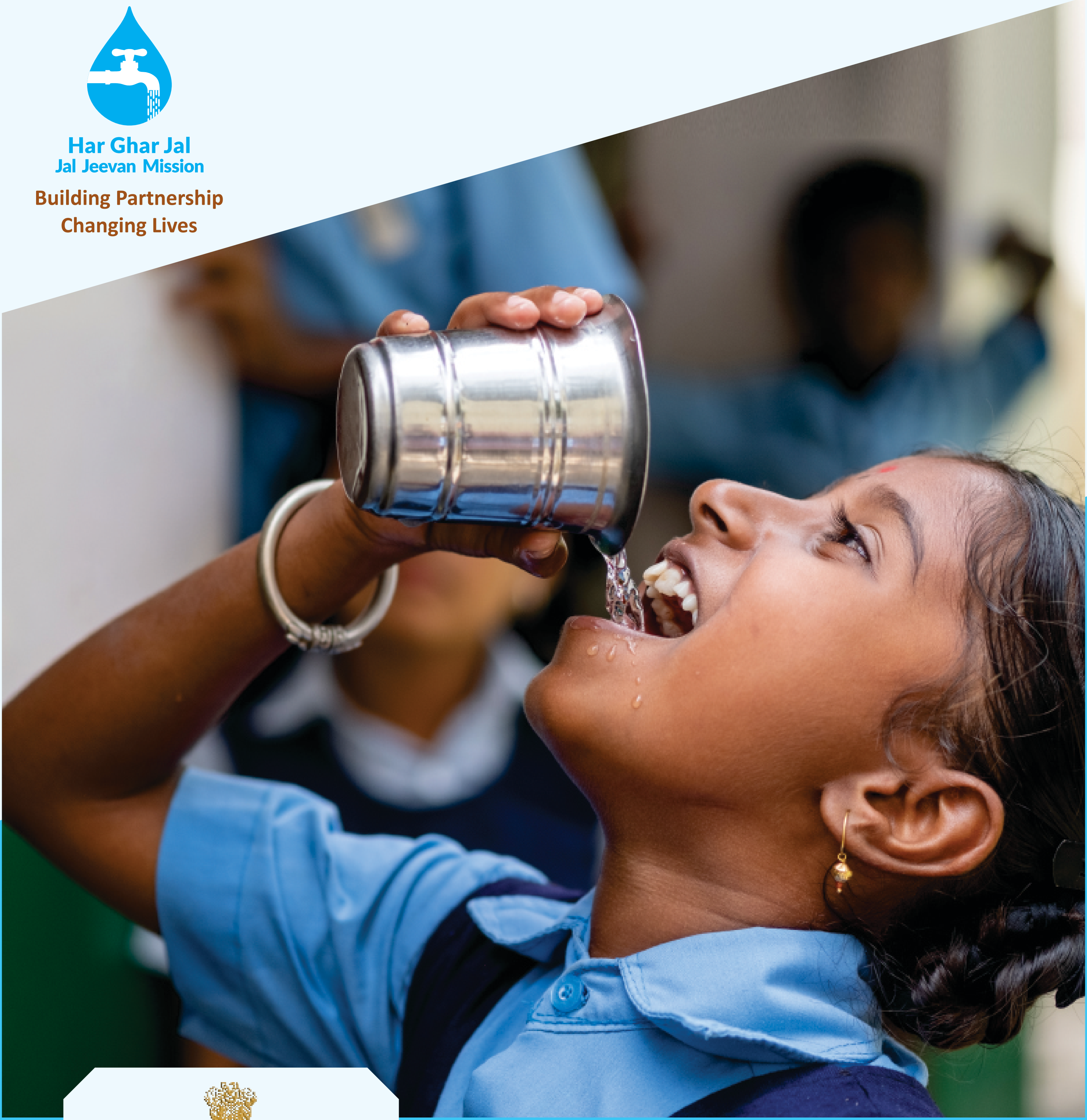
Har Ghar Jal
Jal Jeevan Mission
Building Partnership
Changing Lives



Government of India
Ministry of Jal Shakti
Department of Drinking Water & Sanitation
National Jal Jeevan Mission

March, 2023

Handbook on
Drinking Water Treatment Technologies

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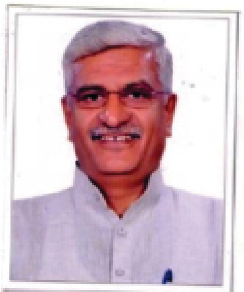

Foreword

The Government of India, under the visionary leadership of Hon'ble Prime Minister has taken various initiatives to improve the ease of living in rural communities. Public health and socio-economic development are dependent on access to clean water and improved sanitation services. Potable Water being essential to sustain life and one of the catalysts to improve ease of living, the Hon'ble Prime Minister of India announced the Jal Jeevan Mission (JJM) on 15th August 2019. The JJM aims to provide adequate potable drinking water through functional household tap connections to every rural household by 2024.

Groundwater contains geogenic contaminants like Arsenic, Fluoride, Iron, heavy metals, etc., which pose serious health issues. Similarly, bacteriological contaminants of drinking water may lead to diseases like cholera, dysentery, diarrhea, typhoid, etc. Therefore, there is a need to have a simple, cost-effective, and easy-to-operate water treatment technologies. It is in this context that the JJM has placed a very strong focus on speedy resolution of any issue around water quality.

This handbook is an attempt of the Department of Drinking Water and Sanitation (DDWS), Ministry of Jal Shakti, to identify appropriate water treatment technologies to suit local conditions. I sincerely believe this document will be of immense use to States and Union Territories (UTs), and other concerned stakeholders such as Panchayats and Paani Samitis etc; to meet the mandate to deliver safe and clean potable water on a regular and long-term basis to all rural households.

This hand book shall also act as basic reference manual on water treatment technologies as per latest development in the field. Moreover, it will be a good practical application booklet for engineers, policymakers, and academicians working on research and development (R&D) in the water sector and for all water warriors who are working to achieve Hon'ble Prime Minister's vision of 'Har Ghar Jal' India.

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सत्यमेव जयते

आज़ादी का अमृत महोत्सव

भारत सरकार
जल शक्ति मंत्रालय
पेयजल एवं स्वच्छता विभाग
चौथा तल, पं दीनदयाल अंत्योदय भवन
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Message

In the last decade, water quality has acquired center stage in the drinking water sector. Acknowledging the challenges and gaps in the provision of safe drinking water, especially in rural areas, the Department of Drinking Water and Sanitation (DDWS) has come out with an updated version of the "Handbook on Drinking Water Treatment Technologies" for disseminating new innovative water treatment technologies as per the latest development in the field. Some parts of rural India are affected by Arsenic, Fluoride, heavy metals, and other contaminations. This document will help implementing agencies to identify appropriate decentralized water treatment technologies for water quality affected habitations and assure provision of safe drinking water not only to rural households but public institution buildings such as schools, Anganwadi centers, public health care facilities, Ashramshalas, etc.

As on 27.02.2023, more than 11 crore rural households have been provided safe drinking water through tap connections. The Department of Drinking Water and Sanitation has also set up a technical committee for the examination of new innovative technologies for geo-genic and anthropogenic water quality issues. All government, public and private sectors are encouraged to register new emerging technologies on the DDWS website for evaluation by the technical committee. It is our endeavor to disseminate new emerging cost-effective water treatment technologies for benefit of large communities.

This handbook would help the Public Health Engineering Departments (PHED), Rural Water and Sanitation Departments (RWS), and other concerned stakeholders such as Panchayat and Paani Samitis to understand and implement the available treatment technologies. States and Union Territories may take advantage of the handbook and implement the new technologies suitable to their context outlined, ensuring clean and safe water delivery, leading to enhanced public health. I am sure that with continued technical as well as financial support under the Jal Jeevan mission (JJM), this new comprehensive document would help in achieving the goal of Har Ghar Jal (HGJ) India by 2024.

(Vini Mahajan)

Vikas Sheel
Addl. Secretary & Mission Director

Har Ghar Jal
Jal Jeevan Mission
National Jal Jeevan Mission
Government of India, Ministry of Jal Shakti
Department of Drinking Water and Sanitation

Preface

Access to assured and safe drinking water is a basic life need. Potable water plays a critical role in the public health and wellbeing of a community. Although, in the last decade, dedicated efforts have been taken for setting up appropriate systems for solid and liquid waste management. Yet, rapid industrialization, use of chemical fertilizers, unsafe disposal of sewage, etc., continue to pose the risk of contamination of water sources.

Large-scale expansion of water quality infrastructure has been undertaken under the Jal Jeevan Mission (JJM). As a result, the number of water testing laboratories has now increased to 2,076. More than 18 lakh women have been trained for water testing through Field Test Kits (FTKs). Except few habitations, reported as affected with Arsenic and Fluoride contaminations have now been provided with at least temporary measures such as Community Water Purification Plants (CWPPs) or household-level interventions through provision of filters, etc. In this handbook, various new technologies which may be applicable in the field for the treatment of contaminated water, whether based on surface or groundwater, have been presented and summarized with a special focus on technologies, efficiency assessment, and cost analysis. The list of technologies covered is only indicative and States and Union Territories are advised to also explore newer options emerging because of rapid technological advancements taking place in the country due to initiatives such as Make in India and start-up India, etc.

These localized treatment technologies for the removal of metals and other contaminants are aimed at improving water quality and thereby ensuring public health so that the consumers may overcome apprehensions, if any, about the quality of drinking water and be able to consume water directly from the tap.

This handbook is an effort to disseminate information regarding new technologies available amongst all stakeholders and seeks to improve the performance and implementation of small drinking water treatment plants using technologies that address local issues and challenges faced in water-quality affected villages. This will in turn help in realizing a broader vision i.e., Jal Prabudh Gaon (water enlightened villages), so that the paucity of clean drinking water doesn't become a limiting factor in the socio-economic development in the quest for sustainable growth.

This document was earlier developed in the year 2015 in the form of a handbook on drinking water treatment technologies. However, keeping in view the importance of clean water and increasing chemical pollutants in water, and capturing the diverse requirement of States and Union Territories, a revised version of the handbook with the inclusion of various new innovative technologies for the treatment of heavy metals has been developed. The process of developing this document has included several deliberations with various stakeholders – States and Union Territories, NEERI, UNICEF, WHO, Ernst and Young (EY), KPMG, and other sector partners.

I am sure that this handbook will be of immense use to various stakeholders associated with the mission, especially the Public Health Engineering Departments (PHEDs) and their parastatal organizations to adopt the utility approach, build a culture of treatment of quality affected water on priority with localized mitigation strategy, and empower communities to shoulder responsibilities of water quality improvement and surveillance. I am confident that this comprehensive handbook will be helpful in ensuring access to clean water to all rural households.

(Vikas Sheel)

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We also compliment Prof. Pradip Kumar Tewari, JJM - Professor Chair & Head, Department of Chemical Engineering, IIT Jodhpur, Dr. Mihir Kr. Purkait, JJM - Professor Chair & Professor, Department of Chemical Engineering, IIT, Guwahati and Dr. (Ms.) Ligy Philip, Dean Planning, Department of Civil Engineering, IIT, Madras for their useful inputs.

We would also like to acknowledge UNICEF and PMUs - KPMG and E&Y supporting the National Jal Jeevan Mission for their meticulous attention to detail and unwavering commitment to excellence. Their hard work and dedication have ensured that the manual is well-written and organized.

We would like to extend our special thanks to Shri Santhosh R., Asst. Advisor (PHE) and Shri Rohan Budhraja, Water Quality Expert, PMU at NJJM for their exceptional contributions in condensing the vast available information, shaping the content and structure of the Handbook. Their expertise and guidance have been invaluable in ensuring that the Handbook meets the highest standards of accuracy and comprehensiveness.

We would also like to extend our gratitude to Ms. Vini Mahajan, Secretary, Department of Drinking Water and Sanitation, Shri Bharat Lal, the then Additional Secretary & Mission Direction and Shri Vikas Sheel, Additional Secretary & Mission Director, National Jal Jeevan Mission, for providing their invaluable guidance and all necessary facilities that were required during the preparation of this Handbook.

Finally, we also acknowledge the dedicated staff of the Water Quality Division at National Jal Jeevan Mission for their efforts in coordinating the various aspects of finalisation of this Handbook. Their commitment and hard work have been crucial in making this Handbook a reality.

Thank you all for your valuable contributions and support in this project.

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Abbreviations

AA	Activated Alumina
ACC	Activated Carbon Cloth
ACF	Activated Carbon Fibrous
AES	Acute Encephalitis Syndrom
AMRIT	Anion and Metal Removal by Indian Technology
APHA	American Public Health Association
ARU	Arsenic Removal Unit
As(III)	Arsenite
As(V)	Arsenate
BAC	Biological Activated Carbon
BARC	Bhabha Atomic Research Centre
BOD	Biological Oxygen Demand
BTU	Bucket Treatment Unit
BUET	Bangladesh University of Engineering and Technology
CBM	Carbonized Bone Meal
CCT	Compact Carbon Trap
CDI	Capacitive De-Ionization
CI	Cast Iron
CIM	Composite Iron Matrix
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CRS	Coarse River Sand
CSIR	Council of Scientific and Industrial Research
CTBM	Chemically Treated Carbonized Bone Meal
CWPP	Community Water Purification Plants
DANIDA	Danish International Development Agency
DC	Direct current

DDWS	Department of Drinking Water and Sanitation
DFID	Department for International Development
DOG	Dissolved Oxygen Generator
DPHE	Department of Public Health Engineering
DRDO	Defense Research and Development Organization
DST	Science and Technology
ECAR	Electro-Chemical Arsenic Remediation
ECP	Electrochemical Precipitation
ED	Electrodialysis
EDR	Electrodialysis Reversal
ELM	Emulsion Liquid Membrane
EMRION	Electro Magnetic Resonance and Ion Trap System
EPA	Environmental Protection Agency
ESR	Elevated Service Reservoir
EY	Ernst and Young
FDA	Food and Drug Administration
FO	Forward Osmosis
FTK	Field Testing Kit
FHTC	Functional Household Tap Connection
GAC	Granular-Activated Carbon
GFH	Granular Ferric Hydroxide
HAIX	Hybrid Anion Exchange
HF	Hydrogen Fluoride
IARC	International Agency for Research on Cancer
ICMR	Indian Council of Medical Research
ICOH	Inter-Country Center for Oral Health

IFC	Iron Fluoride Complexes
ILM	Immobilized Liquid Membrane
IMIS	Integrated Management Information System
IMMT	Institute of Minerals and Materials Technology
IOCS	Iron Oxide Coated Sand
IPCS	International Program on Chemical Safety
ISR	Iron Specific Resin
JE	Japanese Encephalitis
JJM	Jal Jeevan Mission
Kg	Kilogram
KPMG	Klynveld Peat Marwick Goerdeler
LPCD	Liters Per Capita Per Day
LPH	Liters Per Hour
LTTD	Low Temperature Thermal Desalination
MCL	Maximum Contamination Level
MED	Multiple Effect Distillation
MEE	Multi-Effect Evaporation
MF	Microfiltration
MgO	Magnesium oxide
MLD	Million Litres per Day
MMO	Mixed Metal Oxides
MoES	Ministry of Earth Sciences
MoJS	Ministry of Jal Shakti
MRC	Medical Research Council
MS	Mild Steel
MSF	Multi-Stage flash
MVC	Mechanical Vapour Compression
NEERI	National Environmental Engineering Research Institutre

NF	Nano-filtration
NIOT	National Institute of Ocean Technology
PAC	Powder-activated Carbon
PHED	Public Health Engineering Department
PPB	Parts Per Billion
PPM	Parts Per Million
PVC	Polyvinyl Chloride
R&D	Research and Development
RPM	Revolutions Per Minute
RWS	Rural Water Supply
SBM-G	Swachh Bharat Mission – Grameen
SCSS	Silty Clay Sediment Series
SLM	Supported Liquid Membrane
SORAS	Solar Oxidation and Removal of Arsenic
SSF	Single Stage Flash
TDS	Total Dissolved Solids
TVC	Thermal Vapour compression
UF	Ultrafiltration
UNICEF	United Nations Children’s Fund
USEPA	United States Environmental Protection Agency
UT	Union Territory
VC	Vapour Compression
VCD	Vapour Compression Distillation
VOCs	Volatile Organic Compounds
VTE	Vertical Tube Evaporators
WC	Wood Charcoal
WHO	World Health Organization
ZLD	Zero Liquid Discharge

1. Introduction

Water is one of the most essential requirements of life. Assured availability of potable water is vital for human development. India is home to 18% of global human population and 15% of global livestock population. However, it has only 2% land mass and 4% of global freshwater resources. As per estimates, in 1951, per capita annual freshwater availability was 5,177 cubic meters which came down to 1,545 cubic meters in 2011. It is estimated that in 2019 it was about 1,368 cubic meters which is likely to further go down to 1,293 cubic meters by 2025. If the present population trend continues, in 2050, per capita availability is likely to decline to 1,140 cubic meters.

With the growing population and expanding economic activities, there is an increase in demand for water in various sectors, viz., domestic, agriculture, industry, power, recreation, infrastructure development, etc. These competing demands make providing drinking water to everyone, a complex issue. The widening demand-supply gap is further aggravated by other challenges, viz., depletion of groundwater caused by over-extraction, poor recharge, low storage capacity vis-à-vis other countries, erratic rainfall due to climate change, presence of geogenic contaminants, poor operation and maintenance (O&M) of water supply systems, etc.

Non-availability of assured potable water adversely impacts local communities. In the absence of access to potable drinking water at home, families, especially women and young girl children, are forced to spend a lot of time and energy every day in fetching it. During scarcity, State Governments/ local administrations take emergency measures to provide water through tankers, trains, etc. With the Government taking a number of steps to improve 'ease-of-living', people now expect to have tap water supply in their homes.

In this backdrop, Jal Jeevan Mission (JJM) has been launched in partnership with the States, to enable every household in villages to have a Functional Household Tap Connection (FHTC) by 2024. It is envisaged that with a FHTC, each household will have potable water supply in adequate quantity -55 litres per person per day (LPCD), of prescribed quality - adhering to BIS IS 10500:2012, on regular and long-term basis. To implement the mission, comprehensive guidelines have been laid down so that institutional arrangements at various level and State's Public Health Engineering (PHE)/ Rural Water Supply (RWS) Departments play a critical role, to achieve the mission objective. They have to help the Gram Panchayats (GP) and/ or its sub-committee to plan, implement, manage, operate and maintain its in-village water supply systems. A sense of ownership has to be instilled in the village community as they are the soul of this mission.

