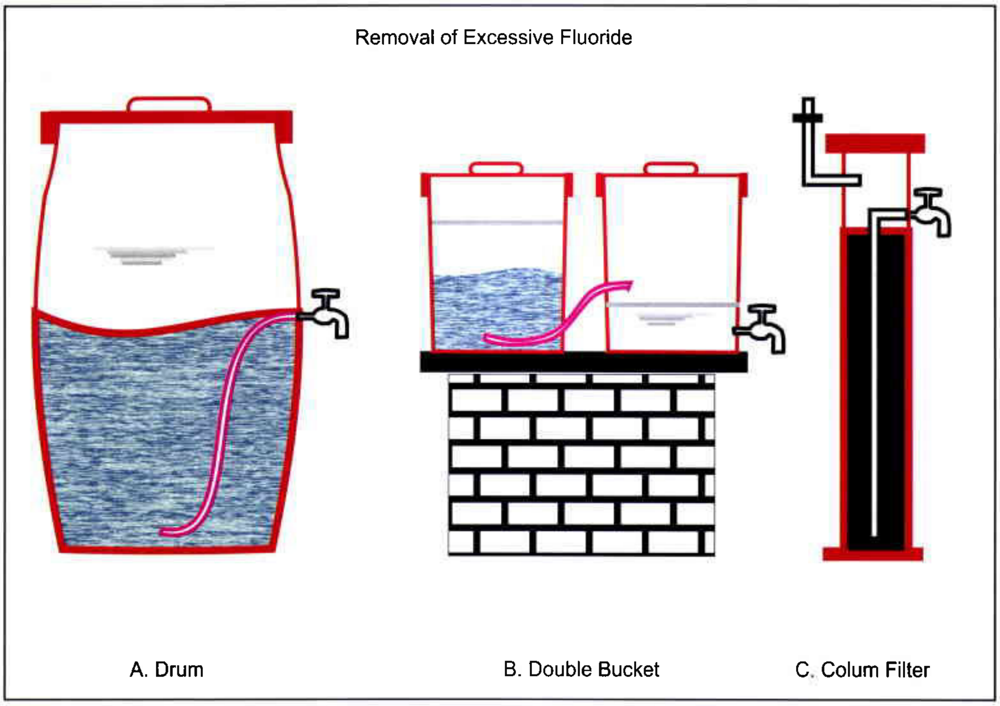


**Figure 3.1:** Common Sorption Defluoridation Units

### 3.3.1.3 Degreased and Alkali Treated Bones

Bone contains calcium phosphate and has a great affinity for fluoride. The bone is degreased, dried and powdered. The powder can be used as a contact bed for removal of fluoride in water. Degreased and alkali treated bones are effective in the removal of fluoride from initial fluoride concentration ranging from 3.5 mg fluoride/L to 10 mg fluoride/L to less than 0.2 mg fluoride/L. The exhausted bed is regenerated with sodium hydroxide solution.

However, use of bone char based defluoridation technologies in India has social acceptability limitations.

### 3.3.1.4 Tri-Calcium Phosphate

The product is prepared by reacting phosphoric acid with lime. The medium is regenerated with 1% NaOH solution followed by a mild acid rinse. It has a capacity to remove 700 mg fluoride/L. A mixture of tri-calcium phosphate and hydroxyapatite, commercially called Florex, showed a fluoride removal capacity of 600 mg of fluoride/L and is regenerated with 1.5% sodium hydroxide solution. Owing to high attrition losses, Florex was not successful and the pilot plants using this material were abandoned.

### 3.3.1.5 Activated Carbon

Most of the carbons prepared from different carbonaceous sources showed fluoride removal capacity after alum impregnation. Alkali digested alum impregnated paddy husk carbon was an efficient defluoridating agent. Investigations have shown that carbonized saw dust when quenched in 2% alum solution forms an excellent defluoridating carbon. The defluoridating process is stoichiometric and equilibrium is established between carbon and fluoride. On exhaustion (after continued use) the carbon can be regenerated by passing 0.2 to 0.5% alum solutions. Alkali digested (1% KOH) and alum soaked (2% alum) carbon removed 320 mg fluoride per kg and showed maximum removal efficiency at pH 7.0.

### 3.3.1.6 Ion Exchange Resins

Batch and column sorption studies were carried out with resin modified by introducing amino group onto the aromatic ring to evaluate sorption of fluoride from water. The study revealed that the fluoride ion can be efficiently adsorbed using modified resin. It was reported that the modified resin is efficient for the removal of fluoride ion from aqueous solution at various pH particularly at 9 pH. Resin is effective even in the presence of other anions such as $Br^-$, $NO_2^-$, $NO_3^-$, $HCO_3^-$ and $SO_4^-$ ions. It is a suitable adsorbent and can be regenerated several times with mineral acid, i.e. HCl (10%).

Strong base exchange resins remove fluorides either on hydroxyl cycle or chloride cycle along with anions. Since the proportional quantity of fluoride as compared to other anions is very small, the effective capacity of such resins works out quite low. Some inorganic ion exchangers, e.g. complex metal chloride silicates, formed from barium or ferric chloride with silicic acid, also exchanged fluoride for chloride.

Cation exchange resins impregnable with alum solution have been found to act as defluoridating agents. Alum treated cation exchange resins were used for defluoridation. 'Avaram Bark' based cation exchange resins, had been reported to work effectively in removing fluoride from water.

Fluoride can be removed from water using a strongly basic anion-exchange resin. The fluoride ions replace the chloride ions of the resin. This process continues until all the sites on the resin are occupied. The resin is then regenerated with water that is supersaturated with dissolved sodium chloride salt. Efficiency of resin is reduced in presence of other ions like sulphate, carbonate, phosphate and alkalinity.

Polystyrene anion exchange resins in general and strongly basic quaternary ammonium type resins in particular are known to remove fluorides from water along with other anions. The resins studied yields 20 – 145 bed volume of defluoridated water per cycle. Subsequent experience showed that these resins lose their fluoride removal capacity on prolonged use (10 – 15 cycles) and a total replacement becomes necessary. The cost of anion resins is Rs. 20 to 35 per litre. The results indicate that anion exchange resins are not economical for removing fluorides from water. Besides, the strong base anion exchange resins impart a taste to the treated water that may not be acceptable to the consumers.

### 3.3.1.7 Serpentine

Serpentine is a mineral name, which applies to the material containing one or both of the minerals, chrysotile and antigorite. The composition of the mineral closely corresponds to the formula $Mg_6Si_4O_{10}(OH)$. The material is green or yellow in colour and is available in Andhra Pradesh. To test the capacity of serpentine to remove fluorides from waters, the green and yellow varieties were studied for their defluoridation capacity. Extensive laboratory investigations were conducted with a view to popularize the mineral, if found suitable as a defluoridating medium. It is concluded that the cost of defluoridation is prohibitive with serpentine.

### 3.3.1.8 Lime Stone, Special Soils and Clay

Limestone and heat-treated soil were tried for fluoride removal. Limestone was used in a two-column continuous flow system (limestone reactor) to reduce fluoride concentrations from wastewaters to below the MCL (Maximum contaminant level) of 4 mg/L. Calcite was forced to dissolve and fluorite to precipitate in the first column. The degassing condition in the second column caused the precipitation of the calcite dissolved in the first column, thus returning the treated water to its approximate initial composition.

Pleistocene soil available locally in Xinzhou, China was able to remove fluoride from local ground water. X-ray diffraction analysis revealed that the soil is composed principally of quartz (50- 60%), Illite (30-

40%), goethite (5-10%) and feldspar (5-10%). A substantial improvement in both the permeability and the fluoride removal capacity of the soil was achieved by heating it in a Muffle furnace. A granular material can then be obtained by crushing the heated product.

The experimental results showed that the heating at 400-500°C has the optimal effect on the enhancement of the material's fluoride removal capacity. A preliminary column experiment showed that 4.0 kg of 400°C heat-treated soil can treat more than 300L of 5 mg/L fluoride feed water before the effluent fluoride concentration reaches 1.0 mg/L. Once the soil's fluoride-sorption capacity had been reached, the material could be regenerated in a cost effective way: rinse the soil first with sodium carbonate solution, then with dilute HCl and finally with distilled water twice. After being air-dried the material is ready for reuse.

Attempts were made to use local Kenyan soil derived from volcanic ash (ex: Ando soils or soils with andic properties) as a fluoride sorbent. The ability of Kenyan Ando soil to adsorb fluoride was determined experimentally. These results were extended to possible technical application using a one dimensional solute transport model. Based on the result it is concluded that the use of Ando soils appears to be an economical and efficient method for defluoridation of drinking water on a small scale in rural areas of Kenya and other regions along the Rift zone. Further research is warranted to evaluate its practical applications and social acceptance.

Fluoride sorption studies were carried out on two clay minerals, montmorillonite KSF and kaolin, and a silty clay sediment series (SCSS, used in earthenware making). The function of fluoride concentration, clay concentration and pH in clay-water suspensions was studied. Kaolinite, a dioctahedral two layered (Silica + alumina) Silicate(1:2 type), exhibited very little tendency for fluoride sorption while montmorillonite,2:1 type material characterized by Octahedral sheet of alumina sandwiched between two tetrahedral sheets of silica, showed significant fluoride sorption.

The fluoride sorption on montmorillonite KSF was found to be greatest at pH 1.9 ± 0.3, the natural pH of montmorillonite-water suspension. At pH 4.0 ± 0.36, the percentage fluoride sorption on montmorillonite decreased, followed by an increase around pH 5-6, after which the percentage decreased with increasing pH. The applicability of the Freundlich isotherm was also verified in case of montmorillonite KSF at low fluoride concentrations. As a result of fluoride adsorption, increased release of $Fe^{2+}$, $Cl^{-}$, $NO^{3-}$ ions from montmorillonite matrix was observed. There was no effect on $SO_4^{2-}$ or $PO_4^{2-}$ solubility. Fluoride adsorption on SCSS was also significant and decreased regularly with increasing pH.

On the basis of experimental data, a plausible mechanism of fluoride sorption by clay minerals is suggested. Based on the results of fluoride sorption mentioned above, a pilot study on defluoridation of water employing clay (SCSS) as an adsorbent was also undertaken which yielded promising results.

Removal of fluoride by adsorption on to low-cost materials like kaolinite, bentonite, charfines, lignite and nirmali seeds was also investigated.

### 3.3.1.9 Fly ash

Retention of fluoride ion in dynamic experiments on columns packed with fly ash was studied at 20°C with a series of aqueous solutions containing 1, 5, 10, 20, 50 and 100 mg fluoride/L. The flow rate through a 450 g bed was 2ml/hr. At the lowest fluoride concentration (1 mg/L), the fluoride level in the effluent initially increased and then gradually decreased down to 0 mg/L after 120 hours. With higher fluoride concentrations in the feed solutions, the fluoride concentration in the effluent steadily decreased reaching 0 mg/L after 120-168 hours. The fly ash was an effective sorbent especially at high concentrations.

### 3.3.1.10 Rare earth based materials

A rare earth metal-based inorganic adsorbent, Cerium- Iron adsorbent (CFA), was developed and its performance for fluoride removal from water was evaluated. The characteristics of the adsorbent were summarized. Experimental results show that the rare earth metal adsorbents had a relatively high adsorption capacity and a good kinetic property for fluoride ion removal. The highest capacity was obtained at pH 3, and it decreased with the increase of pH. The pH effect however, became inconspicuous when the pH was over 5.

An adsorbent, which is a mixture of rare earth oxides was found to adsorb fluoride rapidly and effectively. The effect of various parameters such as contact time, initial concentration, pH and adsorbent dose on adsorption efficiency was investigated. More than 90% of the adsorption occurred within the first 5-10 minutes. The optimum pH was found to be about 6.5. The presence of other ions such as nitrate and sulphate do not affect the adsorption of fluoride significantly (adsorption efficiency reduced from 85% to 79%) indicating the selective nature of the adsorbent. The adsorbed fluoride could be easily desorbed by washing the adsorbent with a pH 12 solutions. This study clearly shows the applicability of naturally occurring rare earth oxides as selective adsorbent for fluoride from solutions.

### 3.3.1.11 Tamarind gel and seed

The concentration of fluoride from the solution of sodium fluoride of 10 mg/L could be brought down to 2 mg/L by the addition of tamarind gel alone and to 0.05 mg/L by the addition of small quantity of chloride with the tamarind gel.

Tamarind seed is also used for the sorptive removal of fluoride from synthetic aqueous solution as well as from field water samples. Tamarind seed is a household material and is left as waste after removing Tamarind pulp for food preparation. It mainly consists of polysaccharides and is used as cattle feed. Batch sorptive defluoridation using tamarind seeds was conducted under variable experimental conditions such as pH, agitation time, initial fluoride concentration, particle size and sorbent dose. Maximum defluoridation was achieved at pH 7.0. Defluoridation capacity decreases with increase in temperature and particle size. Desorption was carried out with 0.1 N HCl and is 90 percent.

### 3.3.1.12 Plant Materials

The plant materials such as barks of *Moringa olifera and Emblica officinalis, the roots of Vetiveria zizanoides* and the leaves of *Cyanodon tactylon* were found to be good defluoridating agents.

## 3.3.2 Coagulation–Precipitation

### 3.3.2.1 Nalgonda Technique

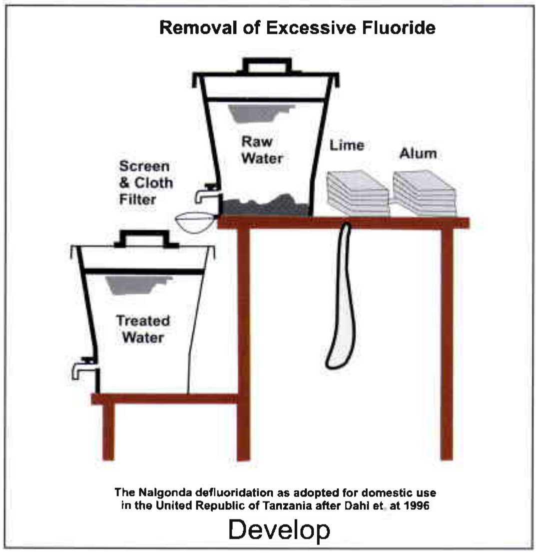
The aluminium sulphate and lime based coagulation-flocculation sedimentation process for defluoridation was adopted by NEERI as the Nalgonda technique and developed for the low cost use at all the levels in India (household, village community and waterworks levels). The Nalgonda technique is based on combined use of alum and lime in a two-step process and has been claimed as the most effective technique for fluoride removal.

Nalgonda Technique involves addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation sedimentation, filtration and disinfection. Aluminium salt may be added as aluminium sulphate or aluminium chloride or combination of these two. Aluminium salt is only responsible for removal of fluoride from water. The dose of aluminium salt increases with increase in the fluoride and alkalinity levels of the raw water. The selection of either aluminium sulphate or aluminium chloride also depends on the sulphate and chloride contents of the raw water to avoid exceeding their permissible limits. The dose of lime is empirically 1/20th that of the dose of aluminium salt. Lime facilitates formation of dense flocs for rapid setting. Bleaching powder is added to the raw water at the rate of 3mg/L for disinfection.

The chemical reaction involving fluorides and aluminium species is complex. It is a combination of two steps involving polyhydroxy aluminium species complexation with fluorides and their adsorption on polymeric aluminium hydroxides (flocs). Besides fluorides, turbidity, colour, odor, pesticides and organics are also removed. The bacterial load is also reduced significantly. All these are achieved by the adsorption on the flocs. Lime or sodium carbonate ensures the adequate alkalinity for an effective hydrolysis of aluminium salts, so that the residual aluminium does not remain in the treated water. Simultaneous disinfection is achieved with bleaching powder which also keeps the system free from undesirable biological growths.

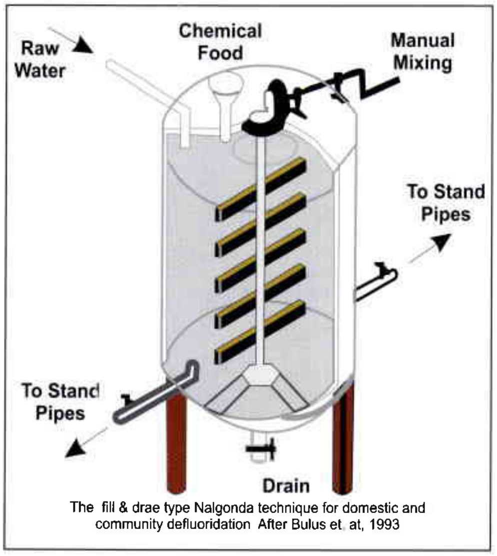
Nalgonda Technique is combination of several unit operations and processes incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration for recover of water and aluminum salt.

The method was investigated under laboratory conditions and then tested in the field. Such field studies included experiments in buckets and in drums (batch type) as well as in pilot plants (continuous type). The technique was seen to be effective in producing clear water, with fluoride within permissible limit. The process is applicable for removal of wide range of fluoride concentration in water. However, due to use of high dose of aluminium sulphate as a coagulant, the sulphate ion concentration in treated water increases substantially and in few cases, it crosses the maximum permissible limit of 400 mg/L. The schematic representation of Nalgonda technique is shown in Figure 3.2.


Removal of Excessive Fluoride

The Nalgonda defluoridation as adopted for domestic use in the United Republic of Tanzania after Dahl et. at 1996

Develop



The fill & drae type Nalgonda technique for domestic and community defluoridation After Bulus et. at, 1993

**Figure 3.2:** Design of Nalgonda technique

### 3.3.2.2 Magnesia

Investigations were conducted to study the usefulness of magnesia in fluoride removal. Crystalline magnesium hydroxide was obtained by reacting a magnesium salt with milk of lime. The precipitate was filtered, washed and dried. The dried product was calcined at 1000°C for 3 hours to obtain magnesia. Varying quantities of magnesia were added to one litre aliquots of test water and stirred for 30 min using a jar test machine. Fluoride contents were estimated on one hour settled sample.

A typical groundwater containing 10 mg/L fluorides, 60 mg/I hardness, 500 mg/L alkalinity and 7.6 pH was studied using magnesia (MgO) concentrations of 10 - 1,500 mg/L. The treated water showed a pH above 9. The average fluoride concentration in the filtrate was 5.8 mg F/L of fluoride/L where the dose was 1,000 mg/L. The fluoride at 100, 250 and 500 mg/L doses were 9.5, 8.9 and 8.4 mg of fluoride/L, respectively. A dose of 1,500 mg/L magnesia and a contact period of 3 hr was required to reduce the fluoride content in the water to 1 mg/L.

The high initial cost, large concentrations required, alkaline pH of the treated water and complexity of the preparation of magnesia are the inhibitive factors to render it acceptable in the field. The study established that magnesia removed the excess fluorides, but large doses were necessary. Moreover the pH of the treated water was beyond 10 and its correction by acidification or recarbonation was necessary. All this adds to the cost and complexity of operations. The acid requirement can be to the extent of 300 mg/L expressed in terms of $CaCO3/L$.

## 3.3.3 Membrane Techniques

Membrane techniques comprising of reverse osmosis, nanofiltration, dialysis and electro-dialysis are briefly discussed in the following sections.

### 3.3.3.1 Reverse Osmosis and Nanofiltration

There are several applications of membrane techniques for removal of fluoride. It was observed that the rejection of fluoride ion was typically higher than 98%, considering that the RO membrane was fully regenerated after each set of experiments.

Nanofiltration makes use of the same overall phenomenon as reverse osmosis. For nanofiltration, the membranes have slightly larger pores than those used for reverse osmosis and offer less resistance to passage both of solvent and of solutes. As a consequence, pressures required are much lower, energy requirements are less, removal of solutes is much less exhaustive, and flows are faster. The selectivity of nanofiltration relative to reverse osmosis is a particular advantage, and much experimental and theoretical research is being devoted to obtaining a clearer idea of the mechanism of solute retention to facilitate production and selection of targeted membranes as well as optimisation of conditions. Retention of solutes is attributed mainly to steric and charge effects and although fluoride is a very small ion it is more strongly hydrated than other monovalent anions because of its high charge density, and the consequent steric effect leads to fluoride being more strongly retained on nanofiltration membranes than competing monovalent anions such as chloride or nitrate, a particular advantage in defluoridation of brackish waters.

### 3.3.3.2 Dialysis and Electro-Dialysis

Dialysis separates solutes by transport of the solutes through a membrane rather than using a membrane to retain the solutes while water passes through it as in reverse osmosis and nanofiltration. The membrane pores are much less restrictive than those for nanofiltration, and the solute can be driven through by either the Donnan effect or an applied electric field. Donnan dialysis process was also studied in a counter current flow system in which the anion-exchange membrane was loaded with sodium chloride and the feed was 0.001 M NaF together with other sodium salts. Fluoride migrated into the receiver as other ions migrated into the feed. This technique was later used to defluoridate solutions made to simulate high fluoride African groundwaters (>30 mg/L fluoride) and whatever other ions were present the fluoride in the feed could be brought below 1.5 mg/L.

Electro-dialysis is the removal of ionic components from aqueous solutions through ion exchange membranes under the driving force of an electric field. In a further project for defluoridation of Moroccan groundwater, efficiency of the process was improved by linking electro-dialysis in tandem with chitosan adsorption.

## 3.4 Available Techniques for Fluoride Removal

### 3.4.1 Eawag Fluoride Removal by Bone Char

To produce bone char suitable use as a filter material, animal bones are charred in a kiln at a defined temperature and oxygen content - in this way the specific surface area of the bones is increased, organic constituents are removed and the inorganic hydroxyapatite matrix is remained. The charred bones are sieved and crushed to produce a granular filter material. Fluoride removal with bone char is based on an adsorption process. The fluoride ions bind to the surface sites of hydroxyapatite, thereby releasing OH- ions into the solution.

$$Ca_5(PO_4)_3OH + F^- \rightarrow Ca_5(PO_4)_3F + OH^-$$

Once the uptake capacity has been reached and most surface sites are occupied, the ability to bind fluoride decreases rapidly. At this point the filter material needs to be regenerated or replaced. Synthetic hydroxyapatite has a higher surface area and adsoprtion capacity than bone char and is generally more effective in removing fluoride (Fig 3.3). As it needs to be imported it is more expensive than the locally available bone char and therefore often not an option for projects in developing countries.

**Figure 3.3:** Eawag Fluoride Removal by Bone Char

### 3.4.2 ICOH domestic defluoridator

The ICOH (ICOH = Inter-Country Centre for Oral Health at the University of Chiong Mai, Thailand) domestic defluoridator was developed in Thailand which uses crushed charcoal and bone char (Figure 3.4). Its defluoridation efficiency depends on the fluoride concentration in raw water as well as the fluoride uptake capacity and the amount of bone char used in the filter. Field trials in Thailand, Sri Lanka and some African countries have shown very encouraging results. Reports from Sri Lanka have shown that with 300 gm charcoal (mainly to remove colour and odour) and 1 kg bone char an ICOH filter can defluoridate on an average 450 litres of water containing 5 mg/l F- at a flow rate of 4 litres per hour. Regeneration of spent bone char is not recommended for these household units. Instead it should be replaced with fresh material commercially available in local shops.

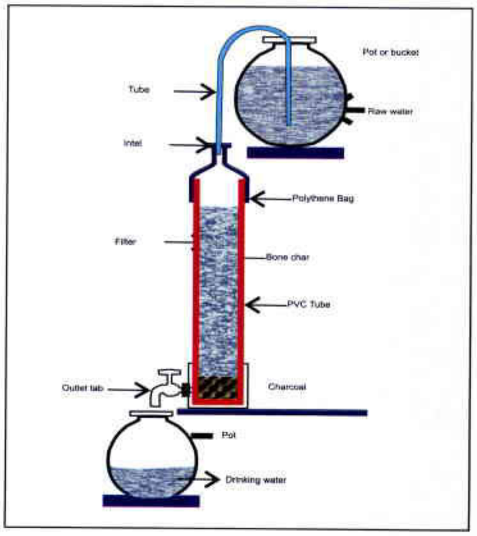


**Figure 3.4:** Bone Char Domestic Defluoridator developed by ICOH-Thailand

### 3.4.3 Electro-Coagulation Methods (NEERI)

Defluoridation technique based on the principle of electrolysis has been developed in NEERI. The process is found effective in removing excess fluoride and also bringing down the bacterial load of the raw water. The defluoridation process is based on the principle of electrolysis, using aluminium plate electrodes placed in the raw water containing excess fluoride. During the electrolysis, anode gets ionized and fluoride is removed by complex formation, adsorption, precipitation, coagulation and settling.

An electrolytic defluoridation unit basically consists of an electrolytic reactor having aluminium anode and cathode. When a DC source is applied across the electrodes, the anode dissolves and hydrogen gas is released at the cathode. During the dissolution of anode various aqueous metallic species are produced, which depend on the solution chemistry. These metallic species act as a coagulant by combining with the fluoride ions present in the water to form large size flocs which can be removed by sedimentation or filtration. The chemical reaction taking place during electrolytic deflouridation is as follow:

$$\text{Anode: Al(s)} \rightarrow \text{Al}^{3+} + 3e^-$$

$$\text{Cathode: } 2\text{H}_2\text{O} + 2e^- \rightarrow \text{H2} + 2\text{OH}^-$$

The $Al^{3+}$ ions further react to form Al (OH)3 flocs which adsorb the fluoride ions present in the water resulting in the formation of the sludge.

$$\text{Al}^{3+} + 3\text{H}_2\text{O(S)} \rightarrow \text{Al(OH)}_3\text{(S)} + 3\text{H}^+$$

$$\text{Al (OH)}_3 + x\text{F}^- \rightarrow \text{Al(OH)}_{3-x}\text{F}_x + \text{OH}^-$$

Direct Current required for electrolytic process is generated either by, conversion of AC electric supply by DC conversion unit of required capacity or by solar photovoltaic system consisting of solar panel, charge controller and tubular battery. The solar panels as per required power (Watt) and time are mounted in south east direction at place where direct sunlight is received. The direct current received through the solar panel is stored in the tubular battery through charge controller and supplied to the aluminium electrodes through direct current regulator.

The novel features of this technology are as follows:

- Simple to fabricate, easy to operate with minimum maintenance
- Suitable for treatment of raw water with fluoride concentration upto 10mg/L
- Produces potable water with palatable taste as against the other available chemical treatment methods
- Quantity of sludge produced is much less (60-70%) than conventional treatment methods
- Simultaneous reduction in hardness, nitrate and bacterial contamination in treated water
- Treatment cost upto Rs.12 per 1000 L

Based on the technology, solar power based electrolytic defluoridation demonstration units (Figure 3.5) were installed at Dongargaon in Chandrapur district, Maharashtra in 2002 and at Usarwara village in Durg district in Chhattisgarh State in 2010. Capacity of these units is 600L and 2000L per batch respectively.

**Figure 3.5 :** Electro-Defluoridation Unit, NEERI, Nagpur

## 3.4.4 Chemo Defluoridation Method of NEERI

**Figure 3.6 :** Chemo-defluoridation Unit, NEERI, Nagpur

In Chemo-defluoridation, (Figure 3.6) the salts of calcium and phosphorous have been used to reduce the raw water fluoride concentration in the range 5 - 10.0 mg/L to < 1.0 mg/L. Required dose of chemicals are added in the fluoride contaminated raw water and mixed with the stick. The chemicals react with each other to form the chemical complex which absorbs fluoride and precipitated out. After 15 to 20 minutes of mixing of the chemicals, water is allowed to flow by gravity into the sand filter at the rate of 300 – 400 ml/min. Filtered water with fluoride concentration less than 1 mg/L is collected in the third plastic container and can be used for drinking and cooking purposes. The layer of chemical complex precipitate formed on the sand filter also removes some fluoride from the water during filtration. After about 1 to 2 months of operation, filter is choked by the formation of thick layer of sludge. The Nylobolt cloth kept below the 2-5 cm of sand layer is lifted along with the sand and the sand is washed separately in a tub or bucket. The Nylobolt cloth is cleaned and replaced on the sand bed. Washed sand is again placed over the Nylobolt cloth. The filter is ready to use.

The process is free from interference of anions concentration of water and does not affect the palatability of water unlike the other chemical treatment process (Nalgonda Technology) for fluoride removal.

Under the research project sponsored by Rajiv Gandhi Science and Technology Commission, Govt. of Maharashtra, 70 defluoridation plants are installed in Sakhara village in Yavatmal District in Maharashtra to test the performance of the units.

## 3.4.5 TERI Defluoridation Unit

TERI (The Energy and Resources Institute) Western Regional centre (WRC) carried out a study to address this critical problem through community effort towards cost-effective treatment and management of fluoride contamination. The designed de-fluoridation units (Figure 3.7) consisted of two buckets equipped with taps and a sieve on which a cotton cloth was placed. Known concentrations of alum and lime were added to the raw water bucket at the same time, and dissolved by stirring with a wooden ladle. The villagers were trained to stir fast while counting till 60 (1 minute), and then slow down while counting till 300 (5 minutes). The flocs formed were left to settle for about an hour. The water was then passed through a sieve into another bucket. Both the containers were plastic buckets of 20 litres capacity, supplied with covers, and equipped with a tap 5 cm above the bottom to enable trapping of sludge. The treated water was then stored in the treated water bucket through the cloth, and collected for drinking or cooking.

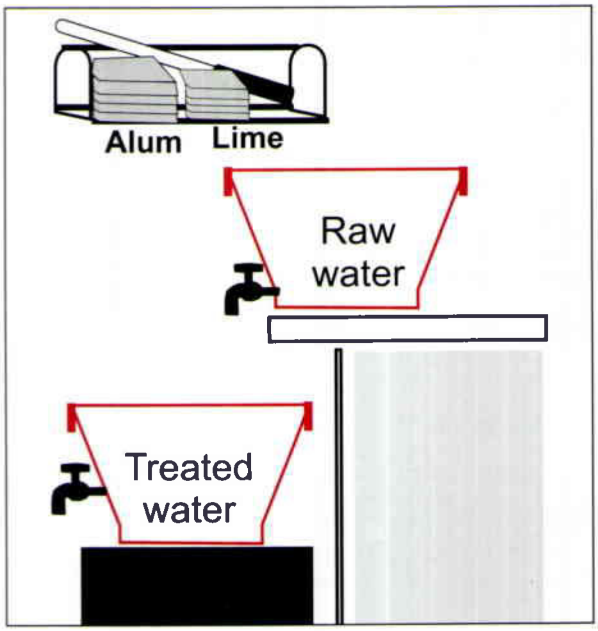


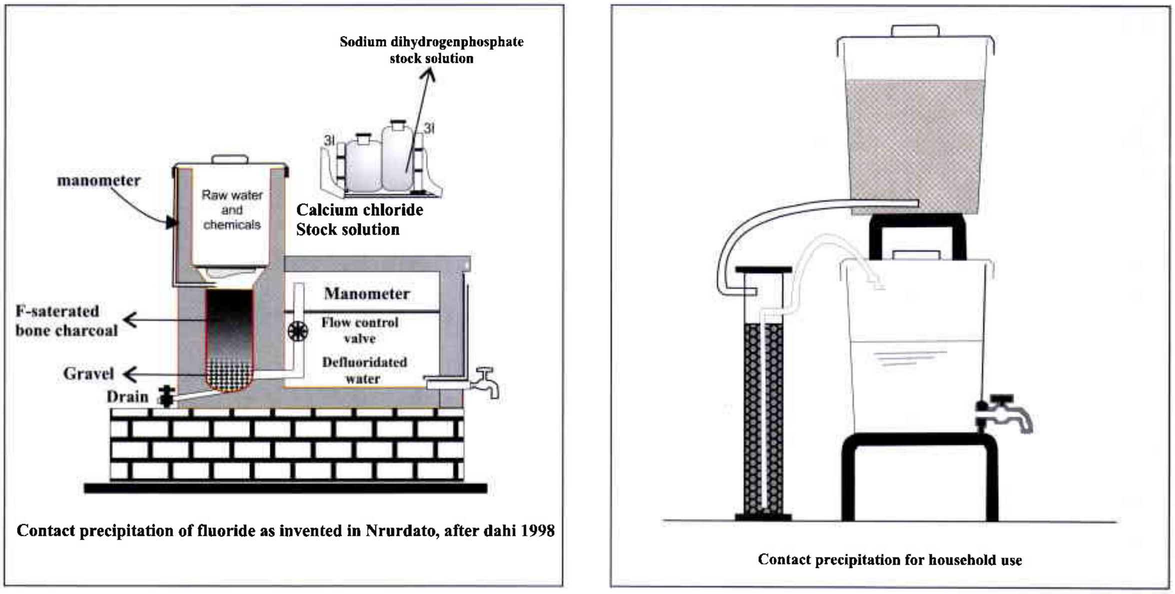
**Figure 3.7:** TERI Deflouridation Unit

**Contact details:**

**The Energy and Resources Institute (TERI)**
Darbari Seth Block, IHC Complex, Lodhi Road,
New Delhi - 110 003, INDIA
Tel. (+91 11) 2468 2100 and 41504900
Fax (+91 11) 2468 2144 and 2468 2145
Email: mailbox@teri.res.in

### 3.4.6 New Adsorbents for Adsorption of Fluoride

In recent years, several new adsorbents for adsorption of fluoride have been investigated. For example, lanthanum-impregnated silica-gel, La(II) and Y(III)-impregnated alumina and aluminium-impregnated carbon have been used for adsorption of fluoride successfully. The use of waste materials and low-cost materials as adsorbents for fluoride has been examined. The method is simple and has shown great potential for selective removal of fluoride. It was found that the mixture of rare earth elements adsorb fluoride rapidly and effectively. Most of the adsorption took place in the first 5-10 minutes. The adsorbent was found to load as high as 12.5 mg of fluoride per gram of adsorbent. The optimum pH was found to be about 6.5 for fluoride adsorption which makes it very suitable for use in drinking water treatment. Other ions such as sulphate and nitrate (up to 100 mg/l) did not greatly affect the adsorption of fluoride thereby indicating that the rare earth oxide is a selective adsorbent for fluoride. Some design for contact precipitation systems are shown in Figure 3.8.



Contact precipitation of fluoride as invented in Nrurdato, after dahi 1998

Contact precipitation for household use

**Figure 3.8:** Designs of Contact Precipitation

## 3.4.7 Domestic defluoridation units in Sri Lanka

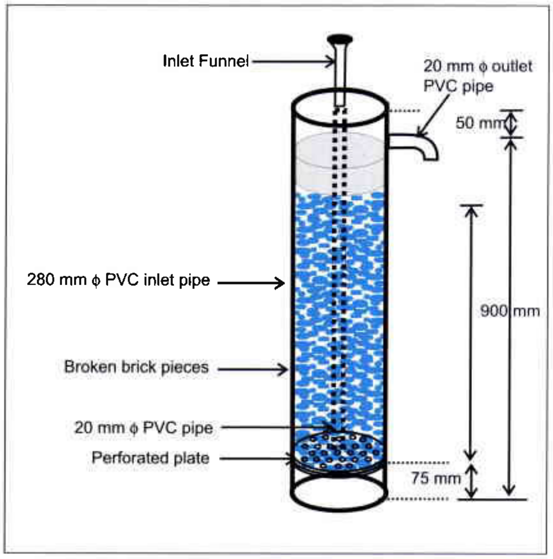


**Figure 3.9:** Domestic Defluoridation Unit using Brick Pieces

Freshly fired brick pieces are used in Sri Lanka for the removal of fluoride in domestic defluoridation units (Figure 3.9). The brick bed in the unit is layered on the top with charred coconut shells and pebbles. Water is passed through the unit in an upflow mode. The performance of domestic units has been evaluated in rural areas of Sri Lanka (Priyanta & Padamsiri 1997). It is reported that efficiency depends on the quality of the freshly burnt bricks. The unit could be used for 25-40 days, when withdrawal of defluoridated water per day was around 8 litres and raw water fluoride concentration was 5 mg/l. As PVC pipes are costly, a defluoridator made out of cement and bricks have also been recommended.

## 3.4.8 Emerging Defluoridation Technologies

Besides the techniques mentioned earlier, following emerging technologies introduced in recent years:

- Crystalactor
- Memstill technology
- WaterPyramid solution
- Solar Dew Collector system

### 3.4.8.1 Crystalactor

In the Netherlands a new type of contact precipitator, named the Crystalactor is developed. The Crystalactor is a fluidized-bed type crystallizer also called a pellet reactor. In the reactor fluoride is removed from the water while calcium fluoride pellets with a diameter of 1 mm are produced. Costs comparisons show that the total treatment costs are typically approximately 25% of the costs for conventional precipitation. However the Crystalactor is more suitable for wastewaters with high fluoride concentrations (> 10 mg/l). For treating drinking water, the Crystalactor is only advisable in case of high fluoride concentrations (> 10 or 20 mg/l). For reaching a concentration below 1 mg/l fluoride, a second technique must be used afterwards.

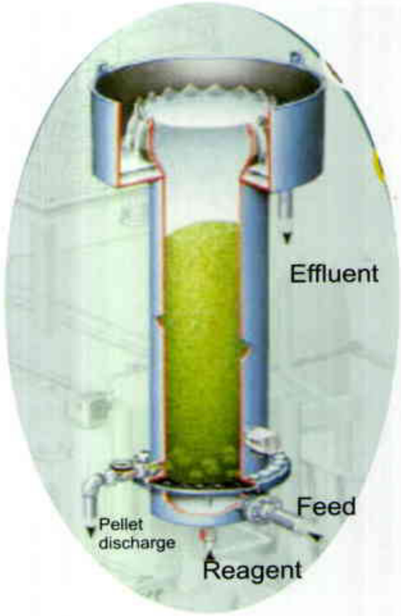


**Figure 3.10:** Crystalactor

**Contact details:**

**DHV B.V. Water**
Laan 1914 no. 35, 3818 EX Amersfoort
P.O. Box 1132 , 3800 BC Amersfoort
The Netherlands
T +31 33 4682290
F +31 33 4682801
E info-water@dhv.com

### 3.4.8.2 Memstill® Technology

The Netherlands Organisation of Applied Scientific Research (TNO) has developed a membrane based distillation concept which radically improves the economy and ecology of existing desalination technology for seawater and brackish water. This so-called "Memstill® technology" combines multistage flash and multi-effect distillation modes into one membrane module. Cold feed water takes up heat in the condenser channel through condensation of water vapour, after which a small amount of (waste) heat is added, and flows counter currently back via the membrane channel. Driven by the small added heat, water evaporates through the membrane, and is discharged as cold condensate. The cooled brine is disposed, or extra concentrated in a next module. The Memstill® technology can produce (drinking) water at a cost well below that of existing technologies like reverse osmosis and distillation. With the Memstill® technology also anions like fluoride and arsenic are removed. It is expected that the Memstill® technology will be also developed for small scale applications using solar heat.

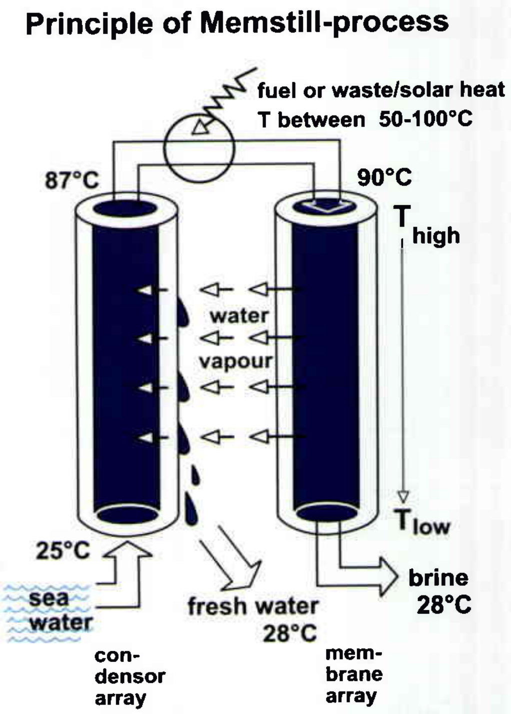


**Figure 3.11:** Memstill® Technology

**Source:** TNO, Netherlands

### 3.4.8.3 Water Pyramid Technology

Aqua-Aero Water Systems has developed the Water Pyramid concept for tropical, rural areas. The Water Pyramid makes use of simple technology to process clean drinking water out of salt, brackish or polluted water. One of the pollutants could be fluoride. Most of the energy needed to clean the water is obtained from the sun. Water Pyramid with a total area of 600 m2 and situated under favourable tropical conditions, can produce up to 1250 litres of fresh water a day. The production rate is dependent on site specific factors such as climate and temperature, cloudiness and wind activity. Desalination is driven by the sun and the energy needed for pressuring the Water Pyramid is obtained using solar cells in combination with a battery back-up system. Intermittent peak demands in electricity, related to e.g. (borehole) pumping and maintenance, are covered using a small generator system.

### 3.4.8.4 Solar Dew Collector System

Solar Dew developed a new porous membrane to purify water using solar energy. The technique is similar to the Water Pyramid. Water sweats through the membrane, evaporates on the membrane's surface and increases the air humidity in the evaporation chamber.

Based on a temperature difference, pure water condenses on the cooler surfaces of the system. The product water quality is very constant and similar to that of distilled water. The quantity depends on the intensity of the solar radiation. To avoid crystallization, the brine has to be drained periodically. The system is able to process: sea, brackish or contaminated waste water (e.g. with heavy metals, oil residue, boron, fluoride) with an allowable pH range of 5-11.

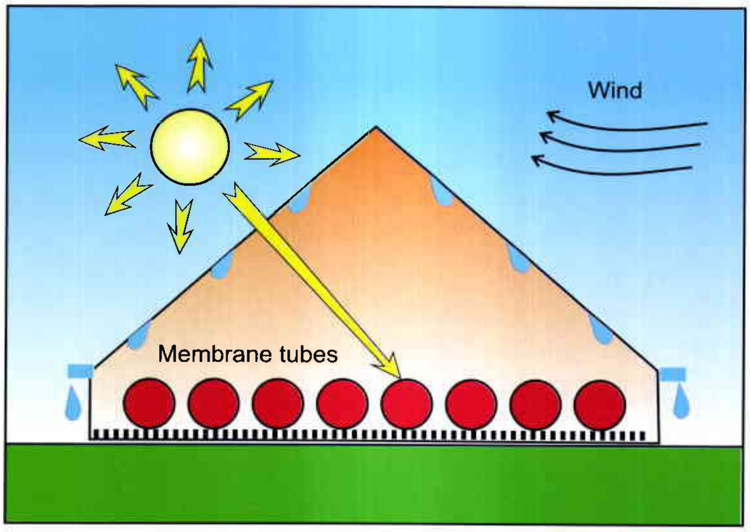


**Figure 3.12:** The Solar Dew Collector System

**Contact details:**

Solar Dew International B.V., Steenoven 5,
3911TX Rhenen
The Netherlands, info@solardew.com, +31 (317) 61 97 73

## 3.4.9 Solar Water Distiller in Ghana's Upper East Region

A team of young graduate engineers from the Kwame Nkrumah University of Science and Technology (Knust) in collaboration with the Centre for Energy, Environment and Sustainable Development (CEESD), an NGO have provided pupils of Annafobiisi Primary School in the Bongo District of the Upper East Region with a solar water purifier for the treatment of fluoride contamination in their source of drinking water.

**Figure 3.13:** Solar Water Distiller Method in Ghana's Upper East Region

### 3.4.10 Defluoridation by reverse osmosis membrane technology, IICT, Hyderabad

Five RO membrane-based defluoridation plants of 600-1000 l/h capacity have been commissioned at Mylaram village of Nalgonda District, AP. The fluoride in the raw water varies from 3 to 5 ppm and is brought down to a concentration of less than 0.5 mg/l.

**Figure 3.14:** RO Technology, IICT, Hyderabad

### 3.4.11 Domestic Defluoridation Unit using Activated Alumina Bai

The membrane assisted sorption process for removal of fluoride from ground/surface water provide safe drinking water and solves the serious problem of aluminium contamination in the product water coming after defluoridation unit, which is more harmful than fluoride. Therefore, by this process it is providing water not only free from fluoride but also free from secondary contaminants like aluminium and microorganisms which will be removed by ultrafiltration membrane. It is a simple, cost effective, adoptable at both domestic and community level and having capability of high decontamination.

It requires minimum contact time for maximum defluoridation. Defluoridation capacity is appreciable at neutral pH and independent of temperature. Productions of safe drinking water not only free from fluoride but also free from secondary contaminants like aluminium and microorganisms. It can be operated with/without the use of electricity.

The technology of UF membrane assisted sorption process/device for removal of fluoride from ground/ surface water used for drinking purposes consists of two steps:

1. Sorption of fluoride on activated alumina sorbent.
2. Separation of leached out secondary contaminant like aluminium using indigenously developed UF membrane device.

The cost of this unit is per unit Rs.3000/- and above for 50-5000 litres per day.

**Figure 3.15 :** BARC Defluoridation Unit

**Contact details:**

Head,
**Technology Transfer & Collaboration Division,**
Bhabha Atomic Research Centre, Trombay,
Mumbai - 400 085
Tel : 091-022-25505337/25593897
Fax : 091-022-25505151
Email : headttcd@barc.gov.in

### 3.4.12 Ion Specific Resin Units for the Removal of Arsenic/Fluoride

Macroporous specific polymeric ion exchangers are prepared by the copolymerization of different monomers and functionalized to introduce complex forming groups on the polymer matrices. The groups are further converted to their respective active forms which have potential to form complex either with Arsenic or Fluoride in the presence of other ions present in water, thereby making the drinking water Arsenic/Fluoride free. The specific polymeric ion exchangers have excellent operating life and can be reused repeatedly after regeneration once they get exhausted. The process is cost effective and safe drinking water can be produced at a cost of Rs. 10/- per 1000 liter of Arsenic free water and Rs. 6/- per 1000 liter of Fluoride free water. The process doesn't require any additional infrastructure and the domestic units can be installed in the households. On large scale community units can be installed which will benefit the people at large.

Specific polymeric ion exchangers for selective removal of arsenic/fluoride have been successfully prepared in 20 liter round bottom flask and their potential use for the removal of Arsenic/Fluoride in the form of domestic units have been successfully tested in the field where Arsenic/Fluoride problems are prevalent.

65 domestic dearsenificating units are already installed in Arsenic affected area of 24 (N) Parganas, West Bengal. 8 domestic defluoridation units are installed in Fluoride affected villages of Gujarat.

A Domestic Unit containing 6 liters of specific polymeric ion exchangers (Height-72 cm, Diameter-11 cm) can produce 25 liter of Arsenic/Fluoride free water per hour and each unit costs about Rs.10,000/-.

**Contact details:**

**Dr. K. M. Popat**
Scientist, Reverse Osmosis Discipline
Central Salt & Marine Chemicals Research Institute, G. B. Marg,
Bhavnagar-364 002
Tel. No. (O) 0278-2562548
(M) 9998275278
E-mail : kmpopat@csmcri.org

### 3.4.13 Electro-Chemical Defluoridation Unit

The electrochemical process is the generation of aluminium hydroxide by employing soluble aluminium anode. The cell consists of aluminium alloy anodes and GI/Zinc cathodes. The fluoride containing water is fed into the cell at a suitable flow rate. The aluminium alloy anode dissolves during electrolysis and produces aluminium hydroxide precipitate in a finely divided are which absorbs the fluoride ion from water.

The electrochemical process is suitable for even water containing higher fluoride levels greater than 25 ppm. In this method, there is no addition of any chemicals in the treatment process, which avoids any possible contamination by any other impurities. The quantity of sludge generated after treatment is comparatively less than chemical treatment process where lime addition to Fluoride containing water increases the volume of the precipitate and the disposal of the sludge becomes difficult. The capacity of unit is 10,000 litres per day and cost of production is Rs. 33/kilolitre.