In water quality affected villages with geogenic contamination like Arsenic, Fluoride, Iron, Salinity, Nitrate and heavy metals, in drinking water sources, there is an anticipated time-lag to provide FHTCs from safe water sources, the JJM guidelines envisage installing and maintaining community water purification plants as a short-term measure to provide 8 to 10 LPCD of safe drinking water for drinking and cooking purposes.

The objective of this handbook is to present consolidated details about various technologies available in the market for treating the geogenic contaminants to provide safe drinking water to rural households. The details collated from different sources are classified based on its use i.e. domestic, hand pump attached, community water purification and piped water supply so that it is useful as a handy manual for the hardworking field engineers.

However, mere mention of the details about the technology here is not to be construed as a recommendation of Department of Drinking Water and Sanitation, Ministry of Jal Shakti, as they are not endorsed for adoption. They are only suggestive in nature and to serve a field reference manual. The States need to select proper technology applicable to the local needs, procure and install them through process in vogue following due diligence of its laid down rules and regulations.

To keep the document dynamic, States are requested to give valuable feedback so that revisions/ updating can be carried out regularly.

2. Arsenic removal methods & technologies

2.1 Preamble

Arsenic is a natural metalloid of the earth's crust in some parts of the world and can also be 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 groundwater sources than in surface water. As per the Bureau of Indian Standards (BIS), maximum permissible limit of Arsenic in drinking water is 0.01 mg/L (10µg/L).

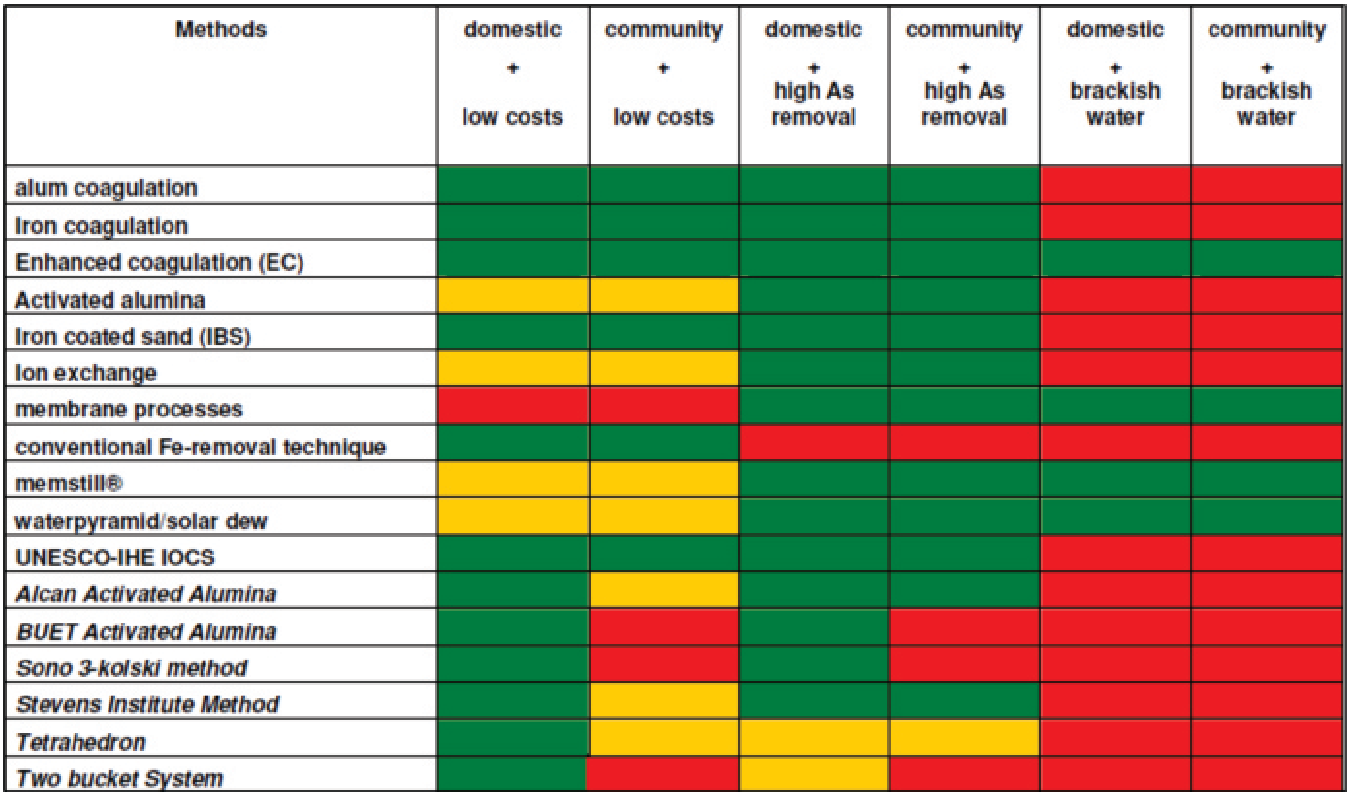
2.2 Health effects of Arsenic

Long-term exposure to Arsenic can result in chronic Arsenic poisoning. Arsenic dissolved in water is acutely toxic and can lead to several health problems. It has been reported that long-term exposure to Arsenic in drinking water probably more than 0.01 mg/L causes increased risks of cancer of 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 results in numerous diseases that have been also confirmed by repeated epidemiological investigations which include dermal effects, cardiovascular effects, respiratory effects, gastrointestinal effects, endocrinological effects (diabetes mellitus), neurological effects, reproductive and developmental effects, cancer effects, and 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 - International Agency for Research on Cancer (IARC) 2004, International Program on Chemical Safety (IPCS) 2001, National Residue Survey (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. The crisis has its roots in another worthy effort to fight water-borne diseases that had impacted this tropical region for a long time.

2.3 Selection of an appropriate Arsenic removal technique

Most Arsenic removal techniques are complex and/ or expensive. Moreover, they often require certain level of technical skills. There are many overviews of Arsenic removal technologies already available. The International Groundwater Resources Assessment Centre (IGRAC) summarises 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 is as follows:

Table 1: Comparison of Arsenic removal technologies



Methods	domestic + 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
- Yellow colour means average suitability
- Red colour means that the method is unattractive or not applicable for the given situation.

Table 2: Advantages and Disadvantages of techniques for Arsenic removal

Technologies	Advantages	Disadvantages
Oxidation/ precipitation • Air oxidation • Chemical oxidation	Relatively simple, low-cost process Relatively simple and rapid process Oxidizes other impurities and kills microbes	The process removes only a part of Arsenic
Coagulation-precipitation • Alum coagulation • Iron coagulation • Lime softening	Relatively low capital cost Relatively simple operation Common chemicals available	Introduces toxic sludge Low removal As (III) More oxidation may be required

Technologies	Advantages	Disadvantages
Sorption Techniques: - Activated Alumina - Iron coated sand - Ion exchange resin - Other sorbents	Relatively well known and commercially available Well defined technique Plenty possibilities and scope of development	Produces toxic solid waste Replacement/ regeneration required High tech operation Relatively high cost
Membrane techniques: - Nano filtration - Reverse osmosis - Electro dialysis	Well defined and high removal efficiency No toxic solid wastes produced Capable of removal other contaminants	Very high capital and running cost High tech operation and maintenance Toxic wastewater produced The product water produced is of very low TDS, there is loss of minerals such as Calcium and Magnesium The reject management of water is difficult and 50% of water gets wasted

* All the Membrane Technologies should be linked with the notification of Green Tribunal RO/Membrane technologies

2.4 Techniques for removal of Arsenic

2.4.1 Oxidation/ Reduction

Arsenic in groundwater may occur in a trivalent form as Arsenite As(III) and pentavalent form Arsenate As(V) in different proportions. Most Arsenic treatment technologies are very effective in removing the Arsenate, but the removal efficiency 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 per-manganate are most commonly used for oxidation process of Arsenic.

$H_3AsO_3 + ½ O_2 = H_2AsO_4^- + H^+$

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

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

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.

2.4.2 Coagulation and Precipitation

Coagulation/ precipitation is a treatment method for Arsenic removal using either metal salts or lime softening. It 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.

2.4.2.1 Iron Coagulation

Arsenic in the As(V) 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 Sulphate can remove up to 90% of As(V) at pH 7 and about 50% of As(III) (Pureflow Filtration Systems, 2005). As(III) 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).

2.4.2.2 Alum Coagulation

Alum can be used to remove As(V) but is less effective than other processes over a narrower pH range for As(V) removal. Alum coagulation is not that efficient for removal of As(III) (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).

2.4.2.3 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 Calcium Hydroxide $Ca(OH)_2$ and Sodium Carbonate 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.

2.4.3 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.

2.4.3.1 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.

2.4.3.2 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.

$$2R\text{-}Cl + HASO_4^{--} \rightleftharpoons R_2HASO_4 + 2Cl^-$$

The regeneration equation using common salt as regeneration agent is

$$R_2HASO_4 + 2Na^+ + 2Cl^- \rightleftharpoons 2R\text{-}Cl + HASO_4^{--} + 2Na^+$$

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 As(V)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.

2.4.3.3 Granular Ferric Hydroxide

This treatment option can remove both forms of Arsenic. Kinetic 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.

2.4.3.4 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 mg/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 As(III) 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).

2.4.4 Membrane Techniques

Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF), Reverse Osmosis (RO) and Electro Dialysis 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.

2.4.4.1 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.

2.4.4.2 Electro dialysis Reversal

Electro dialysis reversal (EDR) is a 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 pre-treatment 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 3µg/L from an influent concentration of 21µg/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.

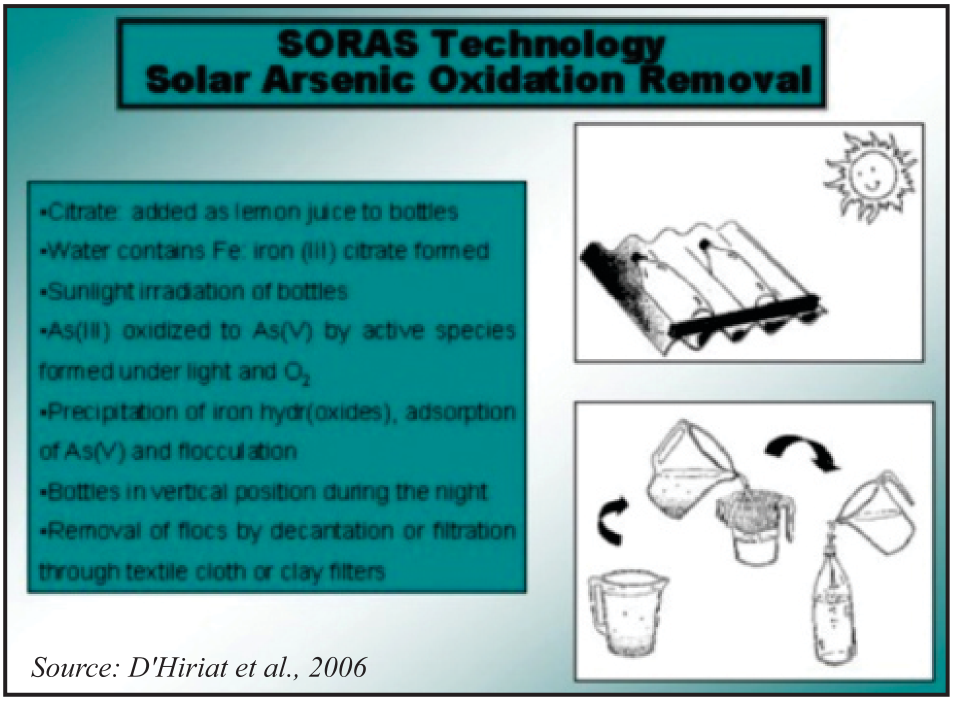
2.4.4.3 Nano-filtration

Nano-filtration (NF) membranes can remove 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 NF 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.

2.5 Technologies for removal of Arsenic from drinking water

2.5.1 Solar Oxidation and Removal of Arsenic (SORAS)

It is a simple method that uses irradiation of water with sunlight in Polyethylene Terephthalate PET or other Ultraviolet (UV) transparent bottles to reduce Arsenic level from drinking water (Figure 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 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.



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 O_2
- 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 1: Solar Oxidation and Removal of Arsenic (SORAS)

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2.5.2 NMRL-DRDO household water filter

Naval Materials Research Laboratory - Defence Research and Development Organisation (NMRL-DRDO) household Arsenic removal filter has been designed and fabricated both in plastic and in stainless steel (Figure 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 can 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 Oxyhydroxides, 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 Oxyhydroxide solids. The filter material and sand are to be replaced periodically as per usage. This filter can treat Arsenic contaminated water to bring down concentration below 50 µg/L.

Figure 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.

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2.5.3 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 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 Rs. 2,000.

Figure 3:Sono Arsenic Mitigation Filter

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2.5.4 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 Aluminium 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.

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 tube well water varied between 375 to 640 ppb.

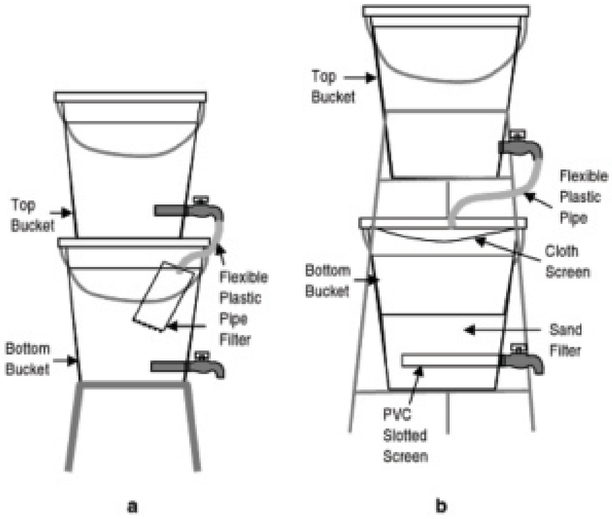

Figure 4: Double-bucket household Arsenic treatment unit

(a) DPHE-Danida unit (b) BUET modified unit

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

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2.5.5 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 Hypochlorite) 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 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. The cost (capital and recurrent) of this unit is Rs. 350.

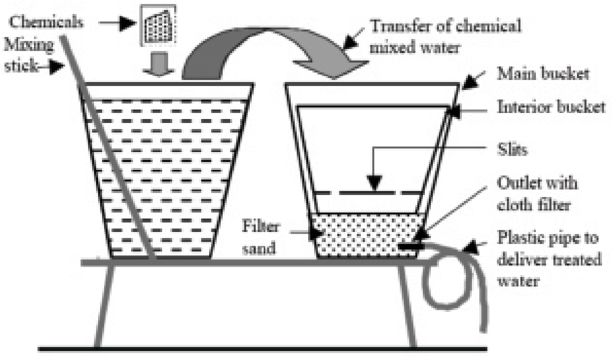

Figure 5: The Star Filter developed by the Stevens Institute Technology

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2.5.6 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 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).

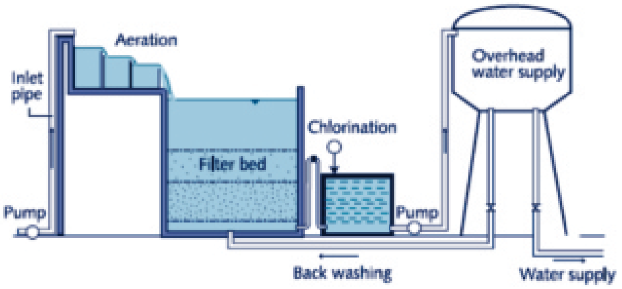

Figure 6: Schematic diagram of Iron and Arsenic plant in Bangladesh

2.5.7 Iron and Arsenic removal unit

This is a small version of an Iron removal plant and is attached to a hand pump/ tube well (Figure 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 hand pump/ tube well is passed through a slotted horizontal Polyvinyl Chloride (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 up-flow roughing filter with coarse aggregates (20-30 mm). Here, flocculation sedimentation occurs in which Iron Hydroxide micro-flocs grow 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 down flow 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.

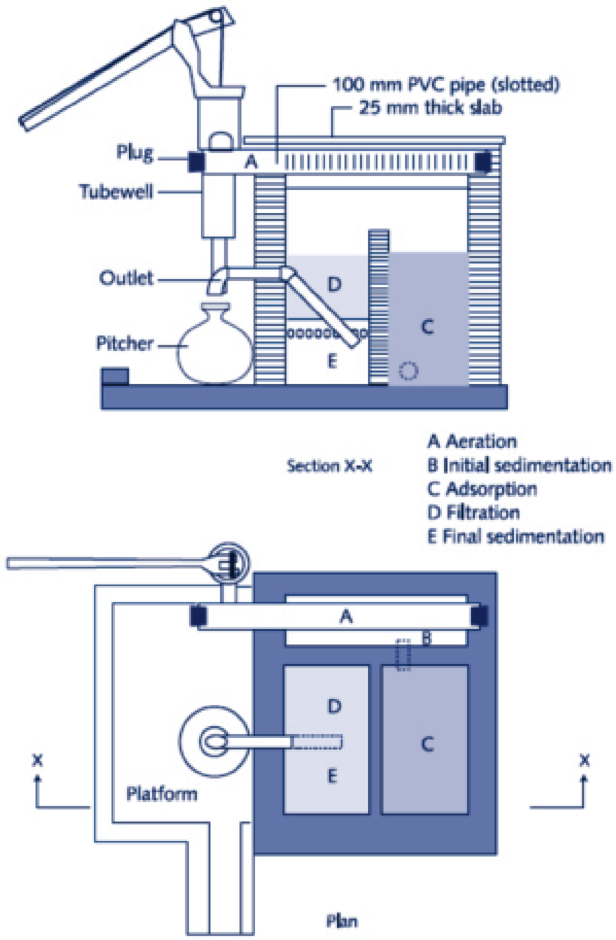

Figure 7: Tube Well Attachable Iron and Arsenic Removal Unit

2.5.8 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 sometimes 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 8. The mixing and flocculation processes in this unit are better controlled to effect higher removal of Arsenic.

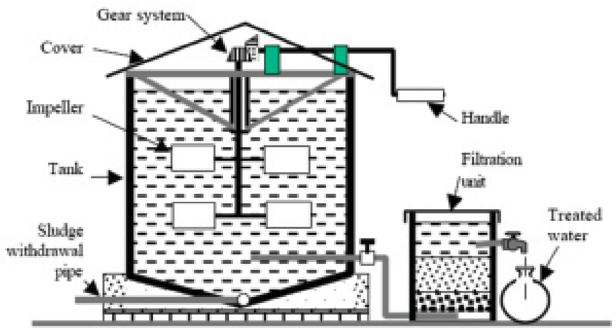

Figure 8: DPHE-Danida Fill and Draw Arsenic Removal Unit

2.5.9 Arsenic Removal unit attached to tube well

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 tube well as shown in Figure 9 has been found effective in removing 90% Arsenic from tube well water having initial Arsenic concentration of 300mg/L. The treatment process involves addition of Sodium Hypochloride and Aluminium Alum in diluted form, mixing, flocculation, sedimentation, and up flow filtration in a compact unit.

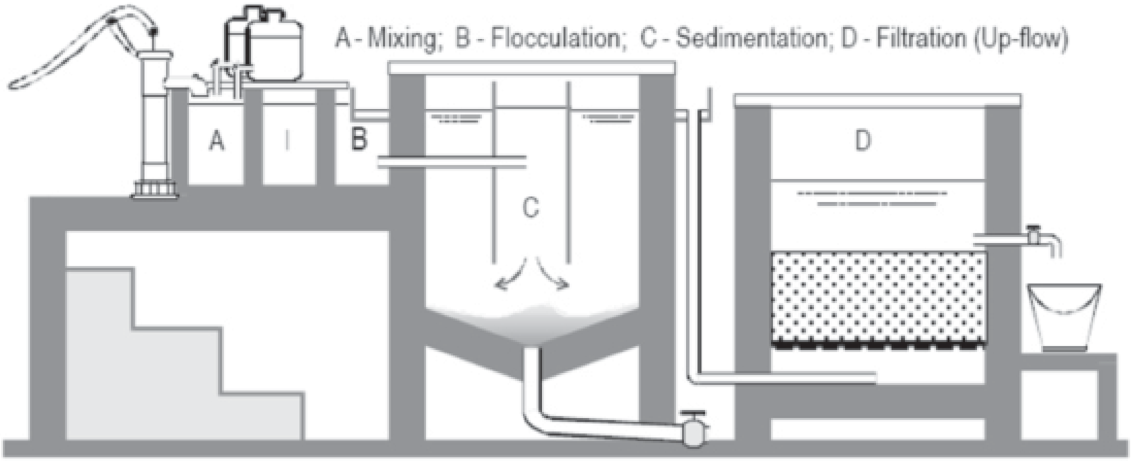

Figure 9 : Arsenic Removal Plants Attached to Tube well

2.5.10 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 drainpipe 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 10.

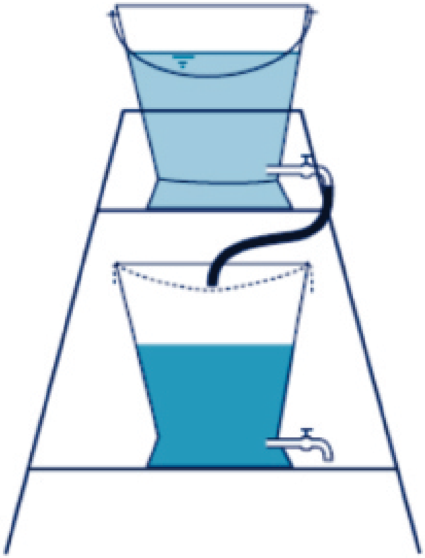

Figure 10: Two-Bucket Treatment Unit

2.5.11 Alcan enhanced Activated Alumina (AA) Unit

In this process, water from a tube well is allowed to pass through an enhanced AA bed and the treated water is collected as shown in Figure 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 AA 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 AA unit is designed for single use and therefore saturated media must be replaced after use. Environmentally safe disposal of spent approximately 40 kg per treatment cycle, is required.

The cost of this unit is USD 500 (Rs. 25,000) (USD 200 for the unit and USD 300 for the material (5-year warranty, expected life 10 years). Annual filter material costs USD 300. Costs could be optimised with increase in demand.

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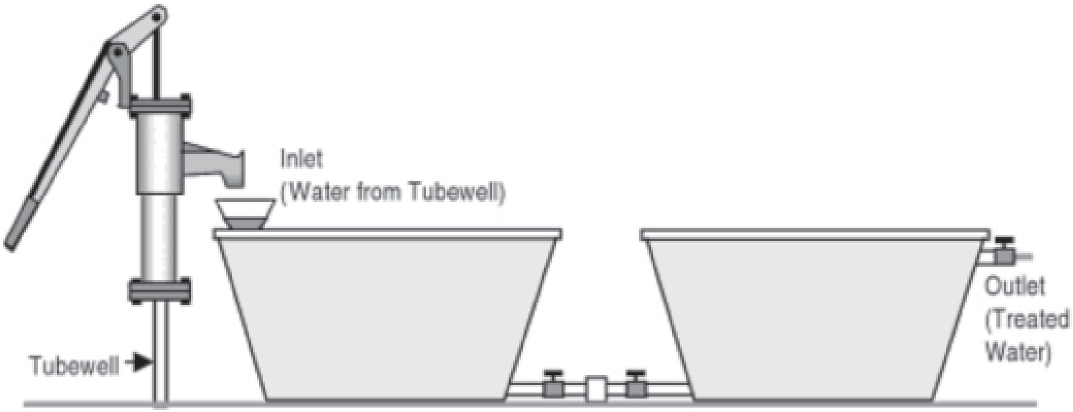

Figure 11: Alcan enhanced activated alumina unit

2.5.12 BUET Activated Alumina (AA) filter

The BUET activated alumina Arsenic removal unit (ARU) consists of sub-units for oxidation-sedimentation, filtration, and AA adsorption. Oxidation and sedimentation are 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 AA 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 sub-units. The problem has been addressed by design modification. The modified BUET activated alumina ARU is shown in Figure 12.

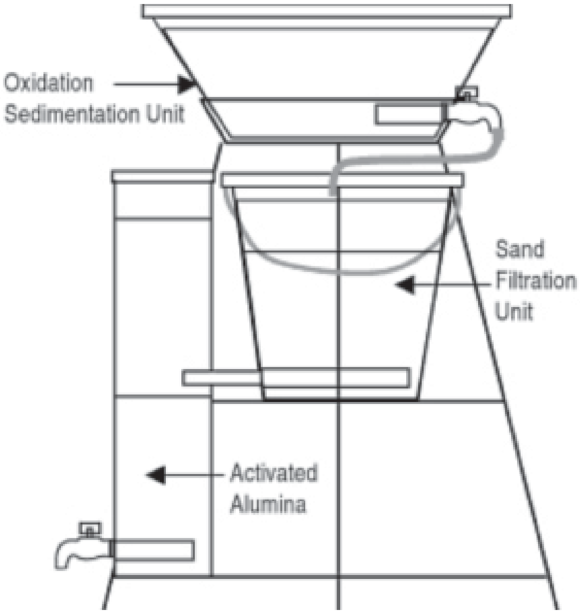

Figure 12: BUET AA Filter

The costs (capital and recurrent) of this filter are Taka 1000 (Rs. 650).

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2.5.13 Iron-Coated sand filter

BUET has tested a unit that utilizes Iron-coated sand for removal of Arsenic from groundwater (Figure 13). Pre-treatment for removal of excess Iron, to avoid clogging of the active filter bed, is required. Pre-treatment 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- 2cm 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 a strainer placed in Iron-coated sand and eventually flows to the tap.

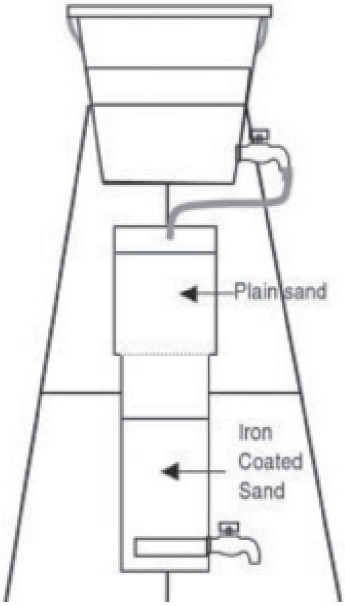

Figure 13: Iron-Coated Sand Filter

2.5.14 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 thylene 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 Taka 230/- (Rs. 150).

Figure 14: Read-F Arsenic Removal Unit

2.5.15 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 15.

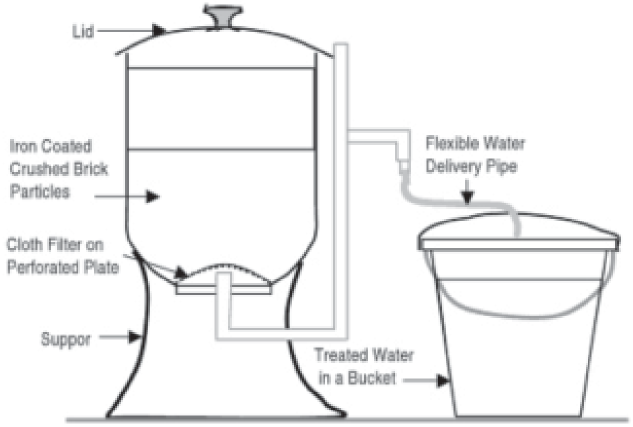

Figure 15: Shapla Arsenic filter

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

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2.5.16 Rama Krishna Mission (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 10 Litre of treated water.

2.5.17 CMFRI filter

This filter is developed by the CSIR Central Mining and Fuel Research Institute (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 fits 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 Rs. 0.10 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 20 L of water is Rs.0.75 to Rs. 1.00.

2.5.18 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 16). It is based on the principle of adsorption of Arsenic ions on AA 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 (12 L 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.

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

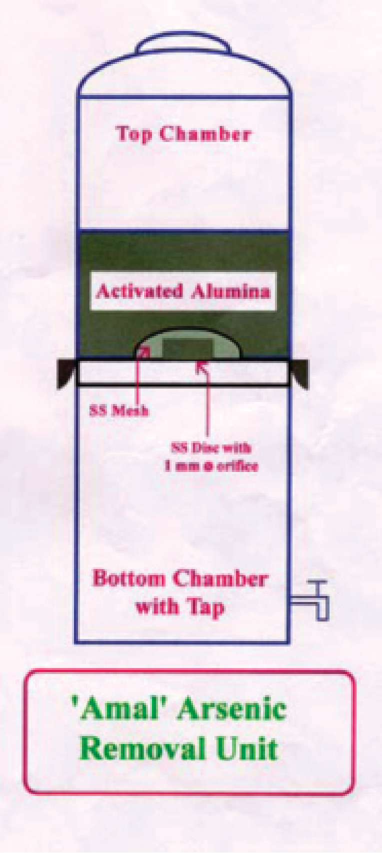

Figure 16: AMAL Domestic Filter

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 absorptive 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. 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

2.5.19 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 m^2/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 AA. Some studies indicate that Ferric Hydroxide has 3 to 10 times higher efficiency than AA 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 m, to operate satisfactorily.

The unit cost is Rs. 4,500 which is considered unaffordable by most villagers. O&M costs are not available.

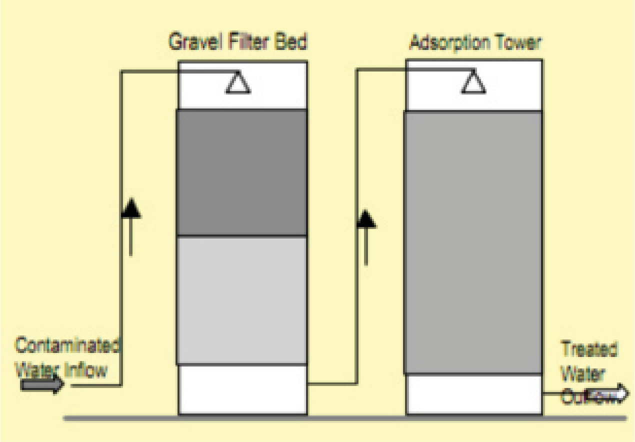

Figure 17: Paul Trockner Filter

2.5.20 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 inFigure 18 .

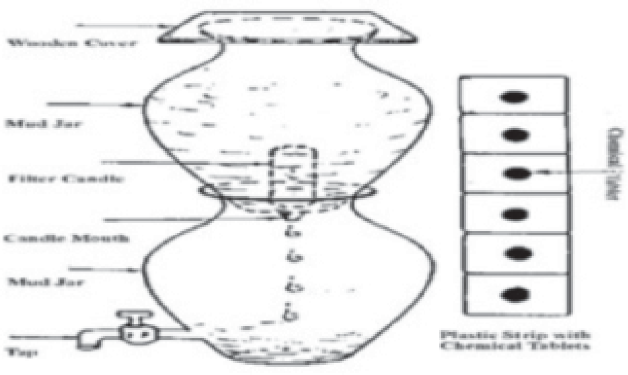

Figure 18: Arsenic Removal Filter Tablet System

The cost of unit varies from Rs. 100 – 1,500. It depends on material of construction of containers. The cost of tablet is approximately Rs. 0.50 – 0.75.

2.5.21 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, in Canada, 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.

2.5.22 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 19. 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. Cost of one unit is Taka 250 (Rs. 150).

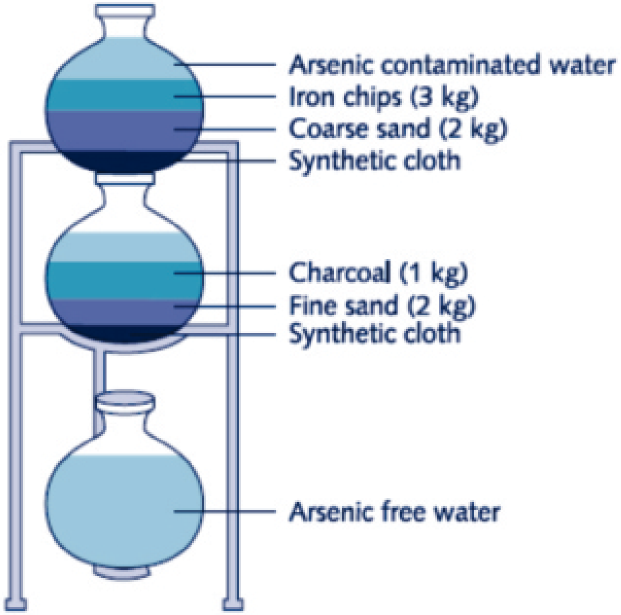

Figure 19: Three pitcher filter

2.5.23 Iron Oxide Coated Sand filter (IOCS)

UNESCO-IHE developed an Arsenic removal method based on adsorption on Iron oxide coated sand (IOCS) (Figure 20). 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 20: Iron Oxide Coated Sand Filter

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2.5.24 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 Danver Town's water system produced a significant reduction in Arsenic (III) levels to below 3 µg/L. The schematic diagram of this unit shown in Figure 21.

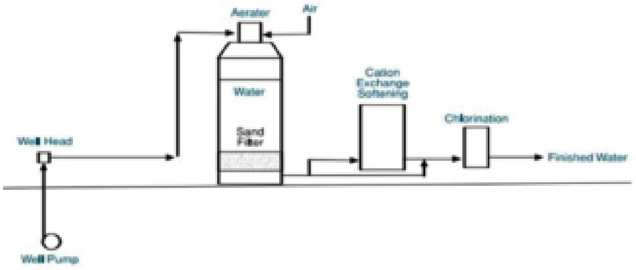

Figure 21: Aeration/Sand Filtration Unit, Cation Exchange Softening and Chlorination

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2.5.25 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 22). A particular effort was made to understand the effects of Phosphate and Iron on the performance.

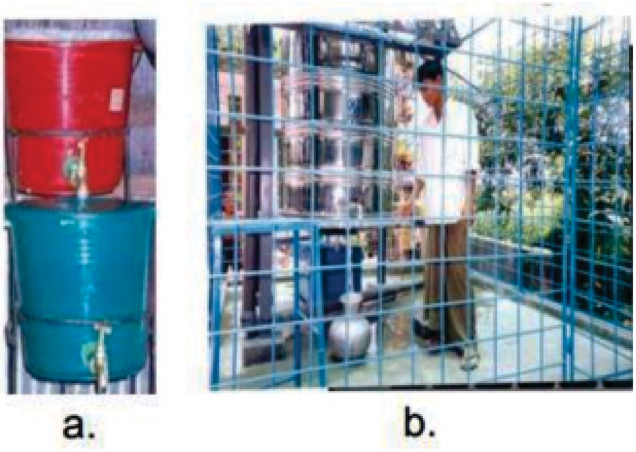

Figure 22: Metal oxy-hydroxide based community level Arsenic removal systems

2.5.26 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 Oxyhydroxide phases. Dissolved Arsenic is removed by precipitation, co-precipitation and adsorption onto the Iron Oxyhydroxides. The Arsenic-rich Iron Oxyhydroxides 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 24). Short-circuiting compromises Arsenic removal and can result in total Arsenic concentration of treated water above the maximum contamination level (MCL) of 50 µg/L.

Figure 23: Zero-Valent Iron Arsenic filters

2.5.27 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 24). 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.

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

2.5.28 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 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).

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

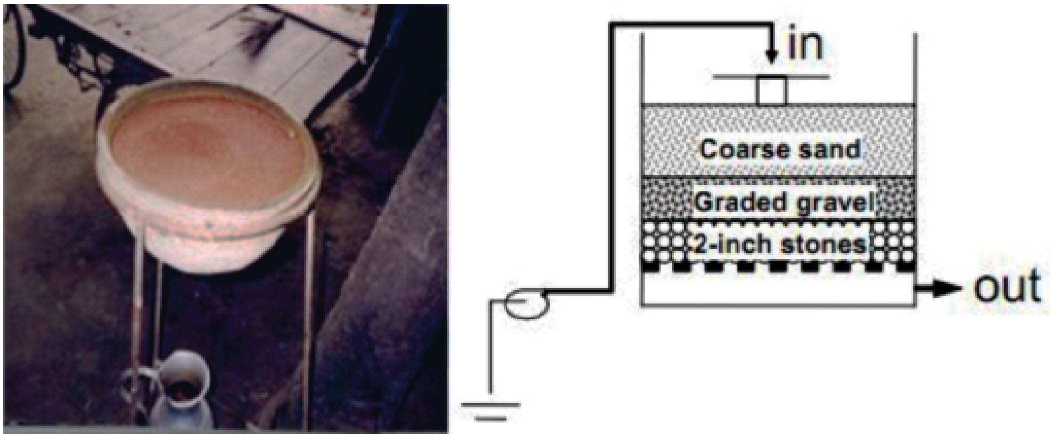

Figure 24: Home-Made Arsenic/Iron Filter from Shibaloy

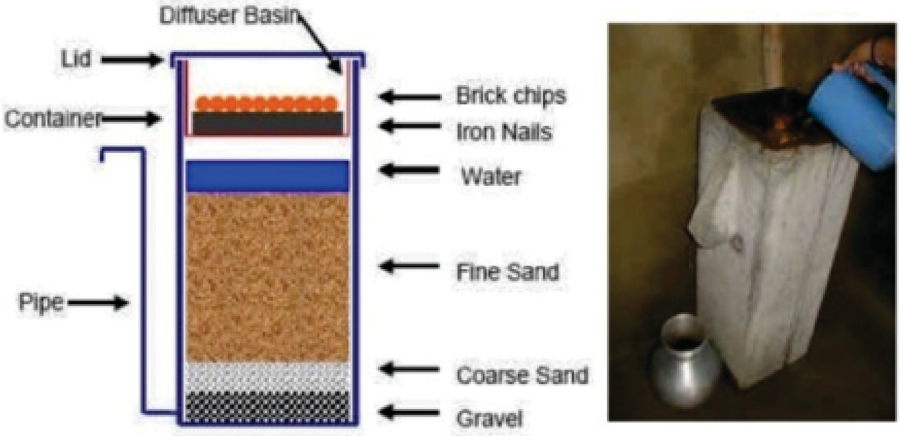

Figure 25: Components of the Kanchan Arsenic filter

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2.5.29 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 tube well water using this technology found that 99.5% soluble Arsenic could be removed from Arsenic concentration of two milligram per litre. The flow rate is about 6 litres 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 several 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 Taka 300 (Rs. 200) which can purify up to 60,000 litres water.