**Contact details:**

**Dr.S.Vasudevan**
Senior Scientist
CSIR-Central Electrochemical Research Institute
Karaikudi - 630 006
Tamil Nadu, India

## Reference:

1. Agnew T., Chuckatuck: **Electrodialysis reversal is used to remove fluoride at water treatment plant.** http://www.suffolknewsherald.com/news/2009/apr/10/water-plants-expansion-almost-done/
2. Althaus P., Solar powered Desalination System for remote areas, ecomagination, 2011
3. Annouar, S., Mountadar, M., Soufiane, A., Elmidaoui, A., Sahli, M.A., Menkouchi, A., 2004. Defluoridation of underground water by adsorption on the chitosan and by electrodialysis. Desalination 165, 437–438.
4. Aqua-Aero WaterSystems, 2007. WaterPyramid. http://www.waterpyramid.nl
5. Bason, S., Ben-David, A., Oren, Y., Freger, V., 2006. Characterization of ion transport in the active layer of RO and NF polyamide membranes. Desalination 199, 31–33.
6. Cervera, J., Garcia-Morales, V., Pellicer, J., 2003. Ion size effects on the electrokinetic flow in nanoporous membranes caused by concentration gradients. J. Phys. Chem. B 107, 8300–8309.
7. Diawara, C.K., 2008. Nanofiltration process efficiency in water desalination. Sep. Purif. Rev. 37, 303–325.
8. Donnan, F.G., 1911. Z. Elektrochem., 572–581, cited by Loeb J 1921, Donnan equilibrium and the physical properties of proteins. J. Gen. Physiol., 667–690.
9. Fluoride in groundwater: A cost-effective community-based solution, TERI, 2011
10. Giesen, A., 1998. Fluoride removal at low cost. European Semiconductor 20 (4), 103–105
11. Hichour, M., Persin, F., Molenat, J., Sandeaux, J., Gavach, C., 1999. Fluoride removal from diluted solutions by Donnan dialysis with anion-exchange membranes. Desalination 122, 53–62.
12. Hichour, M., Persin, F., Sandeaux, J., Gavach, C., 2000. Fluoride removal from waters by Donnan dialysis. Sep. Purif. Technol. 18, 1–11
13. Hu, K., Dickson, J.M., 2006. Nanofiltration membrane performance on fluoride removal from water. J. Membr. Sci. 279, 529–538.
14. International Groundwater Resources Assessment Centre Report nr. SP 2007-1
15. Lanka. Peradeniya, Sri Lanka, University of Peradeniya.
16. Larsen MJ, Pearce EIF. Defluoridation of drinking water by boiling with brushite and calcite. Caries Res 2002;36:341-6
17. Leela Lyengar, Technologies for fluoride removal
18. Lefebvre, X., Palmeri, J., 2005. Nanofiltration theory: good co-ion exclusion approximation for single salts. J. Phys. Chem. B 109, 5525–5540.
19. Lefebvre, X., Palmeri, J., David, P., 2004. Nanofiltration theory: an analytic approach for single salts. J. Phys. Chem. B 108, 16811–16824.
20. Marutamuthu, M. & Venkatanarayana Reddy, J. 1987a A native index of defluoridation by Serpentine. Fluoride 20, 64–67.
21. Meltzer, Y. L. 1976 Water-soluble polymers: Recent developments. Noyes Data Corporation, Park Ridge, New Jersey.Mjengera, H.J.; Mtalo, F.W.; Mashauri D.A. and Tjell, C.H. (1997). 'Fluoride removal using heat activated animal bone media.' In: Dahi, E. and Nielsen, J.M. (eds). Proceedings of the 2nd international workshop on fluorosis and defluoridation of water, Addis Ababa, Ethiopia,

November 19-22, 1997. Dunedin, New Zealand, International Society for Fluoride Research. Mohapatra M., Anand S., Mishra B.K., Giles D.E., Singh P., 2009. Review of fluoride removal from drinking water, Journal of Environmental Management, 91, 67–77.

22. Murugan M. and Subramanian E. 2006. Studies on defluoridation of water by Tamarind seed, an unconventional biosorbent, Journal of Water and Health, 453-461.

23. Ndiaye, P.I., Moulin, P., Dominguez, L., Millet, J.C., Charbit, F., 2005. Removal of fluoride from electronic industrial effluent by RO membrane separation. Desalination 173, 25–32.

24. Palmeri, J., Blanc, P., Larbot, A., David, P., 1999. Theory of pressure-driven transport of neutral solutes and ions in porous ceramic nanofiltration membranes. J. Membr. Sci. 160, 141–170.

25. Paugam, L., Diawara, C.K., Schlumpf, J.P., Jaouen, P., Que´me´neur, F., 2004. Transfer of monovalent anions and nitrates especially through nanofiltration membranes in brackish water conditions. Sep. Purif. Technol. 40, 237–242.

26. Priyantha, N. and Padamasiri, J.P. (eds). (1996). Proceedings: prevention of fluorosis in Srilanka

27. Raichur, A.M., Jyoti Basu, M., 2001. Adsorption of fluoride onto mixed rare earth oxides. Sep. Purif. Technol. 24, 121–127.

28. Rajchagool, S and Rajchagool, C. (1997). 'Solving the fluorosis problem in a developing country'. In: Dahi, E. and Nielsen, J.M. (eds). Proceedings of the 2nd international workshop on fluorosis and defluoridation of water, Addis Ababa, Ethiopia, November 19-22, 1997. Dunedin, New Zealand, International Society for Fluoride Research.

29. Ricoh, Organo Japan Ricoh, Nishiwaki, Organo Japan Fluoride recovery with a Crystalactor 2001, www.dhv.com

30. TSolar Dew, 2007. The Solar Dew Collector Sytem. http://www.solardew.com/index2.htmlechnologies for fluoride removal

31. Szymczyk, A., Fievet, P., 2005. Investigating transport properties of nanofiltration membranes by means of a steric, electric and dielectric exclusion model. J. Membr. Sci. 252, 77–88.

32. Szymczyk, A., Sbaı¨, M., Fievet, P., Vidonne, A., 2006. Transport *properties and electrokinetic characterization of* an amphoteric nanofilter. Langmuir 22, 3910–3919.

33. Tahaikt, M., Ait Haddou, A., El Habbani, R., Amor, Z., Elhannouni, F., Taky, M., Kharif, M., Boughriba, A., Hafsi, M., Elmidaoui, A., 2008. Comparison of the performances of three commercial membranes in fluoride removal by nanofiltration. Continuous operations. Desalination 225, 209–219.

34. Tahaikt, M., El Habbani, R., Ait Haddou, A., Achary, I., Amor, Z., Taky, M., Alami, A., Boughriba, A., Hafsi, M., Elmidaoui, A., 2007. Fluoride removal from groundwater by nanofiltration. Desalination 212, 46–53.

35. www.solardew.com, *SolarDew International B.V.*

36. http://www.barc.ernet.in/technologies/mad/mad.html

37. http://www.csmcri.org/Pages/Technology/Technology_detail.php?id=56

38. http://www.cecri.res.in/Technology/inorganic/EI18.pdf

**Table 2.8 :** Comparative Statement of Technologies available for Disinfection of Water

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eawag Fluoride removal by bone char | Eawag | adsorption process using bone char | Tested in laboratory as well as in field | Eastern Africa, CDN, Kenya | > 7 mg/l | Less than 1.0 ppm for fluoride | -- | -- | -- | No | -- | -- | -- | -- | -- |
| ICOH domestic defluoridator | Inter-Country Centre for Oral Health at the University of Chiong Mai, Thailand (ICOH) | adsorption process using bone char | Tested in laboratory as well as in field | Thailand, Sri Lanka and some African countries | 5 mg/l | Less than 1.0 ppm for fluoride | -- | -- | -- | No | 4 litres per hour | -- | Regeneration of spent bone char is not recommended for these household units. Instead it should be replaced with fresh material commercially available in local shops | -- | -- |
| Electro coagulation methods (NEERI) | National environmental engineering research institute (CSIR-NEERI), Nagpur | Principle of electrolysis | Tested in laboratory as well as in field | Dongargaon in Chandrapur district, and at Usarwara village in Durg district in Chhattisgarh | 10 mg/L | Less than 1.0 ppm for fluoride | Community | NA | Rs.12 per 1000 L | No | Capacity of these units is 600L and 2000L per batch | Rs. 0.012/- (approx) | Quantity of sludge produced is much less (60-70%) | Training required | Less than 1.0 ppm for fluoride and simultaneous reduction in hardness, nitrate and bacterial contamination in treated water |
| Chemo Defluoridation Unit (NEERI) | National environmental engineering research institute(CSIR-NEERI), Nagpur | adsorption process | Tested in laboratory as well as in field | Sakhara village, Yavatmal District, Maharashtra | range 5 - 10.0 mg/L | Less than 1.0 ppm for fluoride | Domestic | No | the rate of 300 – 400 ml/min | No | Capacity of these units is 30L | Rs. 0.10/- (approx) | Yes | -- | -- |
| TERI Deflouridation unit | The Energy and Resources Institute | adsorption process using Alum lime | Tested in laboratory as well as in field | -- | -- | -- | Domestic | No |  | No | 20 litres | -- | -- | Training required |  |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Domestic defluoridation units | Shrilanka | adsorption process using brick bed, charred coconut shells and pebbles | Tested in laboratory as well as in field | Shrilanka | 5 mg/l | -- | Domestic | -- | -- | No | -- | -- | The unit could be used for 25-40 days | -- | -- |
| Crystalact or | DHV B.V. Water Netherlands | fluidized-bed type crystallizer | -- | -- | -- | -- | -- | -- | total treatment costs are typically approximately 25% of the costs for conventional precipitation | -- | -- | -- | Because of the production of water-free pellets, troublesome sludge dewatering is eliminated | -- | -- |
| Memstill® Technology | The Netherlands Organisation of Applied Scientific Research (TNO) | Reverse osmosis and distillation | -- | -- | -- | -- | -- | -- | -- | Yes | -- | -- | -- | -- | -- |
| Water Pyramid Solution | Aqua-Aero Water-Systems | | -- | -- | -- | -- | -- | -- | -- | -- | 1250 litres/day | -- | -- | -- | -- |
| Reverse Osmosis Membrane Tech. | IICT, Hyderabad | Reverse Osmosis Membrane Technology | -- | Mylaram village of Nalgonda District, AP | 3 to 5 ppm | <0.5 mg/l | -- | -- | -- | Yes | 600-1000 l/h capacity | -- | -- | -- | -- |
| Solar Dew Collector system | Solar Dew International B.V. The Netherlands | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Solar Water Distiller | Kwame Nkrumah University of Science and Technology (Knust) in collaboration with the Centre for Energy, Environment and Sustainable Development (CEESD) | -- | -- | Annafobiisi Primary School in the Bongo District of the Upper East Region | -- | -- | -- | -- | -- | No | -- | -- | -- | -- | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Domestic deflouridation unit | Bhabha atomic Research Centre, Mumbai | Ultrafiltration membrane | -- | -- | -- | -- | Domestic | -- | Rs. 3000/- for 50-5000 L/day | No | -- | -- | -- | Not required | Trated water not only free from fluoride but also free from aluminium and microorganisms |
| G. Robert House Water Treatment Plant | Robert House Water Treatment Plant in Chuckatuck | EDR – electrodialysis reversal | -- | Chuckatuck | -- | -- | Community | -- | -- | -- | 1.25 million gallons of water per day | -- | -- | -- | -- |
| Electrochemical defluoridation unit | CSIR-CERI, Tamilnadu | Electrochemical process | -- | -- | > 25 mg/L | Below 1 mg/L | Community | NA | Rs. 33 per kiloliter for capacity of unit 1000 L/Day | Yes | | | Sludge generated is less but disposal of the sludge becomes difficult | Training required | |
| Ion specific resin unit | CSMCRI, Bhavnagar | Ion exchange resin | -- | Gujrat | -- | -- | Domestic | Yes | Rs. 10000/- per unit of capcity 25 L/Hr | -- | -- | Rs. 0.01/- per litre | Regeneration of resins | Not required | -- |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 4.0 Arsenic Removal Technologies

## 4.1 Preamble

Arsenic is a natural metalloid element of the earth's crust in some parts of the world and can also found in water that has flowed through arsenic-rich rocks. Arsenic occurs naturally in the environment and can be released into water through natural activities such as hydrothermal action, dissolution of rocks or human activities. Agricultural applications, mining, and smelting also contribute to arsenic releases in the environment. Higher levels of arsenic tend to be found in ground water sources than in surface water sources. As per Bureau of Indian Standards; the maximum permissible limit of Arsenic in the drinking water is 0.05 mg/L (50µg/L). High concentrations of arsenic in drinking-water are found in various parts of the world including Argentina, Bangladesh, Chile, China, Hungary, India (mostly in West Bengal), Mexico, Pakistan, Thailand, USA, and Viet Nam. Occurrence of arsenic in groundwater in excess to the permissible limit of 50 µg/L are reported in the Ganges-Brahmaputra fluvial plains in India covering states namely, West Bengal, Jharkhand, Bihar, Uttar Pradesh in flood plain of Ganga River; Assam and Manipur in flood plain of Brahamaputra and Imphal rivers and Rajnandgaon District in Chhattisgarh state (NIH, 2010). In addition, arsenic is also reported in Karnataka, Punjab, Haryana and Himachal Pradesh. Arsenic crisis in India dates back to as early as 1976 when a preliminary survey on arsenic in dugwells, hand pumps and spring water from Chandigarh and different villages of Punjab, Haryana and Himachal Pradesh was reported in Lancet by Dr. D.V Datta (SOES, 2006).

## 4.2 Health Effects of Arsenic

Long-term exposure to arsenic can result in chronic arsenic poisoning. Arsenic dissolved in water is acutely toxic and can lead to a number of health problems. It has been reported that long-term exposure to arsenic in drinking-water probably in excess of 50µg/L (there are reported cases of health effects at arsenic concentration below 50µg/L) causes increased risks of cancer in the skin, lungs, bladder and kidney. It is now evident that inorganic arsenic exposure deactivates the function of enzymes, some important anions, cations, transcriptional events in cells and causes other direct or indirect effects. Such toxicity of inorganic arsenic result in numerous illnesses that have been also confirmed by repeated epidemiological investigations which include (i) dermal effects, (ii) cardiovascular effects, (iii) respiratory effects, (iv) gastrointestinal effects, (v) endocrinological effects (diabetes mellitus), (vi) neurological effects, (vii) Reproductive and developmental effects, (viii) cancer effects, and (ix) other effects. Symptoms of arsenicosis are primarily manifested in the form of different types of skin disorders such as skin lesions, hyper keratosis and melanosis (NIH, 2010). During the last decade 4 monographs (IARC 2004, IPCS 2001, NRS 1999, NRS 2001) along with large number of reports and special issues have been published to include the research activities of chronic arsenic exposure and various carcinogenic and non-carcinogenic health effects. Some recent estimates indicate that more than 35 million people in West Bengal (India), Nepal and Bangladesh are potentially at risk from drinking arsenic-contaminated water. The crisis has its roots in another worthy effort to fight water-borne diseases that had impacted this tropical region for a long time.

## 4.3 Techniques for Removal of Arsenic from Water

A number of treatment technologies have been demonstrated to be effective in removing arsenic from contaminated natural groundwater. 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 (Cheng et al., 1994; Hering et al., 1996, 1997; Kartinen and Martin, 1995; Shen, 1973; Joshi and Chaudhuri, 1996). However, question remains regarding the efficiency and applicability/ appropriateness of the technologies - particularly because of low influent arsenic concentration and variety of source water composition. Besides, appropriate technology must be economically viable and socially acceptable. The Techniques available for removal of arsenic from contaminated water are based on mainly four principles:

i. Oxidation/reduction
ii. Coagulation and precipitation
iii. Sorption technique
iv. Membrane technique

### 4.3.1 Selection of an Appropriate Arsenic Removal Technique

Most removal techniques are complex and/or expensive. Moreover, they often require a certain level of technical skills. There are many overviews of arsenic removal technologies already available. This IGRAC's (International Groundwater Resources Assessment Centre) overview summaries information on removal methods and evaluates these methods in terms of efficiency, costs and required technology. Suitability of various removal methods related to scale of application, costs and removal efficiency can be summarized as follows:

| Methods | demestic + low costs | community + low costs | domestic + high As removal | community + high As removal | domestic + brackish water | community + brackish water |
|---|---|---|---|---|---|---|
| alum coagulation | 🟩 | 🟩 | 🟩 | 🟩 | 🟥 | 🟥 |
| iron coagulation | 🟩 | 🟩 | 🟩 | 🟩 | 🟥 | 🟥 |
| Enhanced coagulation (EC) | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |
| Activated alumina | 🟧 | 🟧 | 🟩 | 🟩 | 🟥 | 🟥 |
| Iron coated sand (IBS) | 🟩 | 🟩 | 🟩 | 🟩 | 🟥 | 🟥 |
| Ion exchange | 🟧 | 🟧 | 🟩 | 🟩 | 🟥 | 🟥 |
| membrane processes | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 |
| conventional Fe-removal technique | 🟩 | 🟩 | 🟥 | 🟥 | 🟥 | 🟥 |
| memstill* | 🟧 | 🟧 | 🟩 | 🟩 | 🟩 | 🟩 |
| waterpyramid/solar dew | 🟧 | 🟧 | 🟩 | 🟩 | 🟩 | 🟩 |
| UNESCO-IHE IOCS | 🟩 | 🟩 | 🟩 | 🟩 | 🟥 | 🟥 |
| *Alcan Activated Alumina* | 🟩 | 🟧 | 🟩 | 🟩 | 🟥 | 🟥 |
| *BUET Activated Alumina* | 🟩 | 🟥 | 🟩 | 🟥 | 🟥 | 🟥 |
| *Sono 3-kolski method* | 🟩 | 🟥 | 🟩 | 🟥 | 🟥 | 🟥 |
| *Stevens Institute Method* | 🟩 | 🟧 | 🟩 | 🟩 | 🟥 | 🟥 |
| *Tetrahedron* | 🟩 | 🟧 | 🟧 | 🟧 | 🟥 | 🟥 |
| *Two bucket System* | 🟩 | 🟥 | 🟧 | 🟥 | 🟥 | 🟥 |

**Source :** IGRAC, Report nr. SP 2007-2

The colours in the matrix correspond with the appropriateness of the method for the given situation:

- Green colour means that the method is very suitable

- Orange colour means average suitability
- Red colour means that the method is unattractive or not applicable for the given situation.

Advantages and disadvantages of arsenic removal techniques are given in Table 4.1.

**Table 4.1 :** Advantages and Disadvantages of Techniques for Arsenic Removal

| Technologies | Advantages | Disadvantages |
|---|---|---|
| Oxidation /precipitation<br>• Air oxidation<br>• Chemical oxidation | • Relatively simple and rapid process<br>• Relatively simple, low cost process<br>• Oxidizes other impurities and kills microbes | The process removes only a part of arsenic |
| Coagulation-precipitation<br>• Alum coagulation<br>• Iron coagulation<br>• Lime softening | • Relatively low capital cost<br>• Relatively simple operation<br>• Common chemicals available | • Produces toxic sludge<br>• Low removal As (III)<br>• Pre oxidation may be required |
| Sorption Techniques:<br>• Activated Alumina<br>• Iron coated sand<br>• Ion exchange resin<br>• Other sorbents | • Relatively well known and commercially available<br>• Well defined technique<br>• Plenty possibilities and scope of development | • Produces toxic solid waste<br>• Replacement and regeneration required<br>• High tech operation<br>• Relatively high cost |
| Membrane techniques :<br>• Nanofiltration<br>• Reverse osmosis<br>• Electrodialysis | • Well defined and high removal efficiency<br>• No toxic solid wastes produced<br>• Capable of removal other contaminants | • Very high capital and running cost<br>• High tech operation and maintenance<br>• Toxic wastewater produced |

### 4.3.2 Oxidation / Reduction

Arsenic in groundwater may occur as arsenite As(III) and arsenate As(V) in different proportions. Most arsenic treatment technologies are very effective in removing the pentavalent form of arsenic (arsenate), but the removal efficiency of the trivalent form (arsenite) is very low. Therefore, many treatment technologies include oxidation as a pre-treatment step to convert As(III) to As(V). Atmospheric oxygen, hypochlorite and permanganate are most commonly used for oxidation process of arsenic.

$$H_3AsO_3 + \tfrac{1}{2} O_2 = H_2AsO_4^- + H^+$$

$$H_3AsO_3 + HClO = HAsO_4^{--} + Cl^- + 3H^+$$

$$3H_3AsO_3 + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O$$

Other chemicals that are used include gaseous chlorine, ozone and other oxidizing agents. Natural oxidation of arsenic by air is very slow and can take several weeks, but the above chemicals can oxidise arsenic rapidly.

### 4.3.3 Coagulation and Precipitation

Coagulation/precipitation (C/P) is a treatment method for arsenic removal using either metal salts or lime softening. C/P uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation, flocculation, and filtration (Ahmed, 2001). In this method a coagulant (e.g. alum or ferric chloride) is added and rapidly mixed for about one minute. Aluminium or ferric hydroxide micro-flocs are formed (coagulation). The water is then gently stirred for a few minutes (flocculation) and the majority of the micro-flocs agglomerate into larger settable flocs. During the coagulation-flocculation process many micro-particles and negatively charged ions are attached onto the flocs. Arsenic also attaches to the flocs (adsorption). Subsequently sedimentation and filtration (co-precipitation) are used to separate the flocs, together with the adsorbed arsenic. Commonly used coagulants are alum, $Al_2(SO_4)_3.18H_2O$; ferric chloride, $FeCl_3$; and ferric sulphate, $Fe_2(SO_4)_3.7H_2O$. Pre-oxidation is highly recommended.

### 4.3.3.1 Iron Coagulation

Arsenic in the arsenate form can be readily removed by adding ferric iron salts if the optimum conditions are maintained to affect that removal. Coagulation using iron salts such as ferric chloride and ferrous sulfate can remove up to 90% of As(V) at pH 7 and about 50% of As(III) (PUREFLOW Filtration Systems, 2005). Arsenite is generally less efficiently removed by ferric chloride than As(V) (EPA, 2000). Removal efficiency of 80% can be achieved over the pH range of 4-8 with ferric chloride (Hering et al., 1997). With ferric sulphate, removal efficiency of over 95% As(V) was obtained within pH range of 5-7.5 for dosages between 10 and 50 mg/L (EPA, 2000).

### 4.3.3.2 Alum Coagulation

Alum can be used to remove arsenate, but is less effective than other processes over a narrower pH range for arsenate removal. Alum coagulation is not that efficient for removal of arsenite (Ali et al., 2001). Over 90% of As(V) was removed with alum coagulation, but only at dosages greater than 30 mg/L and within the pH range 5-7 (EPA, 2000).

### 4.3.3.3 Lime Softening

Lime softening, excess lime treatment, split lime treatment and lime-soda softening are all effective in reducing arsenic. Lime softening uses addition of $Ca\ (OH)_2$ and $Na_2CO_3$ for removal of carbonate and non-carbonate hardness and is also capable of removal of arsenic present in water. Removal of both the forms of arsenic by lime softening is pH dependent (EPA, 2000). Addition of lime increases the pH and creates a shift in the carbonate equilibrium. Bicarbonate gets converted to carbonate as the pH increases and calcium is precipitated as calcium carbonate. The formation of calcium carbonate, magnesium hydroxide and ferric hydroxide enhances the removal of arsenic (Veenstra et al., 2004). Sludge disposal is a problem in this treatment method (EPA, 2000) and is recommended to have this type of treatment only if hardness must also be removed.

## 4.3.4 Sorption Technique

When arsenic-contaminated water is passed through a sorption media bed, its media can remove arsenic. The commonly used media are activated alumina, activated carbon, iron and manganese coated sand, activated carbon, kaolinite clay, and hydrated ferric oxide. The efficiency and the total amount of water treated depend on the media and the water composition, as different contaminants and components of water compete for the available sites on the media. In most of the cases arsenic removal is very effective if oxidation is carried out before sorption.

### 4.3.4.1 Activated Alumina

Activated alumina (AA) is effective in treating water with high total dissolved solids (TDS). However, selenium, fluoride, chloride, and sulphate, if present at high levels, may compete for adsorption sites. AA is highly selective towards As(V); and this strong attraction results in regeneration problems, possibly resulting in 5 to 10% loss of adsorptive capacity for each run. Application of point-of-use treatment devices would need to consider regeneration and replacement.

### 4.3.4.2 Ion Exchange

Synthetic ion exchange resins are a special kind of sorption media. They are used in water treatment to remove undesirable ions by replacing ions attached to the resins. With the continuing use of the resins their removal capacity is exhausted and they need regeneration. Systems containing high levels of these constituents may require pre-treatment. The arsenic exchange equation can be represented as follows where **R** represents ion exchange resins and Cl- is an ion attached to the resin.

$$2R\text{-}CI + HAsO_4^{--} \rightleftharpoons R2HAsO_4 + 2CI^- \qquad (4)$$

The regeneration equation using common salt as regeneration agent is

$$R2HAsO_4 + 2Na^+ \, 2CI^- \rightleftharpoons 2R\text{-}CI + HAsO_4^{--} + 2Na^+ \qquad (5)$$

Ion exchange is very effective when the form of arsenic in water is predominantly As(V). Otherwise a pre-oxidation step is necessary. Various anion exchange resins that can remove arsenic (arsenate) concentration below 1 mg/L are commercially available. Conventional sulphate-selective and nitrate-selective resins are suitable for arsenic removal. The arsenic removal capacity depends on the sulphate and nitrate contents of the raw water as they are exchanged prior to arsenic.

### 4.3.4.3 Granular ferric hydroxide

This treatment option is capable of removing both forms of arsenic. Kinetics studies showed that less than 5µg/l of As could be achieved at the pH levels of 6 and 7.6 with a maximum of 96% of As(V) removal at a pH of 7.6 at an equilibrium time of 6 h (Thirunavukkarasu et al., 2003). Research has shown that Granular Ferric Hydroxide (GFH) is less sensitive to pH and has higher capacity than AA. Pre-oxidation of raw water is not required and both arsenic valence states are removed to the same extent. Periodic backwashing of the media is required depending on raw water quality. Research is being conducted to determine the feasibility of regenerating GFH. This type of treatment requires iron removal as pre-treatment to prevent the filter bed from clogging up.

### 4.3.4.4 Iron Oxide Coated Sand

Iron oxide coated sand is prepared by treating river sand with acid solution, then mixed with Iron (III) nitrate nanohydrate at a weight ratio of 10:1 and heating to 110°C for at least 20 hours (Yuan et al., 2002). Batch studies with Iron Oxide Coated Sand (IOCS) showed that effluent arsenic level could be achieved below 5 to 10 µg/L with an adsorption capacity of 136 g/g (Thirunavukkarasu et al., 2005). IOCS had a removal efficiency of 68.85% and 83.65% for As(III) and As(V), respectively and very strong hardness of water affected the removal efficiency of arsenite alone (Yuan et al., 2002). The performance of this treatment option is highly variable. This technology for arsenic removal can be effective with arsenic concentrations up to at least 300 µg/L. It does not seem to be viable with very high concentrations (Ashraf et al., 2001).

## 4.3.5 Membrane Techniques

Microfiltration (MF), utrafiltration (UF), nano-filtration (NF), reverse osmosis (RO) and electrodialysis reversal (EDR) can remove arsenic through filtration, electric repulsion, and adsorption of arsenic-bearing compounds. The use of MF and UF membranes is dependent on the size distribution of arsenic bearing particles in water. To increase removal efficiency with a low percentage of particulate arsenic content, MF can be combined with coagulation processes.

#### 4.3.5.1 Reverse Osmosis

Reverse Osmosis (RO) is very effective in removing dissolved arsenic. Arsenic removal efficiency of greater than 95% can be achieved when operating pressure is ideal. If RO is used by small systems, 60% water recovery will lead to an increased need for raw water. The water recovery is the volume of water produced by the process divided by the influent stream (product water/influent stream). Discharge of reject water or brine may also be a concern. If RO is used by small systems, water recovery will likely need to be optimized due to the scarcity of water resources.

#### 4.3.5.2 Electrodialysis Reversal

Electrodialysis reversal (EDR) is an ED process which reverses the polarity of the electrodes on a controlled time cycle, which reverses the direction of ion movement in a membrane stack. EDR typically requires little or no pretreatment to minimize fouling of the membrane. EDR can also be used for removal of arsenic. A water recovery of 85% is achievable. One study demonstrated arsenic removal to 3 µg/L from an influent concentration of 21 µg/L. While capable of removing arsenic to low levels, the process is equipment, energy and labour intensive. It also creates a concentrate which must be disposed of, and is quite wasteful of water. ED/EDR systems are not considered to be economically viable for any but very small installations.

#### 4.3.5.3 Nanofiltration

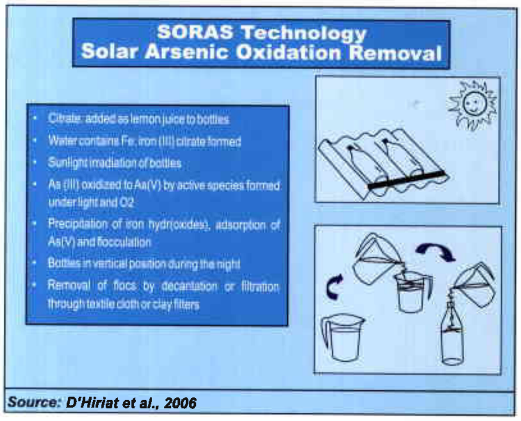
Nano-filtration (NF) membranes are capable of removing significant portions of the dissolved arsenic compounds in natural waters. NF can remove both forms of arsenic and hence is a reliable process for groundwater with 90% dissolved arsenic. The recoveries ranged between 15 to 20%. A recent study showed that the removal efficiency dropped significantly during pilot-scale tests where the process was operated at more realistic recoveries. If nanofiltration is used by small systems, water recovery will likely need to be optimized due to the scarcity of water resources. The increased water recovery can lead to increased costs for arsenic removal.

## 4.4 Additional Arsenic Removal Technologies

Following methods is based on oxidation, co-precipitation and adsorption techniques:

### 4.4.1 Solar Oxidation and Removal of Arsenic (SORAS)

It is a simple method that uses irradiation of water with sunlight in PET or other UV transparent bottles to reduce arsenic level from drinking water (Figure 4.1). The process is developed by Swiss Federal Institute of Environmental Science and Technology, Switzerland (EAWAG) and Swiss Agency for Development and Cooperation (SDC) (Wegelin et al., 2001). The method is based on photochemical oxidation of As (III) followed by precipitation or filtration of As (V) adsorbed on Fe (III) oxides. Field tests in Bangladesh show removal efficiency between 45-78% with an average of 67%. Concerning the Bangladesh guideline



**SORAS Technology**
**Solar Arsenic Oxidation Removal**

- Citrate: added as lemon juice to bottles
- Water contains Fe, iron (III) citrate formed
- Sunlight irradiation of bottles
- As (III) oxidized to As(V) by active species formed under light and O2
- Precipitation of iron hydr(oxides), adsorption of As(V) and flocculation
- Bottles in vertical position during the night
- Removal of flocs by decantation or filtration through textile cloth or clay filters

*Source: D'Hiriat et al., 2006*

**Figure 4.1:** Solar Oxidation and Removal of Arsenic (SORAS)

value of 50 µg/L, SORAS can treat raw water having an arsenic concentration below 100 – 150 µg/L. The method is conceived for usage at household level to treat small quantities of drinking water at virtually no cost.

**Contact details :**

Eawag, Überlandstrasse 133
P.O.Box 611
8600 Dübendorf
Switzerland
Ph. +41 (0)58 765 55 11 Fax +41 (0)58 765 50 28
info@eawag.ch

### 4.4.2 NMRL-DRDO Household Water Filter

NMRL-DRDO (Naval Materials Research Laboratory - Defence Research and Development Organisation) Household Arsenic removal filter has been designed and fabricated both in plastic and in stainless steel (Figure 4.2). The filter comprises of three chambers. The first chamber contains reactant material enclosed in a fine cloth bag. In the second chamber fine cloth bag containing treated sand is placed. The third chamber simply acts as a collector chamber for treated water. Arsenic contaminated water is allowed to enter the first chamber of the filter at a predetermined flow rate from where it passes down to the second chamber and finally gets collected in the third chamber. The arsenic removal filter works on the simple principle of co-precipitation of arsenic with iron and adsorption of this precipitate on iron oxy-hydroxides, followed by further retention of this precipitate in treated sand. Sodium salts of arsenite and arsenate get ionized in the water medium. The arsenite and arsenate ions are removed further by co-precipitation as $FeAsO_4$ and $FeAsO_3$ and by adsorption of these oxides onto ferric oxy-hydroxide solids. The filter material and sand is to be replaced periodically as per usage. This filter is capable of treating arsenic contaminated water to bring down concentration below 50 µg/L.

**Figure 4.2:** NMRL-DRDO household water filter

The cost of the unit is around Rs. 500 for the stainless steel filter and Rs. 150 for the plastic parts. The cost of removing arsenic from the contaminated waters works out to be Rs.27-30 per 1,000 litres of water.

**Contact details:**
**Dr Kshipra Misra, scientist,**
NMRL,
Ambernath, Maharashtra
kmisra99@yahoo.com

### 4.4.3 SONO Arsenic Mitigation Filter

The primary active material used in this filter is the composite iron matrix (CIM), a mass made up of iron turnings. The filter consists of two chambers made up of plastic buckets (Figure 4.3). The upper chamber is fitted with tap and flow control junction with a plastic pipe which enters the second chamber. The upper chamber consists of layers of brick chips, and CIM sandwiched between two layers of coarse sand. The lower chamber is filled with brick chips as the lowest layer followed by fine sand, on the top of which is spread wood charcoal followed by the top layer of coarse sand. The CIM removes inorganic arsenic species quantitatively. The process does not require pre-treatment of water with external oxidizing agents. Further the filter does not require any special maintenance other than replacement of the upper sand layers when the apparent flow rate decreases. The filter can produce potable water for at least 5 years. The cost of this filter is INR 2000.

**Contact details:**

**Dr. A.K.M. Munir**
Manob Sakti Unnayan Kendro 77, Mahatabuddin Road, Courtpara,
Kushtia-7000, Bangladesh
Phone : 88-071-61335, Fax :88-071-61335
NGO Affairs Bureau Reg. # 1719
Directorate of Social Welfare Reg.
# Kushtia-343
E-mail: akmmunir@msuk-bd.org

**Figure 4.3:** SONO Arsenic Mitigation Filter

## 4.4.4 Double 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. It consists of two buckets, each 20 litre capacity, placed one above the other. Chemicals are mixed manually with arsenic contaminated water in the upper red bucket by vigorous stirring with a wooden stick for 30 to 60 seconds and then flocculated by gentle stirring for about 90 second. The mixed water is then allowed to settle for 1- 2 hours. The water from the top red bucket is then allowed to flow into the lower green bucket via plastic pipe and a sand filter installed in the lower bucket. The flow is initiated by opening a valve fitted slightly above the bottom of the red bucket to avoid inflow of settled sludge in the upper bucket. The lower green bucket is practically a treated water container. These units are based on chemical doses of 200 mg/L aluminum sulphate and 2 mg/L of potassium permanganate supplied in crushed powder form. Extensive study of DPHE-Danida BTU under BAMWSP, DFID, WaterAid (2001) rapid assessment program showed mixed results.

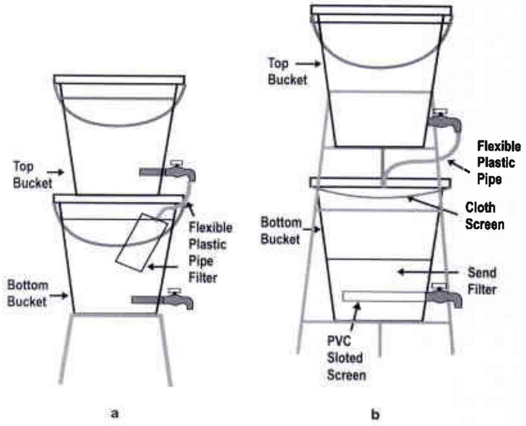


**Figure 4.4:** Double-bucket household arsenic treatment unit. (a) BPHE-Danida* unit; (b) BUET** modified unit (*Department of Public Health Engineering-Danish International Development Agency; **Bangladesh University of Engineering and Technology.)

In many cases, the units under rural operating conditions fail to remove arsenic to the desired level of 0.05 mg/L in Bangladesh. Poor mixing and variable water quality particularly pH of groundwater in different locations of Bangladesh appeared to be the cause of poor performance in rapid assessment. Bangladesh University of Engineering and Technology (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride and 1.4 mg/L of potassium permanganate in modified BTU units. The arsenic contents of treated water were mostly below 20 ppb and never exceeded 37 ppb while arsenic concentrations of tubewell water varied between 375 to 640 ppb.

The cost (capital and recurrent) of this unit is about INR 200-250 depending on the production cost of the flat cover for the lower bucket.

**Contact details:**

**DPHE-Danida Water Supply and Sanitation Components**
Arsenic Mitigation Component
2888, Central Road, Harinarayanpur, Maijdee Court, Noakhali.
Ph. 0321 5582

### 4.4.5 Star Filter

The Star Filter is developed by the Stevens Institute Technology. This technology also uses two buckets, one to mix chemicals (reported to be 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 4.5 to help sedimentation and keeping the filter sand bed in place. The chemicals form visible large flocs on mixing by stirring with stick. 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 (BAMWSP, DFID, WaterAid, 2001). The sand bed used for filtration is quickly clogged by flocs and requires washing at least twice a week.

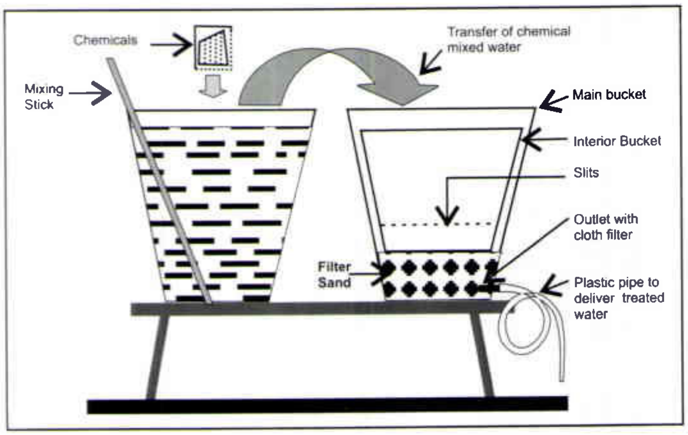


**Figure 4.5:** The Star Filter developed by the Stevens Institute Technology

The cost (capital and recurrent) of this unit is INR 350.

**Contact details:**

**Professor Meng,**
Center for Environmental Engineering,
Stevens Institute of Technology,
Hoboken, NJ 07030.
E-mail: xmeng@stevens-tech.edu
Md. Suruzzaman, Earth Identity Project, House 13A, Road 35,
Gulshan, Dhaka-1212. Tel: 8812049

## 4.4.6 Arsenic-iron removal plant

When groundwater contains an excessive amount of iron (and/or manganese), plants designed for iron removal can at the same time remove arsenic. Depending on the proportion of As(III) in the water, a chemical oxidation step may be required. Many iron removal plants do not use flocculation and sedimentation; the flocs formed as a result of the presence of natural coagulants or added coagulants are removed in the direct filtration step. Figure 4.6 shows a direct filtration process of iron and arsenic removal. Other methods that can be used in small communities are arsenic-specific filter units (like activated alumina filters) and ion exchange resin beds. These units may need a coarse sand pre-filter unit to remove excessive iron so that iron hydroxide flocs formed do not clog the subsequent filter units. Again a chemical oxidation step may be necessary depending on the proportion of As(III).

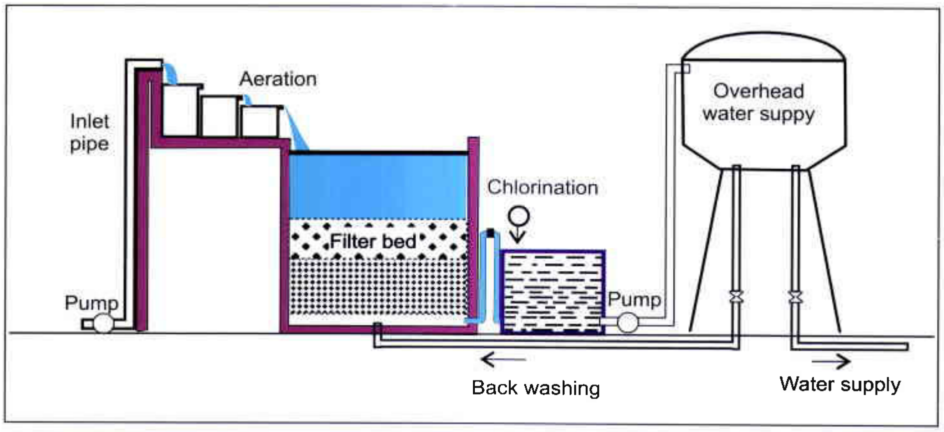


**Figure 4.6:** Schematic diagram of iron and arsenic plant in Bangladesh

## 4.4.7 Iron and Arsenic Removal Unit

This is a small version of an iron removal plant and is attached to a handpump / tubewell (Figure 4.7). It is used where groundwater contains an excessive amount of iron. The treatment method consists of aeration, sedimentation, flocculation and sedimentation in a roughing filter and final filtration. The water from the handpump / tubewell is passed through a slotted horizontal PVC pipe and falls into the cubical structure. The structure consists of three chambers. Water from the slotted pipe falls into the first chamber and aeration occurs. Here partial sedimentation also takes place. Water from the first chamber then enters the bottom of the second chamber, which is an upflow roughing filter with coarse aggregates (20-30 mm). Here, flocculation sedimentation occurs in which iron hydroxide micro-flocs grow in size and most of them settling onto the coarse aggregates. The partially filtered water then overflows into the third chamber, consisting of a bed of coarse sand or small aggregates, and a final downflow filtration takes place. The filtered water is delivered through an underlying compartment and pipes. During the iron removal process arsenic is removed by adsorption and co-precipitation.

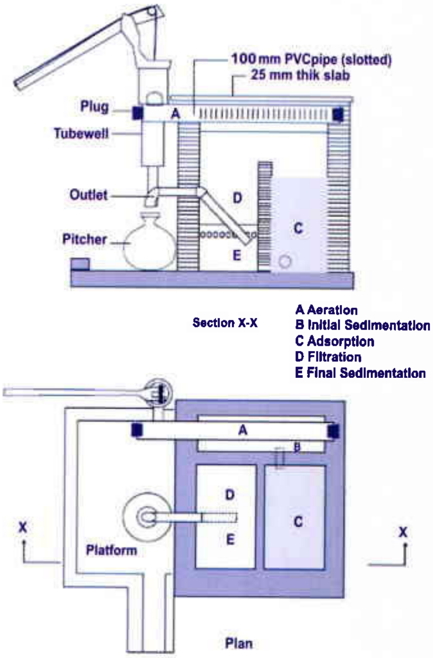


**Figure 4.7:** Tube Well Attachable Iron and Arsenic Removal Unit

### 4.4.8 Fill and Draw Units

It is a community type treatment unit designed and installed under DPHE-Danida Arsenic Mitigation Pilot Project. It is 600 L capacity (effective) tank with slightly tapered bottom for collection and withdrawal of settled sludge. The tank is fitted with a manually operated mixer with flat-blade impellers. The tank is filled with arsenic contaminated water and required quantity of oxidant and coagulant are added to the water. The water is then mixed for 30 seconds by rotating the mixing device at the rate of 60 rpm and left overnight for sedimentation. The water takes some times to become completely still which helps flocculation. The floc formation is caused by the hydraulic gradient of the rotating water in the tank. The settled water is then drawn through a pipe fitted at a level, few centimetres above the bottom of the tank and passed through a sand bed and finally collected through a tap for drinking purpose as shown in Figure 4.8. The mixing and flocculation processes in this unit are better controlled to effect higher removal of arsenic. The experimental units installed by DPHE-Danida project are serving the clusters of families and educational institutions.

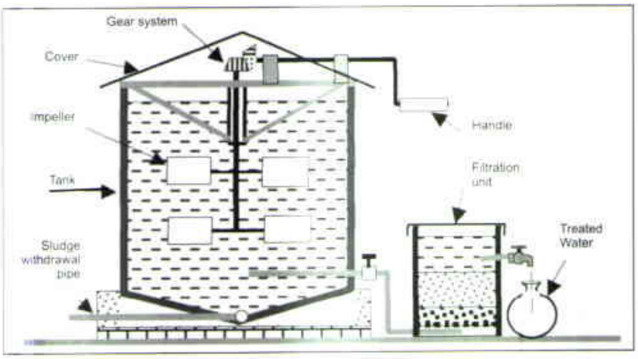


**Figure 4.8:** DPHE-Danida Fill and Draw Arsenic Removal Unit

### 4.4.9 Arsenic Removal Unit Attached to Tubewell

The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment at the village level in West Bengal. The arsenic removal plant attached to hand tubewell as shown in Figure 4.9 has been found effective in removing 90% arsenic from tubewell water having initial arsenic concentration of 300mg/L. The treatment process involves addition of sodium hypochloride ($Cl_2$) and aluminium alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit.

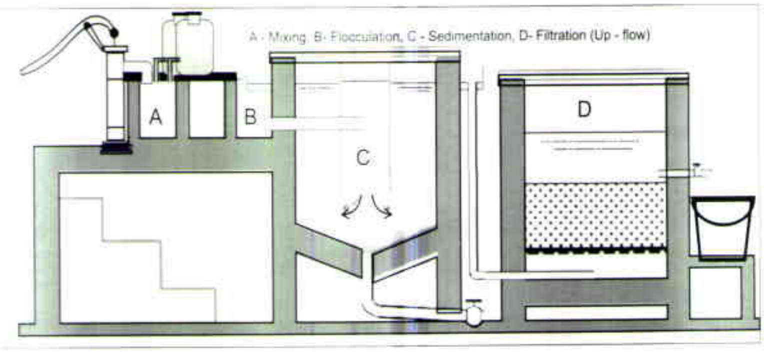


**Figure 4.9:** Arsenic Removal Plants Attached to Tubewell (designed and constructed in India)

### 4.4.10 Two-Bucket Treatment Unit

This method is based on the co-precipitation process. The unit consists of two buckets, each with a capacity of about 20 litres. Normally they are placed one above the other. Arsenic-contaminated water is poured in the top bucket. Chemicals are then added and vigorously stirred with a stick for about one to two minutes. Thereafter the water is gently stirred for flocculation for another two to three minutes. The mixed water is allowed to settle for about two hours. The chemicals added are a mixture of coagulant (e.g. alum, ferric chloride or sulphate) and oxidant (potassium permanganate, calcium hypochloride) in crushed powder form. They are normally supplied in single dose packages.

After settling, the top two thirds of the supernatant water from the first bucket is poured gently (or flows by plastic pipe) into the second bucket. The second bucket is half filled with filter sand and has a perforated under drain pipe connected to an external tap. When the tap is opened the settled water passes through the filter sand, which removes the remaining micro-flocs. A schematic diagram of the two-bucket system is shown in Figure 4.10.