2.5.30 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 Centre 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 inFigure 26, 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 yields to the oxidation of groundwater with high concentrations of soluble Iron and precipitate as $Fe(OH)_3(s)$. Inorganic As(III) species – catalysed 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. 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 (CI) turnings through a proprietary process to maintain active CIM integrity for years. 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 Rs. 210.

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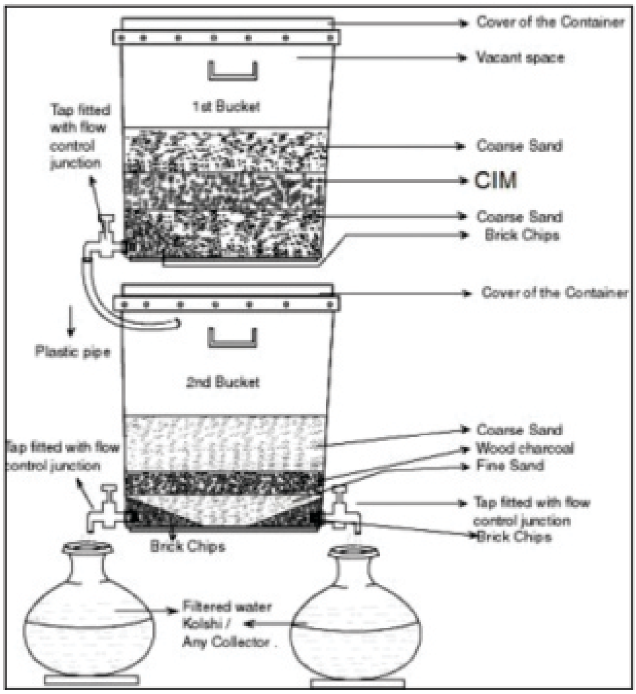

Figure 26: Schematic Diagram of SONO-filter

2.5.31 Cartridge filters

Filter units with cartridges filled with adsorptive 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 feedwater 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.

2.5.32 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 27shows 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 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.) 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 capital cost is Taka. 12,000/- (Rs. 8,000) plus annual costs of Taka. 6,000/- (Rs. 4,000) (ion resin column lasts on average for six months).

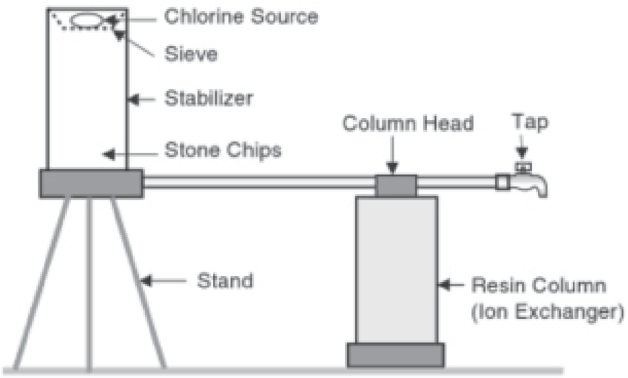

Figure 27: Tetrahedron Technology

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2.5.33 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 the 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 microns in size. The purifier works on the principle of continuous chlorination and filtration through activated Carbon. A special attachment with AA is used to remove Arsenic. It can work without electricity and without inline water supply. Arsenic is removed below 10 ppb for drinking water. 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 is available on their performance. The cost of this filter is Approximately Rs. 2,700.

Figure 28: Pureit Arsenic Removal Filter

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2.5.34 Arsenic Removal technology MRT-1000 of Reid System Ltd.

Jago Corporation Limited promoted a household RO water dispenser MRT-1000 manufactured by B&T Science Co. Limited, Taiwan. This system was tested at BUET and showed As(III) removal efficiency of more than 80%. A wider spectrum RO 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 RO system is relatively high.

2.5.35 Low-pressure Nanofiltration and Reverse Osmosis

Oh et al. (2000) applied Reverse Osmosis and Nanofiltration (NF) membrane processes for the treatment of Arsenic contaminated water applying low pressure by bicycle pump. A NF 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 tube well water in Bangladesh the average ratio of Arsenite to total Arsenic was found to be 0.25. However, the RO 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 Nano filtration with pre-oxidation or RO with a bicycle pump device could be used for the treatment of Arsenic contaminated groundwater in rural areas (Oh et al., 2000).

2.5.36 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.

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2.5.37 Ultra-filtration membrane assisted process

Bhabha Atomic Research Centre (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 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 in-situ 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.

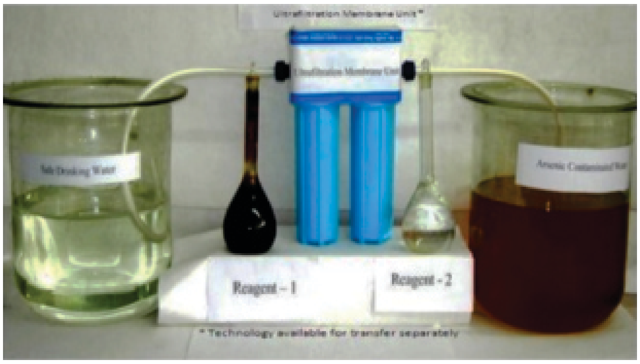

Figure 29: Ultrafiltration Membrane Assisted Process

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2.5.38 Arsenic Removal Using Bottom Ash (ARUBA)

Developed at Lawrence Berkeley National Laboratory (LBNL), Arsenic Removal Using Bottom Ash (ARUBA) 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, 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 USD 7 - 15 (Rs. 350 - 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 is currently designing a community-based water treatment plant which uses ARUBA to remove Arsenic from drinking water.

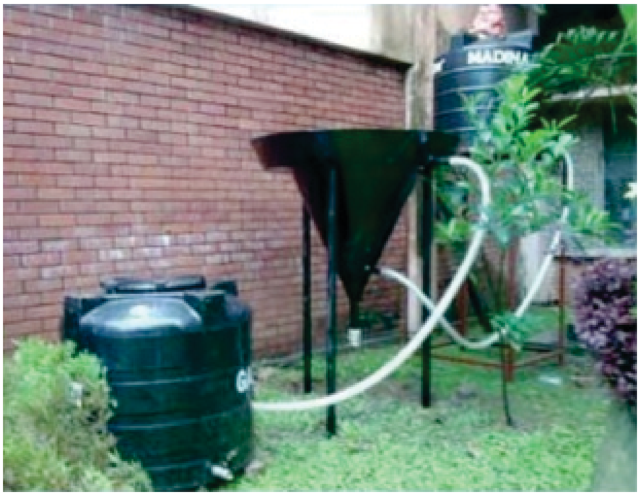

Figure 30: ARUBA Arsenic Removal Plant Prototype

2.5.39 Electro-Chemical Arsenic Remediation (ECAR)

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 electro-chemically 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 alkalis 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 31.

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.

Figure 31: ECAR Prototype Unit

2.5.40 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 feedwater 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. Several 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 are quite promising and ideal for a rural set up where people really cannot afford to pay a substantial amount for the water supply. The only disadvantage is that it takes some time for the whole system to stabilize 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.

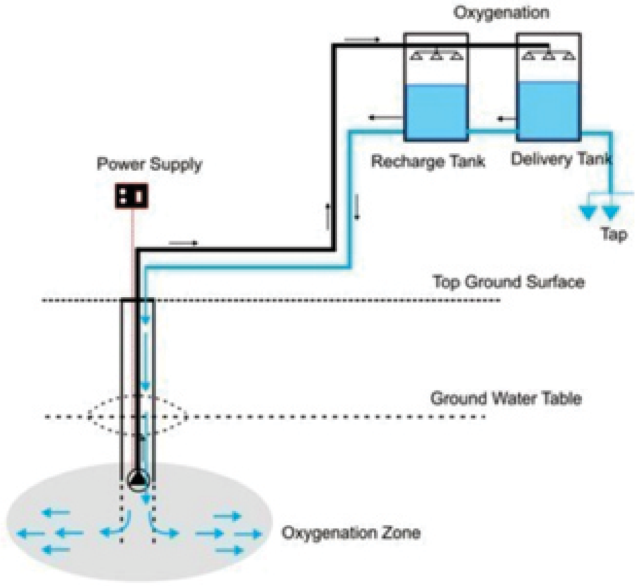

Figure 32: Schematic representation of Subterranean Arsenic Removal (SAR)

2.5.41 Arsenic removal (OxiMax) systems

The process used by the media to remove the Arsenic and Manganese is classic oxidation – the precipitation-filtration. The media does not require periodic regeneration or reactivation (as the greensand does) and does not display a decaying activity to do its catalytic work. The system will only require periodic backwashing to remove the collected solids. Another function of the Chlorine (fed as Sodium Hypochlorite NaOCl using electro-chlorination systems) is that it keeps the media free from bacterial or slime growth and is also used in post-treatment of filtered water. At the same time, the NaOCl is a source of Oxygen more reactive than molecular Oxygen. The technology not only removes the Arsenic from the water, but also removes microbiological contamination from the water with the use of electro-chlorination.

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2.5.42 GEH 102 Granular Ferric Hydroxide

Summary of the Product: Granular Ferric Hydroxide or GEH 102 is the most robust technology for adsorbing Arsenic from the water source. The media granules are manufactured under a patented process at the manufacturing facilities in Germany. The purification technology is an extremely simple process and involves passing the water though a bed of GEH 102 to adsorb Arsenic from the contaminated water. The process efficiency is maintained by backwashing the plant occasionally based on the pressure difference in the water. It must be noted that at the time of backwash no Arsenic is released back from the media filter bed.

Contaminants that can be removed through this Technology: GEH 102 is primarily used for removal of Arsenic - As (III) & AS (V) from natural or wastewater sources. Apart from Arsenic it has been tested and trailed to remove the following contaminants as well:

I.) Phosphate

ii.) Other Dissolved Substances - Molybdenum, Selenium, Antimony, Copper, Chromate

iii.) Dissolved Organic Matters.

Cost of Water Per Litre (Paise per liter): 4.00

Design Capacity: Arsenic filter beds can be designed for various capacities. The basic design parameters are based on the basic assumption of a contact time of greater than or equal to 3 minutes and the bed depth of 0.8m to 1.6m. The diameter of the filter vessel is selected accordingly. The backwash should be at a velocity of at least 26 m/h using preferably Arsenic free water. No other chemicals or required for backwashing.

Pre-Treatment Protocol: The raw water must be free from any Iron Contamination, and it is preferred that the Iron Contamination should be removed before passing it from the GEH 102 filter bed for removal of Arsenic. It must also be free from turbidity, positive redox potential and should not have any Calcium precipitates. It must be noted that groundwater sources which are the primary source of water for using such technology is generally only contaminated with Iron and Arsenic and is not turbid or with Calcium precipitates. In cases where such water is used as source water, other technologies should be used before removal of Arsenic.

Post-Treatment Protocol: Since, the water is used for drinking water, pathogenic microorganism should be removed by using approved technologies for disinfection. At times Activated Carbon Bed is added to remove any odour from the water, and to give it a crystal clear look. But it should be noted that activated Carbon bed is not made mandatory by the GEH 102 Filter Bed for Arsenic Removal, as it does not change the physical attribute of the water and neither does it add any unfavorable taste to the water.

Operations and Maintenance Cost and Protocol: Operation and maintenance of the plant is simple and requires periodic backwash based on the following parameters:

I.) Life of the Media
ii.) Frequency of the Backwash
iii.) Pressure Difference in the Filter Bed

Based on the following parameters, backwash procedure is defined. The cost involved are fairly zero, as it does not require any dosing of chemicals or adjustment of pH.

Reject Management Cost and Protocol: The reject management should be decided based on the following aspects:

I.) Backwash water
ii.) Spent media
iii.) Disposal of spent media
iv.) Safety of waste material.

The backwash water does not release any Arsenic, and the spent media maintains the solid granular form and has passed the Toxicity Characteristic Leaching Procedure (TCLP) test. The reject management is fairly easy and simple.

Certification of Product: GEH 102 is certified by NSF/ANSI 61 as Drinking Water System Component Quality of GEH 102 is in accordance with the European Standard DIN EN 15029. The product itself is not patented but the production process is patented.

Ease of Operations and Management: The adsorption technique of Arsenic Removal Systems with GEH 102 is fixed bed reactor is simple, safe, and effective method for elimination of Arsenic from contaminated groundwater. No complicated dosing of chemicals, no cumbersome adjustment of pH is required. So, the main tasks are periodically monitoring the plant and to observe the whole system is properly running or not. The most important interfering substances are phosphate and Fluoride, which are competing with Arsenic for the covalent binding.

Interference by other Contaminants: The most important interfering substances are Phosphate and Fluoride, which are competing with Arsenic for the covalent binding places on the surface of the media.

Test Trailed: Harbauer India has installed more than 1000 Arsenic Removal Plants across the Arsenic affected districts of West Bengal, Bihar, Uttar Pradesh and Chhatisgarh with GEH 102 as the primary technology for various Government Departments.

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2.5.43 Low-cost non-electric water purifier for Arsenic removal

Summary of the Product: Kent Gold AS is a non-electric, gravity-based water purifier with 3 stages of purification. It uses the most advanced UF membrane & a specially designed media which removes Arsenic from contaminated water besides removing Bacteria & Cysts. It is a low-cost solution for water purification in areas where constant supply of electricity is a problem, especially rural areas. It is a personal water purifier for home use. The technology can be used for mass purification as well.

Contaminants that can be removed through this Technology: Arsenic -As(III) & As(V), as well as Bacteria, Cyst, Suspended particles, Volatile Organic Compounds, hydrocarbons and odor.

Cost of Water Per Litre (Paise per liter): 60.00

Design Capacity: The media used for purifying water has a life of 1500 liters. Kent Gold AS comes with a replaceable media.

Pre-Treatment Protocol: Sediment Filter

Post-Treatment Protocol: UF membrane

Operations and Maintenance Cost and Protocol: Kent Gold AS has 2 consumables.

I.) Arsenic block – to be replaced after 1500 liters and costs Rs. 700/-

ii.) UF Membrane – to be replaced after 4000 liters and costs Rs. 600/-

Reject Management Cost and Protocol: Not Applicable

Certification of Product: From 3 independent Laboratories - SGS Lab Kolkata; TUV Lab; Spectro Labs.

Ease of Operations and Management: Kent Gold AS is a very simple to use water purifier. The purifier can be placed anywhere on a flat surface. Raw water must be poured into the purifier by opening the top lid and purified water may be dispensed using the Pure Water Tap. The water purifier stores 20 liters of water.

Interference by other Contaminants: Not Applicable

Test Trailed: KENT had installed Gold AS water purifier at nine different locations in Kolkata. Laboratory Test was conducted by SGS lab Kolkata. The Arsenic concentration was artificially spiked to 138 ppb. After treating with Kent Gold AS, the reduction of Arsenic was approximately 93% (average) which brought it below permissible levels/ detection limit. Many such tests have been performed and Kent Gold AS has been able to remove Arsenic from all sources of water in 100% of the tests.

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2.5.44 Bharti-Senco Iron cum Arsenic removal unit

Summary of the Product: Bharti-Senco Iron cum Arsenic removal units have been designed and developed for solving the Iron and Arsenic contamination problems in hand pump and tube wells water and providing safe and Iron and Arsenic free water in India.

Cost of Water Per Litre (Paise per liter): 1.00

Contaminants that can be removed through this Technology: It can handle up to Iron up to 20 PPM and Arsenic up to 5 PPM at inlet water and outlet Iron less than 0.30 PPM and Arsenic less than 0.010 PPM at outlet water. It also reduces turbidity of water.

Design Capacity: Different capacity plants are available

Pre-Treatment Protocol: Not Applicable

Post-Treatment Protocol: Not Applicable

Operations and Maintenance Cost and Protocol: Replacement of Iron and Arsenic removal media once in 3 - 4 years. Backwash is needed depending on the Iron content in water. No backwash required for Arsenic removal media. Life of Arsenic removal media is up to 4 years subject to Arsenic content in water.

Reject Management Cost and Protocol: Not Applicable

Certification of Product: ISO 9001: 2015, ISO 14001: 2015, OHSAS 18001: 2007, ISO 22000: 2005 and NSIC Registration Certificate.

Ease of Operations and Management: Bharti Iron cum Arsenic removal unit is an extremely cost effective & efficient product which can solve the problem of red Iron and Arsenic contamination water in hand pumps in rural India. The unit gives Iron and Arsenic free water. It can treat water with up to 20 PPM Iron and 5 PPM Arsenic. This unit is proprietary to Bharti Waters Pvt. Ltd. and has been developed to make it easy to use by people in rural India.

Interference by other Contaminants: Not applicable

Test Trailed: The product has been successfully trialed & tested in dumka district of Jharkhand State and Iron removal unit has also been successfully installed in various states in India like Jharkhand, Uttarakhand & Odisha.

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2.5.45 Community scale IITB Arsenic filter

Summary of the Product: The IIT Bombay Arsenic removal filter developed under the DST project involves the co-oxidation of Fe(II) and As(III) in the presence of dissolved Oxygen and subsequent Arsenic removal by Hydrous Ferric Oxide, which is formed from oxidation of Fe(II) naturally present in groundwater and from leaching of Iron nails, thus As(III) oxidation is achieved without addition of any chemicals. This filter can be fabricated by local plumbers and masons in field using locally available materials. The unit is cost-effective and robust, does not require extensive monitoring. This filter provides drinking water to meet the daily needs of 200-300 families and can achieve Arsenic level of < 10 µg/L (WHO guideline) for initial Arsenic concentrations of up to 500 µg/L at a flow rate of 600-1000 L/h. The cost for producing 1000 L of water varies from Rs. 0.1 to 1.0 (inclusive of maintenance of handpump, Iron replenishment and filter washing labour cost) and the contribution required per family for sustaining the filter is around Rs. 10 per month.

Contaminants that can be removed through this Technology: Arsenic, Iron and Phosphate removal from groundwater.

Estimated Capital Cost (In Rs.): 70,000.00

Technical details of the Technology:

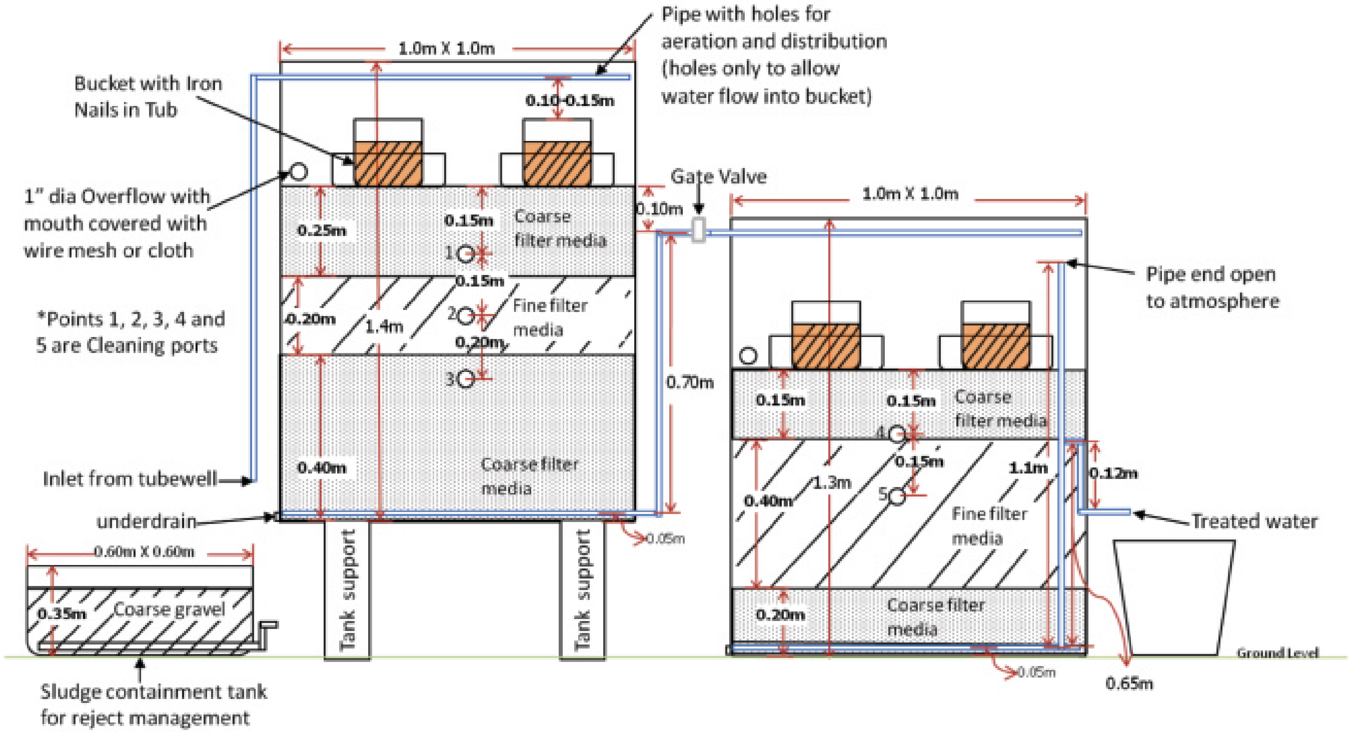

Figure 33: Schematic of IITB Arsenic Filter

The IIT Bombay Arsenic filter consists of the following units:

I.) **Inlet pipe:** A lift and force or Mark 2 hand-pump with third plate arrangement is used for lifting groundwater into the IIT Bombay Arsenic filter. A GI pipe of 1" dia is connected to the handpump and this is then connected, via a 1" socket, to a 1" dia HDPE pipe which is present inside the filter. This HDPE pipe has 3mm dia holes such that water falls uniformly into the Iron contactor. The inlet pipe should be horizontal so that water is equally distributed throughout the length of pipe. The free end of this pipe should be closed and secured to the opposite side of the filter. Care should be taken to ensure that water surges do not disturb the levelling of the pipe and that the holes are allowing water to fall only in the Iron contactor and not on the gravel filter chamber.

ii.) **Iron Contactor:** The Iron contactor is one of the following, i.e. (a) or (b)

a) The Iron contactor is present below the Inlet pipe. The Iron contactor tray has ungalvanized Iron nails of size ranging from ¾" to 1" and is placed on a tray with support from the sides. It comprises of 2 rectangular trays of 0.44m x 0.9m with overflow pipes covering its entire area. These 2 trays are placed alongside each other. The bottom of the tray is drilled, and the overflow pipes are welded to it. Each overflow pipe is a hollow pipe of diameter 2.5cm and height of 11.5cm. The height and number of overflow pipes may vary as per the influent water flow. The top opening of the overflow pipe is covered with conical cover, as per the design. This cover should not be higher than 2.0 cm from the tray bottom. The lower 1.3 cm of the overflow pipe is below the tray. All the welds and joints in the tray are made leak proof. In rural areas Iron contactor tray fabrication takes a lot of time and the workmanship is also not good. Though Iron tray contactor is easy from operational purpose but type b) Iron contactor mentioned below is easy to fabricate.

b) The Iron contactor can also be of bucket and tub type. The inlet pipe is constructed/ modified in such a way that the incoming water is equally divided into 4 or 6 parts. Some (4 or 6) such bucket-tray setups are placed under each part of the inlet. A plastic bucket of diameter 8 inches is taken and 20-30 holes of diameter 2mm are drilled on the bottom of the bucket. The bottom 4 cm of the bucket is filled with gravel of size 10-15 mm. This is done to avoid the clogging of the holes of the bucket by the Iron nails or the corrosion products. Iron nails (1 inch long) are filled into the bucket up to half of the bucket height. Generally, each bucket has 3-4 kg Iron nails. These buckets are now placed on plastic tubs/ trays. The plastic trays are of diameter approximately 12-14 inches. Holes of diameter 2-4 mm are drilled along the side of the plastic tray in a straight line 6cm from the bottom of the tray. It is important to maintain the straight line as otherwise there maybe water flow from only one side of the tray which might lead to short-circuiting in the filter. This bucket and tray arrangement can be used instead of the tray as the tray is difficult to fabricate and can be expensive.

iii.) **Gravel filter:** The filtration zone for separation of Hydrous Ferric Oxide floccules (HFO). This is the design used for the pilot plant. The filtration chamber consists of a tank of dimensions 1 m x 1 m x 1.5 m. The tank is filled with gravel and aggregates of the size of 5-10 mm up to the height of 0.65 m from the bottom. Then another 0.15 m is filled with gravel and aggregates of the size 10-15 mm. The top 0.6 m is left free for Iron contactor tray/ bucket and inlet pipe. If required, Iron mesh (available in hardware stores and called "Jali" in the local language) are added in the filter media at intervals of 10 cm starting from 5cm below the water level, so as to provide extra Iron for formation of HFO. This Iron mesh is cut into 1 m X 1 m squares and 3 such squares are placed on top of each other, and this is layered on the gravel at the desired intervals. This is done in areas where there is low groundwater Iron and high Arsenic. Generally, 3-4 such Iron mesh layers are sufficient to meet the extra Iron requirements. An overflow is provided at 0.80m from the bottom of the tank.

Another filter tank with similar configuration is set up along with the first tank. This is for double stage filtration, as an added failsafe mechanism. The pipe connecting these tanks should have a gate valve. It is important to have the water level no more than 10 cm below the top surface of the gravel layer. This can be ensured by measuring the length of the collection pipe which rises from bottom and ensuring that it is more than 5-7 cm less than total gravel layer depth. These tanks can be fabricated either by brick masonry or from 10 gauge Iron sheets. Even commercially available PVC tanks can be used (but not recommended as the exact dimensions are difficult to find). It is essential to make all the welds, joints and pipe connections leak-proof.

iv.) **Cleaning ports:** Cleaning ports are located in the gravel filter. These ports consist of 1" HDPE pipes with 3 mm dia holes all along their length on the top half of the circumference.

v.) **Cleaning mechanism:** The cleaning mechanism can be divided into 2 activities:

a.) Cleaning of nails

b.) Cleaning of gravel

a.) **Cleaning of nails to dislodge the Iron oxide layer:** The Iron nails are stirred with a rod/ stick in the tray. The action of the nails rubbing against each other dislodges most of the deposited HFO on the nails and the nails become ready for reuse. In the case of bucket and tub arrangement the nails have to be taken out of the bucket and washed under running water. The simple action of emptying the buckets and then refilling under running water can dislodge most of the HFO which sticks onto the nails. The cleaning of nails should be done every fortnight.

b.) **Cleaning of filter to remove the HFO flocs from the gravel:** This is the scheme to be followed while cleaning the IIT Bombay Arsenic filter. The ZVI unit is first dissembled, and the inlet pipe is disconnected from the sludge laden wastewater is directed to the sludge tank using a flexible pipe. The other cleaning ports are sequentially opened, and the wastewater is allowed to drain out. The top 10-15 cm of the gravel layer is taken out manually and cleaned separately by vigorous shaking in bamboo tubs. The friction caused by rubbing of the gravel particles amongst themselves is sufficient for cleaning them. Other reactors require cleaning by backwashing, but it is known to be quite ineffective and cumbersome and require frequent backwashing. In this method complete cleaning can be achieved with low effort and the dirty wash water can be safely directed into a collection tank. The gravel filter may be cleaned once in two-three months (depending upon usage).

vi.) Collection pipe: The collection pipe is similar to the cleaning port pipe arrangement. But instead of the 1” nipple from the cross leading directly out of the filter, using a 1” dia HDPE pipe the collected water is directed upwards. The outlet of the pipe is raised to a height of 65 cm from the bottom and only 10 cm from the top surface of the gravel. It is essential that the top surface of the gravel be no more than 10 cm from this pipe outlet.

Operations and Maintenance Cost and Protocol: The contribution required per family for sustaining the filter is around Rs. 10/- per month.

Test Trailed: Installed in Assam, Bihar, Uttar Pradesh & West Bengal States.

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2.5.46 HAIX: Hybrid Anion Exchange media for removal of Arsenic & Fluoride

Summary of the Product: Hybrid anion exchange (HAIX) technologies have been under development by Dr. Arup K. Sengupta (Lehigh University) since 2003. Polymer ion exchange resins impregnated with metal oxides or HAIX are a robust synergy of organic and inorganic phases. Advanced HAIX formulations have been synthesized and tested in the lab, commercialized, and implemented in field-scale systems for Arsenic, Fluoride, Iron, partial desalination, and Uranium removal. Variations of HAIX are in use across four continents by over one million people to drink safe water because of the higher performance and lower cost of water. Besides having superior aesthetic performance for water quality, HAIX has much superior trace contaminant removal. HAIX capacity and packed-bed performance are significantly better than other adsorbents on the market. When HAIX is combined in a process that optimizes Fluoride/ Arsenic removal through the smart use of ion exchange resins, removal performance is increased over 10 times at unoptimized conditions and the optimized HAIX process is 20 times better than typical AA systems. HAIX is a robust, reusable high-capacity adsorbent for Arsenic, Fluoride, and Uranium.

The hybrid nature of HAIX means it synergizes the high durability and chemical properties of polymeric ion exchange materials with the high capacity of metal oxide nanoparticles for trace contaminants. This synergy creates a long-term water solution with low produced water costs and operational requirements. Due to the Donnan Membrane Principle, impregnating metal oxides inside ion exchange polymers is not a trivial task and is the key underlying piece of intellectual property for HAIX. HAIX doesn't require electricity. In rural Bihar, Arsenic treatment without electricity is on-going over the last three years. Other technologies like RO wastes 50% of groundwater that is pumped out of the ground. HAIX has water recovery of over 99% to protect the precious groundwater resources and reduce the per volume costs of water. Also, as the system is online it can be fitted directly on the line between a submersible pump (electric/ solar) and ESR/ OHT.

Contaminants that can be removed through this Technology: Arsenic & Fluoride

Cost of Water Per Litre (Paise per liter): 5.00

Design Capacity: From 500 LPH to 200 m3/Hr

Pre-Treatment Protocol: Not Required. However, in case of water with suspended solids a dual media Filter is recommended.

Post-Treatment Protocol: Not applicable.

Operations and Maintenance Cost and Protocol: O&M is very crucial for success of these community-based plants. The O&M protocol shall be as below:

(i.) The unit shall be operated & maintained by Rite Water for period of 5-7 years after which the unit shall be handed over to Gram Panchayat

(ii.) A local villager can be trained to operate the plant, as the plant is very easy to operate, the local villager can easily run the plant.

(iii.) Because of automation, the operator intervention is minimal.

(iv.)

(v.) The water will be provided in 20 L jars at a nominal cost of Rs. 2/- per 20 L jar. If required in case of village where the houses are spread far, the operator shall fill the treated water in 20 L cans and distribute it to each household.

Certification of Product: “Certificate- Indian Institute of Science by K Keshav Rao, Bangalore (Chemical Dept)” – letter for certification that HAIX possesses necessary attribution to alleviate the Fluoride crises in India. “Certificate- WB Arsenic Task Force by Prof. KJ Nath”- certified HAIX as an effective technology for Arsenic removal. “Certificate- Maner Filter by Dr. Ashok Ghosh, Professor- in-Charge at A.N. College (Patna, Bihar).”- certified for the effective Arsenic removal by HAIX.

Ease of Operations and Management: This is extremely operator friendly and can be operated by local villager after proper training.

Interference by other Contaminants: Not applicable.

Test Trailed: Small Capacity plants implemented across West Bengal, Bihar and MP based on nano material for Arsenic removal large capacity plant (50 m^3/ hr and 91 m^3/ hr installation is in progress in North 24 Parganas in West Bengal) Hand Pump based plant has been installed and tested by Govt. of Orissa and NEERI based on HAIX nano material.

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2.5.47 Anion and Metal Removal by Indian Technology (AMRIT) by IIT Madras

Brief on the technology: AMRIT technology is based on world's best engineered nanomaterials for the removal of health-related contaminants from drinking water. The solution has been widely implemented as affordable point-of use water purifiers in the worst Arsenic, Iron and Fluoride affected regions of India. These materials-based solutions are green and sustainable (PNAS, 110 (2013) 8459-8464). AMRIT technology has been widely implemented across the country. AMRIT technology was conceptualized, developed, piloted, and implemented through Prof. Pradeep's research laboratory at IIT Madras. There are many contaminants found in water; yet all contaminants do not occur simultaneously. A tailored solution for each contaminant is the key to ensure that local water is made healthy for drinking, without affecting its qualities such as taste. This is possible affordably with the advent of nanotechnology. Contamination of drinking water by diverse species (Fluoride, Arsenic, Iron, and microorganisms in different regions) contributes to major health hazards across the country. Governmental agencies, through proactive efforts, have made a significant difference at grass roots level. However, challenges in drinking water purification are immense.

There is an urging need to implement products based on new technologies; two critical reasons are described here:

1.) Old technologies are increasingly becoming outdated: Activated Alumina for water purification is over 55 years old technology and is outdated today. Adsorption of Fluoride on alumina is extremely poor, which leads to the use of huge quantities of the adsorbent thereby increasing the size of water treatment plants. We are becoming increasingly aware of the health risks of Aluminum due to Alzheimer's disease; and

2.) Reducing limits of allowed concentration of contaminants in water: Allowed concentration of Arsenic in water was 200 ppb in 1960; today it is at 10 ppb (World Health Organization).

Newer technologies must evolve to address this issue. As guardians of the health of the society, we must be prepared to handle them. This is only possible with products based on new technologies – nominee has contributed to making a significant step forward in this direction. Using nanomaterials, it is possible to effectively destroy microorganisms, including enteric viruses, adsorb Arsenic/ Fluoride, remove heavy metals, and degrade pesticides found in drinking water. The technology behind the product has been scientifically validated by the international research community through research articles and patents. Adsorbents used for water purification are typically produced through high temperature synthesis. There are several associated challenges: by-products, power consumption and loss of surface area due to sintering. Nominee has co-developed a new protocol for material production which can be done at room temperature and yet produce a material which is exceptionally strong like river sand and has a large adsorption capacity. AMRIT technology is continuously being implemented by various state governments and non-governmental agencies to provide clean drinking water for people in India, especially those living in rural areas.

Product variants based on AMRIT technology:

i.) Handpump attached unit (1000 Liters per hour);

ii.) School and community centre unit (3000 Liters per day);

iii.) Standalone community unit (10000 Liters per day);

iv.) Automatic Water Dispensation Unit (1000 Liters per hour); and

v.) Village water supply unit (up to 10,00,000 Liters per day).

The technology has been applied in various forms for community water purifiers. The products based on these technologies are designed considering the indigenous context in the products. There are a number of new engineering novelties associated with this work. It is also well-known that water purification units for Iron removal often fail because they require daily maintenance. AMRIT technology has an Iron removal water purification unit which requires no backwashing and generates no sludge. This is the only example of a maintenance-free Iron removal product world-wide. The cost of clean water using this technology in the Arsenic affected areas is under between 2 to 4 paise per litre. It can be implemented at any level - domestic, community, or municipal - levels.

Salient features of AMRIT:

1. Pre-treatment is required for adopting the technology;
2. Overall life cycle cost of the technology excluding taxes: Rs. 2,500/-;
3. The technology has warranty period of 5 years;
4. The technology can be retrofitted into existing system;
5. The technology is scalable;
6. The sludge generated will be in solid form and can be used for landfill;
7. Maximum allowable TDS for inlet water is 1,500 mg/L;
8. It is a patented technology;
9. The cost of production of Arsenic free water is under between 2 to 4 paise per litre; and
10. The technology can be fully automated.