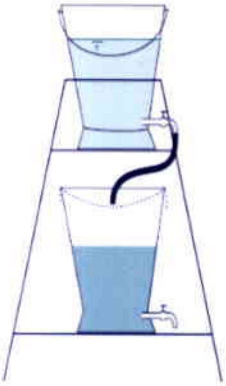


**Figure 4.10:** Two-Bucket Treatment Unit

## 4.4.11 Alcan Enhanced Activated Alumina Unit

In this process, water from a tube well is allowed to pass through an enhanced activated alumina bed and the treated water is collected as shown in Fig 4.11. The unit has a simple and robust design. No chemicals are added during treatment and the process relies entirely on the active surface of the media for adsorption of arsenic. Other ions present in water, such as iron and phosphate, may compete for active sites on alumina and thereby reduce the arsenic removal capacity of the unit. Iron present at elevated levels in shallow tube well water will eventually accumulate in the activated alumina bed and interfere with water flow. The unit can produce more than 3600 L arsenic-safe drinking water per day, enough for 100 families. Alcan's enhanced activated alumina unit is designed for single use and therefore saturated media must be replaced after use. Environmentally safe disposal of spent activated alumina (~40 kg per treatment cycle) is required.

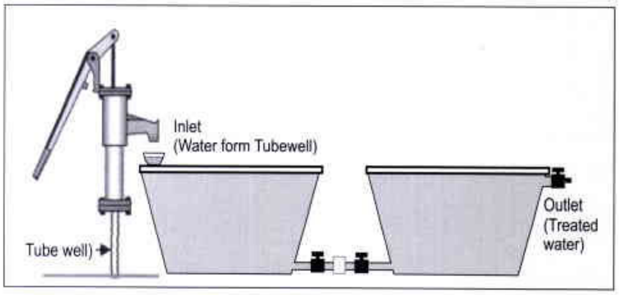


**Figure 4.11:** Alcan enhanced activated alumina unit

The cost of this unit is US$500 (Rs. 25000) (US$200 for the unit and US$300 for the material (5 year warranty, expected life 10 years). Annual filter material costs US$300. Costs could fall if demand is high.

**Contact details:**

**M. Saber Afzal, MAGC Technologies Ltd,**
House 15, Road 5'
Dhanmondi, Dhaka-1205.
E-mail: mendota@bdmail.net

## 4.4.12 BUET Activated Alumina Filter

The BUET activated alumina arsenic removal unit (ARU) consists of subunits for oxidation-sedimentation, filtration, and activated alumina adsorption. Oxidation and sedimentation is performed in a 25-L plastic bowl. Approximately 1 mg/L potassium permanganate is added to water in the bowl to oxidize As(III) to As(V); the mixture is stirred vigorously with a wooden stick and then allowed to settle for about 1 hour.

The settled water is filtered through a sand bed and is then passed through the activated alumina column. The unit is very effective in removing arsenic and iron from tube well water. One practical problem with the ARU is that women have difficulty in raising water to the level required for gravity flow through the subunits. The problem has been addressed by design modification. The modified BUET activated alumina ARU is shown in Figure 4.12.

The costs (capital and recurrent) of this filter is Tk. 1000/- (INR 650).

**Contact details:**
**Dr. M.A. Jalil,**
Department of Civil Engineering,
BUET,
E mail: majalil@buet.edu

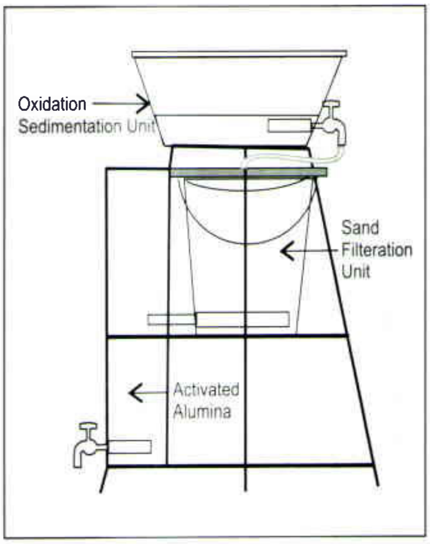


**Figure 4.12:** BUET activated alumina filter

## 4.4.13 Iron-Coated Sand Filter

BUET has tested a unit that utilizes iron-coated sand for removal of arsenic from groundwater (Figure 4.13). Pretreatment for removal of excess iron, to avoid clogging of the active filter bed, is required. Pretreatment consists of precipitating iron by air oxidation. The water is then filtered through sand to trap excess iron. This sand filter, about 10 cm in depth, is placed in a 15-cm-diameter PVC chamber having perforations at its base. Water flows from the top of the bucket into the sand filter via a replaceable plastic pipe. A 1- to 2-cm-thick gravel bed is placed at the bottom to retain sand. The water then passes through a second 40-cm-deep iron-coated sand filter that is responsible for removing arsenic. Water enters into a strainer placed in iron-coated sand and eventually flows to the tap.

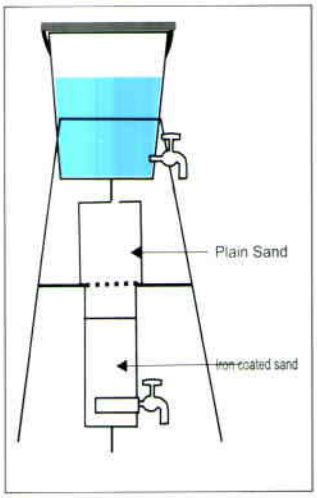


**Figure 4.13:** Iron-Coated Sand Filter

## 4.4.14 Read-F Arsenic Removal Unit

Read-F is an adsorbent produced and promoted by Shin Nihon Salt Co. Ltd., Japan for arsenic removal in Bangladesh. Read-F displays high selectivity for arsenic ions under a broad range of conditions and effectively adsorbs both arsenite and arsenate without the need for pre-treatment. The Read-F is Ethylene-vinyl alcohol copolymer (EVOH)-borne hydrous cerium oxide in which hydrous cerium oxide ($CeO_2.n H_2O$) is the adsorbent. The material contains no organic solvent or other volatile substance and is not classified as hazardous material. Laboratory test at BUET and field testing of the materials at 4 sites under the supervision of BAMWSP have shown that the adsorbent is highly efficient in removing arsenic from groundwater. Monthly water consumption cost of this filter is Tk 230/- (INR 150).

**Figure 4.14:** Read-F Arsenic Removal Unit

## 4.4.15 Shapla Arsenic Filter

The Shapla Arsenic Filter, a household arsenic removal unit has been developed and promoted by International Development Enterprises (IDE), Bangladesh. The unit media constitutes iron-coated brick chips manufactured by treating such chips with a ferrous sulphate solution; the media works on the same principles as iron-coated sand. Water from contaminated tube wells is allowed to pass through earthen containers filled with the filter media; the containers are fitted underneath with a drainage system. A drawing of the Shapla Filter is shown in Figure 4.15

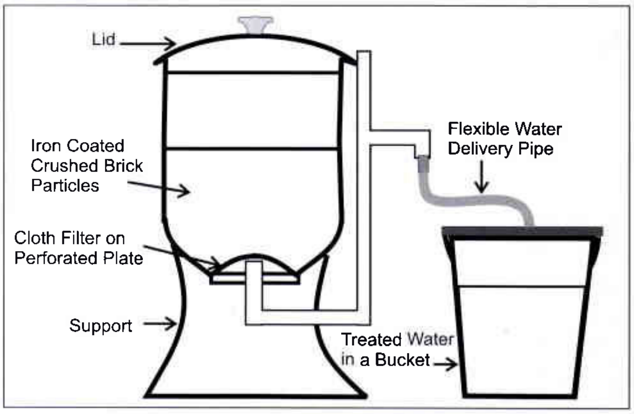


**Figure 4.15 :** Shapla arsenic filter

The cost (Capital and current) per unit is 350-400 Tk (INR 250-300) including media, whereas 20 kg of replacement media cost is 100 Tk (INR 75)

**Contact**
**Professor Fakhrul Islam,**
Department of Applied Chemistry & Chemical Technology
Rajshahi University,
Bangladesh

## 4.4.16 RKM Filter

Since October 1999, the Rama Krishna Mission (RKM) have distributed 135 filter units to households in West Bengal through one of their 'cluster organizations'(Swamiji Seba Sangha in Lakshmipur, North 24 Parganas, West Bengal). Based on an All India Institute of Hygiene and Public Health (AIIH&PH) unit, the RKM filter unit is a particularly low-cost and appropriate design, developed by RKM in conjunction with a local potter. It is also based on the well-known arsenic removal technology of oxidation of As(III) to As(V) followed by coagulation and precipitation. It is hybrid of DANIDA-DPHE filter used in Bangladesh and ceramic filter design. It comprises of a bucket and two clay pitchers – one of them fitted with "Tripura filter" – a low cost earthen replica of ceramic filter. Ferric alum and bleaching powder are required for treating water. In this treatment process ferric alum and bleaching powder is mixed in 10 L water in a plastic bucket and allow the water to rest for 2 hours. 7 L of water is decanted without disturbing sludge. Then this 7 L water is poured into the top pitcher containing "Tripura Filter". Treated water is collected in the bottom pitcher. It can treat 40-50 litres of water per day. Specific performance data is not available.

The capital cost is Rs. 250 per unit. The operation cost is Rs. 0.75-1.00 per 10L of treated water.

## 4.4.17 CMFRI Filter

This filter is developed by the Central Mining and Fuel Research Institute (CSIR-CMFRI), Dhanbad. It is based on the well-known arsenic removal technology of oxidation of As(III) to As(V) followed by coagulation and precipitation. It comprises of two containers (plastic/stainless steel) each of 10-liter capacity. The upper container has a lid and fitted with a candle filter. The bottom container is fitted with a tap 25 mm above the bottom end. The chemicals (a mixture of two chemical) weighing 0.6 g is packed in a capsule. The chemical composition has not been made public by CMFRI. As per the laboratory results obtained, the arsenic level in treated water comes down from 0.3 mg/L to well below 0.05 mg/L. No field test results are available.

The cost of reagents is 10 paisa for treating 10 L of water. When produced in the form of a capsule it may cost Rs. 0.25 for treating 10 L water with high arsenic. Cost of chemicals inclusive of packaging and marketing per 20L of water is Rs. 0.75 to Rs 1.00.

### 4.4.18 AMAL Domestic Filter

The Bengal Engineering College (BEC) has developed an AA-based domestic arsenic removal unit known as "AMAL Filter" – named in the memory of late Dr. Amal K Datta who initiated its development (Figure 4.16). It is based on the principle of adsorption of arsenic ions on activated alumina surface.

It comprises of a lower chamber and an upper chamber. The upper chamber (12 L capacity) contains 2.75 L of 0.4-1 mm particle size granular AA, a micro-filter (slit size < 0.2 mm) with a 1.5 mm hole to regulate flow rate (8-10 liter/hour). The lower chamber (12L capacity) stores treated water, which can be drawn through a tap. Raw water is put into the upper container. Arsenic gets adsorbed by porous surface of AA granules placed in the upper container. The micro-filter controls the flow rate and ensures sufficient bed contact time. The filtered water gets collected in the bottom container. AA gets exhausted after a certain time and will need to be regenerated periodically. Periodicity will depend on the chemical composition of raw water and allowable maximum permissible limit of arsenic in treated water.

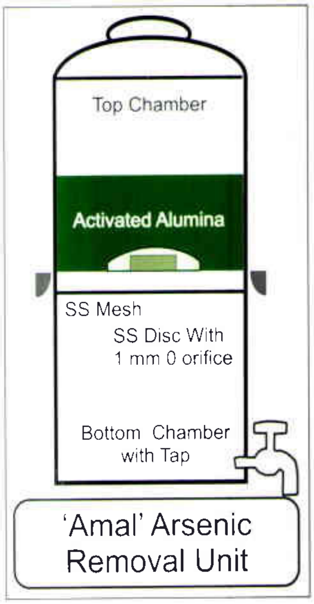


**Figure 4.16:** AMAL Domestic Filter

The cost of a domestic AA-based arsenic removal unit varies from INR 700 to INR 1,500 depending upon the material of construction. A community plant may cost INR 15,000. AA costs INR 100 per kg and it can be regenerated several times. AA regeneration cost is nearly Rs.50 per household per annum.

### 4.4.19 Safi Filter

The Safi filter comprises of two concrete buckets of different sizes, one of which is placed above the other. The upper bucket is fitted with the Safi candle (made from chemical mixture of laterite soil, ferric oxide, manganese di-oxide, aluminium hydroxide and mezoporous silica). Raw water in the upper bucket passes through the candle and gets collected in the lower bucket. The permeable candle adsorbs arsenic and removes bacteria. As per manufacturer, a household of five members can use the candle for two years. Arsenic is absorbed on candle material when raw water passes through candle (Figure 4.17).

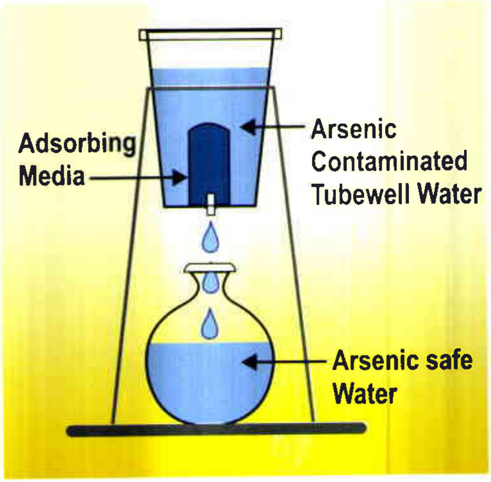


**Figure 4.17:** Safi Filter

During field tests it was observed that the candle gets clogged resulting in significantly reduced flow rates and candle life - less than two months. Moreover, it was not effective in the removal of arsenic to ensure sustained supply of drinking water within the permissible arsenic limit. None of the filters, at any stage of operation, provided bacteria free water. It appears that further development work is in progress to overcome the above weaknesses.

The cost of the 40 L per day filter is Tk 900 (INR 700). The cost of candle is INR 150 which has to be replaced every two months.

### 4.4.20 Paul Trockner Filter

The filter is based on adsorption technique for arsenic removal. Granular ferric hydroxide reactor is fixed bed absorbers operating like conventional filters with a downward water flow. It is poorly crystallized β FeOOH with a specific surface area of 250-300 m²/g and porosity of 75-80%. The grain size varies from 0.2-2 mm. It is expected to yield much higher removal capacity for adsorption of arsenic from water than activate alumina. Some studies indicate that ferric hydroxide has 3 to 10 times higher efficiency than activate alumina for adsorption of both As(III) and As(V). It consists of a cylinder filled with granular ferric hydroxide with inlet and outlet connections. It requires a small head of water, say 1 meter, to operate satisfactorily.

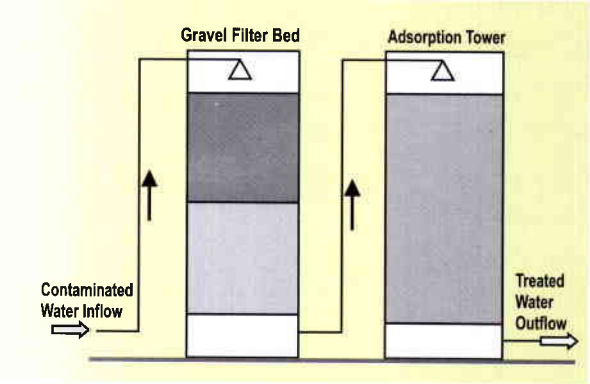


**Figure 4.18:** Paul Trockner Filter

The unit cost is INR 4500 which is considered unaffordable by most villagers. O&M costs are not available.

### 4.4.21 Filter Tablet System

School of Environmental Studies (SOES), Jadavpur University, Kolkata developed household device for arsenic removal from contaminated water in 1993. The efficiency was found in the range 93-100%. This technique is based on oxidation of As(III) to As(V) adding suitable oxidizing agent followed by coagulation- sedimentation-filtration (co-precipitation) shown in Figure 4.19.

The cost of unit varies from INR 100 – 1500. It depends on material of construction of containers. The cost of tablet is approximately INR 0.50 – 0.75.

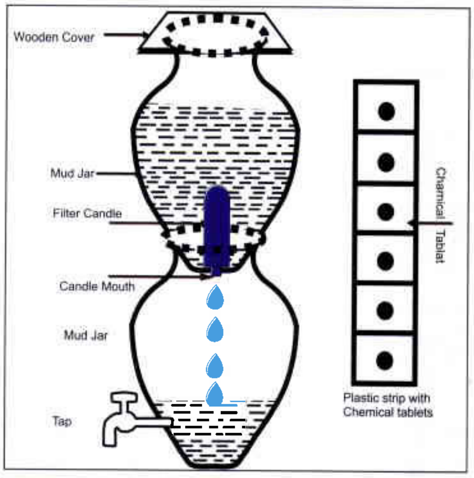


**Figure 4.19:** Arsenic Removal Filter-Tablet System

### 4.4.22 Biological Activated Carbon (BAC) System

The Biological Activated Carbon (BAC) system, developed by the Mainstream BMS Ltd.,Vanscoy, Saskatchewan and

Davnor Water Treatment Technologies Ltd., Calgary, Alberta, is a biologically active filtration unit. In this system a granular activated carbon (GAC) filter is used, which are continuously aerated to enhance the growth of biological activity within the filter media. This system has been used in rural Saskatchewan on experimental basis for seven years with consistent arsenic removal exceeding 90% (Pokhrel et al., 2005). This system could also remove more than 99% of iron and also dissolved organic material.

### 4.4.23 Three-Pitcher Method

The three-pitcher filter consists of three 20-filter clay pitchers stacked in a frame. A schematic diagram of a typical three-pitcher filter is shown in Figure 4.20. The top first pitcher contains 2 kg of coarse sand covered with 3 kg of iron filings. The second pitcher contains 2 kg of coarse sand with 1 kg of charcoal above it. The third pitcher collects the filtered water. The three-pitcher filter has been found to be very effective in arsenic removal for the first four to six weeks. After that, the removal efficiency starts to decline. The flow rate of effluent is slow, about 1-2 litres per hour. Normally the three-pitcher filter needs to be replaced after three to four months as the efficiency declines and the iron filings in the first filter become clogged and hardened and cannot be removed. Although this method is effective in arsenic removal, the bacteriological contamination in effluent water is sometimes high as the open filter media harbour growth of micro-organisms. Several household filter units have been developed that use different kinds of filter media. Some of the promising ones are iron coated sand filters, iron coated granular activated carbon filters, activated alumina and resin filters (see references).

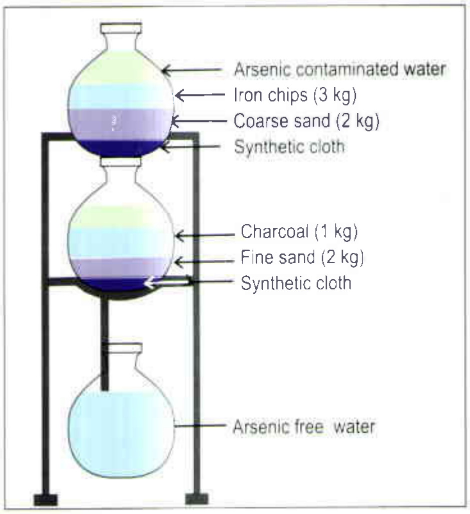


**Figure 4.20:** Three pitcher filter

Cost of one unit is Taka 250 (INR 150).

### 4.4.24 Iron oxide coated sand Filter (IOCS)

UNESCO-IHE developed an arsenic removal method based on adsorption on iron oxide coated sand (IOCS) (Figure 4.21). The filter is highly efficient in removing arsenic, irrespective of its speciation and level of concentration. The unit is very simple, operates under gravity and does not require any chemicals. The Family filter can produce approximately 100 litre of arsenic-free water per day, sufficient for the drinking and cooking needs of more than 20 persons. IOCS is a by-product from groundwater treatment plants and consequently very cheap. This technique is efficient for both As(III) and As(V). Different family scale removal filters were tested in Bangladesh (2004) and also a large scale centralized application was tested in Greece and Hungary (Petrusevski et al., 2007). The UNESCO-IHE family filter is possible and that overall costs are low, which makes the technology appropriate for use in the rural communities.

Arsenic removal 'Family Filter'

Iron oxide coated sand   Source: *UNESCO-IHE*

**Figure 4.21:** Iron Oxide Coated Sand Filter (IOCS)

**Contact details:**

http://www.unesco-ihe.org/education
E-mail: b.petrusevski@unesco-ihe.org

### 4.4.25 Aeration/Sand Filtration Unit

Illinois State Water Survey and University of Illinois researchers experimented with different combinations of chemical additives and steps along the treatment process. They found that the addition of hydrogen peroxide combined with iron that was already present in the groundwater (approximately 2 mg/L) to the Danvers water system produced a significant reduction in arsenic (III) levels to below 3 µg/L. The schematic diagram of this unit shown in Figure 4.22

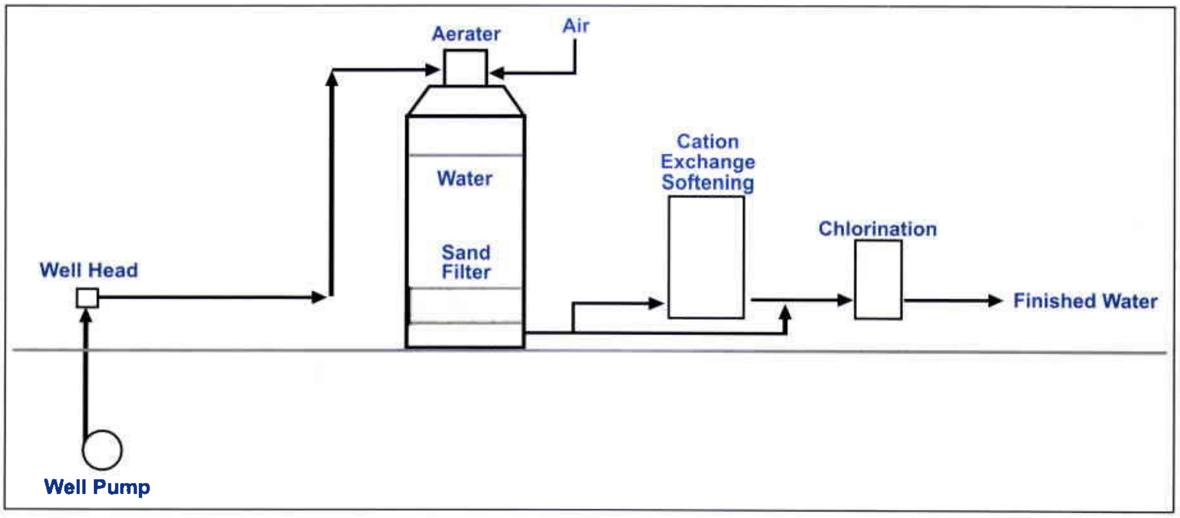


**Figure 4.22:** Aeration/Sand Filtration Unit, Cation Exchange Softening and Chlorination

**Contact details :**

**Midwest Technology Assistance Center**
2204 Griffith Dr.
Champaign, Il 61820-7495
Phone: (217) 333-9321
Fax: (217) 244-3054
Website: mtac.sws.uiuc.edu

### 4.4.26 Metal Oxy-Hydroxide Based Household and Community Systems

The Bangladesh Council of Scientific and Industrial Research (BCSIR), with technical assistance from the Ontario Center for Environmental Technology Advancement (OCETA), evaluated and certified different arsenic removal technologies for use in Bangladesh. The arsenic removal systems were based on ion-exchange, and sorbents of metal oxy-hydroxide and zero valent iron. Household units were evaluated that serve both the cooking and drinking requirements of a single family (35 to 40 Litres/day) and small community units that serve the cooking and drinking needs of ten or more families. The arsenic removal systems were evaluated in different regions with different groundwater matrix (Figure 4.23). A particular effort was made to understand the effects of phosphate and iron on the performance.

**Figure 4.23:** Metal oxy-hydroxide based (a) household and (b) community level arsenic removal systems

### 4.4.27 Zero-Valent Iron-Arsenic Filters

The active ingredient in an arsenic removal filter developed by MIT and being tested in the Tari region of Nepal uses iron from nails. The iron is released as the nails corrode to form dissolved iron and then to iron oxy-hydroxide phases. Dissolved arsenic is removed by precipitation, co-precipitation and adsorption onto the iron oxy-hydroxides. The arsenic-rich iron oxy-hydroxides are then removed by sand filtration. The nails lie on a perforated basket on top of the sand filter and are exposed to air. Water poured on top of the nails then moves through the nails and a perforated plate, and then flows through the sand bed. Over time channelling of flow can bypass the nails and their alteration products (Figure 4.24). Short-circuiting compromises arsenic removal and can result in total arsenic concentration of treated water above the MCL of 50 µg/L.

Zero valent iron based filter introduced by MIT in Nepal.

Zero-valent iron-based arsenic removal filter in a rural house in Nepal.

**Figure 4.24:** Zero-Valent Iron Arsenic Filters

### 4.4.28 Arsenic Removal Solution from A Fish Hatchery

Shibaloy, a village in the Manikjonj district of Bangladesh, found its own solution to arsenic contamination in its fish hatchery. Shibaloy has a fish hatchery, operated by a non-government organization called PRISM, which uses groundwater and provides the fish farmers in the Manikgonj district with fish hatchlings (Figure 4.25). Dissolved iron must be removed ahead of time otherwise it will oxidize upon contact with air to insoluble precipitates, which coagulate fish spawns, preventing germination. A simple slow sand filtration system consisting of layers of local 'Sylhet' sand, gravel and stones was used to remove the iron from around 9.0 mg/L to less than 0.01 mg/L. The groundwater where the filters were successful at removing arsenic to below 50 ppb, had relatively high concentration of iron (>5.0 mg/L), near neutral pH (6.8-7.2), and total arsenic concentration less than or equal to 100 ppb. The arsenic is removed from solution by co-precipitation with the rapidly forming insoluble iron hydroxides which are then caught by the sand filter. The iron oxy-hydroxide coatings on the sand particles also themselves sorb arsenic. The experience at Shibaloy is important because a large percentage of the shallow groundwater wells in Bangladesh contain dissolved iron pointing to the Kolschi filters as a potentially safe, cheap, and socially acceptable means for cleaning the drinking water of Bangladesh.

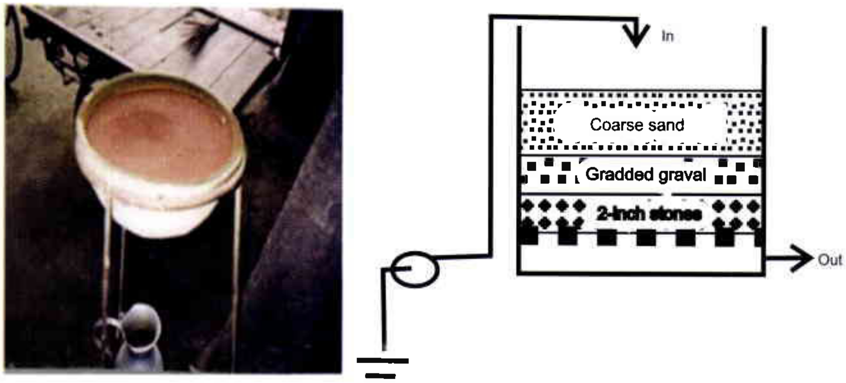


**Figure 4.25:** Home-Made Arsenic/Iron Filter from Shibaloy

These home-made filters have the capacity to process roughly two litres of water per hour and cost about INR 100 only in materials to build.

## 4.4.29 Kanchan Arsenic Filter

Kanchan arsenic filter is a modified slow sand filter with additional arsenic removal capacity, consisting of a plastic or concrete container filled with gravel, sand, and iron nails (Ngai et al., 2007). At the top of the filter, non-galvanized iron nails are exposed to air and water, rusting quickly and producing ferric hydroxide on the iron nails' surface, which absorbs arsenic from the water (Figure 4.26). Some Arsenic-loaded iron particles are flushed on to the sand layer below, and are trapped in the top few centimetres of the fine sand due to straining (Ngai et al., 2007). As ferric hydroxide particles "exfoliate" from the iron nails, new iron surfaces are created, providing additional arsenic adsorption capacity (Ngai et al., 2006).

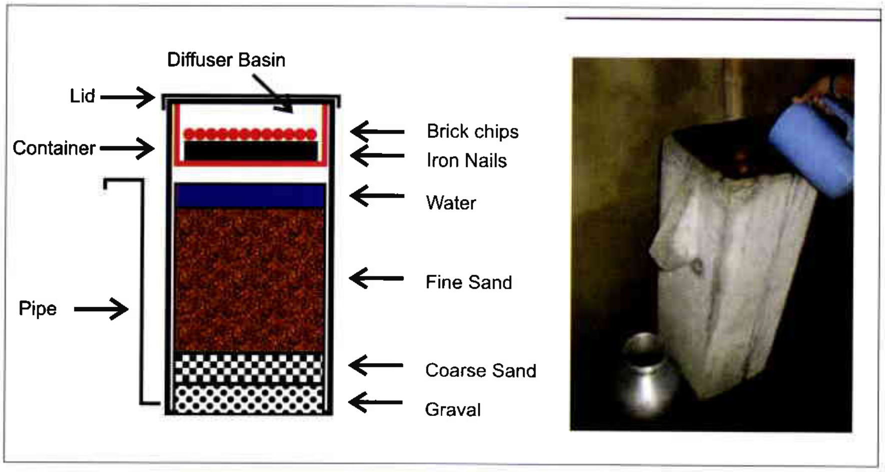


**Figure 4.26:** Components of the Kanchan arsenic filter

Initial costs are US$15 to 25 (INR 750 to 1200), whereas the operating cost have been estimated to be year) 2 to 5 US$ (INR 100 to 250) per year.

**Contact details:**

**Susan Murcott,**
Massachusetts Institute of Technology
Email: murcott@mit.edu

### 4.4.30 Adsorption Technology For Arsenic Removal Developed By Lehigh University, USA

**Figure 4.27:** Arsenic Removal Plant At Rampur - Maner

Lehigh University in Bethlehem, USA and A.N. College, Patna have installed community-based wellhead arsenic removal unit in a remote village – Ramnagar, Maner, in the state of Bihar. The unit is based on adsorption technology developed by Lehigh University, USA. The project has been funded by Tagore-SenGupta Foundation. This unit serves about 200 households of this village with approximately 7,000 liters of treated water produced per day, supplying nearly 1,000 villagers with arsenic-safe water. This unit can provide water without requiring electricity or external addition of chemicals. Many of these units have been running satisfactorily for several years under the supervision of a villagers' committee in West Bengal.

The easy-to-operate unit provides arsenic-safe drinking water using re-generable arsenic adsorbents and can be started or stopped with no real time lag. When the filter is exhausted, the absorbent material is regenerated through a simple process consisting of a well-aerated, coarse sand filter at a central location, thereby decreasing the waste volume by "cleaning" the adsorbents of collected arsenic and catching the leftover arsenic-sludge in the filter. The cleaned absorbent material is then returned to the water unit, filtering water as if the unit were new (Figure 4.27). The Department of Environment and Water Management, A.N. College, Patna with the help of local community is monitoring this arsenic removal system regularly to maintain its quality with the proactive support of the community. This project is trying to transfer the technology for arsenic removal through community participation.

**Contact details:**

**Prof Ashok Ghosh**
Professor Incharge,
Dept. of Environment and Water management,
A.N.College,
Patna – 800013, India

### 4.4.31 3-Kolshi System / SONO 45-25 Filter

The 3-Kolshi System, which basically consists of three clay pots stacked vertically, was initially developed by the SONO Diagnostic Center in Bangladesh and it is based on an indigenous water treatment practice (Ngai et al., 2007). Arsenic is removed by adsorption to iron filings contained in the top pot. A continuous improvement of the filter system has led to a new filter model, the SONO 45-25 filter. This filter technology has passed through several environmental technologies verification programs for arsenic mitigation (ETVAM) projects. As shown in Figure 4.28, the top layer built by coarse river sand (CRS) - an inactive material used as a coarse particulate filter, disperser, flow stabilizer and providing mechanical stability (Hussam and Munir, 2007) yields to the

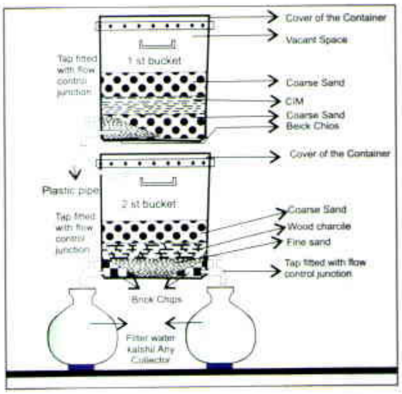


**Figure 4.28:** Schematic Diagram of SONO-filter

oxidation of groundwater with high concentrations of soluble iron and precipitate as Fe(OH)3(s). Inorganic As(III) species – catalyzed by manganese in the composite iron matrix (CIM) - are oxidized to As(V) species by oxidation, which is produced by the oxidation of soluble Fe(II) with dissolved oxygen (Hussam and Munir, 2007).

The removal process of As(III) and As(V) is independent of the input arsenic concentration i.e., a zero-order reaction (Hussam and Munir, 2007). Complexation and immobilization of inorganic arsenic and many toxic metal cations occur within the CIM, the primary active material. It is made of cast iron turnings through a proprietary process to maintain active CIM integrity for years (Hussam and Munir, 2007). Brick chips (BC) are a further inactive material and have similar functions as CRS. The combination of the two materials acts as a protection barrier for the free-flow junction outlet. Wood charcoal (WC) absorbs different organic material, such as pesticides, and therefore the taste of the water is improved. The cost (capital and recurrent) is INR 210.

**Contact details :**

**Professor A.H. Khan,**
Department of Chemistry,
University of Dhaka,
Dhaka-1000,
E-mail: ahkhan@du.bangla.net
Dr. A.K.M. Munir, Director, SDC-Environment Initiative,
College More, Courtpara, Kushtia 7000

### 4.4.32 Cartridge Filters

Filter units with cartridges filled with sorptive media or ion-exchange resins remove arsenic like any other dissolved ions present in water. These units are not suitable for water having high impurities and iron in water. Presence of ions having higher affinity than arsenic can quickly saturate the media requiring regeneration or replacement. Two household filters were tested at BUET laboratories, these are

- Chiyoda Arsenic Removal Unit, Japan
- Coolmart Water Purifier, Korea

The Chiyoda Arsenic Removal Unit could treat 800 BV meeting the WHO guideline value of 10 µg/L and 1300 BV meeting the Bangladesh Standard of 50 µg/L when the feed water arsenic concentration was 300 µg/L. The Coolmart Water Purifier could treat only 20 L of water with an effluent arsenic content of 25 µg/L (Ahmed et al., 2000). The initial and operation costs of these units are high and beyond the reach of the rural people.

### 4.4.33 Tetrahedron Technology

Tetrahedron (USA) promoted an ion exchange-based arsenic removal technology in Bangladesh. The technology proved its arsenic removal efficiency, even at high flow rates. Figure 4.29 shows the schematic diagram of this technology. This process utilizes a stabilizer and an ion exchange (resin column) along with facilities for chlorination using chlorine tablets. Tubewell water is pumped or poured into the stabilizer through a sieve containing a chlorine tablet. The water mixed with chlorine is stored in the stabilizer and subsequently flows through the resin column when

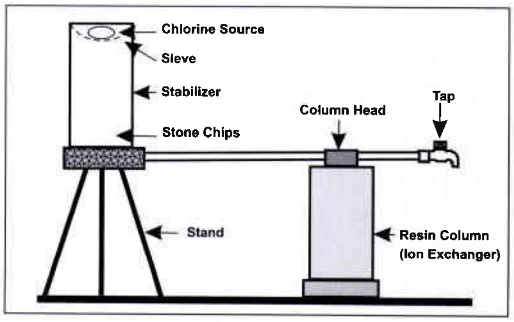


**Figure 4.29:** Tetrahedron Technology

the tap is opened. The stabilizer smoothers flow pulses from the pump and traps iron and other hydroxide precipitates formed in water. Finally, the iron-exchange media adsorbs and cleans arsenic, sulphate, and phosphate from the water. This Tetrahedron filter was tested in Bangladesh (BAMWSP, DFID and Water Aid Bangladesh 2001) and demonstrated promising results. The residual chlorine minimized bacterial growth in the media. The saturated resin can be regenerated by NaCl solution. Liquid wastes from the process, including salt and arsenic produced during regeneration, require safe disposal.

The costs (capital and recurrent) is Tk. 12000/- (INR 8000) plus annual costs of Tk. 6000/- (INR 4000) (ion resin column lasts on average for six months).

**Contact details US:**

Waqi Alam, TETRAHEDRON@prodigy.net
Bangladesh:
Mr. Wazir Alam or Mr. Altaf,
Dhaka
Tel: 9882770

### 4.4.34 Pureit Arsenic Removal Filter

The purifier has key parts which include top chamber for filling and storage of untreated water; pre-filtration system – the stored water from top chamber is first filtered through a 2-stage pre-filtration system consisting of sediment filter which removes particle impurities up to 10 micron particle size, the water from the sediment filter then gets filtered through a specially designed compact carbon trap (CCT) which can remove particulate matter up to 3-5 micron size. The purifier works on the principle of continuous chlorination and filtration through activated carbon. A special attachment with activated alumina is used to remove arsenic. It can work without electricity and without inline water supply (Figure 4.30). Arsenic is removed below 10 ppb for drinking water.

**Figure 4.30:** Pureit Arsenic Removal Filter

The technologies perform most effectively when treating arsenic in the form of As(V). As (III) may be converted through pre-oxidation to As(V). Data on oxidants indicate that chlorine, ferric chloride, and potassium permanganate are effective in oxidizing As(III) to As(V). Pre-oxidation with chlorine may create undesirable concentrations of disinfection by-products. Ozone and hydrogen peroxide should oxidize As(III) to As(V), but no data are available on performance. The cost of this filter is INR 2700 (approximate).

**Contact details:**

**Mr. Vikram Surendran**
General Manager - India operations,
Water division
Vikram.S@Unilever.com
pureit.hul@unilever.com

## 4.4.35 Arsenic Removal Technology MRT-1000 of Reid System Ltd.

Jago Corporation Limited promoted a household reverse osmosis water dispenser MRT-1000 manufactured by B&T Science Co. Limited, Taiwan. This system was tested at BUET and showed arsenic (III) removal efficiency more than 80%. A wider spectrum reverse osmosis system named Reid System Limited was also promoted in Bangladesh. Experimental results showed that the system could effectively reduce arsenic content along with other impurities in water. The capital and operational costs of this reverse osmosis system is relatively high.

## 4.4.36 Low-Pressure Nanofiltration and Reverse Osmosis

Oh et al. (2000) applied reverse osmosis and nanofiltration membrane processes for the treatment of arsenic contaminated water applying low pressure by bicycle pump. A nanofiltration membrane process coupled with a bicycle pump could be operated under condition of low recovery and low pressure range from 0.2 to 0.7 MPa. Arsenite was found to have lower rejection than arsenate in ionized forms and hence water containing higher arsenite requires pre-oxidation for reduction of total arsenic acceptable level. In tubewell water in Bangladesh the average ratio of arsenite to total arsenic was found to be 0.25. However, the reverse osmosis process coupled with a bicycle pump system operating at 4 MPa can be used for arsenic removal because of its high arsenite rejection. The study concluded that low-pressure nanofiltration with pre-oxidation or reverse osmosis with a bicycle pump device could be used for the treatment of arsenic contaminated ground water in rural areas (Oh et al., 2000).

## 4.4.37 Arsenic Removal Tech Developed By BCSIR

Scientists have developed a low cost household technology for removal of soluble arsenic from water suitable for use by rural people. The arsenic research group of the Institute of Glass and Ceramic Research and Testing (IGCRT) of BCSIR has succeeded in developing the technology with locally available raw materials after intensive research for eight months. Field test of fresh tubewell water using this technology found that 99.5% soluble arsenic could be removed from arsenic concentration of two milligram per liter. The flow rate is about 6 liters per hour. The available package consists of a filter and 100 packets (1 packet for five litres) flock forming composition for 500 litres of water. The flock forming composition, prepared by mixing a number of chemicals in certain proportions, is added to the arsenic contaminated water followed by stirring and settling. After settling, it is passed through a filter system developed in BCSIR. The cost of a filter is Tk 300 (INR 200) which can purify up to 60,000 litres water.

## 4.4.38 Zirconium Oxide Based Membrane for Arsenic Removal

MEL Chemicals has developed the ISOLUX media for the removal of heavy metal ions, including arsenic, from water systems. Through the use of patented technology MEL Chemicals have a developed a range of zirconium based materials which offer excellent adsorption properties and high selectivity in the removal of various heavy metal ions. The zirconium adsorbent into a range of amorphous and crystalline forms, with a broad particle size distribution allows the zirconium materials to exhibit superior kinetics versus standard ion exchange resins and other technologies.

Metal ions removed by the patented Isolux technology include Arsenic (both III and V species), Cadmium, Lead, Antimony, and Chromium. The removal is not via chemical reaction; it is an adsorption process, hence several different metal ion species can be removed with high selectivity.

**Contact details:**

**MEL Chemicals**
For Europe and the Far East (excluding Japan)
Phone: +44 (0)161 911 1066
Fax: +44 (0)161 911 1090

### 4.4.39 Ultrafiltration Membrane Assisted Process

**Figure 4.31:** Ultrafiltration Membrane Assisted Process

BARC developed knowhow of ultrafiltration (UF) based membrane technology for water decontamination with respect to microbiological contamination at both domestic and community scale is available for transfer separately. The technology is an Ultrafiltration (UF) membrane assisted physico-chemical process and capable of removing arsenic contamination from ground/ surface water for drinking purposes from a feed concentration of 500 ppb or more to less than 10 ppb. The entire process involves two steps: 1) Sorption of arsenic species on the insitu generated sorbent by simple addition of two reagents. 2) Filtration of arsenic containing sludge using UF membrane device based on the technology developed by BARC. The two reagents required for the first step are to be prepared using the procedure given in the technology transfer document. The details of the device required for the second step is available in the form of technology with BARC and can be taken separately. These devices are also available with several licensees of BARC in the form of commercial products (Figure 4.31).

**Contact details:**

**Bhabha Atomic Research Centre**
Manager
Website: www.indiamart.com/bhabha-atomic-research

### 4.4.40 Arsenic Removal Using Bottom Ash (ARUBA)

**Figure 4.32 :** ARUBA Arsenic Removal Plant Prototype

Developed at Lawrence Berkeley National Laboratory (LBNL), ARUBA (Arsenic Removal Using Bottom Ash) is used to remove arsenic from contaminated drinking water in an efficient, affordable, and safe manner. In this technology, bottom ash from coal-fired power plants is coated with ferric hydroxide to create ARUBA, to which arsenic binds. Water treatment involves adding ARUBA to water, mixing, and filtering. In field experiments in Bangladesh (Figure 4.32), ARUBA treatment has been shown to reduce arsenic concentrations from over 1000 ppb to 3 ppb. After use, spent ARUBA can be safely disposed of in landfills.

The total treated water costs would be $7 - $15 (Rs 350 to 750) per person per year (assuming 10 liters of drinking water per person per day). ARUBA could be used in the home (in conjunction with a household-size sand filter) or at the community level. LBNL are currently designing a community-based water treatment plant which uses ARUBA to remove arsenic from drinking water.

## 4.4.41 Electro-Chemical Arsenic Remediation (ECAR)

**Figure 4.33 :** ECAR Prototype Unit

In Electro-Chemical Arsenic Remediation (ECAR), electricity is used to continuously dissolve an iron electrode, forming a type of rust in the water. Arsenic in the water binds to the rust particles, which can then be removed. The rust particles are created electrochemically at the time of use, eliminating the need for a costly supply chain. In addition, electrochemical processes resulting from the use of electricity greatly enhance the arsenic removal capacity (i.e. arsenic removed per unit iron input) relative to the common chemical methods of arsenic removal.

In ECAR, employing a small amount of electricity allows for a large increase in efficiency, leading to lower operating costs and far less arsenic-laden waste than non-electrical, purely chemical methods. In addition, the electrodes are self-cleaning if current is alternated, reducing maintenance time and eliminating the need to handle strong alkalies and corrosive acids for regeneration (required of activated alumina and other regenerative adsorbents). A small-scale ECAR prototype device operated from a 12-volt car battery at the Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh is shown in Figure 4.33.

ECAR could be used in the home (in conjunction with a household-size sand filter) or at the community level. LBNL are currently designing a community-based water treatment plant that uses ECAR to remove arsenic from drinking water.

## 4.4.42 Subterranean Arsenic Removal (SAR) Technology

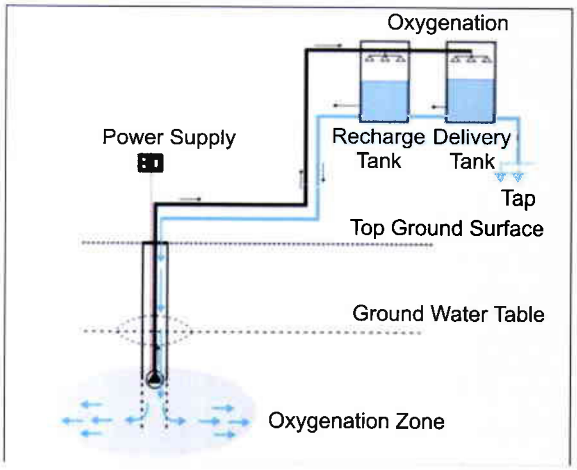


**Fig.4.34:** Schematic representation of Subterranean Arsenic Removal (SAR) Technology

The SAR technology was developed by a consortium of European and Indian scientists led by Dr. Bhaskar Sen Gupta, OBE from Queen's university Belfast, UK and demonstrated at a location near Kolkata during 2005 – 2006. It is basically an in-situ treatment method; the aerated tube well water is stored in feed water tanks and released back into the aquifers through the tube well by opening a valve in a pipe connecting the water tank to the tube well pipe under the pipe head. The dissolved oxygen in aerated water oxidizes arsenite to less-mobile arsenate, the ferrous iron to ferric iron and manganese (II) to manganese (III), followed by adsorption of arsenate on Fe (III) and manganese (III) resulting in a reduction of the arsenic content in tube well water.

Oxidation is further enhanced biologically by living bacteria in the subsurface and is also termed as bioremediation process. A number of different physical, chemical and biological processes are intensified in the surrounding area of the well screen section, the so called oxidation zone. The alternate operation of the wells for delivering groundwater in the tank top and infiltration of the oxygen rich water into the aquifer induces alternating oxidation and adsorption periods on the surface of the solid material in the aquifer.

The process of in-situ oxidation of groundwater virtually transfers the oxidation and filtration process of the conventional above groundwater treatment plants into the aquifer. The underground aquifer is used as a natural biochemical reactor.

This technology involves a very simple and easily adaptable process to remove arsenic and other heavy metals from groundwater using controlled oxidation without production of sludge and not using any chemicals at all. The results obtained in the test site is quite promising and ideal for a rural set up where people really cannot afford to pay a substantial amount the water supply. The only disadvantage is that it takes some time for the whole system to stabilise because of the slow kinetics of the oxidation process. However, once stabilized, it remains steady for years to come.

On the other hand, uncalculated amount of oxidation of the aquifer can really mess up the system resulting in As and Fe precipitation rather than adsorption (resulting in As release in later date). Also, the abrupt change in redox potential and huge oxidation may destroy the existing bacterial population, making the whole process unstable and ineffective.

### 4.4.43 Additional Arsenic Removal Technologies

Some other arsenic removal devices developed by different agencies, and applied to treat for removing arsenic from arsenic contaminated groundwater with some degree of success are given in Table 4.2 and shown in Figure 4.32.

**Table 4.2 :** Arsenic removal devices applied for removal of arsenic from contaminated groundwater

| Name of the device | Operation principle | Filter media | Price | System | Performance |
|---|---|---|---|---|---|
| RPM/ Alcan AAFS -50 media by RPM Marketing Pvt. Ltd., Kolkatta | Adsorption | Activated Alumina + AAFS-50 | Rs.44,300 + Rs.20,000 per Charge | The system consists of two containers; one to remove mud and suspended particles and other one consists of AAFS-50 media to remove arsenic and heavy metal | Although design and model is user friendly but has mixed feelings on performance. Media replacement had showed lesser efficiency than the original |
| Bucket of Resins (BOR) of Water Systems International, USA by Harmonite Impex (Pvt.) Ltd., Kolkata | Ion Exchange | Bucket of Resins | Rs.92,300 + Rs.39,000 per charge | The system 'BOR' is a rectangular container of 100 cm (length) x 65 cm (width) x and 100 cm (height) attached to a tube well hand pump. The container consists of 3 cylinders to process various phases of oxidation and absorption. The system has provision of backwashing depending on content of arsenic and iron. | Field performance of the system was below satisfactory level and inconsistent. |
| Granular Ferric Hydroxide (GFH) of Pal Trockner (P) Ltd., Kolkata – a German Technology | Adsorption | Granular Ferric Hydroxide (GFH) | Rs. 74,100 + Rs.25,000 per charge | The system is based on GFH and user friendly. It does not require complicated dosing of chemicals and claimed to be non-toxic and nonhazardous. | Satisfactory performance, and less cost on operation and maintenance. |

| Name of the device | Operation principle | Filter media | Price | System | Performance |
|---|---|---|---|---|---|
| Arsenic Removal Plant by Oxide India (Catalysts) Pvt. Ltd, Durgapur | Adsorption | Activated Alumina , AS-37 | Rs. 47,300 + Rs.14,400 per charge | The system is made of Stainless Steel, AISI-304. It has a back wash system and removal process is based on adsorption with special grade of Activated Alumina. | Satisfactory performance in all 50 installed places. Company guarantees 2 years O & M, training including performance audit. |
| ADHIACON : AFDWS 2000 – Arsenic Removal Plant | Catalytic precipitation/ Electron Exchange | AFDWS - 2000 | Rs. 75,00 | The system is fitted with lifted head of hand pump. It has basically three chambers - primary, secondary and Micro-filtration chambers. The water is pumped through 3 way valve to primary chamber where raw water first passes through a coarse stainless steel strainer and then comes in contact with filter media in which catalytic precipitation takes place. The purified water from the primary chamber goes to secondary chamber for downward filtration. From secondary chambers water passes through micro-filtration chamber and then purified water goes through three way valve at the outlet | Field performance of the system was below satisfactory level. |
| Handpump Attached Arsenic Removal Plant by AIIH&PH, Kolkatta | Oxidation + Coagulation + Flocculation Precipitation and filtration | Chlorinating agent (BP) + Ferric Alum | Rs. 35,000 + periodic chemical reagents | The system is comprised of a nonmechanical clari-flocculator and upflow gravel filter and it has three chambers. Bleaching powder and alum are the two chemicals used for removal of arsenic. In the first chamber bleaching powder solution is added in appropriate dosage with pumped water where they are thoroughly mixed in presence of baffles. The chemical mixed water is thereafter passed through second chamber for precipitation of the flocs. The clean water is collected in the launder chamber. From launder water is taken to the filter (third) chamber, from where water is allowed to flow in upward direction through graded gravel media. The arsenic safe filtered water is finally collected through a tap provided in the filtered chamber | Periodic daily dosing of chemical reagents are necessary. The system requires constant vigilance and close monitoring and chemical dosing |
| IONOCHEM, Kolkata | Ion exchange | Ferric Hydroxide | Rs. 39,000 | The system is comprised of one Iron Removal Filter and one Arsenic Filter and the system is fitted with Hand Pump. The principal media is bonded compound of Fe(OH)3 and ⊠FeOOH.<br>When Hand Pump is operated, the pressurized raw water is passed initially through iron removal filter filled with catalytic filtering media and reacts with sodium arsenates and Fe(OH)2. Due to chemisorption As is bonded with the material and Arsenic is removed. | Regular backwashing of iron filter is essential, which caused problem of operation and maintenance. Otherwise, the performance remained satisfactory. |
| Apyron Arsenic Treatment Units by Apyron Technologies (P) Ltd. Representing of Apyron Technologies Inc., USA | Adsorption | Aqua Bind (Activated Alumina + | Rs. 80,000 + Rs. 15,000 per charge | The system is comprised of an assembly of Handpump with its outlet connected to the filtering media. When the Hand Pump is operated, the raw water passes through the filter media where arsenic is removed and finally treated water is collected through an outlet pipe from the filter media. The filter media is comprised of manganese oxide and activated alumina. Manganese oxide converts $As^{3+}$ to $As^{5+}$, which is adsorbed on the alumina media. The unit also removes iron. | Showed satisfactory performance, treating arsenic levels as high as 3500 ppb to a safe level of less than 50 ppb. After use, filter media can be disposed safely as ordinary sanitary waste |
| Public Health Engineering Department, Govt. of West Bengal | Adsorption | Red Hematite ($Fe_2O_3$) lumps + quartz + sand activated alumina | Rs. 27,000 | Removal of arsenic is accomplished in 4 chambers. Groundwater is abstracted by Hand Pump and spray into droplets over a bed containing packed hematite lumps ($F_e2O_3$) before sending to first chamber for sedimentation. Sediment free water is conveyed through chambers placed in series containing red hematite lumps quartz and dual media (Sand and Activated Alumina), respectively. | Reported as one of the finest performing devises and capable to remove arsenic from very high level of contamination. However, the weakness is its inability to produce sufficient quantity of filtered water. Towards O & M, it had poor performance |

| Name of the device | Operation principle | Filter media | Price | System | Performance |
|---|---|---|---|---|---|
| Simple Arsenic and Iron Removal System by School of Fundamental Research (SFR), Kolkata | Adsorption | Aluminum Silicate + Ferric Hydroxide | Rs. 8000 + Rs.1200 per charge | The system is fitted to Hand Pump, which connected through the check valve with a vertical PVC cylinder filled with silicate matrix with additional oxidizing element for removal of iron before water enters into As-emoval system. | Performance of the system is yet to be established through field testing. |


RPM / ALCAN AAFS-50 MEDIA


BUCKET OF RESINS OF WRI


GRANULAR FERRIC HYDROXIDE-PAL TROCKNER


ARSENIC REMOVAL PLANT-OXIDE INDIA


ADHIACON-AFDWS 2000


HANDPUMP ATTACHED ARSENIC REMOVAL PLANT-AIIH & PH


IONOCHEM-ARSENIC TREATMENT UNIT


APYRON ARSENIC TREATMENT UNIT


ARSENIC TREATMENT PLANT-PHED MODEL


ARSENIC AND IRON REMOVAL SYSTEM-SFR MODEL

**Figure 4.35:** Arsenic Removal Devices Developed and Promoted by Different Organizations in various places in West Bengal.

## References:

1. Ahmed, M.F. (2001). "An Overview of Arsenic Removal Technologies in Bangladesh and India." Proc., BUET-UNU International Workshop on Technologies for Arsenic Removal from Drinking Water of the UNU-NIES International Workshop, Dhaka, Bangladesh.
2. Ahmed M.F and Rahaman M. M. (2000), Water Supply and Sanitation – Low Income Urban Communities, International Training Network (ITN) Centre, BUET.
3. Ali, M. Ashraf, A.B.M Badruzzaman, M.A. Jalil, Hossain M. Delwar, M.M. Hussainuzzaman, M. Badruzzaman, O.I.Mohammad, O.I., N. Akter (2001). "Development of Low-cost Technologies for Removal of Arsenic from Groundwater." Bangladesh University of Engineering and technology, 2001.
4. Arun Kumar Mudgal Draft Review of the Household Arsenic Removal Technology Options,, HTN Sector Professional – Asia
5. BAMWSP, DFID and WaterAid Bangladesh ( 2001), Rapid Assessment of Household Level Arsenic Removal Technologies, Phase-! and Phase-II, Final Report, WS Atkins International Limited.
6. Bureau of Indian Standard ( 2003) Report of BIS, Drinking water standard.
7. Cheng, C. R., Liang, S. Wang, H. C. and Beuhler, M. D. (1994), "Enhanced coagulation for arsenic removal", J. American Water Works Association, 86(9), p.79-90.
8. D'Hiriat, J., Hidalgo, M.V., Garcia, M.G., Litter, M.I. and Blesa, M.A., 2006. Arsenic Removal by Solar Oxidation in Groundwater of Los Pereyra Tucaman Province, Argenita. Power point presentation, CNEA. http://www.cnea.gov.ar/xxi/ambiental/iberoarsen/docs/presentationAs2006litter.pdf
9. Datta, Amal K., Gupta, Anirban 1997 – Genesis of the arsenic problem, status and alternatives for remediation, Bengal Engineering College, Calcutta, India
10. Drinking Water Standard for Arsenic. 2001. EPA 815-F-00-015. U.S. Environmental Protection Agency, Office of Water
11. Environmental Health Criteria 224 (2001). ARSENIC & arsenic Compounds (2nd Edition); IPCS; WHO; Geneva.
12. EPA (2000). "Technologies and Costs for Removal of Arsenic from Drinking Water." EPA 815-R-00-028, Office of Water.
13. Evaluation of performance of various arsenic removal equipments installed in arsenic infested area of West Bengal, by Central Ground Water Board, March 2001
14. Garelick, H., Jones, H., Dybowska, A. & Valsami-Jones, E. 2008. Arsenic pollution sources, Reviews of Environmental Contamination and Toxicology, 197
15. Ghosh A., Arsenic Mitigation: Low Cost Filtration Technology implemented through community participation.
16. Hering, J. G., Chen, P. Y., Wilkie, J. A., Elimelech, M. and Liang, S. (1996), Arsenic removal by ferric chloride, J. American Water Works Association, 88(4), p.155-167.
17. Hering, Janet G. Pen-Yuan chen, Jennifer A.Wilke, Menachem Elimelech (1997). "Arsenic Removal From drinking Water During Coagulation." Journal of Environmental Engineering, Vol. 123, No. 8, August 1997, 800-807.
18. http://www.zrpure.com/

19. Hussam, A. and A.K.M. Munir. A simple and effective arsenic filter based on composite iron matrix: Development and deployment studies for groundwater of Bangladesh. Journal of Environmental Science and Health, Part A 2007, 42, 1869–1878.

20. IARC (2004), Some Drinking-water Disinfectants and Contaminants, including Arsenic, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, International Agency For Research On Cancer, (WHO),Volume 84

21. IGRAC, 2007, L. Feenstra, J. van Erkel, L. Vasak, Arsenic in groundwater: Overview and evaluation of removal methods, , Report nr. SP 2007-2

22. Joshi, A. and Chaudhury, M. (1996), Removal of arsenic from groundwater by iron-oxide-coated sand, ASCE Journal of Environmental Engineering, 122(8), p.769-771.

23. Kartinen, E. O. and Martin, C. J. (1995), An overview of arsenic removal processes, J. Desalination, 103, p.79-88.

24. Kommineni S., Narasimhan R., Durbin H. Point-of-Use/Point-of-Entry Treatment for Arsenic Removal: Operational Issues and Costs

25. National Research Council (1999). Arsenic in Drinking water. National Academy Press, Washington, DC.

26. National Research Council (2001 update). Arsenic in Drinking water (2001 update). National Academy Press, Washington, DC.

27. Ngai, T.K.K., Murcott, S., Shrestha, R.R., Dangol, B., and Maharjan, M. (2006) Development and Dissemination of KanchanTM Arsenic Filter in Rural Nepal. Water Science & Technology: Water Supply 6(3):137–146

28. Ngai, T.K.K., R.R. Shresta, B. Dangol, M. Maharjan and S.E. Murcott. Design for sustainable development Household drinking water filter for arsenic and pathogen treatment in Nepal. Journal of Environmental Science and Health Part A 2007, 42, 1879–1888

29. NIH (2010), Mitigation and Remedy of Groundwater Arsenic Menace in India: A Vision Document, National Institute of Hydrology, Roorkee, Central Ground Water Board, New Delhi.

30. Oh, J.I., Yamamoto, K., K., Kitawaki, H., Nakao, S., Sugawara, T., Rahaman, M.M. and Rahaman, M.H. (2000), Application of low-pressure nanofiltration coupled with a bicycle pump for the treatment of arsenic-contaminated groundwater, Desalination, 132 : 307-314.

31. Petrusevski, B., Sharma, S., Shordt, K.and Schippers, J.C., 2007. Arsenic in Drinking water, Thematic Overview Papers 17, IRC International Water and Sanitation Centre, March 2007.

32. Petrusevski, B., Slokar, Y., Sharma, S., Kruis, F. and Schippers, J.C., 2007. An Innovative Approach for Arsenic Removal. Power-point presentation UNESCO-IHE, http://www.unesco-ihe.org/education.

33. Pokhrel, D., T. Viraraghavan and L. Braul. (2005). Evaluation of treatment systems for the removal of arsenic from groundwater. Practice Periodical of Hazardous, Toxic and Radioactive Waste Management. Vol.9. No. 3

34. PUREFLOW Filtration Systems, Bulletin A2.9432.4 (2005). "The Removal of Arsenic from Potable Water." <http://www.mhrahome.org/media/arsenic/vendor/pureflow_bulletin.pdf> (May 5, 2005)

35. Robinson Andy, Arsenic Mitigation in West Bengal and Bangladesh, Developing Private Sector Supply Chains to Deliver Rural Water Technology, , Water and Sani tat ion Program, 2000.

36. Shen, Y. S. (1973), Study of arsenic removal from drinking water", J. American Water Works Association, 65(8), p.543-548.

37. Shin Nihon Salt Co. Ltd. (2000), Report on Performance of Read-F Arsenic Removal Unit (ARU), October.

38. SOES (2006), Groundwater Arsenic Contamination In West Bengal – India, School of Environmental Studies, Jadavpur University, Kolkata, India.

39. Thirunavukkarasu, O.S., T. Viraragavan, K.S. Subramanian, O. Chaalal, M.R. Islam M.R. (2005). "Arsenic Removal in Drinking Water- Impacts and Novel Removal Technologies." Energy Sources, 27, 209-219.

40. Thirunavukkarasu, O.S., T. Viraraghavan, K.S. Subramanian (2003). "Arsenic Removal from Drinking Water Using Granular Ferric Hydroxide." Water SA, 29(2).

41. Veenstra, John, Gary Kinder and Greg Holland (2004). "Removal of Arsenic from Drinking Water." Proc., Oklahoma Water 2004, Environmental Institute Oklahoma State University, Oklahoma.

42. Wegelin et al., 2001 M. Wegelin, S. Hug, M. Boller, D. Gechter and S. Vermeal, Back to the house hold-also in water treatment, EAWAG News 48 (2001)

43. Yuan, Tao, Jiang Yong Hu, Say Leong Ong, Qi Fang Luo and Wern Jun Ng (2002). "Arsenic Removal from Household Drinking Water by Adsorption."

## Table 4.3 : Comparative Statement of Technologies Available for Treating Arsenic

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgraded to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SORAS | Swiss Federal Institute of Environmental Science and Technology, Switzerland (EAWAG) and Swiss Agency for Development and Cooperation (SDC) | Photochemical oxidation, Coagulation, precipitation and filtration technique. The adsorbent Fe(III) oxides | Tested in laboratory and field | Bangladesh | 150 ppb | Below 50 ppb | Domestic | No | Virtually no cost | No | -- | Virtually no cost | -- | Training required | -- |
| DRDO filter | Defence Research laboratory, Tezpur, Assam | oxidation, Coagulation, precipitation and filtration through **cheap sand filter** | Tested in laboratory and field | Treated water are within limit (10 ppb) | Upto 1000 ppb | Below 10 ppb | Community and Domestic . Unit with flow rate 3000 L/hr | NA | Rs. 50000/- for 200 L/hr. It can run atleast 10 years without changing adsorbant | No | 200 L/hr and 40000 L/day | Rs. 0.050/- (approx.) | No, only back washing required to clean the system | Not required | The system can take care of iron and arsenic simultaneously. Several units have been distributed to troops for filtration purposes |
| NMRL-DRDO | Naval Materials Research Laboratory - Defence Research and Development Organisation | oxidation, Coagulation, precipitation and filtration technique. The adsorbent Fe(III) oxides | Tested in laboratory and field | 24 paragana, West Bengal | Upto 3000 ppb | Below 50 ppb | Domestic | No | The cost of the unit is around Rs. 500 for the stainless steel filter and Rs. 150 for the plastic unit of 15 L capacity | No | 10 L/hr | Rs. 0.3 per litre (approx.) | Yes. The filter material and sand is to be replaced periodically as per usage | Not required | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/ hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SONO Filter | Center for Clean Water and Sustainable Technologies, Department of Chemistry and Biochemistry, George Mason University, USA | oxidation, Coagulation, Precipitation and filtration technique. on CIM (composite iron matrix) in combination with sand,gravel, and charcoal | Tested in laboratory and field | Bangladesh, India and Nepal. | Upto 3000 ppb | Below 10 ppb | Domestic | No | The cost of the unit is around Rs.2000 | No | 100 L/ hour | Rs. 0.0008 per litre (approx.) | Replacement of the upper sand layers when the apparent flow rate decreases | Not required | The filter does not require any special maintenance and can produce potable water for at least 5 years |
| NEERI Arsenic Removal Unit | National Environmental Engineering Research Institute (NEERI), Nagpur | oxidation, Coagulation, Precipitation and filtration using Fentons reagent | Tested in NEERI laboratory and Chauki block | Ranjnandgaon, Chattisgarh | Upto 3000 ppb | Below 10 ppb | Domestic | No | The cost of the unit is around Rs.4000 | No | 8-10 L/hr | Rs. 0.05 paisa per liter | Yes, Arsenic precipitate generated to be disposed off in a caw dung | Not required | -- |
| NML Filter | National Metallurgical Laboratory, Jamshedpur (CSIR) | oxidation, Coagulation, Precipitation and filtration technique. The adsorbent is Ferruginous manganese ore (FMO) | 50 units field tested in Sahebgunj district of Jharkhand over a period of 18 months | Sahebgunj district of Jharkhand | 4-150 ppb | 10 ppb | Domestic | No | Cost of the unit is unknown but cost of the adsorbent is about Rs. 3000/- per metric ton | No | 20 L/hour | Rs. 0.30/- | Yes, sludge disposal protocol built in the system. | Training required | The unit generate sludge which cause environmental problem |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Community based unit | Agarkar Research Institute, Pune | As is oxidized by bacterial culture (Microbacterium lacticum), adsorption on activated alumina and bacteria from the water are removed by charcoal filtration & UV treat. | 10 months at 5 sites in Chattisgarh | Kandikasa and Murethitola, Rajnandgaon | Upto 2000 ppb | 10 ppb | Community | NA | Rs. 65000/- for 1000-2000 L/day capacity | Yes | 1000-2000 L/day capacity | Rs. 0.40/ | Yes, Arsenic precipitate generated to be disposed off in a concrete pit | Training required | The running cost is huge. Sludge generated in high amount |
| Arsenic removal plant developed by CGCRI | Central glass and Ceramic Res. Instt., Kolkata(CSIR) | A fine iron based adsorbent is mixed with the contaminated water. Then the water along with the adsorbent is pushed through a series of ceramic filters | Tested in pilot plant of 500 L/day at Akrampur, Barasat, North 24 paraganas, West Bengal under DWS, MORD sponsorship since Jan. 2002. Plant steel operational | 4x2500 L/day plants set up under PHED, State Govt. Since March 2003. In Sept. 2006, another 2500 L/day plant set up as SSI on self-finance | Upto 1000 ppb | 10 ppb | Community | NA | Rs. 300000/- lakh for 2500 L/day and Rs. 400000/- lakh for 5000 L/day | Yes | 100-200 L/day | Running cost at Rs. 0.40/- | Yes. In 3-6 months, about 5 L sludge generated | Training required | Both initial and running cost is very high. It has low output with sludge generated through-out a day |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bucket Treatment Unit | Department of Public Health Engineering (DPHE) and Danida Water Supply & Sanitation Components, Bangladesh | Principles of coagulation, co-precipitation with aluminum sulfate (alum) and adsorption processes | Tested in laboratory and Noakhali area. The units were monitored for two and a half months. | Bangladesh | Upto 1500 ppb | Below 20 ppb | Domestic | No | The cost of this unit is about Rs. 200-250 and capacity about 20 Lit. | No | -- | Rs. 0.05 per litre (approx.) | Weekly cleaning of the sludge from the top bucket seems to be sufficient | Not required | Bangladesh University of Engineering and Techn. (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride |
| Fill and draw unit | Dept. of Public Health Engineering (DPHE) and Danida Water Supply & Sanitation Components, Bangladesh | Principles of coagulation, co-precipitation | Tested in West Bengal, India | West Bengal, India | 300 ppb | Below 50 ppb | Community | NA | -- | Yes | 600 L capacity | -- | -- | Training required | -- |
| Star Filter | Stevens Institute Technology, Hoboken | Precipitation and filtration technique. The adsorbent is iron sulphate and calcium hypochloride | Tested in laboratory | Golbahar village under Kachua in Chandpur | Upto 1000 ppb | Below 10 ppb | Domestic | No | The cost of the unit is around Rs.1500 | No | whole process about 20 minutes | -- | The sand bed used for filtration is quickly clogged by flocs and requires washing at least twice a week. | Not required | -- |
| Arsenic Removal Unit Attached to Tubewell | Department of Public Health Engineering (DPHE) and Danida Water Supply & Sanitation Components, Bangladesh | Alum coagulation, sedimentation and filtration | Tested in West Bengal, India | West Bengal, India | 300 ppb | Below 50 ppb | Community | NA | -- | No | Appro. 600L capacity | -- | -- | Not required | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn; Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alcan Enhanced Activated Alumina Unit | MAGC Technologies Ltd, House 15, Road 5 Dhanmondi, Dhaka 1205 | Activated alumina: coagulation, sedimentation and filtration | Studies by Department of Chemistry, Dhaka University, and BRAC (Sonargaon) show a removal rate of 100% | | | Below 10 ppb | Domestic | | The cost of this unit is about Rs 3000/ | No | 100 L/hr | | The unit is designed for single use and therefore saturated media must be replaced after use. | Not required | |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 5.0 Technologies for Iron Removal

## 5.1 Preamble

Iron is one of the most abundant metals of the Earth's crust, the major constituents of the lithosphere and comprises approximately 5% of it. Iron readily complexes with sulphates in the sediments of many surface waters. The primary concern about the presence of iron in drinking water is its objectionable taste.

Iron exists in soils and minerals mainly as insoluble ferric oxide and iron sulphide (pyrite). It occurs naturally in water in soluble form as the ferrous iron (bivalent iron in dissolved form $Fe^{2+}$ or $Fe(OH)^+$) or complex form like the ferric iron (trivalent iron: $Fe^{3+}$ or precipitated as $Fe(OH)_3$). It occurs in some areas also as ferrous carbonate, which is slightly soluble. Since groundwater usually contain significant amounts of carbon dioxide, appreciable amounts of ferrous carbonate may be dissolved by the reaction shown in the equation.

$$FeCO_3 + CO_2 + H_2O \rightarrow Fe_2^+ + 2HCO_3^-$$

The occurrence of iron in water can also have an industrial origin; mining, iron and steel industry, metals corrosion, etc. In oxygenated water Fe (II) is oxidized to Fe (III).

$$4\ Fe_2 + 3\ O_2 \rightarrow 2\ Fe_2O_3$$

$$Fe_2O_3 + 3\ H_2O \rightarrow 2Fe(OH)_3$$

Over the entire pH range of natural water, Fe (II) is thermodynamically unstable in the presence of dissolved oxygen. The reaction rate of ferrous iron is strongly pH dependent. Oxidation of Fe (II) is very slow at pH value below 6. The rate of oxidation increases manifold with the increase in pH.

Iron in groundwater normally remains in dissolved state. When water is drawn through bore wells, oxygen from air gets dissolved in water and iron of ferrous state gets oxidized to ferric state and precipitates as suspended solids in water. Therefore water containing iron slowly becomes turbid and highly unacceptable from an aesthetic view point.

Iron interferes with laundering operations, impart objectionable stains to plumbing fixtures and also develop taste problems. Carrying capacity of pipelines in the distribution system is reduced due to the deposition of iron oxide and bacterial slimes as a result of the growth of microorganisms (iron bacteria) in iron bearing water.

Permissible limit of iron in drinking water as per BIS 10500 is 1 mg/L, however, the desirable limit is 0.3 mg/L. Iron in drinking water has not reported to have any major health impacts and therefore WHO did not specify any guideline value for iron. Iron can affect the taste and colour of water. Water becomes brackish colour, rusty sediment, bitter or metallic taste. A problem that frequently results from iron in water is iron bacteria. Iron bacteria are normally considered non-pathogenic, that is, they are not associated with causing disease. Iron simply imparts colour to water and normally not associated with any adverse health effects. Excess iron causes gastrointestinal distress. Certain types of bacteria thrive in water with iron content and give it a rotten egg smell.

However, public tend to switch over to unsafe water sources from otherwise safe iron rich water sources due to colour and taste it imparts to water. It is therefore suggested to implement simple iron removal techniques in these habitations to avoid people switching over to unsafe sources.

## 5.2 Iron Removal Technologies

Oxidation by aeration or use of chemicals like chlorine, chlorine-dioxide or potassium permanganate followed by filtration alone or by settling and filtration can bring about the precipitation of iron and its removal. Similarly zeolites as well as catalytic oxidation method can also be used for the removal of iron.

Some of the treatment methods for various forms of iron are as following:

- **Aeration:** Introducing oxygen to the water source to convert soluble iron to its insoluble form
- **Filtration:** Media used to entrap and screen out oxidized particles of iron. Usually requires backwashing to remove accumulated iron.
- **Water Softener:** Removal of soluble iron by ion exchange.
- **Manganese Greensand:** An ion exchange sand material which is capable of removing iron. Adsorbs dissolved iron and requires chemical regeneration.
- **Catalytic Filtration "BIRM":** A granular filter medium that enhances the reaction between oxygen and iron and then filters the insoluble iron.
- **Ozonation:** A specialized form of aeration using ozone to convert soluble iron.
- **Ion Exchange:** Substituting an acceptable ion (such as sodium) for soluble iron.
- **Sequestering:** Adding chemical agents to water to keep metals like iron in solution to prevent characteristic red stains.
- **Chlorination:** Chemical oxidizer used to convert soluble iron to an insoluble, filterable form.
- **Electrolysis (electrolytic reaction):** Electrolysis requires electrical current to be passed between an anode and cathode positioned in the water solution. This current creates positive and negative electrochemical charges that separates the water molecule into its component parts, oxygen and hydrogen gas. Being a larger, heavier molecule, oxygen will stay in solution, contributing to the dissolved oxygen content of the fluid, or will dissipate across the water-air interface. Hydrogen is smaller and lighter than oxygen and therefore leaves solution; it can be collected or allowed to dissipate into the atmosphere.

### 5.2.1 NEERI Hand Pump Attachable Iron Removal Plant

NEERI has developed and field tested iron removal plants both for piped water supply and hand pumps. These plants have been installed in the iron affected districts in Assam. The evaluation results indicated that the plants are capable of removing iron from 50 mg/L to below 0.3 mg/L.

This plant is a cylindrical system of 1 $m^3$/hr capacity made from readily available hume pipes or constructed on sites of RCC/ ferro cement (Figure 5.1). The technology involves precipitation of iron by aeration with air then properly settled and finally filtered. This plant comprises of three major components namely aeration chamber, sedimentation tank and filter.

**Figure 5.1:** NEERI Hand Pump Attachable Iron Removal Plant

The only maintenance is the removing top layer of 5 cm of sand when filter is chocked, washing the removed sand in a bucket of water and putting the sand back on the filter. The frequency of filter cleaning is nearly one month for iron concentrations above 5 mg/L and nearly two months where iron is below 5 mg/L. Cost of the plant with capacity 1 $m^3$/hr, for the population of 250 persons, is Rs. 50,000 (as on the year 2011).

## 5.2.2 Iron Removal Plant of CMERI

Central Mechanical Engineering Research Institute (CSIR-CMERI) has developed iron removal plant. Removal of iron from water containing ferrous salt is done by oxidation accompanied by the dissolved oxygen introduced into the water through aeration and precipitating the iron as ferric salt, followed by setting, filtration to remove precipitates. The required raw materials/inputs for this plant is MS plate, pipe valves, consumables including limestone, $MnO_2$, sand, gravel (Figure 5.2).

**Figure 5.2:** CMERI Iron Removal Plant

**Contact details:**

**Central Mechanical Engineering Research Institute**
Mahatma Gandhi Avenue,
Durgapur - 713209
Phone: :(0343)6510701, 6510702

## 5.2.3 Household Iron Removal - CSIR - NEERI Technology

Oxidation followed by filtration is a relatively simple process. The oxidant chemically oxidizes the iron (forming a particle), and kills the iron bacteria as well as any other disease-causing bacteria that may be present. This unit works on the principle of oxidation of iron by $KMnO_4$ and removal of precipitated iron by sand filtration. Required dose of $KMnO_4$ is added in the iron contaminated raw water and mixed with the stick. The chemical oxidises the iron and yellowish brown precipitate is formed. After 5 to 10 minutes of mixing, water is allowed to flow by gravity into the sand filter at the rate of 300 – 400 ml/min. Filtered water with iron concentration less than 0.2 mg/L is collected in the third plastic container and used for domestic purposes. The dose of $KMnO_4$ required is about 50% of the iron concentration in the water.

**Figure 5.3:** Household Iron Removal - CSIR - NEERI Technology

## 5.2.4 Iron Removal by OxyPure™ System

OxyPure™ hydrogen peroxide is based on the principle of oxidation and precipitation of iron. OxyPure™ oxidizes iron to form dense, easily settleable solids, which can be removed through the conventional flocculation/precipitation/filtration systems.

$$2\,Fe^{2}+ + H_2O_2 + 2\,H^+ \rightarrow 2\,Fe^{3}+ + H_2O$$
$$H_2O_2 \rightarrow \tfrac{1}{2}\,O_2 + H_2O$$
$$2\,Fe^{2+} + \tfrac{1}{2}\,O_2 + H_2O \rightarrow 2\,Fe^{3+} + OH^-$$

The equipment cost is $217,000 (INR 10,649,275/-), while operation and maintenance cost is $29,000 (INR 1,423,175/-) per year.

**Contact details:**

**U.S. Peroxide, LLC**
500 Bishop Street, Suite C-3, Atlanta, GA 30318
Phone: (404) 352-6070
Toll-free U.S.: (877) 346-4262
Fax: (404) 352-6077

### 5.2.5 Terra Filtration System for Iron Removal for Community Water System Developed by IMMT, Orissa

**Figure 5.4:** Terafil Filter

Terafil Water Filter is a low cost device to filter impure water into clean drinking water. The filter is developed to cater the needs for clean drinking water, especially when the water is rich in sediments, suspended particles, iron and certain micro-organisms causing water borne diseases. It is most suitable for areas where water from both surface and ground water sources like dug wells, ponds, tube wells and rivers is used for drinking purpose. TERAFIL has been developed at the Institute of Minerals and Materials Technology (IMMT), (formerly known as Regional Research Laboratory), Council of Scientific and Industrial Research, Bhubaneswar after long years of research and trials.

TERAFIL water filtration discs are prepared under license and training from IMMT. Turbidity up to 500 NTU and iron up to 15 mg/l can be easily treated with this Terafil filter (Figure 5.4). The filter consists of a Terafil disc which is a porous sintered red clay disc and treats the raw water through filtration. The rate of filtration can be increased many folds by applying pressure.

The Terafil water filtration disc is produced by mixture of red clay (ordinary pottery clay), river sand and wood saw dust without using any chemicals. Equipment like pulveriser (Atta Chaki), a low cost coal/wood fired kiln, few hand tools and cement platform are required for mass production of Terafil water filtration disc. Terafil water filters consisting of the ferro-cement chambers or masonry structures can be easily built by the local masons. The Terafil can be made in any shape; but circular disc shape is more preferred due to high strength, long operational life, and easy maintenance. Nearly 99% of turbidity, 95-100% of micro-organisms, 90-95% of soluble iron, colour, bad odour etc. is effectively removed from the raw water by filtration through the Terafil disc. The filtrates/ sediments collected after filtration does not contaminate the water sources. Electricity is not required for operation of both domestic and community Terafil water treatment systems.

The Terafil can be built in following capacities for different categories like domestic, community and online models:

- Domestic level filter : 20 & 30 litre with 1-4 LPH (litre per hour) rate of filtration.
- Community level filter : 1000 to 100000 LPD (litre per day)
- On-line pressure filter : 60 to 10,000 LPH

**Technical Details of Terafil**

The dough of the mixture is sintered at high temperature in a low cost coal / wood fired furnace to make the terracotta disc porous. During sintering process, the wood particles are burnt and clay particles are sintered around the sand particles leaving elliptical / circular large size pores in between. These pores are not connected with each other, unlike white ceramic filter candles, but separated by very thin clay walls which are semipermeable in nature.

The thin clay walls contain large numbers of ultra-fine capillary openings. A set of pores are connected by these ultra-fine capillaries only. Average diameter of the capillary openings is in sub-micron size. During filtration process, water flows from one pore to another pore through the capillary openings by pressure of raw water over the Terafil disc. The pores inside the Terafil disc always work like micro-reservoirs of filtered water. Since opening of the capillaries are in sub-micron, almost all suspended particles & microbes etc. cannot enter into the capillaries; hence sediments and impurities are deposited on top of the Terafil disc during filtration. Therefore the core of Terafil disc is never clogged unlike white ceramic candle during filtration. Rate of filtration is dependent upon turbidity and pressure of raw water as well as diameter of Terafil disc inside the filter. The filtrates clog the top surface of the Terafil over time during use and hence reduce the flow rate. Therefore scrubbing or cleaning the top surface of the Terafil disc with a soft nylon brush or coir or similar abrasive materials or by water jet is necessary to remove the sediments and open the new pores for rejuvenation of filtration process. The thickness of the Terafil keeps reducing on scrubbing its top surface; however quality of filtered water is not altered during entire life of Terafil.

**Contact details:**

**Institute of Minerals and Materials Technology**
(Formerly Regional Research Laboratory)
Council of Scientific & Industrial Research
Bhubaneswar - 751 013, Orissa, INDIA
FAX: 91-674-2581160
Telephone : +91-674-2581126, +91-674-237-9400

### 5.2.6 SEUF Iron removal Plant (IRP)

Socio Economic Unit Foundation (SEUF), an accredited agency of the Government of Kerala in the Water and Sanitation sector has developed a household level filter model to remove iron from drinking water with the financial support of the Department of Science and Technology, New Delhi. The design of household water treatment system is shown in Figure 5.5. IRP is an upgraded version of household filter with additional arrangements for aeration and sedimentation. It can bring down the iron concentration to the desirable limit from raw water with iron concentration up to 10 ppm.

IRP consists of a circular ferro-cement container with 45cm diameter and 110 cm overall height. Three separate detachable containers meant for aeration, sedimentation and filtering respectively are assembled together to act as IRP. The sedimentation chamber with four compartments is placed in between the aeration chamber and filter chamber. 20mm PVC pipe pieces are used for drawing water from the filter.

A 40 cm long perforated piece is fixed at the bottom of the container to receive water flowing through the filter media. A vertical piece of 50 cm length is connected to this and is fixed on the inner wall of the container. Another piece of pipe with tap fitted at one end is inserted in to the container through an opening in the wall and is connected to the top end of the vertical piece to act as outlet. The container is filled with river sand, gravel and charcoal as follows after thorough cleaning & drying (figure5.5). The filter media used was fine river sand having an effective size of 0.25mm and uniformity coefficient of 5.6.

1. Bottom most layer of 20 mm gravel, 5 cm thick
2. 2nd layer of 6mm gravel, 3 cm thick
3. 3rd layer of 0.3 mm sand, 40cm thick
4. Top layer of charcoal, 2cm thick

Each layer is separated with nylon cloth for easy replacement during cleaning of filter media.

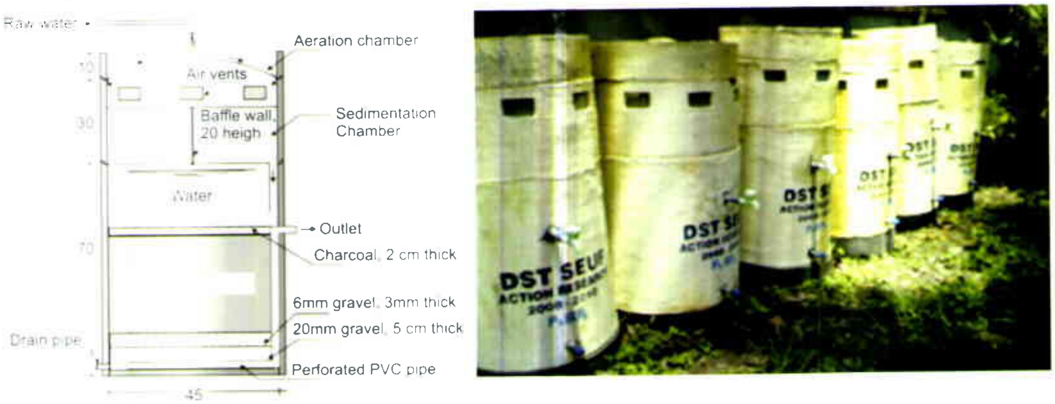


**Figure 5.5:** SEUF Iron Removal Plant (IRP)

The filter is very effective in reducing iron concentration in water and suitable for use at household level. When the discharge from the filter becomes lower than the desirable limit, the top layer of sand has to be taken out, thoroughly washed and replaced. The field-testing data indicates that for use at household level and for an iron content of less than 10 ppm, the unit performs well for a period of 3 to 4 weeks after which the filter needs cleaning. The filtered water can be disinfected by 'Solar disinfection (SODIS)' to make it safe without incurring any additional cost. Several designs for iron removal plants exist, but with a few operational problems. The absence of sedimentation chamber makes the plant to be backwashed more frequently. The SEUF model eliminates these deficiencies by providing a sedimentation chamber. The cost of IRP is Rs 2500/-.

**Contact details:**

**Socio Economic Unit Foundation**
TC 15/74-1, B Street, Elankom Gardens,
Vellayambalam, Sasthamangalam P.O
Thiruvananthapuram - 695 010 Kerala, India
Tel: + 91 471 2315907 Fax: + 91 471 2725914, Email: seufhq@vsnl.net

### 5.2.7 Iron Removal Plant of Balaji Industrial and Agricultural Castings

Balaji Industrial and Agricultural Castings (BLAC) is involved in the manufacture of deep well hand pumps and water supply projects. BLAC developed an iron removal plant which is attached to force lift hand pump (Figure 5.6).

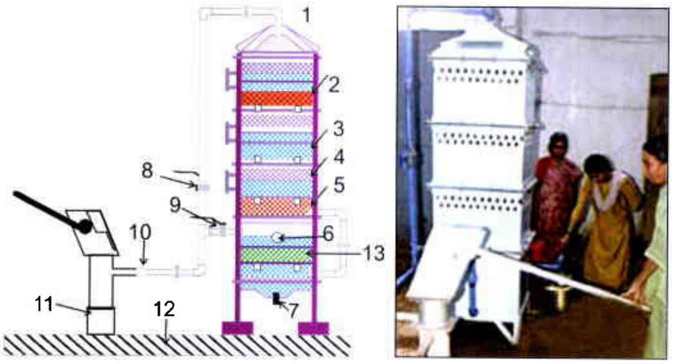


**Figure 5.6:** Iron Removal Plant of Balaji industrial and Agricultural Castings

1. Sprinkler
2. Sprinkled water
3. Lime stone media chamber
4. Activated carbon media chamber
5. Filtered storage chamber
6. Filtered water
7. Treated water outlet
8. Desludging provision
9. Raw water inlet gate valve
10. Backwash inlet gate valve
11. 11/2" to 11/4" reducer
12. Force lift hand pump attached to iron removal
13. Plant platform cum foundation
14. Filter media

**Contact details:**

**Balaji Industrial & Agricultural Castings (BIAC)**
4-3-140, Hill Street,
Secunderabad- 500 003.
ramakrishnak@balajicastings.com
+91 8686400530

### 5.2.8 Iron Removal Unit of DRDO

An iron removal unit has been designed and developed by DRDO for removing high contents of iron from water. The iron removal unit, made of mild steel, is cylindrical in shape, consists of four chambers and has sludge/backwash outlet valves for cleaning. It has an efficient aeration system and a double (up flow and gravity flow) filtration device. Various steps involved for the removal of iron in the unit are: (i) aeration/gas transfer, (ii) pH adjustment, (iii) oxidation of ferrous into ferric ion due to dissolved oxygen and catalytic action of iron oxide coated contact media, (iv) precipitation of ferric iron, and (v) removal of precipitated iron by sedimentation, up flow and gravity flow filtration.

The unit is designed for 300 l/hr output and can cater to the need of small population particularly in rural areas. Iron contents in the water treated through this unit were found below 0.3 mg/l with feed water having iron content up to 40 mg/l.

**Figure 5.7:** Water Iron Removal Unit of DRDO

### 5.2.9 Lenntech Iron Removal Plant

The elimination of the ferrous iron, by physical-chemical way, is obtained by raising the water redox potential by oxidation or by simple ventilation. In the case of water having acidic pH, the treatment could be supplemented by a correction of the pH. Thus, the ferrous ion is oxidized to form ferric ion, which precipitates to iron hydroxide $Fe(OH)_3$. The precipitate is then separated from water by filtration on sand or decantation. The stage of precipitation by chemical oxidation can also be carried out with the stronger oxidants such as the chlorine dioxide ($ClO_2$), ozone ($O_3$) or the potassium permanganate ($KMnO_4$).

This elimination can be carried out by cascade or spraying open-air systems (for an acceptable maximum content of $Fe_2^+$ of 7 mg/L) known as gravitating systems. Those systems require a significant place on the ground, but, in addition to an easy and a cheap exploitation cost, they also make possible aggressive $CO_2$ and hydrogen sulfide ($H_2S$) removal. There are also pressure systems, which in addition to their compactness, make possible to treat water having $Fe_2^+$ concentrations between 7 and 10 mg/L.

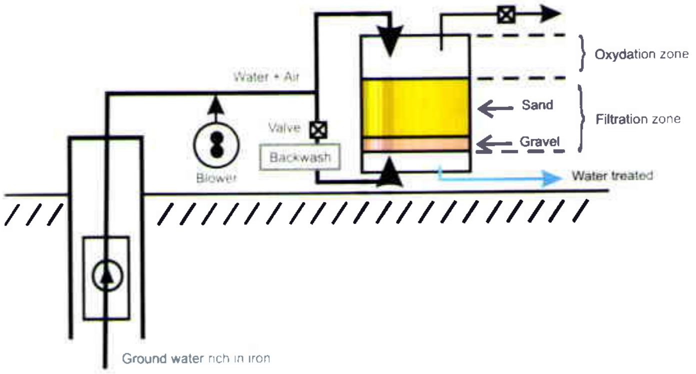


**Figure 5.8:** Schematic Diagram of Lenntech Iron Removal Plant

**Contact details:**

**Lenntech BV., Rotterdamseweg 402 M, 2629 HH Delft**
The Netherlands
tel: +31 15 261 09 00 fax: +31 15 261 62 89
e-mail: info@lenntech.com

### 5.2.10 Iron Removal Unit Of CREPA

This technology is designed to make iron-rich ground water potable, using a simple and low cost technique. The "Iron Removal Unit" (Figure 5.9) is composed of an aeration channel (at its head), from which aerated water drops into a rectangular settling basin. The particles of ferric oxide flocculate and settle at the bottom of the settling basin, creating a deposit of iron mud. At 5 - 10 cm from its bottom, clarified water from the settling basin is removed to an adsorption basin containing two layers of gravel: the first layer of gravel is usually a 45 cm deep layer of 1.5 to 2.0 cm sized gravel; the second layer of gravel is usually a 25 cm deep layer of 2.5 to 5.0 cm sized gravel. Water flows over a weir at the outlet of the adsorption basin to the sand filtration basin. The sand filter is constructed using a 40 cm thick layer of 0.2 to 5.0 cm sized gravel at its bottom, topped by a 20 cm thick layer of 0.2 to 4.0 mm sized sand. The filtered water is collected by a pipe and distributed to the users (CREPA 1992).

Various basins that comprise this system have a different direction of the flow in the these basins: in the settling basin, flow is from top to bottom; in the adsorption basin, flow is from bottom to top; and in the filtration basin, flow is again from top to bottom. A number of water points in Burkina Faso and Mali are equipped with this type of iron removal unit. This is a low cost technology. Typical costs in Mali and Burkina Faso range from $250 to $300 per unit (INR 13,000 to 15,000/-).

Studies have shown that there is a considerable decrease in the iron level in the treated water provided by this technology. Based on these studies, it is observed that the efficiency of iron removal averages between 90% and 96%.

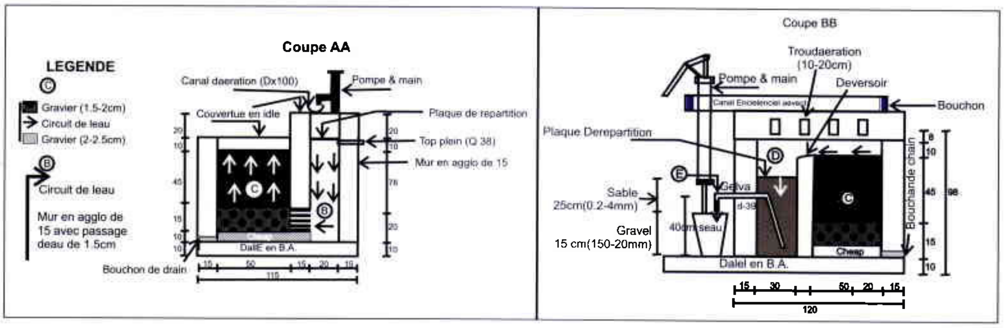


**Figure 5.9:** Schematic of a Typical Iron Removal Unit

The technology uses local materials and labour to install and operate the unit. It is simple to operate, and requires no chemicals except for those necessary to disinfect the unit after each cleaning. Use of the unit can rehabilitate what would otherwise be abandoned water sources.

**Contact details:**

**Centre Regional Pour l'Eau Potable et l'Assainissement a Faible Cout (CREPA),**
03 BP 7112 Ouagadougou 03, Burkina Faso.
Tel (226) 310359/60, Fax: (226) 310361.

### 5.2.11 Ion Specific Resin Units– CSIR-CGCRI

Central Glass and Ceramic Research Institute (CSIR-CGCRI) has developed ion specific resin units for the removal of arsenic/iron from drinking water. This is achieved by coagulation and precipitation from water. Ion specific resin is used for the removal of arsenic and iron. It is easy to install and operate and convenient to carry in the field. Resin has good shelf life upon cycles of regeneration (Figure 5.10). The cost of this filter is Rs.3500-4000/- for 25 liter/hour capacity domestic unit.

**Figure 5.10:** Ion Specific Resin Unit (CSIR-CGCRI)

### 5.2.12 UF Membrane Assisted Device

UF membrane assisted oxidation process for removal of iron from ground/surface water makes it safe for drinking purposes. It is simple, cost effective, adaptable at both domestic as well we community level and is capable of removing high levels of iron.