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2.5.48 ECAR -Electrochemical Arsenic Remediation

Brief on the technology: Chronic ingestion of even low Arsenic levels causes various types of cancer, particularly of the lungs, bladder, and kidneys. Arsenic can lead to diabetes, cardiovascular and reproductive problems and painful skin lesions that can result in Gangrene and eventual amputation. A recent 10-year cohort study published in the Lancet showed that 1 in 5 of all adult deaths in Bangladesh are directly related to Arsenic in drinking water. More recently, evidence has emerged that chronic exposure may have a detrimental effect on the IQ of children. Because nearly all deployed solutions have failed owing to various reasons, Electro Chemical Arsenic Remediation (ECAR) was invented to effectively remove Arsenic within a sustainable service delivery model. ECAR is designed to be so inexpensive and robust that the service model is financially sustainable without subsidies, enables quality control, incentivizes ongoing social marketing, and is rapidly scalable – directly addressing causes of previous failure. The proposed model allows for tiered pricing to ensure equal access to the poorest and helps reduce social exclusion and stigmatization. The service model includes regular awareness campaigns to highlight health and economic benefits of drinking Arsenic safe water, and to emphasize that the community's financial participation is necessary to provide a sustainable solution to the Arsenic crisis. ECAR is a breakthrough technology. The last major technological breakthrough in Arsenic remediation was the appearance of Activated Alumina (AA) adsorbent about 20 years ago. Since then, AA, and similar adsorbent-based technologies have incrementally improved, but still the adsorbents must be centrally manufactured or imported and treated with hazardous chemicals to regenerate, which is logistically difficult and dangerous in rural areas. In ECAR, highly effective adsorbent is generated in-situ from readily available inputs including ordinary mild steel (MS) plates and some electricity (intermittent grid, solar, and battery are all acceptable). In-situ rust particles generated by ECAR have a high adsorption capacity for Arsenic. During the ECAR process, Arsenic-III (more toxic and difficult to remove) is oxidized to Arsenic-V, which is more amenable to adsorption. As a result, ECAR is highly effective and exceeds international standards for Arsenic-safety across diverse groundwater conditions at a locally affordable price while still producing less waste sludge than conventional methods. In fact, ECAR is a Zero Liquid Discharge (ZLD) technology an attribute highly valued among all lists of key environmental metrics for technologies. ECAR performance has been verified for initial Arsenic concentrations up to 3000 ppb in synthetic groundwater containing both As(III) and As(V). Performance to meet the WHO-MCL of 10 ppb has been verified in real groundwater from India, US, Bangladesh and Cambodia, each with a unique composition of natural ions known to interfere with the Arsenic removal process (e.g., Phosphate, Silicate, natural organic matter, etc.) The most recent success of ECAR is a fully operational 10,000 liters per day (LPD) treatment plant installed at Dhapdhapi high school in West Bengal. The project was a collaboration between UC Berkeley, Jadavpur University, and LivPure (an Indian water purification company which licensed ECAR) and was funded by the Indo US Science and Technology Endowment Fund (IUSTEF). As of September 2017, LivPure began selling Arsenic-safe water to the Assured Matrix: Plant: 1 Plant Size: 10 Kl/day community for INR 6 for 10 Liters. As the ECAR technology scales up based on for-profit licensee businesses supported with government policy for safe drinking water, hundreds of thousands, and eventually millions of individuals living in poor rural communities of India will have access to Arsenic-safe drinking water.

Salient features of ECAR -Electrochemical Arsenic Remediation:

i.) No pre-treatment is required for adopting the technology;

ii.) Overall life cycle cost of the technology excluding taxes: Rs. 48,00,000/-;

iii.) The technology has warranty period of 5 years;

iv.) The technology can be retrofitted into existing system;

v.) The sludge generated will be in solid form and can be used for landfill;

vi.) The technology is scalable;

vii.) Maximum allowable TDS for inlet water is 2,000 mg/L;

viii.) It is a patented technology;

ix.) Life of filter media is 10 years; and

x.) The technology can be adopted for any terrain but requires electricity/ solar PV/ DG set.

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2.5.49 Laterite based technology for Arsenic removal by IIT Kharagpur

Brief on the technology: The laterite-based filter assembly is designed to remove Arsenic, Iron and bacteria from groundwater to provide low-cost drinking water in Arsenic affected areas. Naturally abundant laterite soil is used to prepare the filter media which has high Arsenic adsorption capacity (32 mg/g). The Arsenic removal media has a life of 5 years, and the filter life can be extended for several years by changing the Arsenic removal media every 5 years. The filter does not require any regeneration during its service life and meets the toxicology leaching protocol (TCLP) for safe disposal. Domestic filter does not require any power for operation. The filter has been scaled up from 100 l/day to 10 kl/day.

Salient features of Laterite based technology for Arsenic removal:

1.) Pre-treatment is required for removal of Iron from raw water;

2.) Overall life cycle cost of the technology excluding taxes: Rs. 9,00,000/-;

3.) The technology has warranty period of 5 years;

4.) The technology can be retrofitted into existing system;

5.) Arsenic removal media does not generate any effluent. However, Iron removal unit requires backwash once in a fortnight. The effluent thus generated is passed through a soak pit containing treated laterite, gravels and sand bed;

6.) The technology is scalable;

7.) Maximum allowable TDS for inlet water is 2,000 mg/L;

8.) It is a patented technology;

9.) Life of filter media is 5 years; and

10.) The technology can be adopted for any terrain.

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2.5.50 Technology for Arsenic removal developed by Lehigh University

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 34). 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.

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Figure 34: Arsenic Removal Plant at Rampur - Maner

3 Fluoride removal methods & technologies

3.1 Preamble

Fluoride as a groundwater contaminant is a worldwide problem. The groundwater is the source of domestic water for 80% of the rural and 50% of the urban areas in India (UNICEF, 2013). Naturally occurring Fluoride concentrations in groundwater range up to 48 mg/L in India depending on geological factors. Worldwide more than 200 million populations rely on the groundwater for drinking with Fluoride concentration higher than the permissible value of 1.5 mg/L. Elevated concentrations are reported to be associated with leaching from the Fluoride-bearing rocks like Fluorspar, Cryolite, Fluorapatite and Hydroxyapatite, or with weathered formations of Pyroxene Amphibolite and Pegmatites. Health effects caused by excess daily intake of Fluoride, with drinking water as the major contributor, has affected people in more than 20 states of India.

3.2 Health impacts of Fluoride

Excessive Fluoride exposure can cause irreversible demineralization of bone and tooth tissue, a condition known as Fluorosis, and long-term damage to brain, liver, thyroid, and kidney. In India, 60-70 million people are affected with dental and skeletal fluorosis. At a higher concentration affects the teeth causing dental fluorosis. In Fluoride metabolism approximately 75-90% of ingested Fluoride is absorbed. In an acidic stomach, Fluoride is converted into Hydrogen Fluoride (HF), and up to 40% of ingested Fluoride is absorbed from stomach as HF. High stomach pH decreases gastric absorption by decreasing the concentration uptake of HF and later absorbed in intestine. Once absorbed in the blood, Fluoride readily distributes throughout the body, with approximately 99% of body burden of Fluoride retained in Calcium-rich areas such as bone and teeth. Bone Fluoride is considered as a reflection of long-term exposure to Fluoride.

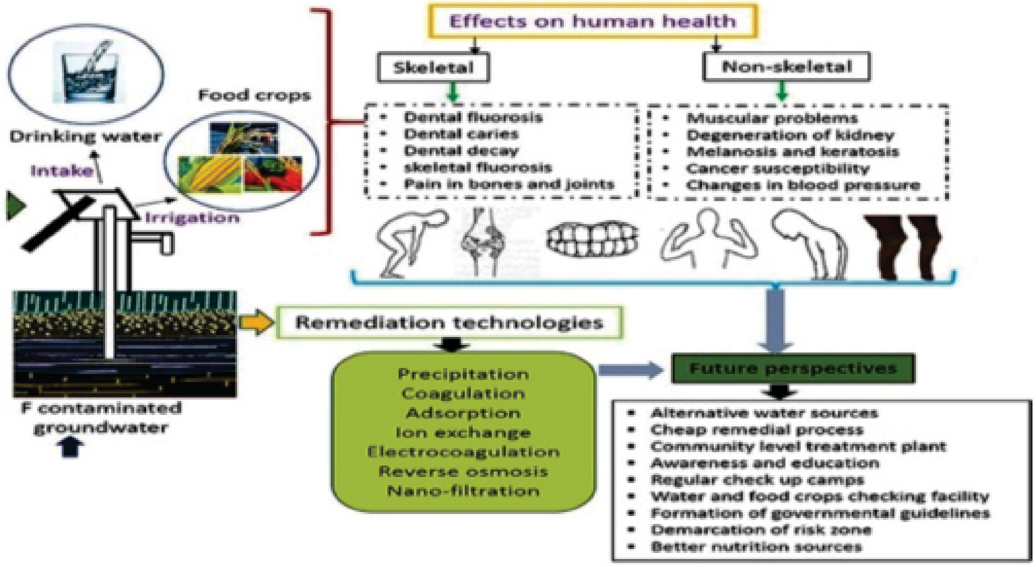

Figure 35: Effects of Fluoride contamination and Treatment Options

In dental Fluorosis, the enamel loses its lustre 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.

3.2.1 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. The 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 bones accumulate 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. The 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 developed due to pressure caused by Osteophytes (bony outgrowth), narrowing of intervertebral foreman and increase in size of the vertebrae or narrowing of the spinal canal, can lead to paralysis.

3.2.2 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, diarrhoea, constipation, blood in the stool, bloated feelings (gas), tenderness in the stomach, feeling of nausea (flu-like symptoms) and mouth sores.
- **Urinary tract:** Urine may be less in volume, red in colour and passed with an 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

To provide the Fluoride-free water to the community, first choice should be provision of safe source with acceptable Fluoride levels, transporting water from a distant safe source, blending high-Fluoride with low-Fluoride water to bring down Fluoride level below 1 mg/l, dual water sources and rainwater harvesting. In the absence of these options the treatment of water can be planned and implemented.

During the years following identification of Fluoride as the cause of fluorosis, extensive research has been carried out on various techniques for removal of Fluoride from water. While several techniques, based on adsorption, ion exchange, coagulation and precipitation, and ionic filtration processes have been developed and implemented but sustainable implementation of these technologies has rarely been achieved in rural communities. This failure is due to a combination of factors including lack of technical support, insufficient material supply, inadequate O&M, and irregular monitoring.

Based on treatment capacity, following de-fluoridation configurations are provided in India:

i.) Household de-fluoridation units: for single family to cater their daily treated water requirement for cooking and drinking purpose, these units are provided at places where community-based water treatment units are not feasible;

ii.) Handpump attachable water treatment units; and

iii.) Community-based water treatment plants; to cater requirement of small, moderate and big community, these units can be engineered according to the need.

There are several de-fluoridation techniques (Figure 36) that have been implemented globally but can be classified broadly in the following categories.

- Adsorption and Ion-Exchange
- Coagulation and Precipitation
- Membrane filtration process

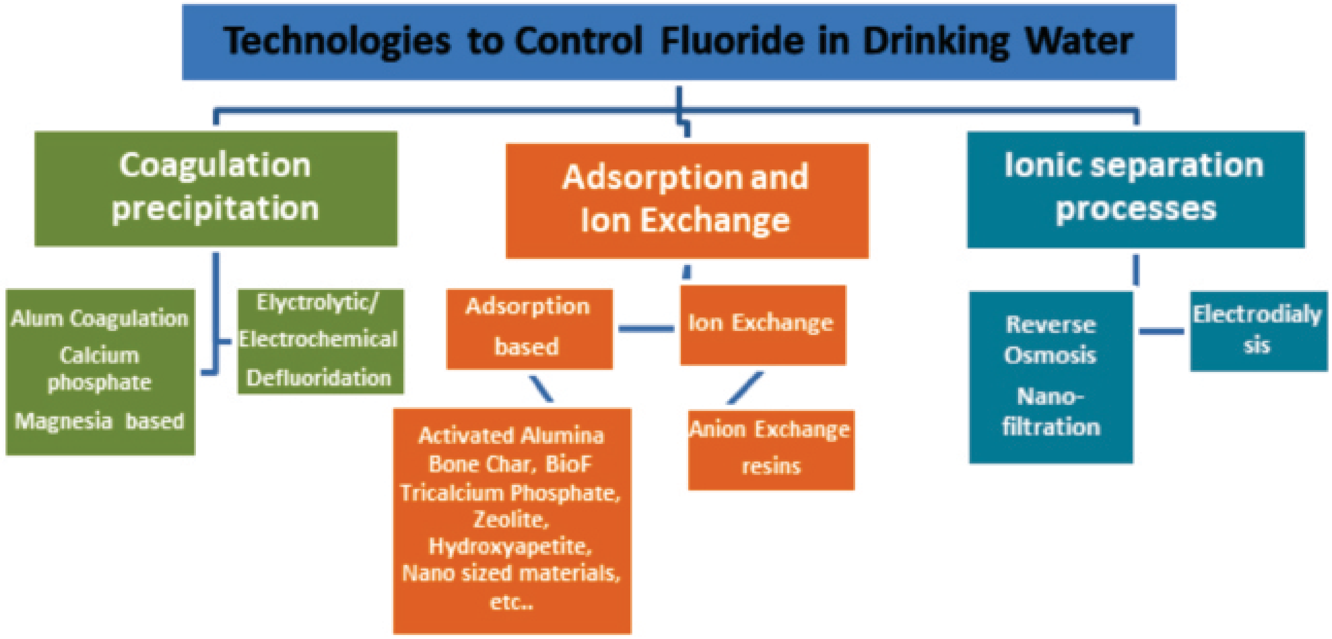

Figure 36: Defluoridation techniques

3.3.1 Adsorption and Ion exchange

Adsorption process involves the passage of water through a contact bed of adsorbent used, the Fluoride gets adsorbed on adsorbent surface and get removed by ion exchange or surface chemical reaction. After a period of operation, the utilized adsorbent gets saturated and must be refilled or regenerated. The adsorption behavior of Fluoride by various adsorbent varies significantly, depending on the affinity and efficacy of bonding between the Fluoride species and active sites on the surface of the adsorbent. In addition to that, all adsorbent shows maximum adsorption at different values of pH. The concentration of other competing ions also affects the adsorption efficiency of adsorbent. Adsorption studies pointed most important characteristics which determined adsorbent suitability for practical application; adsorption capacity, selectivity for Fluoride ions, renderability, compatibility, particle and pore size, and cost while Fluoride removal efficiency always depends on raw water quality profile, i.e., initial Fluoride concentration, pH, temperature, contact time and adsorbent dosage.

Advancements in adsorption process in terms of introduction of new materials and Fluoride adsorption capacity are presented below. Various materials and their combinations have been developed, commercialized, and marketed in India and abroad for Fluoride materials. It appears that development of these materials and Fluoride removal have hit plateau and current application of these materials is limited to evolve various combinations and apply as de-fluoridation materials. This has posed serious problems in evaluating efficiency of these materials for de-fluoridation and often lead to early exhaustion of these materials. As more and more processes are relying on replacement instead of regeneration of exhausted materials, de-fluoridation plants remain non-operational in terms of Fluoride removal. Hence, periodic replacement/ regeneration of these materials (media)should be exercised for providing treated water to the community.

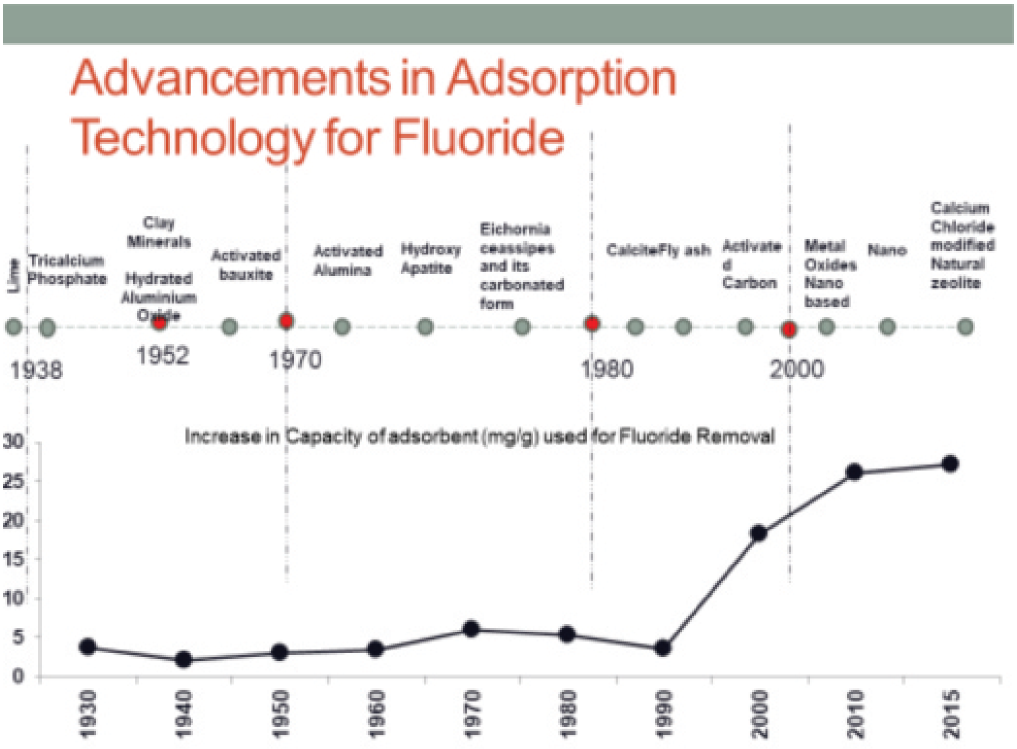

Figure : Advancement in Adsorption Materials (media)

Various adsorbents were used, not limited to, AA, Bone char, Bauxite, Hematite, Magnesia, various rare earth materials, fly ash, limestone and clay, polymeric resins, granular ceramics. The synthesized metal Hydroxide based nano-size materials also showed the high adsorption affinity towards the Fluoride removal from water. Polymeric Anion exchange resin also removes the Fluoride from groundwater.

3.3.1.1 Activated Alumina (AA)

The granular AA is highly porous material consisting especially of Aluminium Trihydrate. Fluoride removal capacity of AA is reported between 1 to 10 mg/g, and is a function of particle size, shape, and porous structure. In addition to that the performance of AA also depends on the regenerant used for regeneration of exhausted adsorbent, raw water Fluoride concentration, alkalinity, pH, and concentration of other competing ions in the raw water adsorption. The optimum pH for Fluoride removal from water is 5.0 – 5.5.