The technologies of UF membrane device used in the process are already available as separate technologies at domestic level (dead-end element type) and community level (back washable flow element type) with Bhabha Atomic Research Centre (BARC) (Figure 5.11). Alternately, these devices may also be procured directly from manufacturers who are manufacturing and marketing these devices in various capacities and configurations as BARC's licensees. This unit operates continuously at low operating pressure of about 2-3 bar.

**Figure 5.11:** UF Membrane Assisted Device for Removal Of Iron

The process of iron removal involves oxidation of dissolved iron ($Fe_2^+$) to colloidal iron ($Fe_3^+$) and then removal of colloidal iron ($Fe_3^+$) using indigenously (BARC) developed UF membrane technology/device. All the raw materials required for the iron decontamination are available in the local market. The cost of the unit with capacity 50-5000 litres per day is Rs. 3000 and above.

**Contact details:**

**Head, Technology Transfer & Collaboration Division,**
Bhabha Atomic Research Centre,
Trombay, Mumbai - 400 085
Tel : 091-022-25505337/25593897
Fax : 091-022-25505151 Email : headttcd@barc.gov.in

### 5.2.13 Iron removal plant (by Shubham inc.)

Iron removal filter is manually operated, processed catalytic filtration unit, where the raw water passes through the layer of compressed air, processed catalyst and quartz filter media respectively. The dissolved ferrous ion salts are converted into insoluble ferric salt and precipitated over the filter bed and then the iron free filtered water comes out. Only backwashing with clear water and compressed air is required for cleaning the bed. In this filter Mild Steel Welded Pressure Vessel fitted with M. S. Control pipe and C.I. diaphragm valve, strainers, sampling cock, pressure gauge, air compressor and first charge filter media (Figure 5.12). The flow range is 50 litres/hour to 50,000 litres/hour.

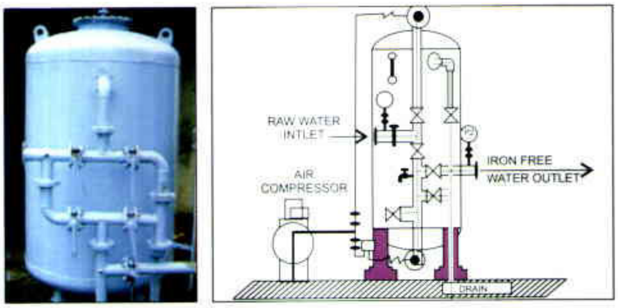


**Figure 5.12:** Iron Removal Plant (by Shubham Inc.)

**Contact details:**

**Shubham Inc.**
501, Kalash - II, Near Jain Derasar,
Navarangpura, Ahmedabad - 380 009,
Gujarat, India.
Phone : +91-79-30086163/66
Fax : +91-79-30086163, Email : info@shubhamindia.com

### 5.2.14 Deferum™ Iron Removal Technology:

Filter Innovations has designed "IRON STOPPER" Treatment System (Figure 5.13) by combining "DEFERUM™" iron removal technology (Figure 5.14) with Filter Innovation's automated controls and separation technology.

**Figure 5.13:** "IRON STOPPER" Containerized Treatment System, including the "DEFERUM™" hydroautomatic filter

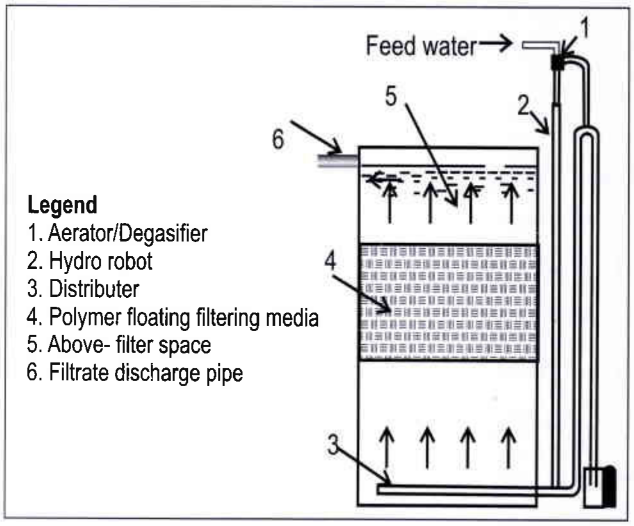


**Figure 5.14:** Simplified Schematic of the "DEFERUM™" hydro-automatic filter based on the polymer floating filtering media.

This system has following features (Automatic self-back flushing treatment component) for removal of Iron:

- Feed water is pumped from the collection tank at 65 PSI (0.45 MPa) to the aerator degasifier, where dissolved gases are removed from the water and atmospheric air oxidizes bivalent iron and partially to the ions of manganese
- Feed water then flows down the hydro-robot and through the distribution system into the hydro-automatic filter containing the floating filtering media, where the oxidized iron particles are removed throughout the depth of the filtering bed.
- After filtration, treated water gravity-flows into a filtrate collector via the discharge pipe, and a pump forward the purified water to the next treatment process to make it free of iron (this water can also be sent by gravity flow).
- As fouling of the filter increases, the water level in the hydro-robot rises, causing the filter to switch into backwash mode.

- Iron free water from the above filter section flows downward, pushing the media down and expand the filtering bed, washing out the accumulated particulates.
- When the water level in the above filter section drops down to a pre-set point, the hydro-robot stops the backwash and switches the filter into a new filtration cycle.
- Backwash water is discharged from the system and is then additionally treated with coagulants and flocculants to generate an agglomerated particle. This large iron coagulated floc is now easily removed in automatic self-indexing filter. The collected iron on the paper media is collected in a hopper and sent to landfill.

The "IRON STOPPER" Treatment system design is common for all flow-rates. However, individual systems may vary in configuration or add-ons depending on the quality of initial water and/or customer's requirements. Tanks and vessels will change in diameter based on flow rates.

**Contact details:**

**Filter innovations inc.**
744 Gordon Baker Road
North York, Ontario M2H 3B4
Tel: (416) 490-7848
Fax: (416) 490-0974
www.filterinnovations.com

### 5.2.15 The WATER D.O.G. Iron Hunter HD

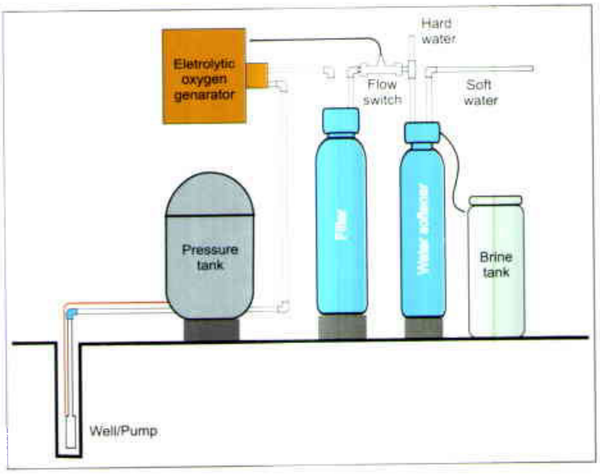


**Figure 5.15:** The WATER D.O.G. Iron Hunter HD

The first home water treatment system that completely oxidizes the iron in water. For the total iron removal it uses a patented dissolved oxygen generator (DOG). It can also reduce the problems related to water issues such as manganese and hydrogen sulphide.

Electrolysis is used to oxygenate water for a variety of specialized industrial water treatment applications where economics is secondary to function. This is an important consideration because current methods of electrolysis utilize large amounts of energy and are inefficient, expensive and slow, making their use in broad applications impossible (Nicole Mitchell, 2008). This technology generates extremely high levels of dissolved oxygen in water (Figure 5.15). It oxygenates water in real-time, at controlled oxygen levels and at various flow rates. The extremely high levels of oxygen produced by the DOG oxidize the 100% of iron and manganese in water for easy removal during filtration, while eliminating iron oxide and hydrogen sulphide causes odour.

**Contact details:**

**Patsy Parker-Kettle pkettle@wcponline.com**

## References:

1. CREPA 1992. *Construction, Operation and Maintenance Manual of an Iron Removal Unit.* Centre Regional Pour l'Eau Potable et l'Assainissement a Faible Cout, Ouagadougou.
2. CSIR, (2010),Water Technologies
3. http://drdo.gov.in/drdo/pub/techfocus/feb02/Water%20Iron.htm
4. http://www.balajicastings.com/watertreatment-en.shtml#
5. http://www.barc.ernet.in/technologies/iron/iron_br.html
6. http://www.cmeri.res.in/rnd/iron.html
7. http://www.filterinnovations.com
8. http://www.h2o2.com/municipal-applications/drinking-water-treatment.aspx?pid= 129&name= Iron- Removal
9. http://www.lenntech.com/feedback/feedback_uk.htm?ref_title=#ixzz1Z2DfZd9k
10. http://www.shubhamindia.com/iron_removal.htm
11. http://www.wcponline.com/buyersguide.cf
12. Margie Damgaard, Iron in drinking water, Public Water Section (2003)
13. Nicole Mitchell, New Technique for Iron Removal, Water Conditioning & Purification 2008
14. SEUF filter, ftp://ftp.solutionexchange.net.in/public/wes/cr/res-16091101.pdf
15. Terafil: A Low Cost Device for supply of Safe Drinking Water http://www.csir.res.in/csir/external/heads/aboutcsir/announcements/ngo/terafil.pdf

## Table 5.1 : Comparative Statement of Technologies available for Treating Iron

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgraied to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEERI hand pump attachable iron removal plant | National Environmental Engineering Research Institute (NEERI), Nagpur | precipitation of iron by aeration with air, sedimentation and fiteration | Tested in laboratory | Assam, Ladoba, Maharashtra | From 50 mg/l | Below 0.3 mg/l | Community | NA | Approx. Rs. 50,000/- of capacity 1 m3/hr | No | -- | -- | maintenance is the removing top layer of 5 cms of sand when filter is chocked, washing the removed sand in a bucket of water and putting the sand back on the filter. | Not required | This plant is a cylindrical system of 1 m3/hr capacity made from readily available hume pipes or constructed on sites of RCC/ ferro cement |
| Iron Removal Plant | Central Mechanical Engineering Research Institute (CSIR- CMERI) | Oxidation by aeration and precipitation and filtration | Tested in laboratory | West Bengal | -- | -- | Community | -- | -- | No | -- | -- | -- | Not required | The required raw materials/ inputs for this plant is MS plate, pipe valves, consumables including limestone, MnO2, sand, gravel |
| Household Iron Removal | National Environmental Engineering Research Institute (NEERI), Nagpur | principle of oxidation of iron by KMnO4 and removal of precipitated iron by sand filtration | Tested in laboratory and | -- | -- | Below 0.2 mg/L | Domestic | -- | -- | No | Flow rate 20-25 L/ Hr | -- | -- | Training required | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Iron Removal by OxyPureTM System | U.S. Peroxide, LLC | principle of oxidation and precipitation of iron by Oxy-Pure™ hydrogen peroxide | -- | -- | -- | -- | Domestic | | The equipment cost is Rs. 10,649,275/- | -- | -- | -- | -- | -- | Cost is very high and operation and maintenance cost is $Rs. 1,423,175/- per year |
| Terafil Water Filter | Institute of Minerals and Materials Technology (IMMT), Bhubaneswar | Adsorption and filtration | -- | Orissa, Karnataka, Meghalaya | -- | -- | Domestic and community | NA | -- | No | Domestic level filter : 20 & 30 litre with 1-4 L/Hr Community level filter : 1000 to 100000 L/Day | -- | scrubbing or cleaning the top surface of the Terafil disc with a soft nylon brush or coir or similar abrasive materials or by water jet is necessary to remove the sediments | Not required | The thickness of the Terafil keeps reducing on scrubbing its top surface; however quality of filtered water is not altered during entire life of Terafil |
| SEUF Iron removal Plant | Socio Economic Unit Foundation (SEUF),Kerala | aeration and sedimentation. | -- | -- | Upto 10 mg/L | Below 0.3 mg/L | Community | NA | -- | No | The cost of IRP is Rs 2500/-. | -- | the filter needs cleaning after 3-4 weeks | Not required | The filtered water can be disinfected by 'Solar disinfection (SODIS)' to make it safe without incurring any additional cost. |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Iron Removal Plant | Balaji industrial and agricultural castings (BIAC), Secundarabad | Adsorption and filtration | | | 10-15 mg/L | Below 0.3 mg/L | Community | NA | 8000 L day capacity | No | | | Backwash | Not required | |
| Iron Removal Unit | Defence Research and Development Organisation | Aeration, Adsorption and filtration | Tested in Laboratory | | 40 mg/L | Below 0.3 mg/L | | | 500 l/hr | No | | | Backwash | Not required | |
| Lenntech Iron removal plant | Lenntech BV., Rotterdamseweg, Netherland | Oxidation, Adsorption, precipitation and filtration | -- | -- | 7-10 mg/L | Below 0.3 mg/L | Community | -- | Low cost | Yes | -- | -- | Backwash | Not required | Removal aggressive CO2 and hydrogen sulfide is possible |
| Iron Removal Unit | Centre Regional Pour l'Eau Potable et l'Assainissement a Faible Cout (CREPA) | Aeration, Adsorption and filtration | -- | -- | -- | -- | Community | -- | Rs. 13,000 to 15,000/- | Yes | -- | -- | -- | -- | It is simple to operate, and requires no chemicals except for those necessary to disinfect the unit after each cleaning |
| DRDO filter | Defence Research laboratory, Tezpur, Assam | oxidation, Coagulation, precipitation and filtration through cheap sand filter | Tested in laboratory and field | Treated water are within limit | Upto 20 mg/L | Below 0.3 mg/L | Community and Domestic . Unit with flow rate 3000 L/hr | NA | Rs. 50000/- for 200 L/hr. It can run atleast 10 years without changing adsorbant | No | 200 L/hr and 40000 L/day | Rs. 0.050/- (approx.) | No, only back washing required to clean the system | Not required | The system can take care of iron and arsenic simultaneously. Several |
| Ion specific resin units | Central Glass and Ceramic Research Institute (CSIR-CGCRI) | Oxidation, Adsorption, precipitation and filtration | -- | -- | -- | -- | Domestic | -- | Rs. 3500-4000/- for 25 L/Hr capacity | | Rs. 3500-4000/- for 25 L/Hr capacity | -- | Regeneration of resin | Training required | -- |
| UF Membrane Assisted Device | Bhabha Atomic Research Centre (BARC), Mumbai | UF membrane assisted oxidation process | -- | -- | -- | -- | Domestic and Community | -- | Rs. 3500-4000/- for 50-5000 L/day capacity | Yes | -- | -- | -- | -- | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Iron removal plant | Shubham Inc., Gujrat | Oxidation, Adsorption, precipitation and filtration | -- | -- | -- | -- | Community | -- | flow range is 50 litres/hr to 50,000 litres/hr | No | -- | -- | These filters purify water from sand without clogging the filter | Not required | Also used to eliminate turbidity, suspended particles, colour, odour and iron that are present in raw water |
| DEFERUM™ Iron Removal Technology | Filter innovations inc. | Oxidation, Adsorption, precipitation and filtration | -- | -- | -- | -- | Community | -- | -- | Yes | -- | -- | Backwash Water is discharged from the system | -- | The "IRON STOPPER" Treatment system design is common for all flowrates |
| The WATER D.O.G. Iron Hunter HD | pkettie@wcpon-line.com | Oxidation, Adsorption, precipitation and filtration | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | It can also reduce the problems related to water issues such as manganese and hydrogen sulphide. |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 6.0 Nitrate Removal Technologies

## 6.1 Preamble

Nitrate contamination in surface and groundwater has become an increasingly important problem all over the world. Although, nitrate is found in most of the natural waters at moderate concentrations but higher levels are thought to result from human activities. Recent studies show an increasing rate of nitrate concentration in surface and especially in groundwater in many parts of India. This is mostly caused by the combined effects of chemical fertilizers, uncontrolled animal-feeding operations, as well as pesticides and waste contamination through storm and urban runoff. As a result, nitrate concentration in surface and groundwater has largely exceeded the required permissible limits prescribed by various agencies for drinking water. Elevated nitrate concentration in surface and ground water can cause several environmental and public health problems. Some of them are given below.

### Primary toxicity

High nitrate intake can cause abdominal pains, diarrhoea, vomiting, hypertension, increased infant mortality, central nervous system birth defects, diabetes, spontaneous abortions, respiratory tract infections, and changes in the immune system.

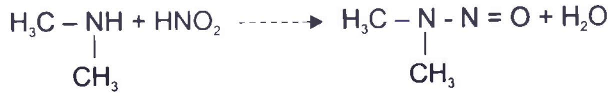
### Secondary toxicity

Secondary toxicity of nitrate is microbially reduced to the reactive nitrite ion by intestinal bacteria. Nitrate has been implicated in methemoglobinemia, especially to infants under six month of age. Methemoglobin (MetHb) is formed when nitrite (for our purposes, formed from the endogenous bacterial conversion of nitrate from drinking water) oxidizes the ferrous iron in hemoglobin (Hb) to the ferric form. MetHb cannot bind oxygen, thereby preventing it from transporting oxygen to the body tissues and the condition of methemoglobinemia is characterized by cyanosis, stupor, and cerebral anoxia. Symptoms include an unusual bluish grey or brownish grey skin colour, irritability, and excessive crying in children with moderate MetHb levels and drowsiness and lethargy at higher levels. Severe methemoglobin can result in brain damage and death.

$$\underset{\text{(Can combine with oxygen)}}{\text{Hemoglobin }(Fe^{2+})} \xrightarrow{NO_2} \underset{\text{(Cannot combine with oxygen)}}{\text{Methemoglobin}}$$

### Tertiary toxicity

Tertiary toxicity of nitrate is due to the reaction between nitrite and secondary or tertiary amine in the human mouth and stomach, under conditions of low gastric acidity, can result in the formation of *N*-nitroso compounds, some of which are known to be carcinogenic, teratogenic and mutagenic.



$$H_3C-\underset{\displaystyle CH_3}{\underset{|}{N}}H + HNO_2 \dashrightarrow H_3C-\underset{\displaystyle CH_3}{\underset{|}{N}}-N=O+H_2O$$

Dimethyl amine

Dimethyl nitrosamine
(Carcinogenic)

To protect consumers from the adverse effects associated with the high nitrate intake, nitrate consumption should be limited. BIS has stipulated desirable standard of 45 mg/l and WHO has guideline value of 50 mg/l.

## 6.2 Techniques for Removal of Nitrates from Drinking Water

Nitrate is a stable and highly soluble ion with less potential for co-precipitation or adsorption. These properties make it difficult to be removed from water by some popular processes such as chemical coagulation, lime softening and filtration which are effective for removing most of the pollutants including heavy metals but unfortunately, they do not work for nitrate. Hence, treatment of nitrate is typically very complicated and expensive.

Following methods exist for removal of nitrates from drinking water:

- Adsorption/Ion exchange
- Biological denitrification
- Catalytic reduction
- Reverse osmosis
- Electrodialysis
- Blending

The utility of these techniques has been limited due to their expensive operation and subsequent disposal problem of the generated nitrate waste brine. These techniques require frequent, careful maintenance and sampling to achieve and confirm effective operation. Improperly installed, operated or maintained plants can result in nitrate passing through the treatment process and in some cases concentrating the nitrate above the incoming levels.

## 6.3 Nitrate Removal Technologies

### 6.3.1 Adsorption/Ion Exchange

Ion exchange process seems to be the most popular physico-chemical process for small water suppliers contaminated by nitrate because of its simplicity, effectiveness, selectivity and recovery and relatively low cost. The ion exchange process involves passage of nitrate contaminated water through a resin bed containing strong base anion exchange resins that are charged with chloride. As water passes over the resin bed, the resin takes up the nitrate ions in exchange for chloride until the exchange capacity is exhausted. The exhausted resin is then regenerated using a concentrated solution of sodium chloride (brine). It offers great potential for application at small and medium–sized treatment plants. Some of popular commercial available resins for nitrate removal whose selectivity is better for nitrate than for sulphate are Duolite A 196, Amberlite IRA 996 etc.,

The disadvantages of ion exchange are high associated cost and the production of highly concentrated brine waste. The backwash solution, which is high in nitrate, must be properly disposed of.

### 6.3.2 Biological Denitrification

Biological denitrification is carried out by facultative bacteria that use nitrate as a terminal electron acceptor for respiration under anoxic conditions. It converts the nitrate to nitrogen gas. There are two types of biological denitrification, the autotrophic and heterotrophic denitrification. Heterotrophic denitrification is a process that uses various carbon compounds as energy and electron sources such as ethanol, methanol etc., while autotrophic denitrification bacteria uses hydrogen, iron or sulphur compounds as energy source and carbon dioxide or bicarbonate as carbon source. The main advantages of heterotrophic denitrification are the high denitrifying rates and treatment capacity. Biological denitrification of drinking water with heterotrophic microorganisms has been widely investigated, due to its efficiency and high performance.

However, products of microbial activity and incomplete degraded organic compounds imparted to the treated water require extensive post treatment to safeguard the drinking water quality. The process is generally time consuming, operates under limited temperature ranges, requires extensive maintenance and mostly used for treating wastewater for which the original nitrate concentration is sufficiently high.

### 6.3.3 Catalytic Reduction / Denitrification

Another promising technology that uses metallic catalysts for the removal of nitrate from water is catalytic reduction. In this process, nitrate reacts with hydrogen gas or formic acid and it is converted into nitrogen and water using a solid catalyst. The activity and selectivity of metallic catalysts plays a crucial role for the effective conversion of nitrate to nitrogen gas. It can be operated over a wide range of temperatures. However this technique has limitations of possible catalyst fouling, post-treatment requirement due to the production of by-products and production of large quantity of sludge.

### 6.3.4 Reverse osmosis

Reverse osmosis is an established technology for removal of various contaminants of water. It is a pressure-driven membrane process that uses a pressure gradient (between the water to be treated and permeate side) as the driving force to transport water contaminated with nitrate across the membrane in order to filter out nitrate along with other minerals. The operating trans-membrane pressure generally ranges from 20 to 100 bar for RO.

In order to increase the life of membrane in reverse osmosis (RO) process, pre-treatment of contaminated water is essential which is generally achieved by passing it through sand filter, activated carbon filter and micron filter to remove iron, organic matter, excess free chlorine and suspended matter. Limitations of the process are high operational cost, disposal of rejects and substantial quantity of reject water.

### 6.3.5 Electrodialysis

Electrodialysis (ED) is an electrically driven process that uses a voltage potential to drive charged ions through a semi-permeable membrane reducing the nitrate/TDS in source water. The separation is accomplished by alternately placed cation and anion selective parallel membranes across the current path to form an ED cell. The DC voltage potential induces the cations to migrate towards the anode through cationic membrane and the anions to migrate towards the cathode through anionic membrane. The electrodialysis reversal system periodically reverses the polarity of electric field. This is an expensive technique, requires high degree of pre-treatment, skilled labour and disposal or additional treatment of the concentrate (brine).

### 6.3.6 Blending/Dilution of Water

Blending is another method which also reduces nitrates in/from drinking water. In this process, nitrate contaminated water is mixed with clean water (nitrate free water) from another source to lower or dilute overall nitrate concentration of raw (untreated) water.

# 6.4 Nitrate Removal/Treatment Technologies

## 6.4.1 Technology From Ion Exchange India Limited

Ion Exchange India Limited (Figure 6.1) has nitrate removal technologies which include handpump attachments, community systems which have the following salient features:

1. Water treatment capacity (500 – 5000 l/h)
2. Nitrates reduced to less than 45 mg/l
3. Nitrates are adsorbed on the resin
4. Compact and economical system requiring less chemicals and no electricity
5. Only sodium chloride is needed for regeneration

**Figure 6.1:** Nitrate Removal Systems of Ion Exchange India Limited

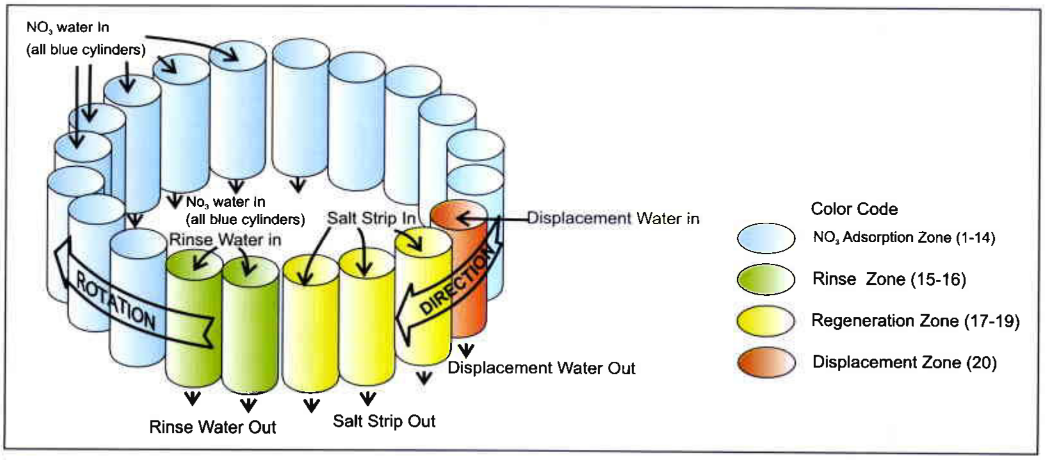
Two nitrate removal systems of 6 m³/hour each were successfully commissioned for NGO CASP (Community Aid & Sponsored Programme) at the community project at Govindpuri, New Delhi, supported by Care India PLUS Project.

**Contact details:**

**Ion House, Dr. E. Moses Road,**
Mahalaxmi, Mumbai-400 011, India
Tel : (91) 22 3989 0909 / 3047 2042
Fax : (91) 22 2493 8737
email : hocro@ionexchange.co.in
ieil@ionexchange.co.in

## 6.4.2 ISEP® Nitrate Removal System

The ISEP® Continuous Ion Exchange produces less waste and claimed to be having simple operation and details of which are shown in Figure 6.2.



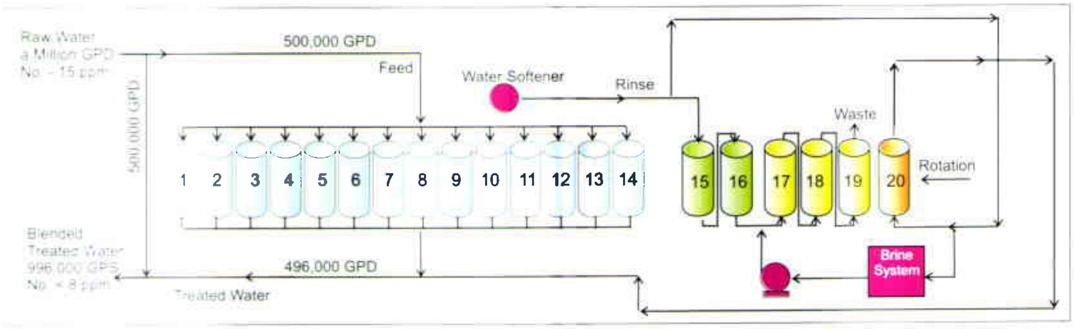


**Figure 6.2:** ISEP® Nitrate Removal System

Raw water is divided into two flows, a by-pass flow and a treated flow, with the blend ratio based on an individual plant water analysis. The flow to be treated is passed through an ISEP® System where nitrates are removed below 2 mg/l as nitrogen.

### Nitrate Adsorption Zone (1-14)

For a 20 port system the adsorption zone (cells 1-14) has 14 ports in parallel for single pass flow where the nitrates will be removed. The zone utilizes 70% of the total resin charge (80% for a 30 port system). In this zone the nitrates and other anions are adsorbed from the feed water onto the resin (Figure 6.2).

### Strip Wash Zone (15-16)

A small amount of pre-softened feed water is used to strip wash cells 15 and 16. The effluent of these ports is then used to dilute the 26% brine solution used for regeneration. This counter current configuration is most effective in preventing salt from regeneration being transferred into the product water. The softening process prevents calcium sulphate precipitating in the resin bed.

### Regeneration Zone (17-19)

The combination brine and strip wash (5-10% NaCl) is directed through cells 17-19 for true counter current regeneration for maximum regeneration efficiency and solids removal from the resin bed.

### Displacement Zone (20)

The displacement zone (cell 20) is set up to ensure that hard water from the feed is displaced using softened city water. This prevents precipitates ($CaCO_3$, etc.) from contaminating the regeneration zone, and forming a scaling layer (Figure 6.2).

### Process Control and Instrumentation

The ISEP® readily adapts to a fully automated system, the heart of which is a small Programmable Logic Controller (PLC)which controls the ISEP® blend ratio and operation of the booster pumps (if required). In most cases an automated perchlorate or nitrate monitoring system is installed at the inlet and outlet to record nitrate levels.

**Contact details:**

**Calgon Carbon Corporation**
500 Calgon Carbon Drive
Pittsburgh, PA15205
Tel 1-800-422-7266Fax 412-787-6713, www.calgoncarbon.com

### 6.4.3 Heterotrophic Denitrification.

This is the most common strategy for drinking water primarily because of its familiarity due to wide scale and successful use in wastewater treatment. Heterotrophs use an organic carbon as the electron donor. In wastewater treatment, the waste provides these carbon feeds and in drinking water treatment, the carbon substrate must be added.

$$6NO_3 + 2CH_3OH \rightarrow 5CO_2 + 3N_2 + 7H_2O + 6OH^-$$

**Autotrophic denitrification using hydrogen gas**

$$NO_3^- + 5H_2 + 2H^+ \rightarrow 2\ N_2 + 6H_2O$$

Or

$$2.5H_2 + NO_3^- \rightarrow 0.5N_2\ (\text{gas-}) + 2H_2O + OH^-$$

Features of this technology are given below:

- High efficiency, low carbon footprint, nitrate removal from groundwater
- Treatment to drinking water standards
- Achieved through Autotrophic denitrification
- Scaleable technology

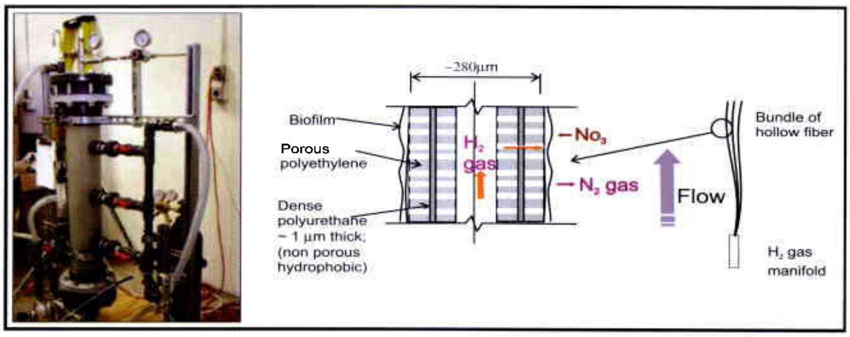


**Figure 6.3:** Advanced Nitrate Reduction Hollow-Fiber Membrane Bio-Reactor

### 6.4.4 MIEX® Treatment Systems

The MIEX® Technology is an advanced magnetic ion exchange process that can be applied to remove nitrate from water supplies. The continuous resin regeneration utilized in the process allows for significant waste reductions over conventional ion exchange treatment and eliminates the occurrence of chromatographic peaking (Figure 6.4).

Pressurized nitrate removal systems are available as packaged units up to 2 MGD (~7.6 MLD) and custom designed systems for all capacities over 2 MGD. Gravity flow systems are also available if it is not necessary to operate the process under pressure. With the lowest waste production of any nitrate removal technology (approximately 0.1-0.3 % of throughput), these systems can provide an environmentally friendly solution to the increasing need for nitrate removal.

**Figure 6.4:** MIEX® Treatment Systems

**Contact:**

www.miexresin.com
Email: miex@orica.com
Asia Pacific 61-3-9665-7111

### 6.4.5 Siemens Nitrate Removal System

In this treatment system perchlorate is first removed using single use ion exchange resin and then nitrate removal with a traditional regenerable ion exchange media. The resin is sluiced in and out of the fixed tanks using a closed process that ensures the cleanliness of the media (Figure 6.5).

**Figure 6.5:** Siemens Nitrate Removal System

**Contact details:**

**Siemens Water Technologies**
2430 Rose Place, Roseville, MN 55113, USA

In addition, membrane filtration, reverse osmosis and electrodylisis are also used for removal of nitrate, details of which are given elsewhere in the document.

## References:

1. Calgon Carbon Corporation, Case history: City of Chino: their road to nitrate removal
2. Gormly S., Borg C., Introducing an Advanced Technology for Sustainable Nitrate Removal for Ground Water Treatment, Applied Process Technology.
3. http://www.ionindia.com/businessunits.html
4. Nitrate Removal with MIEX® Treatment,Application Bulletin,
5. Safe Water Technologies' Nitrate Filter Systems, Water quality association (2008).
6. Schoeman J J (2004) Evaluation of reverse osmosis, ion-exchange and electrodialysis for nitrate-nitrogen removal from borehole water at clinics in the Northern Province. Unpublished report, available from: Japie.schoeman@up.ac.za.
7. Schoeman J. Nitrate-nitrogen removal with small-scale reverse osmosis, electrodialysis and ion-exchange units in rural areas, Water SA (Online) vol.35 no.5 Pretoria Oct. 2009
8. Siemens Water Technologies Corp. (2009) California Water Services Company, Porterville, California
9. http://www.water.siemens.com/SiteCollectionDocuments/Product_Lines/Environmental_Services/Brochures/ES-PORT-PP-0809.pdf

Table 6.1 : Comparative Statement of Technologies available for Treating Nitrate

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ion Exchange India | Ion House, Mumbai | Ion Exchange | | Govindpuri, New Delhi | | Below 45 mg/L | Community | NA | 500 – 5000 L/hr | No | 500 – 5000 L/hr | | NaCl is needed for regeneration | | It's a fully automated system |
| ISEP Nitrate removal system | Calgon Carbon Corporation, Pittsburgh | Ion Exchange | -- | -- | -- | -- | -- | -- | -- | Yes | -- | -- | | Training required | -- |
| Heterotrophic denitrification | | Autotrophic denitrification | -- | -- | -- | -- | -- | -- | -- | Yes | -- | -- | Scalable technology | Training required | Successful used in wastewater treatment |
| MIEX® Treatment Systems | www.miexresin.com Asia pasific | Advanced magnetic ion exchange process | -- | -- | -- | -- | -- | -- | -- | Yes | -- | -- | -- | Training required | These systems can provide an environmentally friendly solution to the increasing need for nitrate removal |
| Siemens Nitrate removal system | Siemens Water Technologies, USA | ion exchange | -- | -- | -- | -- | -- | -- | -- | Yes | -- | -- | Regenerable ion exchange media | Training required | -- |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 7.0 Salinity reduction or Desalination

## 7.1 Introduction

Desalination is a process that removes dissolved minerals (not only limited to salts) from various feed water sources like sea water, brackish water or treated waste-water. There are more than 10000 desalination plants in operation worldwide, of which 60% are located in the Middle East. The world's largest plant in Saudi Arabia produces 128 MGD of desalted water.

In India, various scientific organizations like BARC-Mumbai, CMSCRI-Bhavnagar, BHEL, AMD, NEERI, NIOT, TPL etc., have got various technologies for desalination. About 150 desalination plants have been commissioned in the country by Reverse Osmosis (RO) process, of which, only 77 have been reported to be functional.

Choice of desalination process/technology depends upon a variety of factors and is highly site-specific. These are:

- Salinity of feed water – lower salinity levels like in in-land brackish water could produce higher conversion/product rates.
- Plant capacity – Larger plants reduces the cost per unit product.
- Site conditions – environmental considerations for brine disposal and cost/availability of land for infrastructure
- Qualified labour – some of the technologies require at least semi-skilled and trained labour
- Energy costs – low cost electric system and heating steam have strong impact on unit cost of production
- Availability/easy access to membranes, chemicals and spares
- Operation and maintenance costs and ease in operation
- Provision for enhancement of designed plant capacity

## 7.2 Technologies for Desalination

A number of technologies have been proved while some newer technologies are in the stage of pilot-testing. In general, the techniques used for desalination of water may be classified into three categories depending on the process principle involved. They are

### 7.2.1 Membrane Processes

- Reverse osmosis
- Electrodialysis

### 7.2.2 Distillation Processes

- Multi-Stage Flash Distillation
- Multiple Effect Distillation
- Vapour Compression Distillation

### 7.2.3 Alternative Processes

- Solar Humidification
- Freezing
- Membrane distillation

In India, under rural water supply programme, only reverse osmosis based desalination plants have only been set-up due to its inherent lower capital cost when compared to other technologies.

## 7.3 Membrane Processes

### 7.3.1 Reverse Osmosis

Reverse osmosis (RO) is currently one of the fastest growing techniques for the desalination of different types of water. In RO, the feed water is pumped at high pressure through permeable membranes, separating salts from the water. The feed water has to be pretreated to remove bio-fouling and scaling. The quality of water produced depends upon the pressure, the concentration of salts in the feed water and salt permeation constant of the membranes. Product water quality can be improved by adding a second pass of membranes. Multi-media filters to remove sand sediments down to 20 µm size, activated carbon filters to remove excess chlorine, 5 µm size prefiltration systems, sodium metasulphate for removing excess chlorine residuals, acid/anti-scalant dosing systems are available in the market, and need to be considered on case specific basis, before RO system is chosen for desalination. 10 m$^3$ to 50 m$^3$ per day plants have been installed in India. World wise, RO plants of capacities ranging from 100 m$^3$ to 94, 625 m$^3$/day plants have been commissioned. The product water from RO plants have TDS levels ranging between 30 to 500 mg/L. The conversion rate of product water from feed-water varies between 30-50 %, depending upon various factors. The cost of production of pure water is about 20 to 30 paise per litre of water produced in smaller plants (less than 100 m$^3$ per day capacities) to only 3 paise per litre in case of large RO plants, as per information available world-wide.

### 7.3.2 Electrodialysis

Electrodialysis is an electro-membrane process in which transport of ions present in contaminated or blackish is accelerated due to an electric potential difference applied externally. An electrodialysis cell consists of a large number of narrow compartments through which the feed water for desalination is pumped. These compartments are separated by alternative placed cation and anion selective membranes in a parallel fashion across the current path to form an ED cell. Using a DC electrical field, cations and anions migrate through the appropriate membranes, forming compartments of electrolyte enriched waste water and electrolyte depleted product water.

Non-ionic particulates, bacteria and residual turbidity may also pass through the cells with the product water and therefore, this may require further treatment to achieve the desired product water standards.

The scaling and fouling problem in basic electrodialysis unit has been overcome by recent advancements to the ED technology in the form of Electrodialysis Reversal (EDR) have occurred. The EDR process involves a reversal of the water flow in order to break up and flush out scales, slimes and other foulants deposited in the cells before they can build up and create major fouling problems. This flushing also allows the electrodialysis unit to operate with fewer pretreatment chemicals, hence minimizing costs.

The ED/EDR process is usually only suitable for brackish feed waters with a salinity of up to 12,000 mg/L TDS. With higher salinities the process rapidly becomes more costly than other desalination processes. This is because the consumption of power is directly proportional to the salinity of the water to be treated. As a rule of thumb, approximately 1kWH is required to extract 1 Kg additional salt using ED/EDR.

## 7.4 Distillation Processes

Distillation is one of the oldest and most commonly used methods of water desalination. Distillation is basically a phase separation method whereby saline water is heated to produce water vapour which is then condensed to produce potable or fresh water. The world's first land-based water desalination plant, a multiple-effect distillation (MED) process plant with a capacity of 60 $m^3$/day was installed at Curacao, Netherlands Antilles, in 1928. Further, commercial development of land based seawater distillation units took place during the late 1950. Distillation processes such as Multistage-flash (MSF), MED and vapour compression (VC) have led to the widespread use of distillation to desalinate seawater.

### 7.4.1 Single/Multi-Stage Flash Distillation (SSF/MSF)

Multistage flash distillation is still the most commonly used technique, particularly where energy is still not an issue or inexpensive. In MSF plant, a stream of heated brine flows through a vessel consists of 40 chambers, or stages, each operating at a slightly lower pressure than the previous one. As the brine enters each chamber or stage, a portion of it "flashes" into steam and is then condensed to produce a pure distillate. The concentrated brine remaining at the end of the process is rejected as blow down. MSF operating temperatures range from 100° to 110°C and they produce 6.0 to 11.0 kilograms of distillate per kilogram of steam applied. Depending upon the number of flashes, the process could be termed as SSF or MSF. Smaller systems could be designed on SSF technology with scaling of production invites MSF for economics. The unit cost of production varies between 3.5 paise per litre to 8.3 paise per litre of water/ distillate produced.

### 7.4.2 Multi-Effect Evaporation (MEE)/Multi-Effect Distillation (MED)

Multi-effect distillation has a greater potential as an evaporation technique. It is also similar to condensation but requires a heating device like a boiler or waste heat from any other sources like thermal plants etc., Steam extracted from low and medium pressure turbines provides the heat necessary for evaporation. MEE operates with top-brine temperature of 64 - 70°C. The unit cost of production of MEE systems varies from 3.9 paise to 8.9 paise per litre of water/distillate produced.

### 7.4.3 Vapour Compression Desalination (VCD)

VCD is a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapour. Since, compression of the vapour enhances or increases both the pressure and temperature of the vapour, it is possible to use the latent heat rejected during condensation to generate additional vapour. The effect of compressing water vapour can be done by two methods as given below:

- **Thermal vapour compression (TVC)**

The process of condensation is similar to other distillation processes except that requirement of steam is a pre-requisite for the system. TVC has been clubbed with MEE system for large scale plants for better economies. The unit cost of production of distillate/water is 5.9 paise per litre, as per information available.

- **Mechanical Vapour Compression (MVC)**

The mechanical vapour compression process uses mechanical energy rather than direct heat as a source of thermal energy. Moreover, it is distinguished from other distillation processes by the presence of a mechanical vapour compressor, which compresses the vapour formed within the evaporator to the desired pressure and temperature. The system also includes plate heat exchangers for pre-heating the feed-water using heat exchangers from the brine blow-down and the distillate product. This system is also based on evaporating effect like MEE. This is a good technology and can be adopted for capacities ranging from 100 $m^3$/day to about 20,000 $m^3$/day or more. The cost of production is slightly higher at 22.5 paise per litre of distillate/water produced in case of 100 $m^3$/day to only 2.07 paise per litre of distillate /water produced in case of 20,000 $m^3$/day plant. This technology is often used at resorts and industrial sites.

### 7.4.4 Low Cost Vertical Tube Evaporators (VTE)

VTE technology has been devised on a pilot scale by IIT – Delhi. This is basically a MEE technology but synthesized for smaller applications, specifically the rural sector of India. The principle involved is the recycling of latent heat of condensation/vaporizations of water in successive efforts so as to achieve a good performance ratio. An LPG boiler is used for heating the feed water and with a 6 – effect VTE, the unit cost of production of distillate/water is found to be 30 – 40 paise per litre of water produced at the laboratory conditions. The cost is expected to be around 10 paise per litre of water produced, if bio-mass gassifiers are used in the field. This technology again is site specific and depends upon available of *Prosophis juliflora* and *Acacia auriculiformis*, which are generally the bio-mass used for heating in the boilers. The 6-effect VTE at the laboratory conditions produced 2000 litres per day of product-water with TDS of 10 mg/L. The cost of the plant was reported to be about Rs. 56,000 only.

## 7.5 Alternative Processes

### 7.5.1 Solar Humidification/Solar Stills

Solar energy is one of the most promising applications of renewable energies to seawater desalination. Solar still is basically a large scale shallow water pond if saline water (about 10 cm deep) spread over a large surface area and covered with glass over. The natural sunlight is used for evaporating the saline water and the condensed vapour is collected from the glass-case. Though, the operation and maintenance cost of such plants is near zero and that no power is required, the system is capital cost intensive when compared with the product recovery rate and the cost of land required.

In principle, well-managed and maintained solar stills require a solar collection area of about one square metre to produce up to six litres of fresh water per day, but on average usually return 3L/$m^2$/day. Thus, for an 800L/day facility, land area ranging from 130 – 260 $m^2$ would be required depending on efficiency. The main advantage of this process is its relative simplicity to operate and service and obviously its ability to use renewable energy source such as sunlight makes it an economical option for producing potable (fresh water) from various feedwater sources like sea water, brackish water or treated wastewater.

### 7.5.2 Freezing Desalination

This process is based on the fact that dissolved salts are naturally excluded during the formation of ice crystals. In order to desalinate saline water using this method, the non-frozen saline component is removed at the appropriate time in the freezing process, and the frozen (fresh) water is washed and rinsed to remove any of the remaining salts adhering to the ice crystals. The ice is then melted to produce fresh product water.

There have been a small number of plants developed and constructed over the past 40 years; however, the process has not been commercially developed in the production of potable water for community purposes. At this stage, freezing desalination technology still has a better application in the treatment of industrial wastes rather than in the production of municipal water.

Freeze desalination theoretically has some advantages over distillation methods such as lower theoretical energy requirement, minimal potential for corrosion, and little scaling or precipitation.

### 7.5.3 Membrane Distillation

Membrane distillation is a relatively new process which has been introduced commercially only in the last few years. It uses a specialized membrane which passes water vapour only but not liquid water. This membrane is placed over a moving stream of warm water, and as the water vapour passes through the membrane it is condensed on a second surface which is at a lower temperature than that of the feed water.

## 7.6 Inquest of Integrated Approach (Hybrid Systems)

Selection of desalination technology should therefore be considered on case to case basis, on factors described above. Ideal solution for providing safe drinking water in brackish saline affected habitations is an integrated approach of RO/distillation plant duly augmented by roof-top rainwater harvesting/surface water based rain water harvesting structures. Wherever waste heat is available in abundance from thermal power generation plants located on the seashore/brackish areas, suitable process of distillation could be adopted to achieve economies of scale. Co-generation activities like power generation (captive power plant, reducing energy consumption etc.,) could be thought of, for overall financial sustainability of the plant. Wherever alternate sustained availability of surface/ground water is available, this system of providing safe drinking water could be provided to salinity affected habitations, duly considering the economies of operation with technology based solutions.

**Salient features of Desalination Technologies developed by various Research Organizations and other Private Industries available in the market.**

## 7.7 Commissioning of Low Temperature Thermal Desalination Plant (LTTD)

### 7.7.1 Plant at Kavaratti

Experimental studies in USA and Japan were conducted to prove the ocean temperature driven desalination technology. A spray flash evaporation system was tested at Saga University, Japan. A 10 m$^3$/day plant is under experimentation at Institute of Ocean Energy, Japan. Natural Energy Laboratory tested an open cycle OTEC plant with fresh water and power production using ocean temperature difference of 20°C between the warm surface water and deep-sea water, in 1992 at Hawaii islands. It was operational for 5 years and decommissioned a 25 tonnes per hour desalination plant operating between 28 - 20°C in 1992, which has completed nearly 10 years of commercial production.

National Institute of Ocean Technology (NIOT), Chennai, under the Department of Ocean Development (DoD) had set up an experimental model of 5000 litres per day capacity using LTTD technology. It was proved that 1% of warm feed water can be converted to fresh water under the conditions of 10–20°C temperature difference. A pilot plant was also set up on a barge up the high seas off Tuticorin by NIOT and found the results encouraging. Therefore, NIOT had taken an R & D project for commissioning a 100 $m^3$/day plant at Kavaratti at an estimated cost of Rs. 5 crore.