At pH greater than 7, Silicate and Hydroxide affects the exchange capacity of AA and at pH less than 5, the chances of dissolution of AA enhances. Other competing ions like Phosphates, Sulphates, Nitrates, etc. affect the Fluoride removal capacity of alumina. The exhausted alumina bed can be regenerated by using 2% NaOH, 5% NaCl, Alum and 2N HCl.

3.3.1.2 Bone Char and alkali treated bones

Bone char is the oldest known water de-fluoridation 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. The adsorption capacity of bone char is greatly dependent on the sorbent mass input rate, sorbent flow rate, initial sorbent concentration and pH of raw water. The optimum pH for Fluoride removal is 3.0 and below. The process was reported to be ion exchange in which carbonate radical of the apatite comprising bone, Ca (PO4)6, CaCO3, 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.

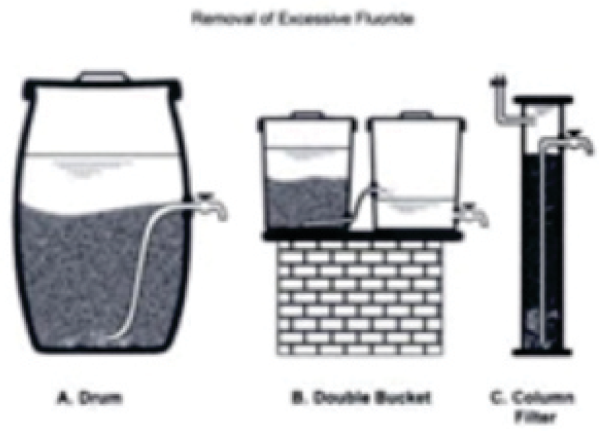

Figure 38: Common Sorption De-Fluoridation Units

3.3.1.3 Tri-Calcium Phosphate

Synthesized Tri-Calcium Phosphate shows high affinity toward the adsorptive removal of Fluoride from aqueous medium. It can be easily prepared by reacting Phosphoric Acid with lime. The exhausted material is easily regenerated with 1% NaOH solution followed by mild acid rinse. It shows the maximum adsorption capacity of around 700 mg Fluoride/ mixture of tri-Calcium Phosphate and Hydroxyapetite, commercially called Florex, showed a Fluoride removal capacity of 600 mg of Fluoride/L and regenerated with 1.5 % NaOH solution. Owing to high attrition losses, Florex was not successful and the pilot plants using this material were abandoned.

3.3.1.4 Activated Carbon

Most of the carbons prepared form different carbonaceous sources showed Fluoride removal capacity after Alum impregnation. Alkali digested Alum impregnated paddy husk Carbon was an efficient de-fluoridating agent. Investigations have shown that carbonized sawdust when quenched in 2% Alum solution forms an excellent de-fluoridating Carbon. The de-fluoridating 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 kilogram and showed maximum removal efficiency at pH 7.0.

3.3.1.5 Ion exchange resins

Ion exchange resin is synthetic polymers that act as a medium for selective removal of Fluoride from water. Polystyerene anion exchange resins in general and strongly basic quaternary Ammonium type resins in particular use to remove Fluoride from water. The metal loaded cation/ chelating type of resin also show enhanced selective Fluoride removal capacity. The modified resins remove Fluoride ion from aqueous phase at various pH. Resins are effective even in the presence of other competing ions such as, Nitrates, Carbonates, Bicarbonate, Sulphates, and Phosphates. Provide 20-145 times bed volume of defluoridated water per cycle. It is suitable adsorbent and can be regenerate several times by using PACl, HCl or NaCl solution depending on the resin type.

Some of the anion exchange resins used for defluoridation are Polystyrene resin, NCL polyanion resin, Tulsion A27, Lewatit MIH-59, Amberlite IRA-400, Deacedodite FF-IP, Waso resin-14, Polystyrene.

3.3.1.6 Serpentine

Serpentine is a mineral, 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 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 defluorination capacity. Extensive laboratory investigations were conducted to popularize the mineral if found suitable as a defluoridating medium. It is concluded that the cost of defluorination is prohibitive with Serpentine.

3.3.1.7 Limestone, 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 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 groundwater. 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. Granular material can then be obtained by crushing the heated product.

The experiment results showed that the heating at 400-500^{0}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^{0}C heat-treated soil can treat more than 300L of 5 mg/L Fluoride feedwater 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 a 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 concentrations 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 the 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 form 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.

Based on 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, Char fines, Lignite and Nirmali seeds was also investigated.

3.3.1.8 Mixed metal-based oxides and hydroxides materials

Various mixed metals oxides (i.e. Activated Alumina, La(III), Ce(III), Y(III), Fe(III) and Zr(III) etc.) have been investigated as potential adsorbent material because of their strong affinity towards the Fluoride. Recent investigation shows that these metal (hydro)oxides are very effective in removing Fluoride from water. The optimum adsorption pH was in the acidic range of 3 to 5.5, which strongly restricts their use for neutral groundwater treatment due to surface charge and low ion exchange capacity of adsorbent at neutral pH.

An adsorbent, 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 does 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 for Fluoride from solutions.

3.3.1.9 Tamarind gel and seed

The concentration of Fluoride from the solution of Sodium Fluoride of 10mg/L could be brought down to 2 mg/L by the addition of tamarind gel alone and 0.05 mg/L by the addition of a 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. De-fluoridation capacity decreases with increase in temperature and particle size. Desorption was carried out with 0.1 N HCl and is 90 percent.

3.3.1.10 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.

3.3.1.11 Advantages of adsorption and Ion exchange-based technologies

- Simple operation process and easy to handle;
- Low operation and maintenance cost;
- Wide range of adsorbent are available;
- Generally, gravity based and do not required electricity; and
- Most of the adsorbent/ polymeric resins are regenerable and can be regenerated by using simple chemicals which enhance the life the media and for the routine O&M without the need of highly skilled manpower.

3.3.1.12 Drawbacks of adsorption and Ion exchange-based technologies

- Regular regeneration of exhausted media is required, regeneration of media creates toxic liquid waste need to be treated at site;
- Replacement of media after multiple regeneration;
- Replacement of media creates solid waste which needs to handle carefully;
- Sometime deterioration in water quality and taste; and
- Variation in dose of chemicals with change of Fluoride and alkalinity.

3.3.2 Coagulation and Precipitation

Coagulation-precipitation is the earliest and most established technique of Fluoride removal which involves stirring or mixing of metal salt in Fluoride-containing water, allowing the precipitate to settle and decanting. The scale of implementation of this process ranges from household to large scale community operations and the chemicals such as Al, Ca, Mg salts are commonly used.

Coagulation-precipitation based techniques work on the principle of formation of Metal-F complex ions which further react with Metal-$(OH)_n$ to form heterogeneous phase which separates from the water as a precipitate:

$$M\text{-}(OH)_n + F^- \rightarrow M\text{-}F\downarrow + nOH^-$$

One of the advantages of coagulation precipitation-based techniques is the adsorbent gets generated in-situ, which makes the mass transfer of soluble Fluoride from surrounding to adsorbent surface quite faster. Some of the limitations of precipitation technologies include management of quantity of sludge produced, uncontrolled finish water pH, difficulty in establishing dose requirement, and high dose requirements for higher Fluoride concentrations. Steps involved in coagulation precipitation technique are shown in Figure 39.

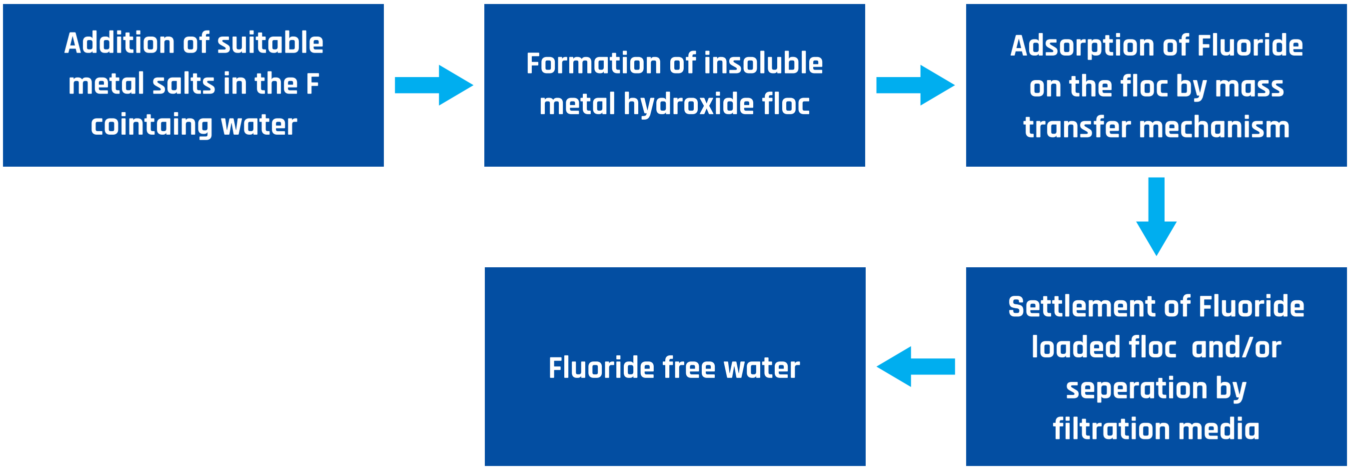

Figure 39: Steps in coagulation precipitation technique

Coagulation-precipitation technique is applied in household de-fluoridation units and community-based de-fluoridation plants. Details of various existing technologies are given below.

3.3.2.1 Nalgonda Technique

The Aluminum salt and lime based low-cost de-fluoridation technology developed by CSIR-NEERI is used at household and community levels. This technology involves rapid mixing of aluminum salts (Aluminum Sulfate or Aluminum Chloride) and lime followed by flocculation, sedimentation, filtration, and disinfection. Aluminum salt is responsible for Fluoride removal as its co-precipitates as $Al\ (OH)_3$ and $AlF_{6.}$ Dose of Aluminum salt increases with increase in Fluoride and alkalinity levels of the raw water. Selection of either Aluminum Sulphate or Aluminum Chloride also depends on Sulphate and Chloride contents of the raw water to avoid exceeding their permissible limits in treated water. Addition of lime is to ensure neutral pH of treated water and to facilitate forming dense flocculent for rapid settling.

Chemical reaction involves formation of Polyhydroxy Aluminum species (flocs) which adsorb Fluoride from water. Besides Fluoride, turbidity, colour, odor and organics are also removed. Nalgonda technology is combination of several unit operations and process incorporating rapid mixing, chemical interactions, flocculation, sedimentations, filtration, disinfection, and sludge concentration for recovery of water and Aluminum salt. The technology is applicable for the removal of wide range of Fluoride concentration and was seen to be effective in producing water with Fluoride within the permissible limit. Configuration of Nalgonda technology is shown in Figure 40.

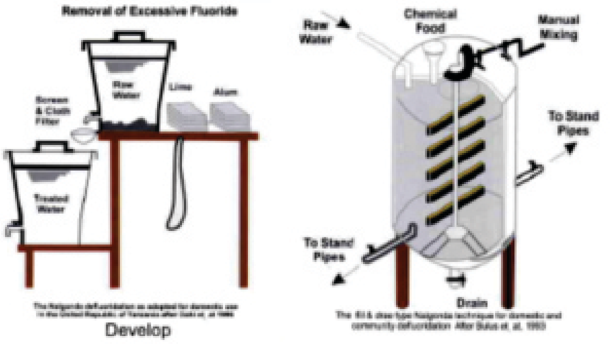

Figure 40: Configuration of Nalgonda Technology

Types of Nalgonda De-fluoridation System

i.) Domestic Unit;

ii.) Fill-and-Draw Plant for Small Community (upto 200 population);

iii.) Fill-and-Draw Plant for Rural Water Supply (up to 5000 population); and

iv.) Continuous DF for Large Scale Community Water supply (>5000 population).

Salient Features

i.) No regeneration of media;

ii.) No handling of acids and alkalis;

iii.) Readily available chemicals used in water treatment;

iv.) Simultaneous removal of colour, odour, turbidity and organic contaminants;

v.) Adaptable to domestic or any community level;

vi.) Applicable in batch or continuous operation to suit the needs;

vii.) Simplicity of design, construction and O&M;

viii.) Local Skills can be easily employed; and

ix.) Needs minimum of mechanical and electrical equipment.

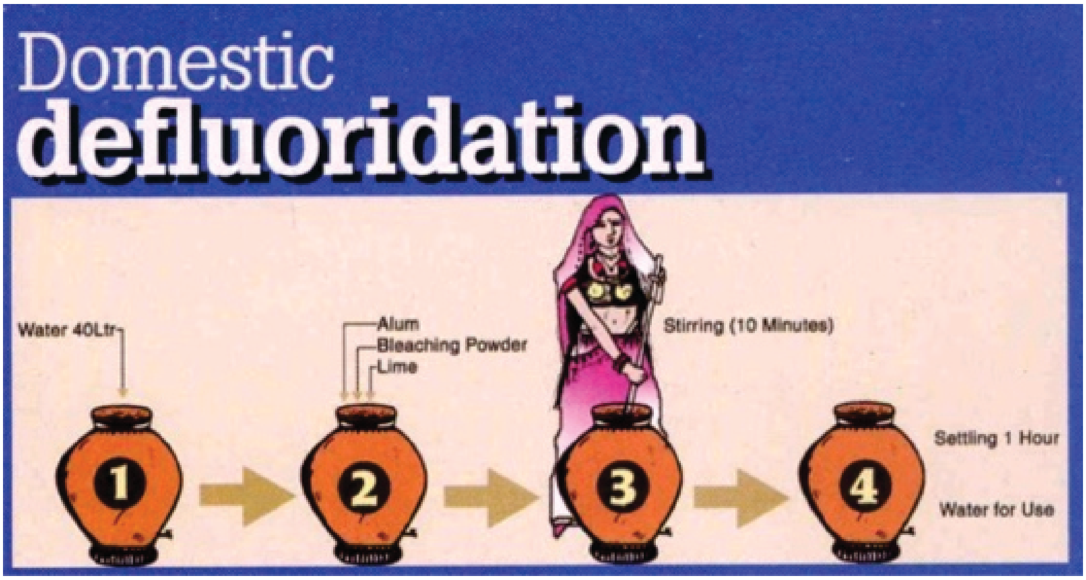

Figure 41: Household de-fluoridation unit based on Nalgonda technology

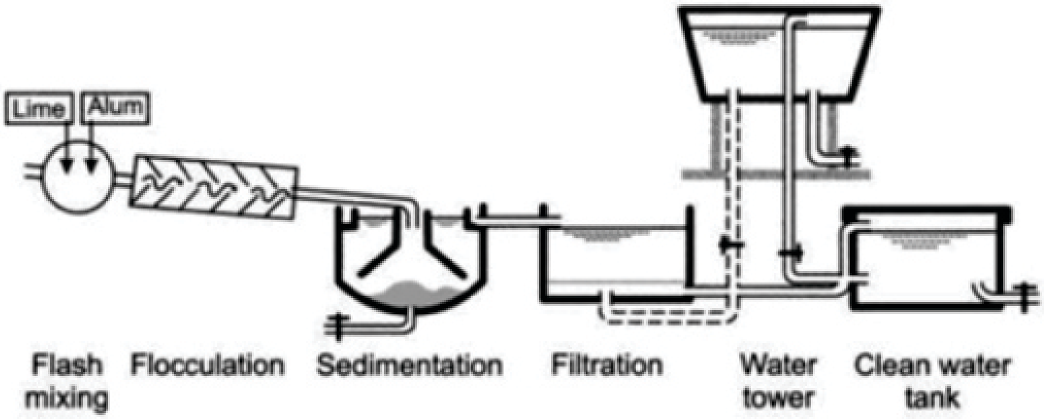

Figure 42: Fill and draw de-fluoridation plant based on Nalgonda technology

3.3.2.2 Magnesia

Magnesium oxide (MgO) can be used in a precipitation-sedimentation-filtration technique to reduce Fluoride. The mechanism for removal of Fluoride ions is suggested as chemisorption or adsorption. MgO added to water forms Magnesium Hydroxide ($Mg(OH)_2$), which then combines with Fluoride to produce insoluble Magnesium Fluoride (MgF_2). The insoluble MgF_2 settles out. Alkaline pH of treated water and complexity of the preparation of magnesia are the inhibitive factor to render it acceptable in the field. All this add to the cost and complexity of operation.

The Fluoride-magnesium chemistry is suggested as:

$$MgO + H_2O \rightarrow Mg(OH)_2,\ Mg(OH)_2 + 2F^- \rightarrow MgF_2\downarrow + 2OH^-$$

3.3.3 Membrane filtration process

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

3.3.3.1 Reverse Osmosis (RO) and Nano-filtration (NF)

Reverse Osmosis (RO) is a technique that forces a solvent through a semi-permeable membrane by applying a pressure greater than the osmotic pressure of the solution. Membrane filtration processes remove particulate constituents based on size exclusion, but RO does not. RO can reject constituents due to electrostatic repulsion at the membrane surface, chemical solubility, diffusivity and straining of solutes. The Fluoride removal efficiency is 98%.

Drawbacks to RO include a high-energy requirement associated with operation of high-pressure pumps, the complexity of the process, the fact that all dissolved constituents are removed which creates a waste management challenge, and the loss of water associated with the disposal of the high solute concentrate. However, these processes may still be used for the final polishing of the treated effluent.

NF is a low-pressure (compared to RO) membrane separation process that removes constituents by size exclusion and ion rejection. For NF the membranes have slightly larger pores than those used for RO and often less resistance to passage both of solvent and of solute. Therefore, pressure required is much lower, energy requirement is less, removal of solute is much less exhaustive, and flow is high. In NF, a large percent of feed volume, nearly 20% is wasted. A study indicates that rejection of Fluoride is high (97.8% for F concentration of 2.32 ppm) and costs are comparable between existing NF drinking water facilities and a NF facility designed for selective Fluoride removal.

If the only pollutant of concern is Fluoride and TDS is less than 500 mg/l, RO & NF is not recommended technology to be used for de-fluoridation of water. In such cases other de-fluoridation technologies should be explored.