### Technology of LLTD

The technology basically envisages taking the 15°C temperature difference between the warm surface sea water and the deep-sea cold water. Bathometry studies were done by NIOT to establish the thermocline variations off the coast of Kavaratti island of Lakshadweep, in 2003. Preliminary design was completed by NIOT in consultation with BARC, Mumbai in September 2003. Cold water from 330m depth was envisaged to be brought through a 660 m HDPE pipeline. Off the shore to about 300m, a well was constructed where the surface water and deep–sea cold water are being pumped to the plant located on the shore. The well was connected by a trussle bridge. The warm water was then subjected to low pressure by a vacuum pump and is flashed. The vapour was then subjected to a condenser where deep sea cold water runs through. The condensed water on the outer surface of the cold water pipes is tapped as the distillate water. About 1.02% recovery was observed at the plant site and the total production of water 1,02,000 litres on 27/10/2005. Electrochlorination unit is also available to avoid biofouling, though the same is not anticipated. The warm water and cold water were then discharged from plant at the shore. Fresh water generation is upto 1.2 lakh litres per day and total cost of production is 18.2 paise per litre.

## 7.7.2 Desalination Unit Developed at BARC

The process involves preparation of a membrane casting solution consisting of basic polymer, selected additive and solvent, and then coating of a polymeric film from this solution on a porous support by phase inversion process. Rest of the things is simple assembly of this membrane filter in appropriate housing etc. All the raw materials like polysulfone polymers, additives and solvents are produced within the country and are available in local market.

A small room with window air-conditioner/ dehumidifier is needed to coat ultrafiltration membrane unit. All the steps in the presented technology are manual in nature and hence do not require electrical power for process. Constant source of water is needed to produce and test the membrane device. Single unit capacity varies from 1000-7000 LPD depending on dimensions and cost is Rs. 6000 – 40,000 depending upon size.

**Figure 7.1 :** Demonstration Unit developed at BARC

**Contact details:**

**Head, Technology Transfer & Collaboration Division,**
Bhabha Atomic Research Centre,
Trombay, Mumbai - 400 085.
Fax: +91-22-25505151/25519613
Phone: +91-22-25593897
E-mail: headttcd@barc.gov.in

### 7.7.3 Membrane Reverse Osmosis and Microfiltration

The GeoPure treatment process is a combination of pre-treatment, microfiltration, and RO. These three treatment steps are operated in series to treat produced water compositions and generate clean water stream that can then be discharged or reused. This technology was specifically developed for the desalination of oil and gas produced waters. Depending on the quality of the feed water, the process implements various pretreatment processes to remove dispersed oil, suspended solids, or dissolved hydrocarbons. The pretreated water is then further purified with polymeric microfiltration and RO. To increase RO efficiency, the microfiltration step filters out suspended solids prior to final RO treatment. Feed Capacity is 5,000 bpd and cost is $0.94 Bbl (based on costs reported for Barnett Shale study).

**Contact details:**

**GeoPure Hydrotechnologies**
777 Main Street, Suite 600, Fort Worth, Texas 76102
817-887-8452
www.geopurewt.com

### 7.7.4 Siemens Water Technologies

Siemens Water Technologies developed an automatic blending valve purposely to blend the RO permeate with the well water to meet the desired water quality. The FlexRO unit is a portable, skid mounted, self-contained unit that provides a flow rate of 100 gpm and is ideal for temporary use. A Mobile Reverse Osmosis system from Siemens Water Technologies provides temporary treatment for nitrate removal and TDS reduction Siemens Water Technologies delivers cost-effective, reliable systems guaranteed for quality, safety, and compliance.

**Figure 7.2:** Siemens Water Technologies

**Contact details:**

181 Thorn Hill Road,
Warrendale, PA 15086-7527
337-837-3071
http://www.water.siemens.com/en/Pages/default.aspx

### 7.7.5 TERI - Solar Desalination Unit

Desalination processes have been used for many a decade but its high energy requirement and, therefore, their prohibitive costs have prevented their widespread adoption across countries. Researchers at TERI have found an innovative way to bypass the limitations of conventional desalination technology and solve the acute water scarcity problem of both urban and rural areas with a solar desalination unit. Designed in collaboration with the SEC (Solar Energy Centre) of the Ministry of Non-conventional Energy Sources, this desalination unit is the first of its kind in the country and the current prototype has been specifically designed to cater to the needs of remote, rural households. The prototype has already been tried and tested at the Solar Energy Centre and the results have been more than promising.

TERI's current solar desalination unit consists of 10 flat-plate solar collectors, 4 trays that hold brackish water and an efficient and compact heat exchanger in the bottom tray (Figure 7.3).

The unit is designed to deliver 100 litres of water, translating to 42% more output vis-à-vis the commercially available single-basin solar still.

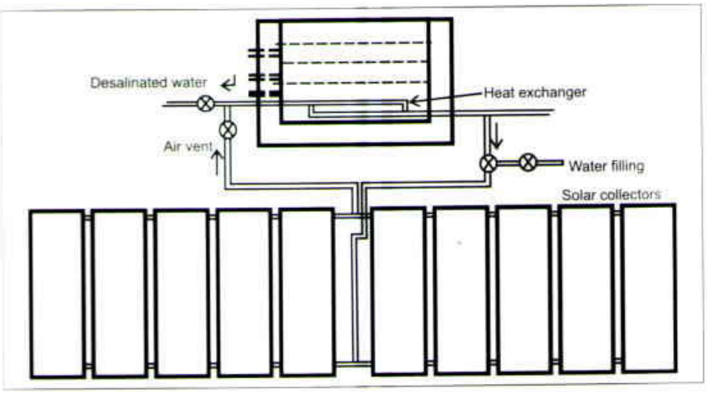


**Figure 7.3:** Schematic Assembly Arrangement of TERI's Solar Desalination Unit

**Figure 7.4:** Flat-plate-collector-based solar desalination system installed at the Solar Energy Centre, Gual Pahari, Gurgaon

Economic analysis establishes that the annual cost of desalinated water from the TERI-SEC prototype desalination system is less than that from a solar still. This cost-effective medium is a positive step towards providing fresh water to those condemned to drink saline water.

**Contact details:**

**The Energy and Resources Institute**
Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi - 110 003, INDIA
Tel. (+91 11) 2468 2100 and 41504900
Fax (+91 11) 2468 2144 and 2468 2145
For general inquires contact
mailbox@teri.res.in

### 7.7.6 Dolphin Desalinators

Dolphin Desalinators offers large capacity desalination units under rental agreements. We have a range of portable units and generators for rent, all with production capacities from 50 tonne per day.

These units are usually supplied for emergency short to mid-term water supply during dry season or equipment maintenance periods. Rental units are freighted to your location and our staffs commission the unit and train the designated operators of the unit on operation and maintenance procedures.

**Contact details:**

**Dolphin Desalinators**
18 Dividend Street
Mansfield Qld 4122
Phone:07 3347 1600 (Intl: +617 3347 1600)
Fax: 07 3219 2266 (Intl: +617 3219 2266)

### 7.7.7 Desalination Techniques Developed by US Researchers

A device that can 'push' the salt out of seawater has been developed by US researchers. Efficient enough to be powered by sunlight, the process could lead to small-scale or portable desalination devices that could provide vital drinking water in disaster zones or areas of severe drought. Using modern semi-permeable membranes to convert seawater into fresh water is increasingly popular as a solution to global water shortages. Two common techniques are reverse osmosis, where seawater is forced through a sieve-like membrane to filter out salt and electrodialysis, which uses electrical current to pull salt ions through a membrane.

But in both cases, organic matter and salt accumulate on the membranes and clog up the system. Now, an alternative technique has been developed, which overcomes this problem but remains highly energy-efficient. When a voltage is applied across a small membrane made from an ion-selective material such as Nafion, something unusual happens. On one side of the membrane, charged particles are repelled - and on the other side, they are collected.

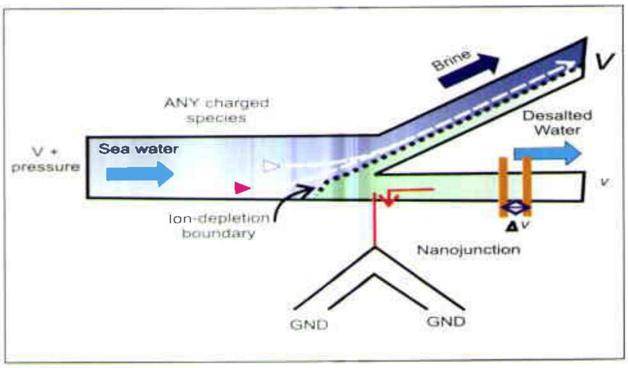


**Figure 7.5:** Salt and other Charged Particles are diverted off, Leaving Desalted Water to Flow down a Separate Channel

Han's team developed a microchip-sized device that funnels a stream of water down to a fork and splits into two channels. The entrance to one channel is covered with a charged Nafion membrane, which shields the water flowing down it and pushes any salt down the other channel. Crucially, the shield also repels other charged particles, both positive and negative, which includes most organic matter and microorganisms, such as bacteria, viruses and other contaminants.

But to function effectively the process requires very small water channels and these can only produce tiny amounts of water on their own. There can be number of water channels on a single chip the goal is to make systems that can produce around a litre of purified water over ten minutes. Although this is a relatively small amount, it may be possible to run the device continually for a long time using solar power, which could be extremely valuable in areas of critical water shortage. However more work is needed as there are some problems to overcome. Gold and titanium electrodes are currently used, so finding cheaper or alternative materials is needed to scale the technology up into devices. Also, some non-charged particles may cause fouling of the membrane so a system of pre-treatment may be required.

### 7.7.8 A&M mobile desalination unit

The A&M mobile desalination unit was constructed to test both pre-treatment by membranes and RO desalination at field sites. Different types of membranes are tested and RO salt rejection efficiency can be determined directly. It is equipped to run either single stage or multi-stage membrane treatments and can be configured either for parallel or series membrane flows. The unit is shown in Figure 7.6 in Washington County, Texas in 2006.

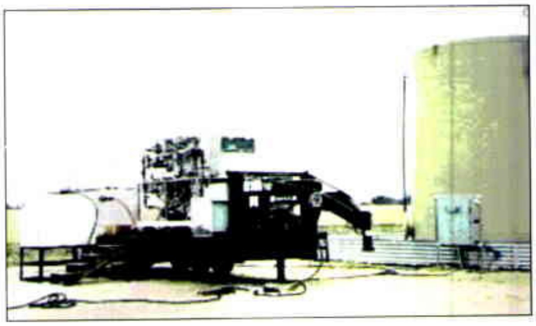


**Figure 7.6:** A&M Mobile Desalination Unit

In addition to testing the capability of different types of membranes, the unit has power transformers to utilize oil field power and an electrical meter to measure power consumption, one of the most cost factors in desalination. The cost of desalination is directly related to the power used to pump brine past the filters. As salinity increases, power consumption rises. Data from four different field sites are given for comparison, collected on four types of saline feed brines.

In Texas, the three proposed desalination facilities on the Gulf Coast have cost estimates ranging from $3.58 to $4.23 per 1,000 gallons.

**Contact details:**

**David Burnett,**
**Global Petroleum Research Institute (GPRI)**
Department of Petroleum Engineering
Carl Vavra,
Institute of Food Science & Engineering Bill Fox,
Texas Water Resources Institute (TWRI)
Texas A&M University
979 845 2274
burnett@pe.tamu.edu http://www.gpri.

## References:

1. Squire, D., Murner, J., Holden, P., Fitzpatrick, C. (1996), "Disposal of reverse osmosis membrane concentrates". Desalination, 17 (1996) 165-175.
2. www.oas.org/used/publications/unit/oea59e/ch20. Desalination by Reverse Osmosis
3. Schonfeldt, C. (2000), "Future Water Resources for South Australia". Focus. No. 11, Mar/Apr. the Australian Academy of Technological Sciences and Engineering.
4. T.M. Pankratz, Advances in desalination technology, International Journal of nuclear desalination, Vol.1 (2005), 450 – 455.
5. O.K. Buros, et al., The USAID Desalination Manual. Englewood, New Jersey, U.S.A. IDEA Publications, 1982.
6. Kunze, H. "A new approach to solar desalination fro small and medium size use in remote areas", Desalination 139 (2001) 35-41.
7. Buros, O.K. The ABC's of desalting. Second Edition. Produced by the Saline Water Conversion Council for The International Desalination Association, Riyadh, Saudi Arabia.
8. Lourdes Garcia-Rodriduez, Seawater desalination driven by renewable energies: A review, Desalination 143 (2002) 103 – 113.
9. Water Corporation, Desalination: A Viable Resource. A Strategic review of desalination Possibilities for Western Australia. September.
10. Pers. Comm., Neil Wends, Operations Manager, Occtech Engineering Pvt. Ltd.
11. Buros, O.K. et al. 1982. The USAID Desalination Manual, Englewood, N.J. IDEA Publications (Reprint; originally USAID/CH2M Hill International Corporation).
12. Curacao Eilandgebied. 1991. Alvalwaterstructuurplan Samenvatting. Willemstad, Curacao.
13. Desalination & Water Reuse. 1995. "Water Costs From the Seawater Desalting Plants at the US Virgin Islands," 2 (2), pp. 25 – 31.
14. Eisden, R.L. 1981. Awa I Electricidad pa Curacao. Prome edition. Willemstad, Curacao.
15. UN. 1985. Non-Conventional 'Water resource Use in Developing Countries. Report on an Inter-Regional Seminar in Willemstad, Curacao. New York. (United Nations Report No. TCD/SEM.85/2-INT-84-R29).
16. Brindley Lewis, Drinking water from sunlight and seawater, 2010
17. S J Kim *et al, Nature Nanotechnology,* DOI: 10.1038/NNANO.2010.34
18. http://www.rsc.org/chemistryworld/News/2010/March/21031002.asp
19. Jacqueline Ribiero, Irving Spiewak, (1998) "Desalination Research Priorities: a European Survey" Institute For Prospective Technological Studies, Seville
20. http://www.barc.gov.in

**Table 7.1 :** Comparative Statement of Technologies available for Desalinition

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. Of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/ No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OTEC Desalination plant | Natural Energy Laboratory | Ocean thermal energy conversion (OTEC using ocean temperature difference of 20°C between the warm surface water and deep-sea water) | Tested in laboratory and field | Hawaii islands | -- | -- | Communiy |  | -- | Yes | 25 tonnes/ hr | -- | -- | Training required | -- |
| LTTD Desalination model | National Institute of Ocean Technology (NIOT), Chennai | Low-temperature thermal desalination | Tested in laboratory and installation at field is proposed at Kavaratti | Proposed at Karavatti | -- | -- | -- | NA | Estimated cost is Rs. 5 crores for 100 m3/hr | Yes | 5000 litres per day | Rs. .18 per liter | -- | Training required | -- |
| Membrane based Desalination unit | Bhabha Atomic Research centre (BARC), Mumbai | Polymeric membrane prepared by basic polymer, selected additive and solvent and then coating of a polymeric film from this solution on a porous support by phase inversion process | Tested in laboratory and field | -- | -- | -- | Communiy | Yes | Rs. 6000-40000 for 1000-7000 LPD | No | 40-280 liter/hr | -- | -- | Training required | -- |
| GeoPure | GeoPure Hydrotechnologies | pre-treatment, microfiltration, and RO | Tested in laboratory and field | Bangladesh, India and Nepal. | Upto 3000 ppb | Below 10 ppb | Domestic | No | 578 m3/day | Yes | 48 m3/ hour | -- | Yes | Training required | -- |
| FlexRO | Siemens Water Technologies | Reverse Osmosis | Tested in laboratory and field | -- | -- | -- | Community | No | -- | Yes | 23 m3/hr | -- | Reject water | Not required | -- |
| Solar desalination unit | The Energy and Resources Institute | evaporating water by heat exchange, condensing and collecting pure water | Tested in laboratory and field | Solar Energy Centre, Gurgaon | -- | -- | Domestic | -- | -- | No | 100 liter/ batch | -- | Yes | Training required | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. Of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lr of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dolphin Desalinators | Dolphin Desalinators | Desalination technology | Tested in laboratory and field | | | | Community | NA | 50 Tonne/day | Yes | | | Yes | Training required | |
| Desalination | Massachusetts Institute of Technology | Ion concentration polarisation to "push" the salt out of seawater | Tested in laboratory and field | NA | | | | Yes | | Yes | | | | Training required | |
| TEAM | Membrane Technologies Ltd. | Reverse osmosis having stages prefiltration, coagulation, biogrowth control and membrane regeneration | Tested in laboratory and field | Marina Beach, chennai | -- | -- | community | NA | 50,000 litres/day | Yes | -- | -- | Yes | Training required | 140 desalination plants to be installed nationwide under National drinking water mission |
| Reverse osmosis (RO) Plant | -- | The feed water is pumped at high pressure through permeable membranes, separating salts from the water | Tested in laboratory and field | -- | | 30 to 500 mg/l. | Community | NA | 100 m3 to 94,625 m3/day | Yes | -- | 20 to 30 paise per litre | -- | Training required | |
| Single/Multi-stage flash distillation (SSF/MSF) | -- | This system are equipped with condenser tube bundles to pre-heat the brine recycle system. | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3.47 paise per litre to 8.28 paise per litre | -- | Training required | Smaller systems could be designed on SSF technology with scaling of production invites MSF for economies. |
| Multi-effect evaporation (MEE) | -- | MEE is also a similar process of condensation but requires a heating device like a boiler or waste-heat from any other sources like thermal plants | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3.92 paise to 8.78 paise per litre | -- | Training required | -- |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. Of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/ No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mechanical Vapour Compression (MVC) | -- | The presence of a mechanical vapour compressor., which compresses the vapour formed within the evaporator to the desired pressure and temperature | -- | -- | -- | -- | -- | -- | 22.5 paise / litre for 100 m3/day & 2.07 paise / litre 20,000 m3/day plant. |  | 100 m3/ day to about 20,000 m3/day | -- | -- | Training required | -- |
| Solar Stills | Solar still is basically a large scale shallow water pond of saline water (about 10cm deep) spread over a large surface area and covered with glass cover. The natural sunlight is used for evaporating the saline water and the condensed vapour is collected from the glass-case. | -- | -- | -- | -- | -- | -- | -- | -- | No | -- | Nearly zero | -- | Not required | the system is capital-cost intensive when compared with the product recovery rate and the cost of land required |

| Name | Technology Supplier | Principle behind Technology | Whether field tested? When and for what period | Whether field tested and results | Max. Conc. Of contaminant treated | Conc. Level after treatment | Domestic or community level size | If domestic can it be upgrated to community level? | Capital cost, capacity etc. | Electricity needs (Yes/No) | Production (Litres/hr) | Cost of treated water (rs. Per Lt of treated water) | Whether techn. Generate sludge? | Training required to operate | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low cost vertical Tube Evaporator (VTE) | IIT Delhi | the recycling of latent heat of condensation/ vaporizations of water in successive efforts so as to achieve a good performance ratio | Tested in laboratory and field | | | 10 mg/l | | | | | | 30 - 40 paise per litre | | Training required | This tech again is site specific and depends upon available of Prosophis juliflora and Acacia auriculiformis, which are generally the bio-mass used for heating in the boilers. |
| Thermal vapor compression (TVC) | | distaillation processes | -- | -- | -- | -- | -- | -- | -- | -- | -- | 5.9 paise per litre | -- | Training required | -- |
| Thermocline desalination | | SSF technology | | Kavaratti island | -- | -- | -- | -- | -- | -- | -- | -- | -- | Training required | -- |

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 8.0 Chromium Removal from Water and Wastewater

## 8.1 Introduction

Chromium is the seventh most abundant element on the earth and twenty first in the crustal rocks. Chromium abundance in Earth's crust ranges from 100 to 300 µg/g. Soils may contain between 5 and 3000 µg/g. The world production of chromium is in the order of 107 tons per year; 60 – 70 % is used in alloys, including stainless steel and 15% is used in chemical industrial processes mainly leather tanning, pigments and electroplating. Its widespread use has converted chromium into a serious pollutant of air, water and soil. Chromium can be introduced into natural waters either by natural weathering of chromite ore and other chromium bearing minerals present in bedrock and soils or mostly widely by contamination from several of industrial wastewaters sources. Chromium is a steel-gray, lustrous, hard metal that takes a high polish and has a high melting point. Chromium is able to exist in several oxidation states, the most stable and common forms are the trivalent Cr (III) and hexavalent Cr (VI) species which display quite different chemical properties. Chromium (VI), considered the most toxic form of chromium, is usually associated with oxygen as chromate ($CrO_4^{-2}$) or dichromate ($Cr_2O_7^{-2}$) ions while chromium (III) in the form of oxides, hydroxides or sulphates, is much less mobile exists mostly bound to organic matter in soil and aquatic environments.

Chromium (VI) is mobile in the environment and also highly toxic, carcinogenic and mutagenic to living organisms. It can easily penetrate the cell wall and exert its noxious influence in the cell itself, being also a source of various cancer diseases.

On the other hand, chromium (III) is less toxic than Cr (VI) and also due to the fact that it has limited hydroxide solubility, it is less mobile and less bioavailable. It is listed as an essential element, as micronutrient to maintain good health and helps in maintaining the normal metabolism of glucose, cholesterol, and fat in human bodies although in excess it can cause allergic skin reactions and cancer.

## 8.2 Health Effects of Chromium

The health effects associated with exposure to chromium are dependent on its oxidation state [i.e. whether it is chromium (III) or chromium (VI)].

### 8.2.1 Chromium (III)

Chromium (III) is an essential nutrient for humans and shortages may cause heart conditions, disruptions of metabolisms and diabetes. But the uptake of too much chromium (III) can cause health effects as well, for instance skin rashes.

### 8.2.2 Chromium (VI)

Chromium (VI) dangerous to human heath and is known to cause various health effects as listed below:

#### 8.2.2.1 Short term

EPA has found chromium to potentially cause the following health effects when people are exposed to it above the Maximum Contamination Level (MCL) for relatively short periods of time: Skin irritation or ulceration

### 8.2.2.2 Long term

Chromium has the potential to cause the following effects from a lifetime exposure at levels above the Maximum Contamination Level (MCL): Damage to liver, kidney, circulatory and nerve tissues, skin Irritation, Lung cancer, respiratory problems etc.,

## 8.3 Standards and Guidelines

The following agencies have set the standard and guideline values and the maximum permissible limit of total chromium in drinking water are shown below in Table: 1

**Table 8.1**
**Standard and guideline values of total chromium in drinking water**

| S.No | Agencies | Maximum permissible limit (mg/L) | Reference |
|---|---|---|---|
| 01. | World Health Organisation (WHO) | 0.05 | WHO (2006) |
| 02. | Environmental Protection Agency, United States of America (USEPA) | 0.10 | USEPA (1987) |
| 03. | European Community (EC) | 0.05 | Schippers et al., (2004) |
| 04. | Bureau of Indian Standards (BIS) | 0.05 | M. Jain et al., (2009) |

According to Minimum National Standards given by Central Pollution Control Board, India, the permissible limit for chromium (VI) for discharge of industrial effluents in different water bodies namely, Inland surface water, Public sewers and marine coastal areas is 0.1, 2.0 and 1.0 mg/L, respectively.

## 8.4 Reduction of toxicity:

Reduction of chromium (VI) to chromium (III) is relatively easy to accomplish. It involves providing a source of electrons (reductant) so that Cr (VI) can be reduced to chromium (III). Potential reductants include stannous chloride, ferrous compounds etc., Literature reveals that reductants such as stannous chloride and ferrous iron are the most effective reductants for treating chromium (VI) in drinking water. The chromium (VI) reduction reactions involving ferrous iron and stannous chloride are given below in equations 1 and 2.

Ferrous iron

$$3\ Fe\ (OH)_2 + CrO_4^{2-} + 4\ H_2O \rightarrow 3\ Fe\ (OH)_3 + Cr\ (OH)_3 + 2\ OH^- \qquad \text{.............}(1)$$

Stannous chloride

$$2H^+ + 3/2\ Sn\ (OH)_2 + CrO_4^{2-} + 4H_2O \rightarrow 3/2\ SnO_2 + Cr\ (OH)_3 + H_2O \qquad \text{.......}\ (2)$$

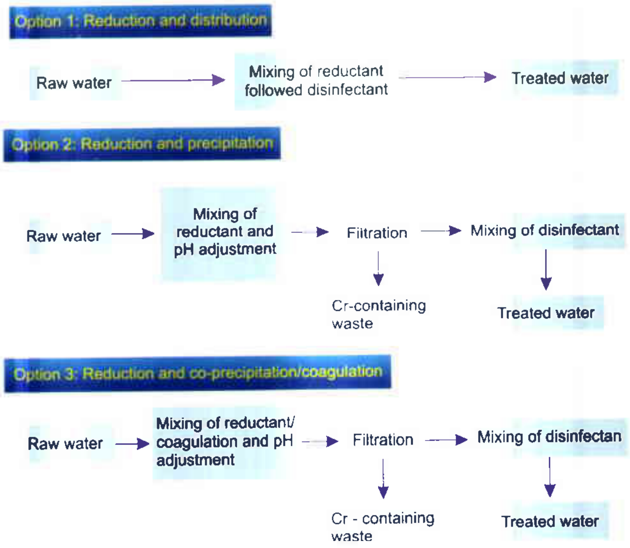


**Fig. 8.1:** Treatment options involving the reduction of chromium (VI) to chromium (III)

The kinetics of stannous chloride reaction appears to be faster than that of the ferrous iron reaction, and therefore, smaller doses of stannous chloride are required to complete the reduction reaction compared with ferrous iron.

After reduction, at moderate pHs, chromium (III) precipitates as insoluble Cr $(OH)_3$. Insoluble Cr $(OH)_3$ may be removed from treated water by filtration. Coagulation or co precipitation with ferric hydroxides will increase the apparent size of Cr $(OH)_3$ precipitates. , making them more amenable to removal by filtration.

## 8.5 Methods of Chromium Removal

Contamination of groundwater by chromium at numerous localities mostly results due to the uncontrolled or accidental releases of chromium containing solutions, used in various industrial applications. Chromium in such solutions mostly occurs as oxyacids and oxyanions of chromium (VI). In this oxidation state, chromium is highly soluble, mobile and toxic. Chromium removal from contaminated groundwater remains an important issue because of the carcinogenic characters of various chromium compounds.

A wide range of treatment methods are available for the removal of chromium from water and wastewater. Conventional treatment methods which use chemical coagulation and precipitation are less effective for removal of chromium (VI) from water. Advanced treatment methods are effective for the removal of Chromium (III) and chromium (VI). The following treatment methods are used for the removal of chromium from drinking water.

### 8.5.1 Coagulation and Flocculation

Literature reveals that removal of chromium (III) by conventional coagulation and flocculation process followed by filtration varies greatly according to the nature of water source and the coagulant used. Chromium (VI), however, is not removed by conventional treatment processes using alum or ferric sulphate as coagulants because the chromate and dichromate ions are extremely soluble. Effective removal by hydroxide precipitation requires that the chromium (VI) is first is reduced to Cr (III) using a chemical reducing agent such as ferrous sulphate, stannous chloride etc., Principally, the coagulation destabilizes colloidal particles by adding a coagulant and results in sedimentation. To increase the particle size, coagulation is followed by flocculation of the unstable particles into bulky floccules. In coagulation, alum and ferric iron coagulants has been used for the chromium (III) removal which is due to the precipitation as Cr $(OH)_3$ (s) and co-precipitation with $Al(OH)_3$ or $Fe(OH)_3$.

The aluminium sulphate $[Al_2(SO_4)_3]$ is a most effective coagulant for the removal of insoluble chromium. The filtration provides the final removal of the chromium by dual media filtering of all flocs and suspended solids.

The merits and demerits of the coagulation and filtration method are as follow:

**Merits**

- Economically viable
- Lowest overall operation and maintenance cost
- Less pre-treatment requirement
- Effective for chromium (III) removal

**Demerits**

- Chemical dosing requires skilled operator
- Removal of the microflocs formed is often difficult and critical for the process efficiency
- Generation of high sludge volume

### 8.5.2 Chemical precipitation

The oldest and most frequently used method for the removal of chromium (III) from the water and wastewater is chemical precipitation. After pH adjustment to the basic conditions, the dissolved metal ions are converted to insoluble solid phase via a chemical reaction with a precipitating agent such as lime. Although, lime is mostly used but other precipitating agents like sodium hydroxide, magnesium oxide etc., are also used for the precipitation of chromium from water. Typically, the metal precipitated from the solution is in the form of hydroxide [23]. The conceptual mechanism of heavy metal removal by chemical precipitation is presented below:

$$M^{2+} + 2OH^{-} \rightarrow M\,(OH)_2 \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where $M^{2+}$ and $OH^{-}$ represent the dissolved metal ions and precipitant, respectively while $M\,(OH)_2$ is the insoluble metal hydroxide.

Many factors affect the process of chemical precipitation including the type of precipitating agent, pH, velocity of precipitation, sludge volume, time of mixing and complexing agents. The process is aimed at the formation of solids (insoluble precipitation) within a solution.

Elmaeili et al., (2005) studied the removal of chromium from the tanning process by using lime, sodium hydroxide (15%) and magnesium oxide (10%). The optimum pH for precipitating chromium from tannery wastewater is 8 – 9 and good sludge with high settling rate and lower volume was obtained when magnesium oxide (MgO) as the precipitating agent. Magnesium oxide is much more desirable for removing and recovering chromium from tannery wastewater.

The solubility is controlled by the pH of the chromium solution. Under the most conditions, chromium (III) is removed from solution as $Cr\,(OH)_3$ (s) precipitated phase, or as a chromium-Iron hydroxides solid solution $(Cr, Fe)\,(OH)_3$ (s) when dissolved iron is present (Rai et al., 1986).

Reduction of chromium (VI) can be achieved by using the Fe (II) salts and Fe(II) ions are oxidised to Fe(III) compounds. The removal of chromium by coagulation – precipitation is pH dependent. In general, the reduction of chromium (VI) to chromium (III) is done under acidic conditions and then, precipitation of hydrated chromium oxide is achieved by raising the pH with the addition of NaOH or lime.

**Merits**

- Process is simple and effective
- Inexpensive equipment requirement
- Convenient and safe operations
- Recovery of chromium for recycling

**Demerits**

- Excessive sludge production that requires further treatment.
- Skilled operator is required for chemical dosing
- Large amounts of chemicals to reduce metals to an acceptable level for discharge
- Precipitation is often ineffective if metals are complexed or present as anions
- Slow metal precipitation and poor settling.
- Long-term environmental impacts of sludge disposal.

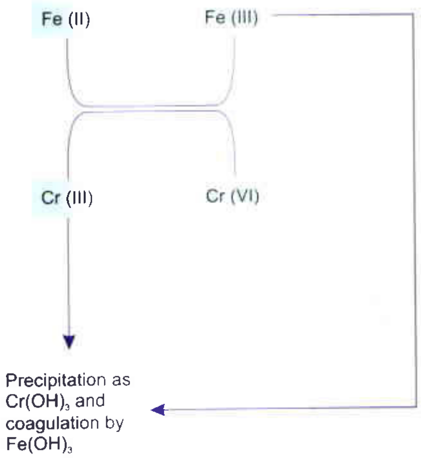


**Fig. 8.2:** The Chromium removal by reduction and precipitation / coagulation process

## 8.5.3 Membrane Filtration Techniques

Membrane filtration technique has received a significant attention for drinking water and wastewater treatment. Membranes are capable of removing all forms of chromium species. Different types of membrane filtration such as inorganic, polymeric and liquid membrane can be employed for the removal of chromium (VI) and are presented as below:

### 8.5.3.1 Inorganic Membrane

Inorganic membranes are one of the most significant porous materials because of their high chemical and great thermal stability. Most of the ceramic and other inorganic membranes today are in the tubular configuration. Dzyazko et al., (2007) used ceramic membranes containing ion-exchanger, such as hydrated zirconium oxide for the removal of hexavalent chromium from dilute solutions.

### 8.5.3.2 Polymeric Membrane

Nowadays, polymeric membrane separation systems have become an important wastewater treatment technology, which facilitates the removal and recovery of pollutants as well as solvent such as water. Muthukrishnan and Guha (2008) successfully studied the removal of Cr (VI) with different nanofiltration composite polyamide membranes. Similarly, Bohdziewiez (2000) used nonmatted polyacrylonitrile fiber (PAN) membrane for the removal of chromium (VI) from underground water by means of complexed hexadecylpyridine chloride.

### 8.5.3.3 Liquid Membrane

High selectivity is one of the biggest advantages of liquid membranes. Basically, there are two types of liquid membranes, emulsion liquid membrane (ELM) and immobilized liquid membrane (ILM) which is also known as supported liquid membrane (SLM). The emulsion liquid membrane uses surface forces to maintain a very thin yet stable immiscible membrane between the two miscible phases. Immobilized liquid membrane consists of a polymer support impregnated with a viscous solution of carrier. Many different types of polymer supports are available to prepare ILM including cellulose acetate reverse osmosis membrane, microporous propylene ultrafiltration membrane, polyvinylchloride filter, and hollow fiber membrane. Liquid membranes are an effective and inexpensive method with potential application for the removal of heavy metals.

**Table 8.2**

**Uptake of chromium Cr (VI) using various membranes from synthetic wastewater**

| S.No | Type of membrane | Initial Cr (VI) Conc. | Removal system | Rejection rates | References |
|---|---|---|---|---|---|
| 01. | Carbon membrane | 1000 mg/L | Batch | 96% | Pugazhenthi et al., (2005) |
| 02. | Nitrated carbon membrane | 1000 mg/L | Batch | 84% | Pugazhenthi et al., (2005) |
| 03. | Aminated carbon membrane | 1000 mg/L | Batch | 88% | Pugazhenthi et al., (2005) |
| 04. | Polymer-enhanced ultrafiltration | 10 mg/L | Continuous | 30% | Aroua et al., (2007) |
| 05. | Composite polyamide membranes (NFI) | 1000 mg/L | Continuous | 99% | Muthukrishnan and Guha (2008) |

| S.No | Type of membrane | Initial Cr (VI) Conc. | Removal system | Rejection rates | References |
|---|---|---|---|---|---|
| 06. | Composite polyamide membranes (NFII) | 1000 mg/L | Continuous | 94% | Muthukrishnan and Guha (2008) |
| 07. | Polyacrylonitrile fibre | 0.2 mg/L | Continuous | 90% | Bohdziewiez (2000) |
| 08. | Polyamide thin –film membrane | ......... | Continuous | 77% | Hafiane (2000) |

### 8.5.4 Ion Exchange Techniques

Among the various physicochemical methods developed for the removal of chromium from drinking water and wastewater, ion exchange is one of the best available technologies as per USEPA recommendation for the removal of chromium. It is well proven technology for small systems for the removal of low concentration of chromium. Cation exchangers are effective for chromium (III) while anions exchangers are appropriate for chromium (VI). Ion exchangers are insoluble granular substances with their molecular structure acidic or basic radicals that can exchange the ions. The positive or negative ions fixed on these radicals are replaced by ions of the same sign in solutions in the liquid in contact with them. Ion exchange is a physical process in which an ion with a high affinity for the resin material of the ion exchange column replaces an ion with a lower affinity that was previously bound to the column resin. As water flows through resin bed, dissolved chromium (VI) ions bind to the resin and displace the previously bound ions (mostly chloride or hydroxide ions). The resins used for the sequestration of chromium (VI) are typically either a naturally occurring inorganic zeolite or a synthetic weak base or strong base anion exchanger resin. Once the resins are saturated with chromium (VI), they must be regenerated. In many studies, various kinds of ion exchange resin were used to study the uptake of chromium (VI) and some of them are listed in Table - 3. The merits and demerits of the ion-exchange method are as follows:

**Merits**

- Highly reliable
- Ease of operation
- Resin will not wear out with regular regeneration
- Effective and widely used
- Suitable for small and large installations

**Demerits**

- Expensive process
- Pre-treatment lime softening may be required
- Requires salt storage and regular regeneration
- Requires concentrate disposal
- Usually not feasible with high levels of total dissolved solids (TDS)

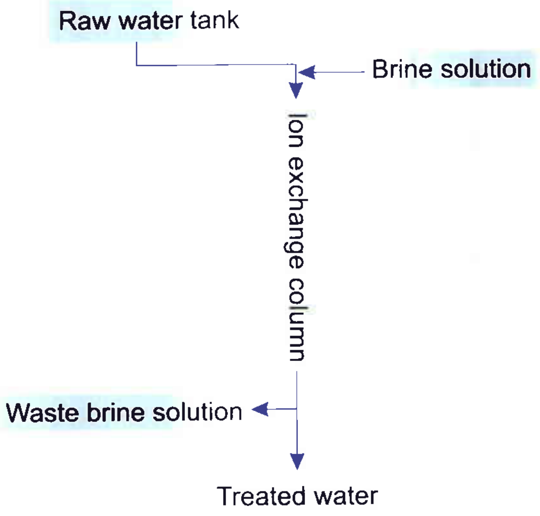


**Fig. 8.3:** The Chromium removal by ion exchange process

### Table 8.3
### Chromium (VI) uptake using ion exchange resins

| S. No | Ion-exchanger | Nature of the resin | Capacity (mg/g) | Removal Efficiency | Refere-nces |
|---|---|---|---|---|---|
| 01. | Dowex 2-X4 | Strongly basic resin with trimethylbenzylammonium as the active group | ........ | 100.0 | Sapari et al., (1996) |
| 02. | Ambersep 132 | Strongly basic (H-type) | 92.1 | ...... | Lin and Kiang (2003) |
| 03. | Solvent impregnated resin with aliquat 336 | An acidic resin based on hydrophilic polymer | 38.0 | 99.5 | Kabay et al., (2003) |

## 8.5.5 Electrochemical Treatment Techniques

Electrochemical treatment techniques are becoming an alternative wastewater treatment method because many industrial processes produce toxic wastewaters, which are not easily biodegradable and require costly physical or physicochemical pretreaments. The two effective electrochemical techniques for the removal of chromium are described below:

### 8.5.5.1 Membrane Electrolysis

Membrane electrolysis is one of the upcoming techniques useful for the removal of chromium (VI) from wastewater. Membrane electrolysis is a chemical process driven by an electrolytic potential. There are two types of cathodes used: a conventional metal cathode (electrowinning) and a high surface area cathode. When electrical potential is applied across an ion exchange membrane, reduction-oxidation reaction takes place in electrodes.

In the anode, oxidation reaction occurs as below:

$$M_1 \text{ (insoluble)} \leftrightarrow M_1^{n+} \text{ (Soluble)} + ne^-$$

$$4OH^- \leftrightarrow 2H_2O + O_2 + 4e^-$$

$$2Cl^- \leftrightarrow Cl_2 + 2e^-$$

In the cathode, the following reduction takes place as shown below:

$$M_2^{n+} \text{ (Soluble)} + ne^- \leftrightarrow M_2 \text{ (insoluble)}$$

$$2H^+ + 2e^- \leftrightarrow H_2 \text{ (g)}$$

"M" and "*n*" represent the metal and the coefficient of the reaction component respectively. Where "*n*" depends on the oxidation state of the metal ions.

### Table 8.4
### Electrochemical treatment technologies used for the removal of chromium

| S. No | Cathode | Anode | Electrical current (A/m²) | Power consumption (kWh/m³) | Initial metal conc. (mg/L) | pH | Removal efficiency | Reference |
|---|---|---|---|---|---|---|---|---|
| 01. | Carbon aerogel | Carbon aerogel | 0.8 | ......... | 8 | 2.0 | 98.5 | Rana et al., (2004) |
| 02. | Iron rotary | Iron rotary | 113.0 | $7.9 \times 10^3$ | 130 | 8.5 | 99.6 | Martinez et al., (2004) |

| S. No | Cathode | Anode | Electrical current (A/m$^2$) | Power consumption (kWh/m$^3$) | Initial metal conc. (mg/L) | pH | Removal efficiency | Reference |
|---|---|---|---|---|---|---|---|---|
| 03. | $Fe_3O_4$ | .......... | 1.7 | 12 | ........ | 10-11 | 77.0-100.0 | Kongsricharoen and Polprasert (1995) |
| 04. | $Fe_3O_4$ | .......... | 6.7 | 20 | 2100 | 10-11 | 85.1 | Kongsricharoen and Polprasert (1996) |

### 8.5.5.2 Electrochemical Precipitation

To maximize the removal of heavy metal from contaminated wastewater, electrical potential has been utilized to modify the conventional chemical precipitation. Generally, electrochemical precipitation processes can treat inorganic effluent with a metal concentration higher than 2000 mg/L. Depending on the characteristics of the electrodes, the electrochemical process can be worked at either acidic or in basic atmospheres. Tunay et al., (1994) used electrochemical precipitation (ECP) technique for the removal of chromium (VI) from real electroplating wastewater and achieved more than 80% of chromium removal.

## 8.5.6 Adsorption

Adsorption is one of the most widely applied techniques for pollutant removal from contaminated medias. Basically, adsorption is a mass transfer process in which a substance, originally present in one phase, is removed from that phase by accumulation at the surface or interface between that phase and a separate phase. The process can occur at an interphase between any two phases, such as liquid-liquid, gas-liquid or liquid-solid interphase.

Adsorption based process is capable of removing metals over a wider range of pH and to much lower level than process based on precipitation. The adsorption technique is one of the preferred methods for the removal of heavy metals because of its high efficiency and low cost. In addition to offering more reliable and more efficient removal of uncomplexed cationic metals, adsorption process can often remove inorganically and organically complexed metals that would not be removed by conventional treatment methodology as well as oxyanionic metal such as $SeO_3^-$, $CrO_4^{2-}$ and $AsO_4^{3-}$.

The main causes of adsorption may be:

- The driving force for adsorption may be reduction in interfacial (surface) tension between the fluid and the solid adsorbent as a result of the adsorption of the adsorbate on the surface of the solid.
- The high affinity of the solute for the sorbent.

The merits and demerits of adsorption process are as follows:

**Merits**

- Effective for the removal of heavy metals over a wider range of pH.
- More reliable and efficient method for the removal of uncomplexed cationic metals.
- Removal of inorganically and organically complex metal.
- Adsorption filter media can be regenerated and reused.

- Considerably less sludge production.
- Relatively less expensive

**Demerits**

- Disposal of exhausted adsorption media.
- Sensitive to operating such as pH and ionic strength.
- Replacement of exhausted adsorption filter media

### 8.5.6.1 Adsorption of chromium on different media

Chromium can be removed from water and wastewater by conventional as well as advanced treatment methods. Among them, adsorption method, has become popular, interesting and attractive method for the removal of heavy metals due to its easy availability and cost effectiveness. There are several natural and synthetic adsorption filter media used for the removal of chromium from water and wastewater. The following are some of the adsorption filter media that can be used for the removal of chromium as shown below:

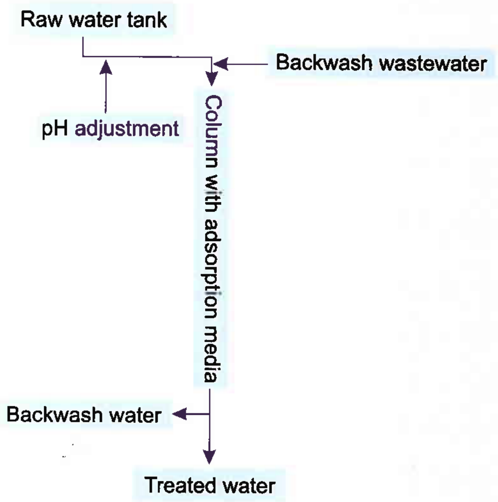


**Fig. 8.4:** Chromium removal by adsorption process

#### 8.5.6.1.1 Activated Carbon

Literature reveals that activated carbon derived from various sources is the most studied adsorbent for the adsorption of chromium from water and wastewater. Activated carbon adsorption seems to be an attractive choice for chromium removal both for its exceptionally high surface areas which range from 500 to 1500 $m^2/g$, well developed internal microporosity structure as well as the presence of a wide spectrum of surface functional groups. Based on its size and shape, activated carbon is classified into four types: Powder-activated carbon (PAC), Granular-activated carbon (GAC), activated carbon fibrous (ACF) and activated carbon clothe (ACC). Due to the different sources of raw materials, the extent of chemical activation, and the physicochemical characteristics, each type of activated carbon has its specific application as well as inherent merits and demerits in wastewater treatment. Table - 5 summarized the chromium (VI) adsorption capacities for different activated carbons based on their size and shape.

**Table 8.5**

**Adsorption capacities (mg/g) for different activated carbons based on size and shape from synthetic chromium wastewater**

| S. No | Activated carbon | mg $Cr^{6+}/g$ | Surface area | pH | Adsorption system | Reference |
|---|---|---|---|---|---|---|
| 01. | Powder activated carbon (PAC) | 390.00 | 1264 | 2.0 | Batch | Candela et al., (1995) |
| | | 145.00 | ....... | 2.5 – 3.0 | Batch | Sharma and Forster (1996) |
| 02. | Granular activated carbon (GAC-Filtrasorb 400) | 0.18 | ....... | ....... | Batch | Han et al., (2000) |
| | | 53.19 | 832 | 2.0 | Batch | Hamadi et al., (2001) |
| 04. | Activated carbon fibrous (ACF) | 40.00 | ...... | ....... | Batch | Park and Jung (2001) |

**Table 8.6**

**Adsorption capacities (mg/g) for activated carbons prepared from different sources from synthetic chromium wastewater**

| S. No | Source | mg $Cr^{6+}$/g | pH | Initial Conc. (mg/L) | Adsorption system | Reference |
|---|---|---|---|---|---|---|
| 01. | Bituminous coal | 7.0 | 5.0 - 8.0 | 25 | Batch | Natale et al., (2007) |
| 02. | Coconut shell | 6.0 | 3.0 – 4.0 | 120 | Batch | Selomulya et al., (1999) |
| 03. | Wood | 5.1 | 2.0 | 120 | Batch | Selomulya et al., (1999) |
| 04. | Dust coal | 4.4 | 3.0 – 4.0 | 120 | Batch | Selomulya et al., (1999) |
| 05. | Hazelnut shell | 170.00 | 1.0 | 1000 | Batch | Kobya (2004) |
| 06. | Coconut shell | 20.00 | 2.5 | 50 | Batch | Alaerts et al., (1989) |
| 07. | Hazelnut shell | 17.7 | 2.0 | 30 | Batch | Cimino et al., (2000) |
| 08. | Terminalia arjuna nuts | 28.4 | 1.0 | 10 | Batch | Mohanty et al., (2005) |
| 09. | Rubber wood sawdust | 44.1 | 2.0 | ...... | Batch | Karthikeyan et al., (2005) |

### 8.5.6.1.2 Industrial Waste Sorbents

Industrial wastes can be used as low-cost adsorbents for the removal of heavy metals from water and wastewater. Iron (III) hydroxide is a waste material of fertilizer industries and one of the principal sorbents of the oxyanionic pollutants such as phosphates, arsenates and chromates in aqueous systems. It has been extensively investigated for removing chromium (VI) from wastewater. Table 8.7 summarized the chromium (VI) adsorption capacities of different industrial waste adsorbent.

**Table 8.7**

**Adsorption capacities (mg/g) of different industrial waste adsorbents from synthetic chromium wastewater**

| S. No | Adsorbent | mg $Cr^{6+}$/g | pH | Adsorption system | Reference |
|---|---|---|---|---|---|
| 01. | Iron (III) hydroxide | 0.5 | 5.6 | Batch | Namasivayam & Ranganathan (1993) |
| 02. | Waste slurry | 640.00 | ...... | Batch | Srivastava et al., (1989) |
| 03. | Blast – furnace slag | 7.5 | ...... | Batch | Srivastava et al., (1997) |
| 04. | Bagasse fly ash | 260.00 | 1.0 | Batch | Gupta et al., (1999) |
| 05. | Red mud | 1.60 | ...... | Batch | Pradhan et al., (1999) |

### 8.5.6.1.3 Chitosan

Chitin is the world's second most naturally occurring polysaccharide in terms of abundance and is found in the exoskeletons of crabs and other arthropods and in the cell walls of some fungi (Berkeley 1979). Chitin is also waste product of the crab meat canning industry. Chitosan is the deacetylated form of chitin which can be produced chemically from chitin and is found naturally in some fungal cell walls. The growing need for new sources of low-cost adsorbent, the increased problems of waste disposals, the increasing cost of synthetic resins undoubtedly make chitosan and its compounds as one of the most attractive materials for wastewater treatment. Table – 8 summarized the chromium (VI) adsorption capacities of different chitosan adsorbent.

**Table 8.8**

**Adsorption capacities (mg/g) of different types of chitosan adsorbents from synthetic chromium wastewater**

| S. No | Adsorbent | mg $Cr^{6+}$/g | pH | Adsorption system | Reference |
|---|---|---|---|---|---|
| 01. | Chitosan | 273 | 4 | Batch | Udaybhaskar et al., (1990) |
| 02. | Non-crosslinked chitosan | 80 | 5 | Batch | Schmuhl et al., (2001) |
| 03. | Crosslinked chitosan | 50 | 5 | Batch | Schmuhl et al., (2001) |
| 04. | Chitosan based polymeric surfactants | 180 | 5.3 | Batch | Lee et al., (2005) |
| 05. | Chemically modified chitosan beads | 625 | 3 | Batch | Sankararamakrishnan et al., (2006) |
| 06. | Chemically modified chitosan flakes | 256 | 3 | Batch | Sankararamakrishnan et al., (2006) |
| 07. | Quaternary chitosan salt | 68 | 4.5 | Batch | Spinelli et al., (2004) |

## 8.5.7 Biological Treatment Techniques:

Biosorption of chromium (VI) using bacterial biomass or algal, fungal (growing, resting and dead cells) and biological and agricultural waste materials has been recognized as a potential alternative to the existing conventional methods for detoxification of industrial wastewaters. The major advantages of the biosorption process over conventional treatment methods include:

- Low cost
- Increased metal removal
- Regeneration of biosorbent
- Possibility of metal recovery

The chromium (VI) removals from the wastewaters using biological materials have long been used. Several authors have investigated the adsorption of chromium (VI) from aqueous solution using cellulosic, lignocellulosic and agricultural waste materials briefly reported in Table 8.9.

**Table 8.9**

**Biosorption of Cr (VI) using various agricultural waste materials**

| S. No | Biosorbent | Reactor/conditions | Initial Cr (VI) Conc. | Maximum Cr (VI) removal | Reference |
|---|---|---|---|---|---|
| 01. | Plataneus Orientalis leaves | Batch reactor, pH=3.0 – 9.0, Dose=2.0 g/L, 20 - 30°C, 300 rpm, 30 – 240 min | 2.0 – 4.0 mg/L | 5.01 mg/g | Mahvi et al., (2007) |
| 02. | Plant Ulmus leaves | Batch reactor, pH=3.0 – 9.0, Dose=1.0 g/L, 20 - 30°C, 300 rpm, 30 – 240 min | 2.0 – 4.0 mg/L | 5.0 mg/g | Gholami et al., (2006) |
| 03. | Lignocellulosic material peat | Batch reactor, pH=2.0 – 7.0, Dose=2.0 g/L, 30°C | 10 – 200 mg/L | 30.16 mg/g | Dean and Tobin (1999) |
| 04. | Plant water hyacinth (Eichhornia Crassipes) | Batch reactor, pH=2.0 – 6.0, 30°C, 8 h | 10 mg/L | 6.0 mg/g | Lytle et al., (1998) |

| S. No | Biosorbent | Reactor/conditions | Initial Cr (VI) Conc. | Maximum Cr (VI) removal | Reference |
|---|---|---|---|---|---|
| 05. | Cellulosic materials Sugar cane bagasse Saw dust Sugar beet pulp Maize cob | Batch reactor, pH= 1.5 – 10.0, Dose=4.0 g/L, 25°C, 100 rpm | 10 – 1000 mg/L | 13.4 mg/g<br>39.7 mg/g<br>17.2 mg/g<br>13.8 mg/g | Sharma & Forster (1994) |
| 06 | Rice hulls | Batch reactor, pH=2.0 – 8.0, 30°C, | 20 – 200 mg/L | 99 – 38% | Cici and Keles, 1990 |

### 8.5.7.1 Bacteria

The use of bacterial species as biosorbents has raised the possibility of using these microorganisms as a biotechnological tool for the removal of Cr (VI) from wastewaters because of their small size, their ubiquity and their ability to grow under wide range of environmental situations. The complexity of microorganisms structure implies that there are many ways for the metal to be captured by the cell. Various mechanisms involved in metal removal by bacteria include cell surface binding, extra cellular precipitation, intracellular accumulation, oxidation and reduction and methylation/demethylation.

**Table 8.10**

**Biosorption of Cr (VI) using various bacterial biomass**

| S. No | Biosorbent | Reactor/conditions | Initial Cr (VI) concentration | Maximum Cr (VI) removal | Reference |
|---|---|---|---|---|---|
| 01. | *Bacillus circulnas biofilm* | Batch adsorption non-living cells, pH=2.0 – 7.0, 30°C, 24 – 96h, 120 rpm | 50 – 500 mg/L | 48%<br>pH=7.0,<br>96h | Khanafari *et al.*, 2008 |
| 02. | Distillery sludge | Batch reactor non-living cells, dose = 1-20 g/L, pH = 3.0 – 10.0, 30°C, 24 – 96h, 120 rpm | 10 – 40 mg/L | 64%, pH=3,<br>5 g/L | Selvraj *et al.*, (2003) |
| 03. | *Shewanella oneidensis MR-1 (Facultative Gram negative bacteria)* | Batch reactor growing cells, pH = 3.0 – 10.0, 30°C, 200 rpm, aerobic conditions | 60 – 400 μm | 100 μm | Sarah *et al.*, (2003) |
| 04. | *Bacillus circulan,*<br>*Bacillus megaterium,*<br>*Bacillus coaglans* | Batch reactor resting cells, pH = 2.5, 30°C, 150 rpm, 24h, 28°C | 0 – 100 mg/L | 34.5 mg/g<br>32 mg/g<br>23.8 mg/g | Srinath *et al.*, (2002) |
| 05. | *Bacillus coaglans or*<br>*Bacillus megaterium,* | Batch reactor non-living cells, dose = 1-20 g/L, pH = 2.5, 28°C, 150 rpm, 24h, | 100 mg/L | 39.9 mg/g<br>30.7 mg/g | Srinath *et al.*, (2002) |
| 06. | Microbacterium liquuefaciens MP 30 | Batch bioreactor resting cells immobilised in (PVA) alginate beads, 30°C, 100 rpm, 4d<br>continuous flow bioreactor, flow rate = 0<br>95 mL/h, 20 d | 100 μm<br>50 μm | Complete removal (90% removal) | Pattanapipit Paisa, et al., (2001) |
| 07. | Dried activated sludge | Batch reactor non-living cells, pH=1.0 – 6.0, 25°C, dose=0.5 g/L,24 h, 150 rpm | 25 – 500 mg/L | 27.7 mg/g | Aksu *et al.*, (2001) |
| 08. | *Bacillus sp. QCI-2* | Batch reactor resting cells, 30°C, 20 h, Cell conc = 1 x 109 cells/mL | 0.3 mM | Complete removal | Campos *et al.*, (1995) |

| S. No | Biosorbent | Reactor/conditions | Initial Cr (VI) concentration | Maximum Cr (VI) removal | Reference |
|---|---|---|---|---|---|
| 09. | *Zoogloea ramigera* | Batch reactor non- living cells, pH = 2.0, 100 rpm, 25°C, 30 min. | 0 – 75 mg/L | 3.40 mg/g | Nourbaksh *et al.*, (1994) |
| 10. | *Agrobacterim radiobacter EPS-916* | Batch reactor resting cells, pH= 5.0 – 8.0, 10 - 40°C, 6h. | 0.5 mM | Complete removal | Liovera *et al.*, (1993) |

### 8.5.7.2 Algae

They are photosynthetic organisms. The cell surface binding is the first step involved in the binding of chromium (VI) ions to algal species which is a rapid process and is metabolized independently. It is followed by the second step of intracellular accumulation of metal due to the simultaneous effect of growth and surface biosorption. This step is metabolism dependent and is a much slower process. Both growing and non-living cells of algae are capable of removing chromium (VI) and are shown in Table 8.11.

**Table 8.11**

**Biosorption of Cr (VI) using various algal biomass**

| S. No | Biosorbent (Algal species) | Reactor/conditions | Initial Cr(VI) Conc. | Maximum Cr(VI) removed | Reference |
|---|---|---|---|---|---|
| 01. | *Sargassum Seaweed (marine algae)* | Batch reactor non-living cells, dose=2.5 g/L, 22°C, pH = 3.5, 10 – 60 min | 10 – 100 mg/L | 60 mg/L | Barkhordar and Ghaiseddin. 2004 |
| 02. | *Sptrogyra species (green filamentous algae)* | Batch reactor non-living cells, dose=1-15 g/L, 25 - 35°C, pH = 1.0 – 6.0, 180 min | 1 – 25 mg/L | 90% | Gupta *et al.*, (2001) |
| 03. | *Chlorella vulgaris*<br>*Scenedesmus accutus (filamentous algae)* | Fluidized bed<br>Packed bed Kappacarragenan (natural biopolymer)<br>Polyurethane foam (cells immobilized in columns) | 50 mg/L | 48%<br>34%<br>36%<br>31% | Travieso *et al.*, (1999) |
| 04. | *Chlorella vulgaris*<br>*Chlorella crispate* | Batch reactor non-living cells, 25 - 35°C, pH = 1.0 – 5.0, 30 – 60 min | 0 – 200 mg/L | 2.98 mg/g/min 6.20 mg/g/min | Nourbakash *et al.*, (1994) |

### 8.5.7.3 Fungi

Fungi and yeasts are the eukaryotic organisms which are used as biosorbents for the removal of heavy metals due to the production of high yields of biomass. They grow easily under wide range of environmental situations and can also be modified genetically to produce enzymes (reductase, DNA polymerase etc.) which are helpful in higher metal removal from the wastewaters. The fungal organisms, in general, are resistant to higher metal ion concentrations. Heavy metals such as zinc, copper, manganese, nickel and cobalt in trace amount serve as micronutrients for the growth of the fungus. The fungi can also accumulate non-nutrient metals such as cadmium, mercury, lead, uranium, silver and gold in substantial amounts. The fungi and yeasts (*A. Niger, T. Reessii, R. Arrhizus, R. Nigricans, S. Cerevisiae etc.*) are used in a variety of industrial fermentation processes and can serve as an economical and constant supply of biomass for biosorption of heavy metals. They can also be grown using inexpensive media and unsophisticated fermentation techniques. Therefore, the cost of a biosorbent (obtained from an industrial fermentation process in which biomass is generated as waste) will be significantly lowered as compared to the cost of the conventional adsorbent.

A wide range of fungal species under non-living condition have been studied by different researchers for chromium (VI) removal from the wastewaters. The fungal cells can be killed for biosorption by physical and chemical methods. The physical methods include boiling, autoclaving, vacuum and freeze drying and mechanical disruption. The chemical methods include the treatment of biomass with various organic and inorganic compounds. Table: 04 shows the Chromium (VI) biosorption potential of various fungal biomasses under growing, resting and non-living conditions.

Metal ion uptake by fungal biomass similarly takes place as discussed in algal cells. The first uptake mode involves the surface binding of chromium (VI) ions to the cell wall and extra-cellular material, which is metabolism independent. The second mode of chromium (VI) uptake into the cell across the cell membrane is dependent on the metabolic activity and is referred to as intra cellular accumulation. The first mode of metal uptake is common both in dead and living cells. Chromium (VI) uptake by the second process, which is metabolism dependent, occurs only in the living cells.

**Table 8.12**

**Biosorption of Cr (VI) using various fungal biomass**

| S. No | Biosorbent (Fungal species) | Reactor/conditions | Initial Cr(VI) Conc. | Maximum Cr(VI) removed | Reference |
|---|---|---|---|---|---|
| 01. | *Aspergillus Sp.* (filamentous) | Batch reactors, non-living cells, pH=2.0-6.0, dose=4.5 g/L, 150 rpm, 8h, 30°C | 50 – 500 mg/L | 10 – 27.5 mg/g | Sen *et al.*, (2010) |
| 02. | *Aspergillus Sp.* (filamentous) | Batch reactors, resting cells, pH=2.0-6.0, dose=2.4 – 5.2 g/L, 180 rpm, 8h, 30°C, culture age 12 – 48 h | 0 – 500 mg/L | 34.8 mg/g | Sen and Ghosh Dastidar(2007) |
| 03. | *Fusarium sp.* (filamentous) | Batch reactors, growing cells, pH=5.0, 180 rpm, 30°C, Continuous flow bioreactor (single & multistage), dilution rates= 0.01 – 0.04/h, pH = 5.0, 30°C) | 100 – 500 mg/L<br>50 – 500 mg/L | 18.2 – 17.0 mg/g<br>40 mg/L, 0.02/h<br>420 mg/L, 0.01/h | Sen *et al.*, (2007) |
| 04. | *Fusarium sp.* (filamentous) | Batch reactors, non-living cells, pH=1.0-6.0, dose=4.0 g/L, 150 rpm, 8h, 30°C | 50 – 500 mg/L | 12.5 – 47.5 mg/g | Sen *et al.*, (2005) |
| 05. | *Candida utlis* | Batch bioreactor, resting cells (immobilised in PVA alginate beads) 100 rpm, 30°C, 4d, Continuous flow bioreactor, flow rate = 0.95 mL/h, 20d | 100 µm<br>50 µm | Complete removal<br>90% | Pattanapipit Paisa, *et al.*, (2001) |
| 06. | *R. arrhizus*<br>*S. cerevisiae* | Batch reactors, non-living cells, pH=1.0-5.0, 25 - 30°C, 30 – 60 min | 0 – 100 mg/L | 8.40 mg/g/min<br>4.30 mg/g/min | Prakasham *et al.*, (1998) |
| 07. | *Zygomycetes* (Mucor heimalis MP/92/3/4) | Batch reactors, resting cells, pH=1.0-5.5, 30°C, metal enrichment time = 30 min | 50 mg/L | 4.3 mg/g | Pillichshanmer *et al.*, (1995) |
| 08. | *Candida utlis* & different species of yeast | Batch reactor resting dehydrated cells, 30°C, 72 h (dehydrated to different moisture level) & intact cells 75% of moisture (without dehydration) | 150 mg/L | 9.0 mg/g dehydrated cells | Rapport & Muter (1994) |

### 8.5.8 Full Scale chromium (VI) removal technology developed by Lawrence Liverpool National Laboratory, California.

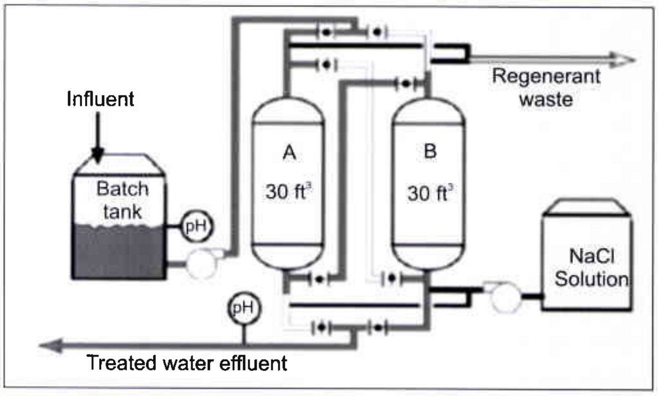


**Fig. 8.5:** Schematic representation Lawrence Liverpool National Laboratory's hexavalent chromium removal unit.

The Lawrence Liverpool National Laboratory (LLNL), designed and constructed an ion-exchange unit to treat hexavalent chromium in the ground water which is operated for the Department of Energy by the University of California. In this treatment unit, the ground water is filtered to remove particulate and sediment to a nominal 5 μm, then passed through two tank-type air strippers in series, where the volatile organic compounds (VOCs) are removed and collected onto vaporphase granular activated carbon. The groundwater then travels through two columns, connected in series, which are filled with ion exchange resin. After passing through both ion exchange columns, the treated ground water is discharged to a surface area.

The resin used was Purolite® A – 600, a strongly basic Type I quaternary ammonium anion exchange resin with a styrene - divinylbenzene copolymer gel matrix. It has a nominal capacity of 1.5 eq/L of resin bed. The ion exchange system removes chromium (VI) to below its limit of detection. This ion exchange unit for the removal of chromium (VI) costed 150,000 USD including the initial resin. The estimated yearly cost to operate the unit is: salt 1000 USD; resin replacement 6,000 USD; filter, valve, pump maintenance, 2,000 USD and waste disposal, 1,900 USD.

### 8.5.9 Siemens Water Technologies

Siemens water technologies offers, a service based treatment option for handling hexavalent chromium and trivalent chromium contamination. For non-potable applications it uses wastewater ion exchange resin (WWIX) and for potable applications, it uses potable ion exchange resin (PIX) for the removal of chromium from wastewater and groundwater. For details go through the website: information.water@siemens.com

**Fig. 8.6 :** Siemens ion exchange resin canister

## 8.6 Pilot study on Filters used for Chrome remediation

#### Optimization of Filter

A novel sorbent filter for hexavalent chrome removal from drinking water was prepared and field tested in 3 three villages of Jajmau, viz. Allaulapur, Shiekhpur and Kulgaon for a period of 3 years. The project was proposed by an NGO with active support and technical guidance from Dr. Padma S. Vankar, Principal Research Scientist, FEAT Lab, IIT, Kanpur. The UNDP GEF SGP came forward to support the pilot for a small experiment to learn, document and find alternative strategies and to consider possible alternatives and choices for the community. The focus was also to look into the cost-benefit and the economics of the remediation technology. A project titled 'To protect poor farmers from Chrome VI menace through remediation of ground water and soil affected by tannery effluents containing Cr VI' was implemented under the sponsorship of UNDP/GEF/SGP. Initial studies have demonstrated very exciting results as the developed domestic filter has been able to completely remediate chromium from ground water.

In the pilot scale studies various Filters including Silica filters and Polypropylene filters were checked for aqueous hexavalent chromium remediation. Upto 18% Chromium removal was obtained with Silica filters with no filling for contact time of 4 hours, while Polypropylene Plain Spun Filter showed 31% Chromium removal.

**A view with netted top Polypropylene Filter**

Regeneration of filter media will have to be done after the breakthrough point with washing the media in the acidic medium. Efficient, economic and easy to use regeneration methodology will have been optimized and an easy to use regeneration kit should be developed for regeneration at the model nodule centers.

Cost of Filter designed for remediation of groundwater for the ease of use by the inhabitants

| | | |
|---|---|---|
| 1. | Cost of Polypropylene filter | Rs 150.00 |
| 2. | Zeolite (50 gms) | Rs 180.00 |
| 3. | Activated Charcoal (75 gms) | Rs 35.00 |
| | **TOTAL** | **Rs 365.00** |

## References

1. S.P. Mc Grath, and S. Smith, (1990) Chromium and nickel. In: Heavy metals in soils (Alloway, B.J., Ed.), pp. 125 – 150. Wiley, New York.
2. C. Cervantes, J.C. Gracia, S. Devars, F.G. Corona, H.L. Tavera, J.C.T. Guzman, R.M. Sanchez, FEMS Microbiological Reviews, 25 (2001) 335 – 347.
3. M. Owlad, M.K. Aroua. W.A.W. Daud, S. Baroutian, Water Air Soil Pollut. 200 (2009) 59 – 77.
4. K.K. Krishanani, S. Ayyappan, Rev. Environ. Contam. Toxicol. 188 (2006) 59 – 84.
5. J. Kotas, Z. Stasicka, Environ. Pollut. 107 (2000) 263 – 283.
6. M. Cieslak-Golonka, Polyhedron, 15 (1995) 3667 – 3689.
7. www.freedrinkingwater.com/water-contamination/chromium-contamination-removal-water.htm.
8. World Health Organisation (WHO) (2006), WHO's Drinking Water Standards.
9. www.epa.gov/drink/contaminants/index.cfm.
10. J.C. Schippers, B. Petrusevski, S.K. Sharma, (2004) Module, UNESCO-IHE Institute for water Education, The Netherlands,
11. M. Jain, V.K. Garg, K. Kadirvelu, Journal of Hazardous Materials, 162 (2009) 365 – 372.
12. P. Brandhuber, M. Frey, M.J. Mcguire, P.F. Chao, C.S. McGuire, G. Amy, J. Yoon, L. McNeill, K. Banerjee, Awwa Research Foundation, 2004.
13. T.J. Sorg, Part 4. J. AWWA 71 (1979) 454 – 460.
14. E.B. Besselievre (1969), The treatment of industrial wastes. New York: McGraw Hill.
15. N.K. Shammas, Coagulation and flocculation, in: L.K. Wang, Y.T. Hung, N.K. Shammas (Eds.), Physicochemical treatment processes, vol. 3, Humana press, New Jersey, 2004, pp. 103 – 104.
16. L. Semerjian, G.M. Ayoub, Adv. Environ. Res. 7 (2003) 389 – 403.
17. US Department of interior (2001), Bureau of Reclamation, Technical service centre, Water Treatment Engineering and Research Group, Chromium fact sheet, http://www. usbr.gov/pmts/water/media/pdfs/Cr.pdf [Accessed November 2008
18. O. Tunay, Developments in the application of chemical technologies to wastewater treatment, Water Sci. Technol. 48 (2003) 43 – 52.
19. A. Esmaeili, A. Mesdadghi, R. Vazirinejad, Chromium (III) removal and recovery from tannery wastewater by precipitation process, American Journal of Applied Sciences, 10 (2005) 1471 – 1473.
20. D. Rai, J.M. Zachara, L.M. Early, D.C. Grivin, D.A. Moore, C.T. Resch, B.M. Sass, R.L. Schmidt, (1986), Chromium reaction in geological materials, Interim report, EPRI EA 5741, Palo Alto, Calif.
21. S.K. Sharma, B. Petrusevski, G. Amy, Journal of Water Supply: Research and Technology – Aqua, 57 (2008) 541 – 553.
22. Y.S. Dzyazko, A. Mahmud, F. Lapieque, V.N. Belyakov, Journal of Applied Electrochemistry, 37 (2007) 209 – 217.
23. N.N. Li and J.M. Calo, (1992) Separation and purification technology, CRC Press, PP. 198 – 199.
24. T. Araki and H. Tsukube (1990), Liquid membranes: Chemical applications CRC Press, pp. 35 – 36.

25. G. Pugazhenthi, S. Sachan, N. Kishore, N. Kumar, Journal of Membrane Science, 254 (2005) 229 – 239.
26. M. Muthukrishnan and B.K. Guha, Desalination, 219 (2008) 171 – 178.
27. M.K. Aroua, F.M. Zuki, N.M. Sulaiman, Journal of Hazardous Materials, 141 (2007) 752 – 758.
28. J. Bohdziewicz, Desalination, 129 (2000) 227 – 235.
29. A. Hafiane, D. Lemordant, M. Dhahbi, Desalinaton, 130 (2000) 305 – 312.
30. K. Thapa, (2009), Effect of water quality matrix M.Sc Thesis, UNESCO-IHE Institute for Water Education Delft.
31. N. Sapari, A. Idris and N. Hisham, Desalination, 106 (1996) 419-422.
32. S.H. Lin and C.D. Kiang, Chemical Engineering Journal, 92 (2003) 193-199.
33. N. Kabay, M. Arda, B. Saha, M. Streat, Reactive and Functional Polymers, 54 (2003) 103 – 115.
34. L.J.J. Janssen, L. Koene, Chem. Eng. J 85 (2002) 137 – 146.
35. J.P. Chen, S.Y. Chang, Y.T. Hung, Electrolysis, in: L.K. Wang, Y.T. Hung, N.K. Shammas (Eds.), Physicochemical Treatment Processes, vol. 3, Humana Press, New Jersey, 2004, pp. 359 – 378.
36. M. Owlad, M.K. Aroua, W. A. W. Daud, S. Baroutian, , Water Air Soil Pollution, 200 (2009) 59 -77.
37. P. Rana, N. Mohan and C. Rajgopal, Water Res. 38 (2004) 2811 – 2820.
38. S.A. Martinez, M.G. Rodriguez, R. Aguolar, G. Solo, Water Science and Technology, 49 (2004) 115 – 122.
39. N. Kongsricharoern and C. Polprasert, Water Science and Technology, 31 (1995) 109 – 117.
40. N. Kongsricharoern and C. Polprasert, Water Science and Technology, 34 (1996) 109 – 116.
41. T.A. Kurniawan, G.Y.S. Chan, W.H. Lo, S. Babel, Chemical Engineering Journal, 118 (2006) 83 – 98.
42. O. Tunay, N.I. Kabdasli, Water Res. 28 (10) (1994) 2117 – 2124.
43. Q. Li, J. Zhai, W. Zhang, M. Wang, J. Zhou, Journal of Hazardous Materials, 144 (2007) 163 – 167.
44. D. Mohan and C.U. Jr. Pittman, Journal of Hazardous Materials, 137 (2006) 762 – 811.
45. P. Chingombe, B. Saha, R.J. Wakeman, Carbon, 43 (2005) 3132 – 3143.
46. M.P. Candela, J.M. Martinez, R.T. Maria, Water Research, 29 (1995) 2174 – 2180.
47. D.C. Sharma and C.F. Foster, Water.S.A, 22 (1996) 153 – 160.
48. I. Han, M.A. Schlautman, B. Batchelor, Water Environment Research, 72 (2000) 29 – 39.
49. N.K. Hamadi, X.D. Chen, M.M. Farid, M.G.Q. Lu, Chemical Engineering Journal, 84 (2001) 95 – 105.
50. S.J. Park and W.Y. Jung, Carbon Science, 2 (2001) 15 – 21.
51. F.D. Natale, A. Lancia, A. Molino, D. Musmarra, Journal of Hazardous Materials, 145 (2007) 381 – 390.
52. C. Selomulya, V. Meeyoo, R. Amal, Journal of Chemical Technology and Biotechnology, 74 (1999) 111 – 122.
53. M. Kobya, Adsorption, Adsorption Science and Technology, 22 (2004) 51 – 64.
54. G.J. Alaerts, V. Jitjaturant, P. Kelderman, Water Science and Technology, 21 (1989) 1701 – 1704.
55. G. Cimino, A. Passerini, G. Toscano, Water Research, 34 (2000) 2955 – 2962.

56. K. Mohanty, M. Jha, B.C. Meikap, M.N. Biswas, Chemical Engineering Science, 60 (2005) 3049 – 3059.

57. T. Karthikeyan, S. Rajgopal, L.R. Miranda, Journal of Hazardous Materials, 124 (2005) 192 – 199.

58. C. Namasivayam and T. Ranganathan, Environmental Pollution, 82 (1993) 255 – 261.

59. S.K. Srivastava, V.K. Gupta and D. Mohan, Journal of Environmental Engineering, 123 (1997) 461 – 468.

60. S.K. Srivastava, R. Tyagi and N. Pant, Water Research, , 23 (1989) 1161 – 1165.

61. V.K. Gupta, D. Mohan, S. Sharma and K.T. Park, Environmentalist, 19 (1999) 129 – 136.

62. J. Pradhan, S.N. Das, and R.S. Thakur, Journal of Colloid and Interface Science, 217 (1999) 137 – 141. (Industrial waste adsorbents)

63. R.C.W. Berkeley, Chitin, Chitosan and their degardative enzymes. In R.C.W. Berkeley, C.W. Gooday & D.C. Elwood (Eds.). Microbial polysaccharides (pp. 205 – 236). New York: Academic Press.

64. P. Udaybhaskar, L. Iyengar and A.V.S.P. Rao, Journal of Applied Polymer Science, 39 (1990) 739 – 747.

65. R. Schmuhl, H.M. Krieg and K. Keizer, Water. S.A, 27 (2001) 1 – 7.

66. M.Y. Lee, K. J. Hong, Y. Shin-Ya, T. Kajiuchi, Journal of Applied Polymer Science, 96 (2005) 44 – 50.

67. N. Sankararamakrishnan, A. Dixit, I. Iyengar, R. Sanghi, Bioresource Technology 97 (2006) 2377 – 2382.

68. V.A. Spinelli, M.C.M. Laranjeira, V.T. Favere, Reactive and Functional polymers, 61 (2004) 347 – 352.

69. M. Sen and M.G. Dastidar, Iran J. Environ. Health. Sci. Eng. 4 (2001) 191 – 196.

70. A.H. Mahvi, R. Nabizadeh, F. Gholami, A. Khairi, Iran J. Environ. Health. Sci. Eng. 4 (2001) 191 – 196.

71. F. Gholami, A.H. Mahvi, G.A. Omrani, A.G.S. Nazmara, Iran J. Environ. Health. Sci. Eng. 3 (2006) 97 – 102.

72. S.A. Dean and J.M. Tobin, 27 (1999) 885 – 982.

73. C.M. Lytle, F.M. Lytle, N. Yang, J.H. Qian, D. Hansen, A. Zayed, N. Torey, Environmental Science Technology, 32 (1998) 3087 – 3093.

74. A. Khanafari, S. Eshgdoost, A. Mashinchian, Iran. J. Environ. Health. Sci. Eng. 5 (2008) 195 – 200.

75. K.S. Selvaraj, S. Manonmai, Pattabhi, Bioresource Technology, 89 (2003) 207 – 211.

76. S. Sarah, R. Middleton, L. Bencheikh, R. Mason, M. Mackey, H. Mark, B. Ellisman, M. Tebor, C. Craigs, (2003). Cometabolism of Cr (VI) by Shewanella Oncendensis MR – 1 produced cell associated reduced chromium and inhibit growth, Wiley Interscience.

77. T. Srinath, T. Verma, P.W. Ramteka, S.K. Garg, Chemosphere, 48 (2002) 427 – 435.

78. Z. Aksu and D. Akpinar, Biochemical Engineering, 7 (2001) 183 – 193.

79. P. Pattanpipitpaisal, N.L. Brown, L.E. Mabaskie, Biotech. Lett. 23 (2001) 41 – 43.

80. J. Campos, M. Martinez-Pacheco, C. Cervantes, Antonie Van Leeuwenhoek, 68 (1995) 203 – 208.

81. M. Nourbaksh. Y. Sag. Z. Ozer, Z. Aksu, T. Kustal, A. Caglar, Process Biochemistry, 29 (1994) 1 – 5.

82. S. Llovera. R. Bonet, M.D. Simon-Pujol, F. Congregado, Appl. Microbial. Biotechnol. 39 (1993) 424 – 423.

83. B. Barkhordar. M. Ghiasseddin, Iranian J. Health. Sci. Eng. 1 (2004) 58 – 64.

84. V.K. Gupta, A.K. Shrivastava, N. Jain, Water Research, 35 (2001) 4079 – 4085.

85. L. Travieso, R.O. Canizarez, R. Borja, F. Benitez, A.R. Dominguez, R. Dupeyron,V. Valiente, Bull. Environ. Contam. Toxicol. 62 (1999) 144 – 151.

86. M. Nourbaksh. Y. Sag. Z. Ozer, Z. Aksu, T. Kustal, A. Caglar, Process Biochemistry, 29 (1994) 1 – 5.

87. B. Volesky. (1990) Biosorption and biosorbents in Biosorption of heavy metals, ed. B. Volesky, CRC press Inc. Boca Raton.

88. M. Gulan. P. Keller, D. Malki, Science, 219 (1983) 285 – 286.

89. C.C. Townsley, J.S. Rose, A.S. Atkins, Biorecovery of metallic residues from various industrial effluents using filamentous fungi, In Fundamental and Applied Bio hydrometallogy, eds R.W. Lawrence, R.M.R. Brancon and H.G. Enner, Elsevier, Amsterdam, (1986) 279 – 289.

90. A. Kapoor. T. Viraraghavan, D. Roy Cullimore, Bioresource Technology, 70 (1999) 95 – 104.

91. M. Sen and M.G. Dastidar, Iran J. Environ. Health. Sci. Eng. 7 (2010) 182 – 190.

92. M. Sen and M.G. Dastidar, Asian Journal of Chemistry, 22 (2010) 2331 – 2338.

93. M. Sen. M.G. Dastidar, P.K. Roychoudhury, Enzyme and Microbial Technology, 41 (2007) 51 - 56.

94. M.Sen. M.G. Dastidar, P.K. Roychoudhury, American Society of Civil Engineers (ASCE), Prac. Period. Hazard. Toxic Radioact, Waste Management, 9 (2005) 147 – 151.

95. P. Pattanpipitpaisal, N.L. Brown, L.E. Mabaskie, Biotech. Lett. 23 (2001) 41 – 43.

96. R.S. Prakasham, J. S.M. Sheela, N. Saswathi, S.V. Ramakrishna, Environmental Pollution, 104 (1998) 421 – 427.

97. M. Pillichshammer, T. Pumpel, R. Poder, K. Eller, J. Klima, F. Schinner, 8 (1995) 117 – 121.

98. A.I. Rapport, O.A. Muter, Process Biochemistry, 30 (1994) 145 – 149.

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 9.0 Uranium Removal from Water

## 9.1 Introduction

Uranium, since its discovery in 1789 by Martin Klaporth is best known and is feared for its involvement in nuclear energy. Uranium is a radioactive metal which occurs naturally in low concentrations (a few parts per million) in soil, rock, surface water and ground water. Uranium is the heaviest natural element, with an atomic number of 92. Uranium in its pure form is a silver – coloured heavy metal that is nearly twice as dense as lead. Uranium occurs naturally in the +2, +3, +4 and +6 valence states, but it is most commonly found in the hexavalent form. In nature, hexavalent uranium is commonly associated with oxygen as the uranyl ion, UO22+. Naturally occurring uranium is a mixture of three radionuclides ($^{234}$U, $^{235}$U and $^{238}$U), all of which decay by both alpha and gamma emissions. Natural uranium primarily consists of $^{238}$U (99.274%), along with $^{235}$U (0.72%) and $^{234}$U (0.0057%) by weight. Uranium is widespread in nature, occurring in granites and various other mineral deposits.

Uranium is present in the environment as result of leaching from natural deposits, release in mill tailings, emissions from the nuclear industry, the combustion of coal and other fuels and the use of phosphate fertilizers that contain uranium. Uranium leaching from natural deposits, mining and other industrial activities can contaminate air, water and soil. Intake of uranium through air is extremely low, and it appears that intake through food is between 1 and 4 µg/day. Intake through drinking water is normally low; however, in circumstances in which uranium in present in a drinking water source, the majority of intake can be through drinking water. The chemical toxicity of the metal constitutes the primary environmental health hazard, with the radioactivity of uranium a secondary concern.

## 9.2 Health Effects of Uranium

Naturally occurring uranium has very low levels of radioactivity. However, the chemical properties of uranium in drinking water are of great concern than its radioactivity. However, a small amount is absorbed and carried out through the bloodstream. Studies show that drinking water with elevated levels of uranium can affect the kidneys over time. Bathing and showering with water containing uranium is not a health concern.

## 9.3 Standards and Guidelines

The WHO, Health Canada, Australia and USEPA drinking water guidelines fixed the maximum uranium concentration in drinking water to be less than the values given below in Table 1.

**Table 9.1**

**Guideline values for maximum uranium concentration in drinking water**

| S. No | Agencies | Maximum permissible limit (µg/L) | Reference |
|---|---|---|---|
| 01. | World Health Organisation (WHO) | 9 | WHO (2003) |
| 02. | Environmental Protection Agency, United States of America (USEPA) | 30 | T.E. Milja et al., (2011) |
| 03. | Health Canada | 20 | A.P. Gillman et al., (1998) |
| 04. | Australia | 20 | A.P. Gillman et al., (1998) |

## 9.4 Analytical methods

Following analytical methods can be used for the measurement of uranium in water.

- Uranium in water is most commonly measured by using solid fluorimetry with either laser excitation or ultraviolet light following fusion of the sample with a pellet of carbonate and sodium fluoride. The detection limit of this method is 0.1 µg/L. The main demerit of this method is sample preparation which is tedious and also, there is interference from other metals.
- Uranium can also be determined by inductively coupled plasma mass spectrometry with the detection limit of 0.1 µg/L and a between – run precision of less than 6%.
- Alpha – spectrometry has been used for the determination of uranium in bottled waters and environmental media, although the recovery is often highly variable owing to the low specific activity of natural uranium.

## 9.5 Control methods and technical achievability:

A review of various treatment technologies for uranium removal from water and their technical achievability as reported by various researchers are given below in Table: 2.

**Table 9.2**

**A review of control methods for uranium removal from water and their technical achievability**

| S. No | Treatment methods | Technical achievability (%) | Reference |
|---|---|---|---|
| 01. | Coagulation/filtration at high pH (10+) | >95 | Aieta et al., (1987) |
| 02. | Lime softening | 85 – 99 | Aieta et al., (1987) |
| 03. | Anion exchange | 99 | Aieta et al., (1987) |
| 04. | Reverse osmosis | >95 | Aieta et al., (1987) |
| 05. | Coagulation/filtration | 80 – 89 | Lowry & Lowry (1988) |
| 06. | Lime softening | 85 – 99 | Lowry & Lowry (1988) |
| 07. | Anion exchange | 90 – 100 | Lowry & Lowry (1988) |
| 08. | Reverse osmosis | 90 – 99 | Lowry & Lowry (1988) |
| 09. | Activated alumina | 90 | Lowry & Lowry (1988) |

## References

1. T.E. Milja, K.P. Prathish, T.P. Rao, Journal of Hazardous Materials, 188 (2011) 384 – 390.
2. M. Giddings, and J. Fawel, Uranium in drinking water, Background document for development of WHO guidelines for Drinking Water Quality, 2004.
3. C.R. Cothern and W.L. Lappenbusch, Health Physics, 45 (1983) 89 – 99.
4. D.R. Lide, ed. (1992 – 1993) Handbook of chemistry and physics. Boca Raton, FL, CRC Press.
5. D. Brugge and V. Buchner, Rev. Environ. Health, 26 (2011) 231 – 249.
6. C.E. Roessler, Z.A. Smith, W.E. Bolch, R.J. Prince, Uranium and radium – 226 in Florida phosphate minerals. Health Physics, 37 (1979) 267 – 269.
7. Fact sheet, Connecticut Department of Public Health, Environmental & Occupational Health Assessment Program, Hartfort. (www.state.ct.us/dph).
8. WHO: Guidelines for Drinking Water Quality, 3rd edition, 2003.
9. A.P. Gilman, D.C. Villencuve, V.E. Seccours, A.P. Yagminas, B.L. Tracy, J.M. Quinn, V.E. Valli, R.J. Willes, M.A. Moss, Toxicol. Sci. 41 (1998) 117 – 128.
10. H.L. Kreiger and E.L. Whittaker EL (1980) Prescribed procedures for measurement of radioactivity in drinking water. Washington DC, US Environmental Protection Agency (EPA-600/4-80-032).
11. D.W. Boomer and M.J. Powell, Analytical Chemistry, 59 (1987) 2810 – 2813.
12. I. Gans, The science of the Total Environment, 45 (1985) 93 – 99.
13. N.P. Singh and M.E. Wrenn, The Science of the Total Environment, 70 (1988) 187 – 203.
14. E.M. Aieta, J.E. Singley, A.R. Trussel, Journal of the American Water Works Association, 79 (1987):144 – 152.
15. J.D Lowry and S.B. Lowry, Journal of the American Water Works Association, 80 (1988) 51 – 64.

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

# 10.0 Behavioural, Motivational and Community Support

## 10.1 Preamble

In India it is observed that a particular water treatment technology remains in operation at a place, whereas same technology becomes dysfunctional at another place. This indicates that other factors such as behavioural, motivational and community support is required for successful operation of any technology. The use of technologies to treat water in community and household is best accomplished if it is accompanied by or supported with economic incentives and other cost recovery methods and with programs designed to support community participation, education and other efforts to achieve acceptance and sustainability. Government of India through Ministry of Drinking Water and Sanitation offers economic incentives for provision of safe water at community level which also include provision of water treatment in quality affected habitations.

Information, education and communication (IEC) combine strategies and methods that enable individuals, families, and communities to play active roles in achieving, protecting and sustaining services such as water supply system. IEC is an important component of any development programme particularly related to water and environmental sanitation. The failure of Central Rural Sanitation Programme of Department of Drinking Water Supply was due to lack of demand, lack of participation in programme implementation and, lack of awareness among the community regarding health and hygiene aspects of safe drinking water and clean sanitation facilities. Therefore, it is proposed to educate the public; create awareness among them regarding health effects of poor water quality; provide integrated mitigation solutions including water treatment; and create long term success by facilitating community involvement and ownership by integrating IEC with IFM. The available IEC material on fluorosis mitigation concentrates simply on health effects of excess fluoride in drinking water and defluoridation of water particularly using activated alumina filter.

Managing water supply and treatment is evolving concept and an appropriate IEC material will help to popularize the concept particularly among rural community. Water treatment technologies discussed in this Guidance Manual are meant for application in rural areas and IEC will be an important component for making the manual effective. The IEC material should be developed in local language considering socio-cultural conditions and disseminated to reach panchayat level. Wherever socio-cultural, behavioural and economic components in community and household water treatment and storage technologies are lacking, sustainable implementation, operation and maintenance of these technologies is difficult.

It is recognised that provision of safe water is not only due to lack of treatment technologies or funding, but because lack of community involvement, failure in adopting proper business model, cultural attitudes and behaviour towards treating water to be free commodity and being always safe. Microbial contamination prevails in the areas where open defecation is the practice, people and officials responsible for rural water supply must make a radical shift in their cultural practice of disposing human waste and learn to take charge of their water supply and sanitation needs. In villages, people should be convinced to stop open defecation and try using indoor facilities, along with other hygienic practices (e.g., washing of hands, safe preparation of food). A combination of factors traps them into this practice, including tradition, lack of awareness about the importance of sanitation, and misconceptions about the costs involved. In addition, communities should be explained that water treatment is not only to be managed by engineers and technocrats however, should be collective responsibility. For policymakers and program implementers, experience has shown that information, education, and communication (IEC) campaigns involving communities and grassroots organizations can accelerate the process of change and hasten the adoption of treatment technologies.

It is to be understood that demand for safe water provision naturally comes fromwomen, as they bear maximum brunt of non-availability of these facilities. Womenhave, by far, the most important influence in determining household hygiene practices andin forming habits of their children. It is observed that social marketing of many sanitation programs often starts with making house-to-house contact to educate and motivate women in target communities. Similar approach can be adopted in managing water treatment assets and women can play greater role in this sector. Some of the more successful interventions rely on empowering people to analyze their own environment and water requirement, instead of implementing off-the-shelf models. This grassroots approach of some of the successful sanitation programme can also be adopted which will help people to recognize that they need provision of safe water; that they should mobilize themselves to at least operate and maintain water supply schemes if not able to construct it. It should also be realised that everyone in the village needs to contribute to make the effort successful, including planning, implementation, and monitoring.

Intensive awareness campaign should be undertaken with respect to the adverse health effects of contaminated drinking water to motivate community to adopt preventive measures in cooperation with local bodies, NGOs and others. All modes of IEC tools such as mass media and communication facilities of government / nongovernmental organization(s) in this matter for increasing the awareness should be explored and used. Specific communication materials such as posters, leaflets and brochure should be developed for this purpose considering local contaminants and socio-cultural background. These activities should be undertaken in an integrated and coordinated manner combining the health and water supply interventions.

Training need assessment should be undertaken after situational analysis related to water safety and treatment and an appropriate mechanism for capacity-building and institutional development should be established. Continuous education programme for doctors and paramedical staff, water supply engineers and laboratory staff should be established. There should be exclusive training programme for water supply engineers in designing, operating and maintaining treatment plants with inclusion of role of community in managing the system.

The information, education, and communication (IEC) activities should form an integral part of the water treatment technologies in order to educate the general public and professional organizations on contamination of drinking water. Integrate the arsenic-related disease surveillance into other national disease surveillance programmes (e.g. National Cancer Surveillance) and activities relating to nutrition and reproductive health. Improved community mobilization can result in better actions at the local level and operation and maintenance of water treatment plants. Earlier examples of such intervention in eradication of polio through community-centred, nationally-driven vaccination schemes, demonstrate that it is achievable.

## 10.2 Techniques for IEC

There are various techniques of communication, which include mass communication as well as inter personal communication. These techniques can be applied for IEC on IFM.

### 10.2.1 Mass Communication

Mass Communication technique helps in providing information to large audience in a short time. The communication process is information centered for awareness creation. In certain case, it results into change in cognitive level but change of attitude for expected behavioural change cannot be achieved through mass communication.

### 10.2.2 Mass Media

- Electronic Media: message through radio, television, documentary and short films
- Print Media: Information booklets, flash card, posters, flip charts, leaflets, pamphlets, newsletter / bulletins, calendars, wall writing, newspaper, magazine

### 10.2.3 Traditional Media

- Folk Media: Performance attracts audience and reaches all (Folk songs, street plays, puppet shows / drama)
- Rural Resources: Wall painting slogans, exhibition, banner display during fairs and festivals, bulletin or public notice boards, drum beater, local entertainment artists.

### 10.2.4 Interpersonal Communication

Interpersonal communication differs from other forms of communication in which few participants are involved, the interactions are in close physical proximity to each other and feedback is immediate. The campaigner should introduce himself / herself to local authorities, local leaders and community and brief them about the programme. This will make the work easier and help the programme managers to get adequate support from everybody. Home contact drive, group meetings, focus group discussion etc. are a part of interpersonal communication. Some of the individuals and institutions that could be effectively involved for creating awareness are school teachers and children, Anganwadis workers, scout and guides, NSS, NCC, health workers, PHED staff and community based organizations.

## 10.3 Partnerships for Improved Management of Water Supply

Water supply services particularly involving water treatment should encourage partnership to improve service coverage and quality. This partnership can come from wide range of sources as possible, including the private sector and the consumers themselves. Successful public–private partnership (PPP) models can help to overcome the limitations of local governments, which are under tremendous pressures due to various reasons.

Partnership among the public and private agencies, with the involvement of community networks, such as NGOs and CBOs have proven to be successful in water and sanitation sector. There is transition among several Indian NGOs that have actually crossed over to become formal private operators while retaining their NGO character. It is pertinent to note that public-private-partnership is being exercised extensively in urban water supply and gradually private sector is being invited to operate in rural water supply in some of the states in India.

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

ANNEXURE I

# I. Salient features of water purifiers available in the market

### i. Arogya Water Filter

In collaboration with TATA Consultancy Services Ltd., Pune, Centre of Science for Villages (CSV), Wardha has introduced a low cost water filter known as Arogya water filter.. This filter generally uses rice husk ash, pebbles and a binder for the fabrication of the filter bed. Various types of containers can be used for housing the bed. These can be plastic buckets, plastic pipes or even earthen pots. The choice depends upon requirement and affordability. The filter can be produced either in a factory setting by a village entrepreneur or can be made in a 'do-it-yourself' mode. The filter is very cheap and can be fabricated at the village level by the women folk, with very little investment. The filter is very hygienic and kills about 98% bacterial in the water and keeps it free from fluorides and arsenic. Village women have now come out with a Programme of manufacturing initially 1000 filters and they have already started working on the same.

**Figure 1:** Arogya Water Filter

### ii. Tata Swach

Tata Swach purifier is an offline household water purification system which uses natural materials and nanotechnology to deliver safe and affordable drinking water. Tata Swach has following features:

**Figure 2:** Tata Swach

- Does not require electricity or running water, thus, making it feasible for use in both urban and rural areas.
- Does not use chemicals such as chlorine, iodine or bromine
- Contains the bulb that uses patented TSRF technology to destroy harmful bacteria and viruses in water
- Includes a Fuse system that prompts the user well in advance that it is time to replace the bulb. Blb shuts down automatically once its purification power is exhausted.
- Each bulb purifies 3,000 litres of safe drinking water
- Water purifier is made of natural rice husk and nano-silver particles.
- Tata Swach purifies a litre of water at a cost of a mere 10 paise

### iii. Water Guard – Spring by Usha Shriram Brita Pvt. Ltd

**Principle:** This is gravity water filter working on natural pressure and without electricity. USB's purifier technology is iodinated base resins. This is filtration media where iodine is bound to a positively charged structure. Waterborne bacteria and viruses are negatively charged, so the positive charge attracts these contaminants, and then iodine is released to penetrate and kill the microorganism. This attraction reduces the contact time necessary to inactivate the microorganisms. This system, is capable of treating 20 minutes/ liter, was found to reduce E. coli by greater than 6 log reduction (99.9999%), and MS-2 bacteriophage (a surrogate for viruses) by greater than 99.9%. Iodine is removed by the carbon filters.

### Process development

Water Guard Spring is a fully integrated, gravity – fed microbial water treatment system designed for use at the household level with water of unknown microbiological quality. It was also intended to produce a sufficient volume of water to meet the average household demand for drinking water and to do so below a 0.15 Rupee/liter target cost to consumers. This is designed to give 10.5 liter purify water within 3 hour. There are three stages in purifier:

**Pre-sediment Filter:** This is made by non woven poly propylene cloth to trap physical impurities from the water. The pre size of this filter is 5 µm.

**Health Cartridge (HC):** This yellow cartridge contains Iodine resin, which is contact type of disinfection by iodine-based resin formed by adsorption of iodine on a strong alkaline anion exchange resin. Water are get in contact with residues of Iodine for 20 ± 03 minute/liter, this contact time removes all of bacteria, virus as well as protozoa.

**Taste Cartridge (TC):** This white cartridge contains 0.2% silver impregnated 16 x 50 ASTM GAC (Granular Activated carbon) which not only remove all residues of Iodine but also recover quality of water by removing pesticides, insecticides, trihalomethane, PAHs and bad odor, taste and color. 0.2% silver gives bacteriostatic property in water and increase shelf life.

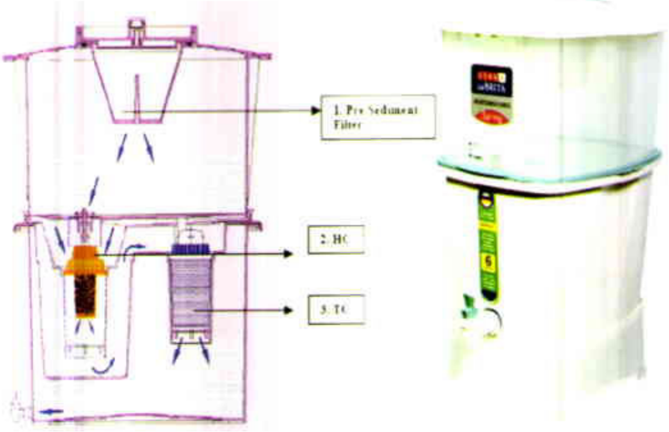


**Figure 3:** Schematic drawing of the treatment unit

**Process of reaction:** The design of system is patented and made as so that water should be getting in contact with iodine residue in reaction chamber between HC and TC for at least 20 ± 03 minute/liter. This much of contact time is enough to remove all type of micro-organisms. After all water getting contact with TC (contain –GAC) which removes all residues of Iodine and made water potable.

**Cartridge Life and replacement:** The average amount of water would be treating by consumable i.e. cartridges (HC and TC) are 1500 litres or six months, which is earlier. Replace the cartridge after same.

**Tentative capital cost for various capacities:** 1100 INR – 17 liter

**Capital cost for per KL:** 733.0 on first purchase with system and 333.00 for per KL to change cartridge.

### iv. Systems by Ion Exchange India Pvt. Ltd. Mumbai

a. **Zero B Suraksha plus** (Purifier cartridge with modular plastic containers) by

**Principle:** Disinfection by poly iodinated resin + Activated carbon Adsorption

**Process:**

- Inlet water passes through filter dome of 5-10 micron which removes sand, silt and turbidity
- The filtered water passes through polyiodinated resin, it releases small amount of iodine in a controlled fashion. The leached out iodine on contact kills bacteria and viruses.
- Bacteriostactic Activated carbon at the final stage removes excess Iodine, bad taste, odour and colour from the water.

**Specifications:** Cumulative Flow rate = 500 ml/min; Life = 3000 litres; Non electric

**Capital cost:** Rs. 2090/-

b. **Suraksha plus mataka purifier** (purifier cartridge in bucket placed on matka)

**Specifications:** Cumulative Flow rate = 500 ml/min; Life = 3000 litres; Non-electric

**Capital cost:** Rs. 500/-

c. **Suraksha Matka purifier** (purifying element in bucket placed on matka).

**Specifications:** Flow rate =1000 ml/min; Life = 7000 liters; Exhaust indicator; Non electric

**Capital cost:** Rs. 300/-

### ONLINE CUM STORAGE TYPE WALL MOUNTED PURIFIER

d. **Zero B Solar -7 K** (Solar powered End of life indicator) cartridges

**Principle:** Disinfection by poly iodinated resin

**Process**

- Inlet water passes through sediment of 10 micron which removed sand, silt and turbidity
- Filtered water passes through poly iodinated resin which provides germicidal protection.
- Medium at the next stage removes heavy metals like lead and Aluminum from the incoming water
- Bacteriostactic activated carbon at the final stage removes excess Iodine, bad taste, odour, and colour from the water.

**Specifications:** Flow rate =2 L/min; Life = 7000 liters; Solar intelligence; Non electric

**Capital cost:** Rs. 7500/-

### ONLINE TAP ATTACHMENT

e. **Zero B Suraksha**

**Principle:** Disinfection by poly iodinated resin

**Process:**

- Inlet water passes through a filter pad of 25 micron for removal of particulate.
- When the filtered water passes through polyiodinated resin, it releases small amount of iodine in a controlled fashion. The leached out iodine on contact kills bacteria and viruses.

**Specifications:** Flow rate =1000 mL/min; Life = 7000 liters; Exhaust indicator; Non-electric; Solar intelligence;

**Capital cost:** Rs. 295/-

## ONLINE WATER PURIFIER FOR COMMUNITY

f. **Zero B Solar – K series** (Solar powered End of Cartridge life indicator) 50 K, 75 K, 100 K.

**Principle:** Disinfection by poly iodinated resin

**Process:**

- Inlet water passes through a 10 micron filter which removes sand, silt and turbidity.
- The filtered water passes through polyiodinated resin which gives germicidal protection.
- Bacteriostatic activated carbon at the final stage removes iodine, bad taste, odour and colour from water.

**Specifications:** Flow rate =4 L/min; Life = 50,000 liters, 75,000 litres, 1, 00,000 litres; Solar intelligence; Non-electric

**Capital cost:** Rs. 15,000/- ; 17,000/-; 25,000/-

g. **Zero B Solar K series with heavy metal removal system for community**

**Principle:** Disinfection by poly iodinated resin + Adsorption

**Process:**

- Same as Zero B K series
- The heavy metal removal medium at the next stage removes metals like lead and aluminum from the incoming water.

**Specifications:** Flow rate =3 L/min; Life = 50,000 liters; Solar intelligence; Non-electric

**Capital cost:** Rs. 17,500/-

h. **Ecopuriline**

**Principle:** Disinfection by poly iodinated resin + Adsorption

**Process:**

- Inlet water passes through a 10 micron filter which removes sand, silt, and turbidity
- The filtered water passes through polyiodinated resin which gives germicidal protection.
- Bacteriostatic activated carbon at the final stage removes excess iodine, bad taste and colour from water.

**Specifications:** Flow rate =4 LPM; Life = 40,000 liters.

**Capital cost:** Rs. 9,731/-

## ONLINE SOLAR POWERED WATER PURIFIER

i. **Solar puriline**

**Principle:** Disinfection by silver ionization purification system

**Process:**

- Sediment filter at the first stage removes sand, silt, and turbidity
- The electrolytic purification system disinfects water by silver ions, hydroxyl radicals and nascent oxygen.
- Bacteriostatic activated carbon at the final stage removes excess iodine, bad taste and colour from water.

**Specifications:** Flow rate = 120 L, 250 LPH, 500 LPH, 1000 LPH, 2000 LPH; Solar and Electric

**Capital cost:** Rs.15000/-; 17,500; 20,000/-; 23,000/- and 30,000/-.

j. **Name of the system: Jalshudhi tablet**

**Principle:** Disinfection and flocculation

**Process:**

- Jalshudhi contents are added to raw water. The treated water is allowed settle, it is then passed through a filter. Water is disinfected by chlorine releasing compounds.

**Specifications:** One sachet treats 20 litres of water

**Capital cost:** Rs.3/-

### v. Pureit Hindustan Unilever Limited. Mumbai

Pureit in –home purification system uses a 4 stage purification process to deliver "as safe as boiled water" without the use of electricity and pressurized tap water. Pureit purifies the input drinking water in four stages, namely,

- **Micro-fiber MeshT™** – Removes visible dirt
- **Compact carbon Trap™** – removes remaining dirt, harmful parasites and pesticide impurities
- **Germkill Processor™** –uses 'programmed chlorine release chlorine technology' and its stored germ kill process targets and kills harmful virus and bacteria.
- **Polisher™**– removes residual chlorine and all disinfectant by-products, giving clear odourless and great tasting water.
- **Battery Life Indicator** – Ensures total safety because when the germ kill power is exhausted, the indicator turns red, warning you to replace the battery.


Pureit - Blue Pureit - Maroon

**Figure 4:** Pureit purifier systems

Pureit runs with a unique "Germkill Battery Kit"™ that typically lasts for 1500 litres of water. The "Germkill Battery Kit"™ is priced at Rs. 365/-. This means consumers gets 4 liters of water that is "as safe as boiled water" for just one rupee, which works out to an extremely affordable 24 paise per litre.

For more information go through: www.pureitwater.com

### vi. Aqua guard water purifiers by Eureka Forbes

They have developed a range of water purifiers which mostly use the e-boiling, reverse osmosis and ultraviolet technology for water purification.

For more information go through: www.eurekaforbes.com

**Figure 5:** Aqua guard Classic

### vii. Pot Chlorinators for Disinfection of Dug Well and Storage Tanks Waters

NEERI has developed simple chlorination system which is suitable for disinfection of dug wells and storage tank waters. The systems maintain the residual chlorine concentration of 0.2 to 0.5 mg/L in waters for nearly 15 to 20 days ensuring bacteriologically safe drinking water. There are two types of pot chlorinators single pot and double pot depending on the quantity of water to be disinfected.

In a single pot chlorinator, earthen pot of 7 to 8 L capacity is used and is suitable for community dug wells and storage tanks of 9000 to 13000 L capacity. Dry mixture of 1.5 kg bleaching power (BP), sodium hexametaphosphate (5% of BP) and 3 kg coarse sand is placed in the pot over the pea gravel. Addition of sodium hexametaphosphate helps in prolonging the chlorination period. Pot is lowered in the well/tank and kept 0.9 to 1.2 m below water level with the help of rope. One pot is enough for daily drawl of 900 to 1300 L (40-50 people per day). With higher drawl rates two pots are necessary per well.

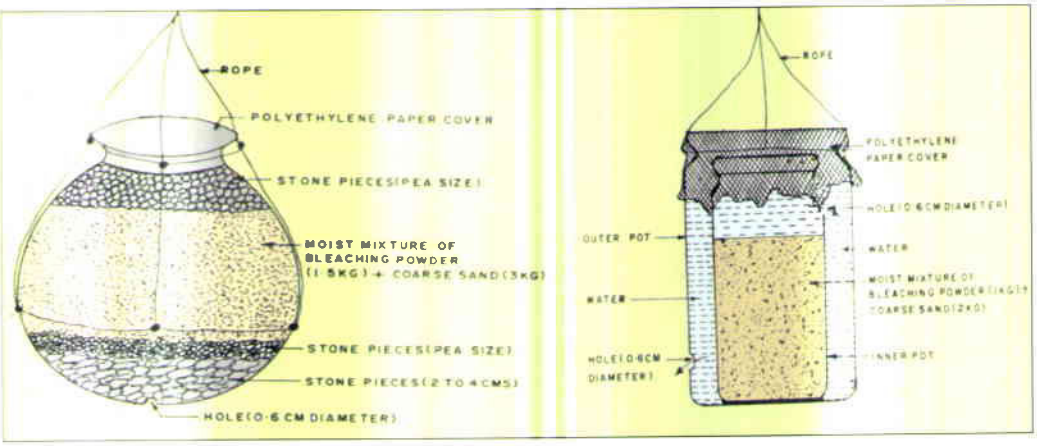


**Figure 6:** Schematic diagram of Pot Chlorinators

Double pot system is suitable for household dug wells of 4000 L or less capacity having withdrawal rate of 360 to 450 L of water per day. The unit consists of two cylindrical pots, one inside the other. Moist mixture of 1 kg bleaching power (BP) and 2 kg of sand is kept in the inner pot with 0.6 cm diameter hole above the level of sand and BP mixture. Pot is lowered in the well and kept 0.9 to 1.2 m below water level with the help of rope.

The pot chlorinators can also be used for disinfection of bacteriologically contaminated potable water sources during emergency situations such as cyclones and floods.

### viii. Puritech (Nanosilver coated Ceramic Candles) by ARCI, Hyderabad & SBP Aquatech Pvt. Ltd.

**Figure 7:** Puritech (Nanosilver coated Ceramic Candles) by ARCI

At ARCI, Hyderabad, the conventional method of ceramic candle filtration has been combined with nanotechnology to produce nanosilver coated Ceramic Candle Filters. In India, several people depend on these filters because they remove turbidity but by adding nanosilver into the same material, water is also being disinfected from bacteria, providing a low cost and convenient solution. The antibacterial effect of the nano silver coated ceramic drinking water filter conforms to IS 1622:1981 for E-coli and was also put on field trials in rural areas in collaboration with the Byrraju Foundation. The price of the candle is ` 75 (£1). One disadvantage is that chemicals, if present in the water, remain. The main aim of this project is making all the household drinking water free of contamination bacteria and viruses. The ARCI technology for nanosilver based candle filter has been transferred to SBP Aquatech Pvt. Ltd., a Hyderabad company, which will have an initial capacity to product 500 candles a day.

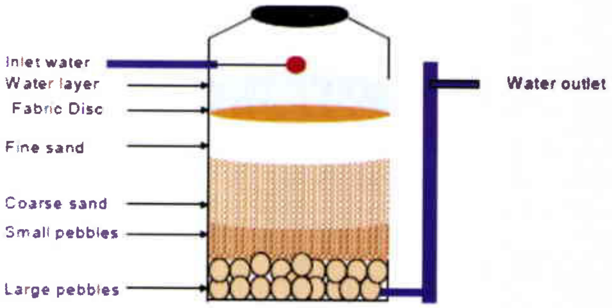
**Contact details:**

**SBP Aquatech Pvt. Ltd.**
G.Bharatkumar
gbkumar2@gmail.com
Hyderabad-500659
www.sbptechnology.com
Phone: 040-64594712

### ix Jal-TARA Water filter-A Slow sand filtration system at community level

The Jal-TARA water treatment system is a revolutionary approach employing the technique of slow sand filtration. Slow sand filtration ensures a simultaneous bacteriological, chemical and physical improvement in water quality comparable to the natural percolation of water through underground strata.

Jal-TARA Filter is designed to treat drinking water using slow sand filtration technique. The main principle of Jal-TARA water filter is based on the traditional process of slow sand Filtration system. Filter is a biological filter merged with advanced technique of Fabric protection to improve and simplify the traditional process of slow sand filtration. Generally two types of filtration processes take place in the filter, viz. Physical filtration and Biological Filtration, the fabric filter prevents most organic matter, silt and mud particles from passing through. Biological community builds up on fabric filter and sand bed, scavenging and breaking down pathogens and organic matter in the raw water.



Inner View of Jal-TARA Filter

**Figure 8:** Jal-TARA filter

Jal-TARA filter is standardized in 1000 litres water tank with the output water supply of 2500-3000 litres per day. The filter contains pebbles and sand of different sizes. System is provided with a synthetic fabric filter designed with advanced technique of fabric protection. The system can be fed under gravity flow or through conventional pumps or operated by solar photo-voltaic. It is replication of natural water seepage as in ground aquifer. However, particle size of sand plays an important role in efficiency.

Large and fine particles of suspended matter are deposited on the surface of the filter bed by the action of mechanical straining and sedimentation respectively. The colloidal and dissolved impurities are removed by adsorption, whilst the organic matter is converted into organic salts by the purification mechanics. The filtered water is collected at the bottom via pipe system. Most microbiological action takes place in the' Schmutzdecke' (Bio- film) formed in the fabric filter at the top of the filter and top of the sand bed. Jal-TARA filter.

**Contact details:**

B-32, TARA Crescent, Qutab Institutional Area, New Delhi – 110 016
Phone : 011-2685 1158, 2696 7938
Fax : 011-2686 6031
E-mail :temf@devalt.org

### x. Household-based Ceramic Water Filter

**Figure 9:** Filter with one ceramic candle in plastic vessels on the left side and on the right side different types of ceramic candles. Source: CAWST (2009)

Ceramic candle filters are simple devices made out of clay and used to filter drinking water in order to removes turbidity, suspended materials and pathogens. Removal takes place by physical process such as mechanical trapping and adsorption on the ceramic candles, which have micro-scale pores. Water is poured into the upper of two container and flows through a candle situated in the bottom. Once the water has passed through the candle, it is collected in the lower container. This system both treats the water and provides safe storage until it is used. The filters are easy to assemble and no energy is required. Maintenance includes frequent scrubbing with a brush and proper care during transport and its use.

The candles are made up of clay and the container can be made from plastic, aluminium, cσpper, steel or clay material. Though clay containers keep water cold and tasty, due to its fragile nature other materials nowadays replace it.

Ceramic candle filters are easy to set up and operate, cheap and effective in removing bacteria, ***protozoa, helminths*** and turbidity from water. It also removes some viruses and iron and taste, smell and colour of water are improved. But due to the limited *flow rate* (i.e. 1-2liter/hour) and storage capacity, filters are only suitable for small families, organizations or school classroom. It is suitable where drinking water is little turbid (<5NTU) and contaminated and with little iron (<0.3mg/L). In the case of too high turbidity, water can be presettled. Chlorinated water should not be used in candle filters! Except for clay, filter containers of other materials are easy to transport and handle. The capital cost of this filter is US$15-30

### xi. Household Biosand Filter

The biosand Filter (BSF) is a simple household water treatment device, which is an innovation on traditional slow sand filters specifically designed for intermittent use. A BSF consists of a concrete or plastic container filled with specially selected and prepared sand and gravel. As water flows through the filter, physical straining removes pathogens, iron, turbidity and manganese from drinking water. A shallow layer of water sits atop the sand and a biofilm (Schmutzdecke) develops. The biofilm contributes to the removal of pathogens due to predation and competition for food of non-harmful microorganisms contained in the biofilm and the harmful organisms in the water.

The filter container can be made of concrete, plastic or any other water-proof, rust-proof and non-toxic material. The most widely used version is however the concrete container, approximately 0.9 m tall and with a surface of 0.3 m2 (Lantagne 2006). The concrete filter box is cast from a steel mold or made with a pre-fabricated pipe (CAWST 2009a). The container is filled with layers of sieved and washed sand and gravel, also referred to as filter media (CAWST 2009a). There is a standing water height of 5 cm above the sand layer, which is maintained by adjusting the height of the outlet pipe (Lantagne 2006; CAWST 2009a). A diffusion layer avoids that water reaches the sand surface too fast, which could disturb the biofilm layer. The filter operation is very simple. Concrete filters have the outlet pipe embedded in the concrete, protecting it against breaks and leaks (CAWST 2009a).

**Figure 10 :** Plastic version of biosand filter connected to traditional water storage recipient (canari). Source: A. DOUCET - left, HydrAid – right

*Pathogens* and suspended solids are removed through a combination of biological and physical processes that take place in the biofilm layer and within the sand layer. These processes include mechanical trapping, predation, *adsorption,* and natural death (Ngai et al. 2007; EAWAG/SANDEC 2008; CAWST 2009a)

### xii SODIS

When microbially polluted water is exposed to solar light in transparent PET bottles, bacteria, virus and some parasites are inactivated by the solar UV-A radiation. 1 to 2 litres of water are filled into clean bottles and exposed to the sun for at least 6 hours if the sky is bright. UV-A radiation is strongly attenuated by clouds; furthermore, turbidity or water depth protects the pathogens from UV-A radiation. Hence the process depends strongly on the local climate, and only low volumes with relatively low turbidity can be treated at a time. Solar Water Disinfection (SODIS) is extremely low-cost and simple and is one of the WHO recommended household level water treatments.

SODIS is a simple water treatment technology that can be used at household level. As a point-of-use water purification method, SODIS improves the microbiological quality of drinking water with solar radiation at almost zero investment and maintenance costs. Today, SODIS is one of the recommended household level water treatment technologies by the World Health Organisation (WHO).

**Figure 11:** Corrugated iron sheets are the best bottle supports for *SODIS.* (Source: http://www.ziemia.org/.../sodis/Sodis-in-Bolivia.jpg)

PET (Polyethylene terephthalat) bottles or plastic bags with a volume of 1 to 2 litres are filled with water of low turbidity and exposed to the sun for a certain time, depending on the local weather conditions. The SODIS reference centre (www.sodis.ch) recommends, that 6 hours are sufficient under bright to 50% cloudy sky, whereas 2 days of exposure are required for 100% cloudy sky (OATES 2003, EAWAG/SANDEC 2006). The treatment efficiency can be improved if the plastic bottles are exposed on sunlight-reflecting surfaces such as aluminium- or corrugated iron sheets (MEIERHOFER 2002). During periods of continuous rainfall, SODIS does not perform satisfactorily and rainwater harvesting is recommended during these days.

## II. Available Electrochlorinator

### i. ENCEE CHLOR Generator:

ENCEE CHLOR is a unique onsite Sodium Hypo Chlorite Generator. It's an ideal, convenient and economical solution to water disinfection system using chlorination (Fig. 12 & 13). The generation of Chlorine is instantaneous and provides maximum safety to operating personnel as the Hypo chlorite generated is at 1 % concentration and at these concentrations it is absolutely safe for handling.

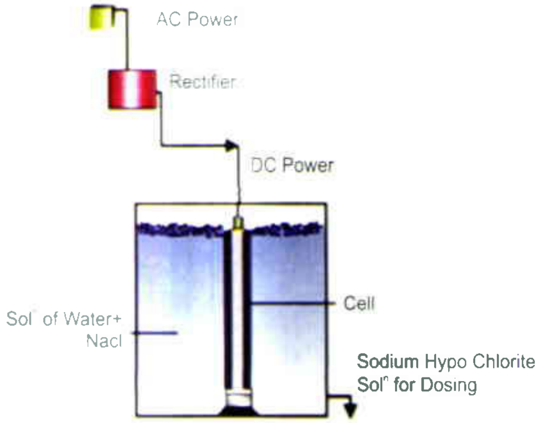


Figure 12: Electrochlorinator

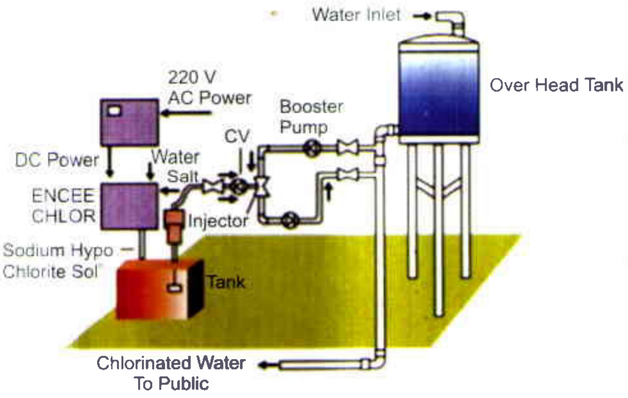


Figure 13: Electrochlorinator OHT installation

**Contact details:**

**NAGPUR AQUATECH (P) LTD.Works (Nagpur)**
K - 60, MIDC, Hingna Road, Nagpur - 440016, MS
India, Telfax : +91 7104 234739
Head Office (Nagpur):
14-A, Sri Devi Ratan Complex, Agyaram Devi Sq.
Subhash Rd., Nagpur - 400018 Tel: +91 98900 46693
Email: info@enceechlor.com

### ii. SOLAR MAC® Electrochlorinators:

SOLAR MAC® Electrochlorinators are designed to generate hypochlorite for a wide range of applications in safe, low cost, reliable and portable packages. These units need salt and water and will run on solar energy (Fig 14).

**Figure 14:** Solar Mac7

### Features

- Ensure drinking water to isolated villages where there is no electricity.
- Drinking water from solar power and common salt.
- Produce 36,000 litres of drinking water per day.
- Providing drinking water for 12,000 6000 people per day.
- Generates 54 gms of free chlorine per batch (8 Hrs) as Sodium hypochlorite solution.

### Advantages

- Green Technology oriented environmentally safe water disinfection systems.
- Sodium Hypochlorite generated by SOLAR MAC® is neutral and absolutely safe for use.
- No gases, hazardous chemicals or damage to environment is done by the system.

### Applications

- Disinfection for potable water.
- Onsite production of Sodium hypochlorite for general disinfection/sanitization.

### SOLAR MAC® consists of

- Generator Module/Electrolyser equipped with DSA® anodes.
- Three Solar panels of 60 Watt/each.
- Solar Rectifier.
- Two Batteries 12V and 60 Ah/each (optional).
- Power cables.

As an environmentally sensitive and responsible company De Nora India is one of the first reputed company to develop electrochlorinator based on sola energy to cater to the need of un electrified and partially electrified villages of India.

Branded as SOLAR MAC® the electrochlorinator unit has been successfully tested rigorously under the guidance of Goa under Ministry of New & Renewable Energy state Nodal Agency Goa Energy Development Authority (GEDA).

M/s Goa Energy Development Agency (GEDA) has registered De Nora India as manufacturer of chlorinator based on solar photo voltaic power GEDA has also placed an order of two SOLAR MAC® units upon De Nora based on the successful tests in various sites in Goa.

### iii. SEACLOR Mac® Batch/Continuous Model

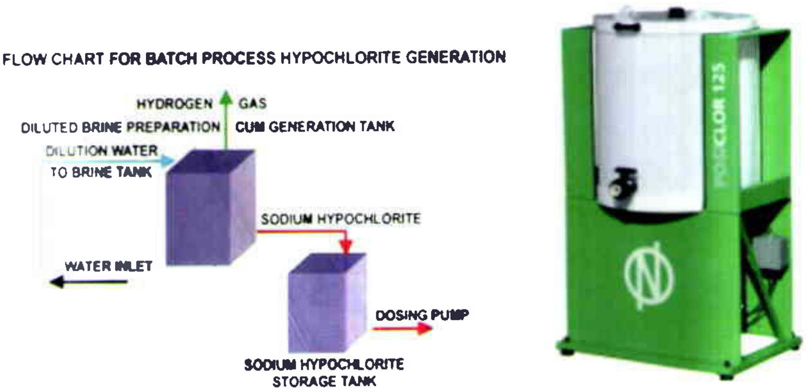
SEACLOR MAC® is a Brine Based Electrochlorination System for On-Site Chlorine Generation, with this Systems De Nora has brought to India the latest technologies in electrochemical processes. About 800 units are in operation in INDIA trusted by reputed customers in Government sector, MES, Corporations, CPWD, Railways, PHED, PSU, Refineries, Sail, NTPC, BHEL, World Health Organization and many more.

(a) SEACLOR Mac® Batch Models

- SEACLOR Mac® 25
- SEACLOR Mac® 50
- SEACLOR Mac® 100
- SEACLOR Mac® 300

SEACLOR Mac® batch models are designed to generate hypochlorite in a batch of 8 hours for a wide range of application in a safe, low cost reliable and comprehensive package. Each system includes the electrolyser, power supply and control system, dosing system, titration kit and storage tank (Fig 15).

SEACLOR Mac® batch models are suitable for applications where low capacity of water needs to be disinfected. Among others, these systems are suitable for Panchayati Raj, Rural Water Supply scheme, small swimming pools and hospitals

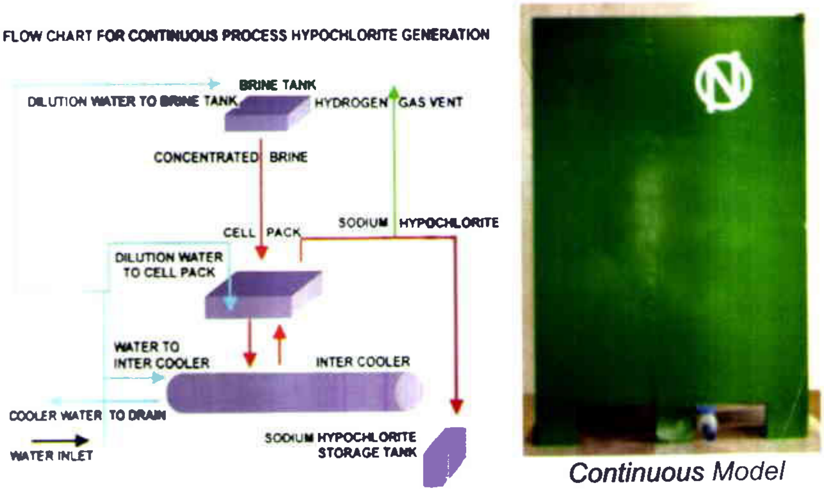


*Batch Model*

**Figure 15:** SEACLOR Mac® batch models

**(b) SEACLOR Mac® Continuous Models**

- SEACLOR Mac® 500
- SEACLOR Mac® 1000
- SEACLOR Mac® 2000
- SEACLOR Mac® 3000



*Continuous Model*

**Figure 16:** SEACLOR Mac® continuous Models

SEACLOR Mac® continuous models are designed keeping in the need for chlorination of water where the requirement of higher volumes. These models are suitable for urban and semi urban water supply schemes, waste water application, industrial processes, large swimming pools, Railways, Defence establishment etc (Fig 16).

Each skid mounted system comes as a complete package, comprising of electrolyser, generation tank, power supply and control system and storage tank.

**Contact details:**

**DE NORA INDIA LIMITED**
Plot Nos.184,185& 189, Kundaim Industrial Estate / Kundaim, Goa - 403 115
Ph: (0832) 3981100 - Direct: 3981141/42 - Fax: 3981101 - Mobile 9860090475
E-mail: vinay.chopra@denora.com – Web: www.denoraindia.com

### iv. Smart Electrochlorinator 200 (SE200)

With support from the Laird Norton Family Foundation, PATH identiied electrochlorination as a promising core technology for community water treatment. PATH worked with Cascade Designs, Inc. (CDI) in Seattle to develop a prototype for a portable, battery-powered, easyto-use electrochlorinator.

The Smart Electrochlorinator 200 (SE200) (Fig 17) produces enough chlorine in a 7-minute cycle to treat up to 200 liters and has the lexibility to allow a user to easily measure smaller doses to support a variety of water container sizes. Additionally, the second-generation device has clearer indicators and a more appliance-like look with brighter colors (PATH, 2010).

**Figure 17:** Smart Electrochlorinator 200 (SE200)

**Contact details:**

**PATH**
PO Box 900922
Seattle, WA98109USA
info@path.org, www.path.org

### v. Florichlor (AGIL power control system)

AGIL power control system is the sole manufacturer and supplier of Elctrochlorinator, which converts cooking salt with water into sodium hypochlorite (Active Chlorine) through help of electric current. The required dosage of chlorination can be found by horrocks test. These Industrial Electrochlorinators are manufactured by using quality raw materials, which are procured from the most reputed company to ensure reliability and durability of products. The range of products offers outstanding performance to customers at highly cost-effective prices. These products

**Figure 18:** Florichlor (AGIL power control system)

are manufactured under the brand name of **'Florichlor'** (Fig 18). They are manufacture and supply Portable model Electrochlorinators, which is perfect for disinfection of water during disasters like earthquakes, Floods or Epidemics. Industrial Electrochlorinator are designed for rural and village 'point-of-use' disinfection of drinking water.

**Contact details:**

**Agil Power Control System**
Mr. M Vijayarajan
45/11b, Pillayar Koil St., Tam,
Chennai, Tamil Nadu, India 600045
+91-44-22264779, +91-9840050348

## vi. PERFECT CHLORO SYSTEM

PERFECT CHLORO SYSTEM markets a wide range of Chlorination Equipments and related accessories to cater to this requirement.

Depending upon the mode of operation, Electrochlorinators are classified into two types namely **Batch Production Electrochlorinators** with capacity from 15 gms / hr to 500 gms/hr and **Continuous Production Electrochlorinators** with capacity ranging from 15 gms/hr to 15 kgs /hr.

### (a) Batch Production Electro Chlorinators

Batch production electrochlorinators (Fig 19) are designed for small capacities and are available from 15 gms/hr to capacity of 500 gms/hr chlorine equivalent, using our unique Multimetallic Oxides Titanium Nobel Anodes and Electrochemical Process. Production of Sodium Hypochlorite is completed in a batch of every 8 hours, to concentration of around 6-8 gms/litre.

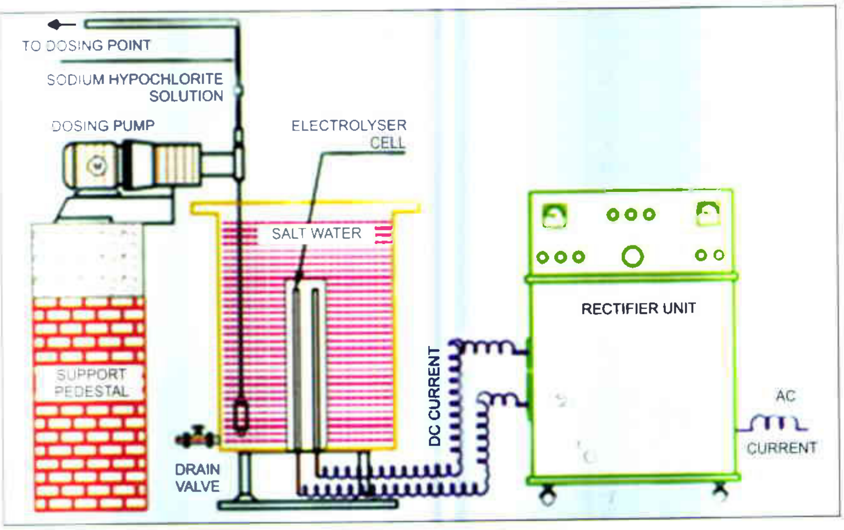


**Figure 19:** Batch production electrochlorinators

A metered amount of water is mixed with common salt to form brine of required concentration [or Seawater is used]. This is the electrolyte used in the process. Electrolyser Cells are dipped in this measured quantity of Brine Solution, contained in a specially made FRP Tank [Bisphenol Resin]. These cells are connected to a rectifier, which converts Alternate current to Direct current. When DC Current passes through these Titanium Anodes with MMO Coating, Sodium Hypochlorite evolves instantaneously with negligible quantities of hydrogen rising up to the surface, which is vented out. This process is based on the chemistry of Electrolysis of Sodium Chloride. The Sodium Hypochlorite thus generated is collected in a storage Tank and applied directly or pumped to the point of application.

### (b) Continuous Production Electrochlorinators

Continuous Production Electrochlorinators are On-Site Sodium Hypochlorite [Hypo] Generator designed for small / medium / large capacities.

Continuous Production Electrochlorinators (Fig 20) are capable of producing from 500 gms/hr to 15Kgs/hr active chlorine using our unique Multimetallic Oxides Coated, Titanium Nobel Anodes and Electrochemical Process. Brine solution passes through an Online Electrolyser with inbuilt heat exchanger pack. This is connected to a DC Rectifier. When low voltage DC is passed through the Electrolyser Cell, Sodium Hypochlorite solution to concentration of 6-8 gms/litre approx. is evolved continuously. This can be stored in a Storage Tank and pumped / used at required rates.

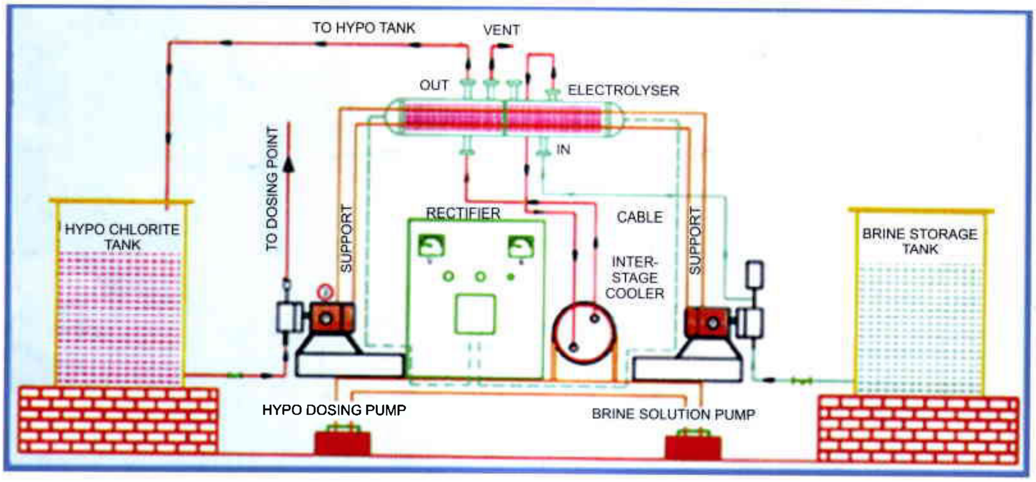


**Figure 20:** Continuous production electrochlorinators

A metered amount of water is mixed with common salt to form brine of required concentration (or Seawater is used). This is the electrolyte used in the process. This electrolyte is pumped to Electrolyser cells, when DC Current passes through these Titanium Anodes with special MMO Coating, Sodium Hypochlorite solution to concentration of 8 gms/litre approx. evolves continuously and this is collected in Hypo StorageTank and applied directly or pumped to the point of application at required rates. To maintain the temperature at correct levels, prevent dissipation and get correct concentration of Sodium Hypochlorite output, Brine/ seawater is cooled through a chiller or heat exchanger.

**Contact details:**

**PERFECT CHLORO SYSTEM**
**ADMINISTRATIVE OFFICE & WORKS:**
A-24, SIDCO Industrial Estate, Villivakkam, Chennai - 600049.India.
Phone: 044-26173445 - 216173045.
Fax : +91-44-26173455 / 26257749
Cell : 0-98400-29244
Email: perfectchloro@vsnl.com, perfectchloro@yahoo.co.in, perfectchloro@eth.net

### vii. Electrochlorinator by Pristine Water:

#### (a) Compact Electrochlorinator

Compact Electrochlorinator is a Batch type disinfectant generator which produces Sodium Hypochlorite, a strong disinfectant, by the process of electrolysis from salt and water. With is equipment the need for buying and storing Liquid chlorine or Bleaching powder is totally eliminated (Fig 21). The disinfectant generated by 'Compclor' can be directly injected into water or wastewater to disinfect up 60000 liters of water per day depending on the contamination. This equipment is a total system by itself, Reaction tank, Hypo Tank, Power supply unit and Dosing pump are all integrated into one single unit. They are prewired and piped, so they can be installed any were without any civil foundation or support stands.

**Figure 21:** Compact Electrochlorinator

#### (b) Batch Process Electrochlorinator

Batch type Electrochlorinator produces required chlorine in the form of Sodium Hypochlorite in 8 hours. Add salt and water and switch on the power supply. The system automatically stops after producing required chlorine (Fig 22). Supplied with Reaction Tank fitted with the Titanium Electrolyzer and Power Supply Unit with Auto Timer Controls. Storage Tank and Dosing Pump are optional. To inject Gas Chlorine, Liquid Chlorine or Bleaching powder to disinfect water or waste water is a common practice all over the world. But hereafter you do not have to face the problem of procuring and the hazard of storing of these chemicals. Our Electrochlorinator produces Liquid Chlorine (Sodium Hypochlorite) from common salt as per your requirement. It is safe and cost saving.

**Figure 22:** Batch process Electrochlorinator

#### (c) Solar Electrochlorinator

Solar Electrochlorinator is a Batch type disinfectant generator which produces Sodium Hypochlorite, a strong disinfectant, by the process of electrolysis from salt and water (Fig 23). With is equipment the need for buying and storing Liquid chlorine or Bleaching powder is totally eliminated. All you need is Salt and Electricity. The disinfectant generated by 'Compclor' can be directly injected into water or wastewater to disinfect up 60000 liters of water per day depending on the contamination.

**Figure 23:** Solar Electrochlorinator

This equipment is a total system by itself, Reaction tank, Hypo Tank, Power supply unit and Dosing pump are all integrated into one single unit. They are prewired and piped, so they can be installed any were without any civil foundation or support stands.

It's no more a problem to disinfect water in remote areas where electric power is not available. Two of natures gifts, Sunlight and Salt help to produce a strong disinfectant in a technologically advanced process. "Sunclor" Solar Electrochlorinator produces Liquid Chlorine (Sodium Hypochlorite) from common salt and Solar power. When sodium hypochlorite is injected into water it kills all the disease causing pathogens and renders the water pure.

### (d) Automatic Electrochlorinators

Automatic Electrochlorinators are compact low capacity systems which produce Sodium Hypochlorite continuously from Saltwater or seawater, by the process of Electrolysis. Sodium Hypochlorite is a strong disinfectant and is useful in disinfecting Drinking water and Waste Water (Fig 24). There is no need to buy and stock Gas or Liquid Chlorine. This is a wall mounted compact model with automatic control. Sodium Hypochlorite is a strong disinfectant that kills all the pathogens which lead to water borne diseases like cholera, typhoid, paratyphoid etc. Our system also leaves some residual Sodium Hypochlorite in water to prevent bacteria from getting picked up during storage or redistribution.

**Figure 24:** Automatic Electrochlorinator

**Contact details:**

**Pristine Water Office**
B305, Okhla Industrial Area, Phase I, New Delhi 110 020
Phone: + 91 11 32712655, Telefax: + 91 11 26811710
Email : sales@pristinewater.in, E : support@pristinewater.in
W : www.pristinewater.in

## References:

1. AGIL power control system,
2. CAWST (Editor) (2009): Biosand Filter Manual, Design, Construction, Installation, Operation and Maintenance. Alberta: Center for Affordable Water and Sanitation Technology (CAWST). URL [Accessed: 07.04.2010].
3. CAWST (Editor) (2009): Ceramic Candle Filter. Fact Sheet - Academic. Center for Affordable Water and Sanitation Technology (CAWST). URL [Accessed: 01.04.2010].
4. EAWAG/SANDEC (Editor) (2006): Training Material for SODIS Promotion. pdf presentation. Duebendorf: Water and Sanitation in Developing Countries (SANDEC) at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG). URL [Accessed: 17.03.2010].
5. EAWAG/SANDEC (Editor) (2008): Household Water Treatment and Safe Storage (HWTS). Lecture Notes. Duebendorf: Swiss Federal Institute of Aquatic Science (EAWAG), Department of Water and Sanitation in Developing Countries (SANDEC). URL [Accessed: 08.04.2010]. PDF
6. file:///C:/Documents%20and%20Settings/g%20e%20m/Desktop/Electrochlorinator/AGILElectrochlorinator%20Manufacturer%20India,Industrial%20Electrochlorinator%20Supplier,Water%20Electrochlorinator%20Mmanufacturer,Salt%20Water%20Electrochlorinator%20Supplier,India.htm
7. http://www.denoraindia.com/LinkClick.aspx?fileticket=mGTxXroDFqQ%3d&tabid= 408
8. http://www.denoraindia.com/Products/Electrochlorinators/SEACLORMACRange/tabid/406/Default.aspx
9. http://www.nagpurchemicals.com/electrochlorinatorimages.htm
10. http://www.sswm.info/category/implementation-tools/water-purification/hardware/point-use-water-treatment/ceramic-candle-f
11. http://www.sswm.info/category/implementation-tools/water-purification/hardware/point-use-water-treatment/bio-sand-filtrat
12. Lantagne, D. S.; Quick, R.; Mintz, E.D. (2006): Household Water Treatment and Safe Storage Options in Developing Countries. Review of Current Implementation Practices. In: Woodrow Wilson International Center for Scholars (2006): Water Stories: Expanding: Opportunities in small-scale Water and Sanitation Projects, 17-38. URL [Accessed: 18.01.2011].
13. Meierhofer, R.; Wegelin, M. (2002): Solar Water Disinfection: A Guide for the Application of SODIS. Duebendorf: Water and Sanitation in Developing Countries (SANDEC) at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG).
14. Ngai, T.K.; Roshan, R.R.; Dangol, B.; Maharjan, M.; Murcot; Susan (2007): Design for Sustainable Development – Household Drinking Water Filter for Arsenic and Pathogen Treatment in Nepal. In: Journal of Environmental Science and Health Part A 42, 1879–1888.
15. Oates, P.; Shanahan, P.; Polz, M. (2003): Solar disinfection (SODIS): Simulation of Solar Radiation for Global Assessment and Application for Point-of-Use Water Treatment in Haiti. In: Water Research 37, 47–54.

16. PATH's Smart Electrochlorinator Project, Safe water for small communities, Factsheet (2010), http://www.path.org/files/TS_swp_electrochlorinator_fs.pdf

17. Peter Schmid, Martin Kohler, Regula Meierhofer, Samuel Luzi, Martin Wegelin; Elsevier Water Research, 42, pp 5054-5060; 2008; http://www.sodis.ch/methode/forschung/publikationen/papers/schmid_plasticiser_2008.pdf (PDF, 100 Kb)

18. Samuel Luzi, Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water?, Eawag, Duebendorf

19. Suman K.Apparusu, Sustainable Sanitation and Water Management Toolbox, Change Planet Partners Climate Innovation Foundation, Hyderabad. http://www.sswm.info/category/implementation-tools/water-purification

20. www.perfectchloro.com

21. www.pristinewater.in

**NOTE : GOVERNMENT OF INDIA DOES NOT RECOMMEND ANY SPECIFIC TECHNOLOGY OR PRODUCT. VARIOUS TECHNOLOGIES AND PRODUCTS ON DRINKING WATER PURIFICATION MENTIONED IN THIS HANDBOOK ARE SUGGESTIVE IN NATURE. THERE COULD BE MANY OTHER SIMILAR TECHNOLOGIES AND/OR PRODUCTS WHICH ARE NOT MENTIONED IN THIS HANDBOOK. THEREFORE STATES ARE ADVISED TO SELECT APPROPRIATE TECHNOLOGY/PRODUCT AS PER LOCAL NEEDS AND PROCURE THEM ACCORDING TO THEIR STATE PROCUREMENT POLICY.**

सत्यमेव जयते

Ministry of Drinking Water
& Sanitation (MDWS)

नीरी
NEERI

National Environmental Engineering
Research Institute (CSIR-NEERI)