3.3.3.2 Electro-Dialysis

Electrodialysis is like RO but uses an electrical gradient to pass ions through semipermeable membranes rather than pressure. The membrane pores are much less restrictive than those for nano-filtration. Negatively charged ions (such as F) migrate towards positively charged anodes and are prevented from further migration due to a negatively charged cation exchange. Thus, the mainstream going through the exchange loses its contaminants. Electrodialysis requires pre-treatment to reduce fouling on the anodes. Waterworks in the U.S. use this technology. Donnan dialysis is an irreversible ion-exchange equilibrium non-porous membrane separation process. This technology is not presently in use as experiments have shown it to be highly efficient but very expensive.

3.4 Technologies for removal of Fluoride from water

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 remains. 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.

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

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 adsorption capacity than bone char and is generally more effective in removing Fluoride. 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 43: Eawag Fluoride Removal by Bone Char

3.4.2 ICOH domestic de-fluoridator

The Inter-Country Center for Oral Health (ICOH) at the University of Chiong Mai, Thailand) domestic de-fluoridator was developed in Thailand which uses crushed charcoal and bone char. Its de-fluoridation 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 de-fluoridate 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.

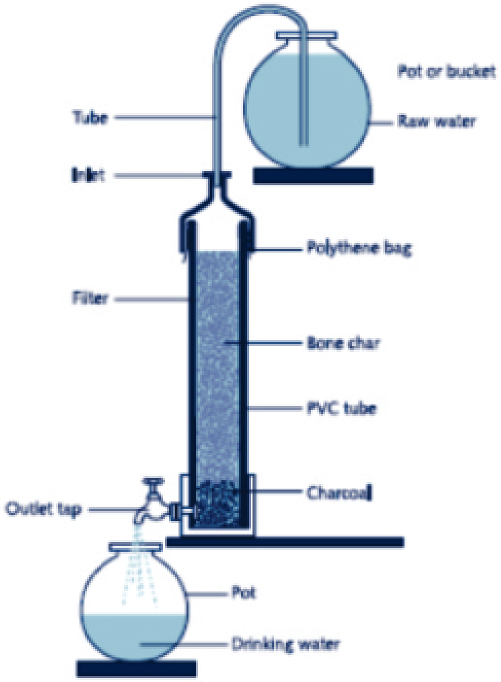

Figure 44: Bone Char Domestic De-fluoridator developed by ICOH-Thailand

3.4.3 Electrolytic De-fluoridation Technology (CSIR-NEERI)

De-fluoridation technique based on the principle of electrolysis has been developed in NEERI. The process is found effective in removing excess Fluoride and bringing down the bacterial load of the raw water. The de-fluoridation 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 de-fluoridation technique 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 de-fluoridation is as follow:

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

Cathode: $2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$

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.

$$Al^{3+} + 3H_2O(S) \longrightarrow Al(OH)_3(S) + 3H^+$$

$$Al(OH)_3 + xF^- \longrightarrow Al(OH)_{3-x}F_x + OH^-$$

Direct Current required for the electrolytic process is generated either by, conversion of AC electric supply by DC conversion unit of required capacity or by a 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 a place where direct sunlight is received. The direct current received through the solar panel is stored in the tubular battery through the charge controller and supplied to the Aluminium electrodes through a direct current regulator.

Salient Features

1. Simple to fabricate, easy to operate with minimum maintenance;
2. Suitable for treatment of raw water with Fluoride concentration up to 10mg/L;
3. Produces potable water with palatable taste as against the other available chemical treatment methods;
4. Quantity of sludge produced is much less (60-70%) than conventional treatment methods;
5. The simultaneous reduction in hardness, Nitrate and bacterial contamination in treated water; and
6. Treatment cost up to Rs. 12 per 1000 L.

Based on the technology, solar power based electrolytic de-fluoridation demonstration plant (Figure 45) was installed at Dongargaon in Chandrapur district, Maharashtra in 2002 and Usarwara village in Durg district in Chhattisgarh State in 2010. The capacity of these units is 600L and 2000L per batch respectively.

Figure 45: Electro-Defluoridation plant

3.4.4 Chemo-defluoridation technology (CSIR-NEERI)

In chemo-defluoridation technology developed by CSIR-NEERI, Calcium and Phosphate salts are added for the formation of Hydroxyapatite complex to adsorb Fluoride from water. This complex precipitate and settles down. After about 1-2 months of operation, when the flow rate of treated water gets reduced by the formation of a thick layer of sludge, the whole unit needs to be washed by water and reassembled again. Various process steps of chemo-de-fluoridation technology are shown in the Figure below. The technique is free from interferences of anion concentration in raw water and does not affect the taste of treated water.

Figure 46: Chemo-defluoridation technology

Salient Features

- Simple to fabricate and easy to operate, gravity-operated;
- Palatable taste of treated water;
- The process involves the formation of insoluble Fluoride complex with salts of Calcium and Phosphorous and filtration through a sand filter;
- Most reliable for small Fluoride affected villages where community water treatment plant is not economically feasible;
- Reduces the Fluoride conc. In water to <1 mg/l;
- Suitable for treating the water up to Fluoride concentration of 10 mg/l;
- Taste of the treated water is palatable; and
- Operating cost Rs. 0.20 per litre.

3.4.5 De-fluoridation technology (TERI)

The Energy and Resources Institute (TERI) 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 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.

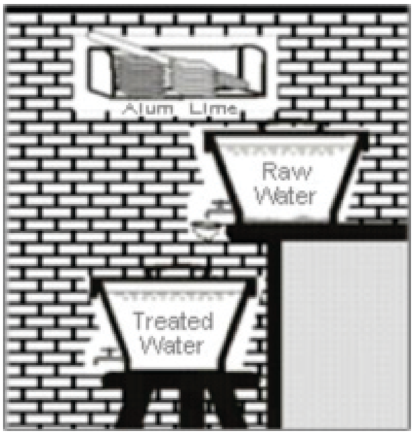

Figure 47: TERI Deflouridation Unit

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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 adsorbs 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.

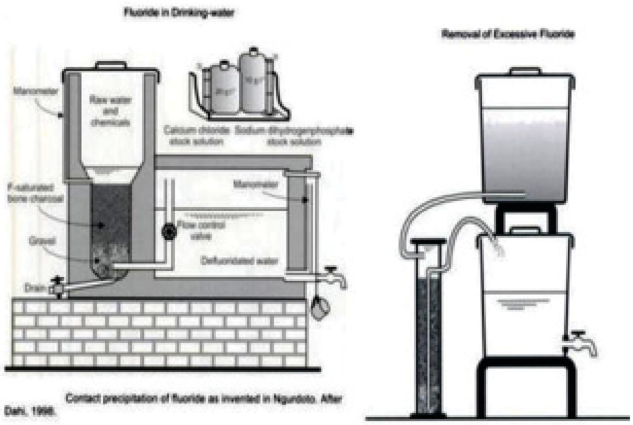

Figure 48: Designs of Contact Precipitation

3.4.7 Domestic De-fluoridation unit using Brick Pieces

Freshly fired brick pieces are used in Sri Lanka for the removal of Fluoride in domestic de-fluoridation units. The brick bed in the unit is layered on the top with charred coconut shell and pebbles. Water is passed through the unit in an up-flow mode. The performance of the domestic unit has been evaluated in rural areas of Sri Lanka. It is reported that efficiency depends on the quality of freshly burned bricks. The unit could be used for 25-40 days when withdrawing of water per day was around 8 litres and raw water Fluoride concentration was 5 mg/l. As PVC pipes are costly, a de-fluoridation unit made out of cement and bricks have also been recommended.

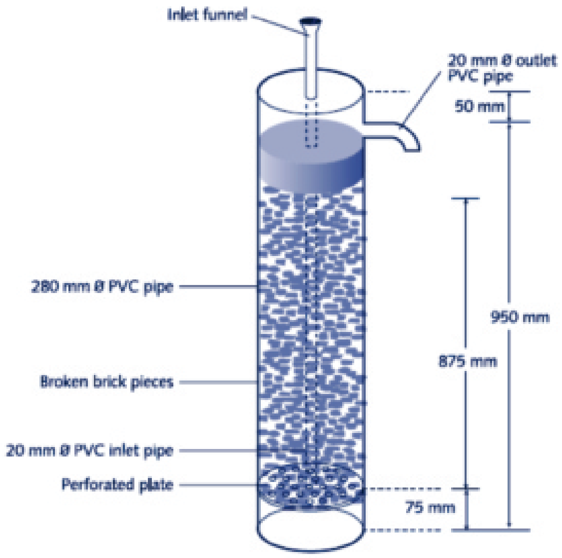

Figure 49: Domestic De-fluoridation unit using Brick Pieces

3.4.8 Emerging De-fluoridation technologies

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

(i.) Crystalactor

(ii.) Memstill technology

(iii.) Water-pyramid solution

(iv.) 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. Cost 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 0r 20 mg/l). For reaching a concentration below 1 mg/l Fluoride, a second technique must be used afterwards.

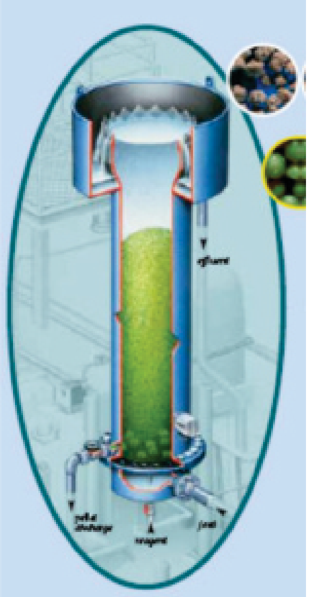

Figure 50: Crystalactor

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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 multi-stage flash and multi-effect distillation modes into one membrane module. Cold feedwater takes up the 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 RO and distillation. With the Memstill technology also anions like Fluoride and Arsenic are removed. It is expected that Memstill technology will be also developed for small scale applications using solar heat.

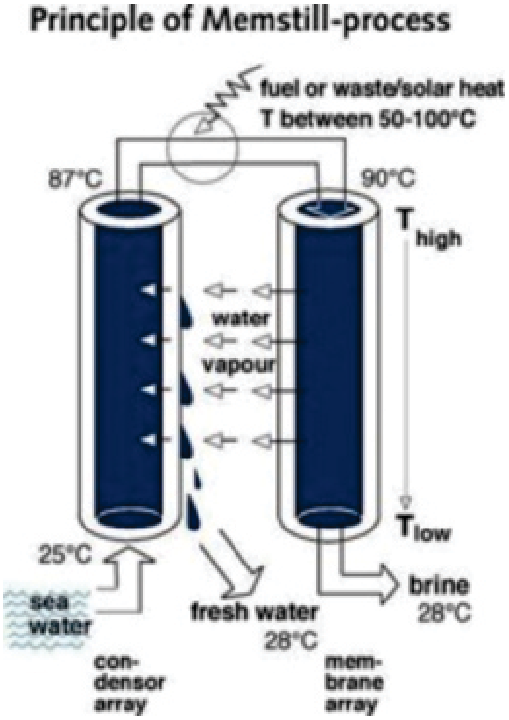

Figure 51: Memstill Technology

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 m^2 and situated under favourable tropical conditions, can produce up to 1250 litres of freshwater 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 evaporate 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 surface of the system. The product water quality is very constant and similar to that of distilled water. The quantity depends on the intensity of solar radiation. To avoid crystallization, the brine has to be drained periodically. The system can process sea, brackish or contaminated wastewater (e.g., with heavy metals, oil residue, Boron, Fluoride) with an allowable pH range of 5-11.

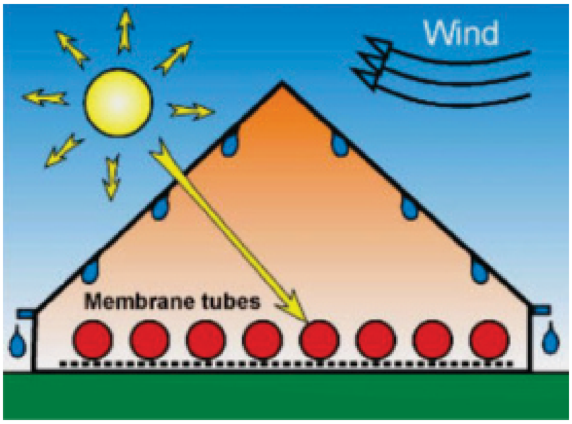

Figure 52: The Solar Dew Collector System

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+31 (317) 61 97 73

3.4.9 De-fluoridation by Reverse Osmosis Technology (CSIR-IICT, Hyderabad)

Five RO membrane-based de-fluoridation plant 600-100 l/h capacity is commissioned at Mylaram village of Nalgonda District, Andhra Pradesh. The Fluoride in raw water varies from 3 to 5 mg/l and after treatment is brought down to a concentration of less than 0.5 mg/l.

Salient Features

- Greater water recovery (80%) with low reject volume and reject water can be reused for washing water, laundry and other purposes;
- Retention of sufficient mineral contents such as Ca, Mg, P, Na, K essential for human consumption and health;
- Longer membrane life and lower fouling; and
- Operating cost is about Rs. 50-70 per 100 L of purified water generated.

Figure 53: RO based de-fluoridation technology

3.4.10 Domestic de-fluoridation unit using Activated alumina

The membrane assisted sorption process for removal of Fluoride from ground/ surface water to provide safe drinking water and solves the serious problem of Aluminium contamination in the product water coming after de-fluoridation 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 the ultrafiltration membrane. It is a simple, cost-effective, adaptable at both domestic and community level and having capability of high decontamination.

It requires minimum contact time for maximum de-fluoridation. De-fluoridation capacity is appreciable at neutral pH and independent of temperature. It can be operated with/without the use of electricity.

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

- Sorption of Fluoride on AA sorbent;
- 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 54: BARC De-fluoridation Unit

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3.4.11 Ion specific resin units for the removal of Arsenic/ Fluoride

Macro-porous 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 litre of Arsenic-free water and Rs. 6/- per 1000 litre 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 litres 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 de-arsenificating units are already installed in Arsenic affected area of 24 North Parganas, West Bengal. 8 domestic de-fluoridation units are installed in Fluoride affected villages of Gujarat.

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

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3.4.12 Electro-chemical De-fluoridation unit (CSIR-CECRI)

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 area which adsorbs 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 the 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 the unit is 10,000 litres per day and the cost of production is Rs. 33/kilolitre.

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Tamil Nadu, India

3.4.13 Water purification plant systems

These systems are ideal for flood and earthquake relief operation due to the unit's mobility to purify almost any source water and ease in setup and operation. The units can also be configured as a standalone basis for water treatment for the permanent public health water supply installations. The entire treatment system can be mounted on a truck and can be moved from one village to another. The system design allows the plant to work for surface water as well as ground-water.

(i.) Arsenic Removal Systems: WSI patented Reverse Osmosis technology.

(ii.) Resin based BOR system for Arsenic Removal System: The system can be attached to hand pump and hence O&M is very less hence no expenses on manpower, electricity and spare parts except chemicals replacement that are necessary once in six months. Technological is patented.

(iii.) Patented Reverse Osmosis technology for Fluoride removal.

3.4.14 Solar-operated/ standalone groundwater treatment plant

The system works using solar energy and is suitable for treatment of Arsenic, Fluoride and TDS. Arsenic is removed using disposable granulated media while Fluoride is removed by using either regenerative or disposable type granular media. Surface water is treated with micro and ultrafiltration. Saline water is treated with RO system. The capacity is 5.7 KLD for compact system and 40-50 KLD for Mini WS System.

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2.4.17 CDI (Capacitive De-Ionization)

Summary of the Product: Aquasphere has introduced a new water treatment system called Plimmer in the market that is ideally suited for drinking water applications. This is a new generation of water treatment system that can treat ground or surface water containing high dissolved salts to produce clean drinkable water that meets WHO standards. Plimmer is an excellent alternative to t technology. This is a high recovery system where water wastage is just 20% as against 70% from a RO system. It does not use any chemicals, consumes very low power and has the lowest operating cost for treating water when compared to any system in the market today. Plimmer is based on a technology called Capacitive Deionization (CDI). This innovative technology is used to desalinate water without using resin or membrane filters. It does not require chemicals to treat water and uses very low power to separate salts in water.

Contaminants that can be removed through this Technology: Total Dissolved Solids, Total Hardness, Calcium Carbonate, Magnesium Carbonate, Sodium Chloride, Phosphates, Sulphates, Chlorides, Nitrates, Fluoride, Chrome, Iron, Arsenic, Nickel, Copper, Zinc, Cadmium, Mercury, Manganese, Lead Vanadium, Bacteria, Humic & Folic Acid, Ammonia and Chromium.

Design Capacity: 100 LPH to 2000 LPH

Pre-Treatment Protocol: Ozonation, Ultrafiltration, Activated Carbon filter and Pressure Sand filter

Post-Treatment Protocol: Ozonation or Ultrafiltration

Operations and Maintenance Cost and Protocol: 3 to 5 paisa per liter

Reject Management Cost and Protocol: The reject water can be again diluted with raw water and send to the system, there by further reducing the reject water. The other alternative is to use it for tertiary uses like cleaning, gardening etc.

Ease of Operations and Management: The complete system works automatically and is web enabled, when connected through an internet, the system can also be accessed from anywhere for monitoring and maintenance purposes.

Interference by other Contaminants: The reject water concentration can be prevented or managed based on the contaminant's concentration and their reactivity.

Test Trailed: Yes

About Innovator and Contributors: Idropan Dell'Orto Depuratori SRL Idropan is a water treatment company based out of Milano, Italy. The company has been in existence since 40 years and has pioneered many innovative developments in the field of water treatment. The company's main competence is in the field of technology, and they have over 40 patents in the field of water treatment and close to 14 patents in CDI technology. The company has customers across the world and mainly in USA, Australia, Europe, and India.

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3.4.15 EMRION-Nano Technology for Fluoride, Arsenic and Heavy metal reduction

Summary of the Product: Electro Magnetic Resonance and Ion Trap System (EMRION) technology is a patented and indigenously developed technology for the reduction and elimination of Arsenic, Fluoride, Nitrates, heavy metals including Iron and lead, Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in ground or surface raw water and in wastewater. The EMRION raw and wastewater treatment system challenges the existing highly expensive methods of wastewater treatment such as Reverse Osmosis (RO), Ion Exchange or Multi-effect evaporator (MEE) by delivering the following benefits:

i.) The rejected water from EMRION technology is based on the extent of contamination and can be less than 5% compared to the rejection ratio of about 50% in RO based technologies;

ii.) Unlike RO and Ion Exchange systems, EMRION does not require membranes and is a chemical free process;

iii.) The maintenance cost of raw or wastewater treatment in the system is less than 75% the cost of wastewater treated by RO and MEE based systems;

iv.) The patented ozone technology included in the treatment system is highly effective in treatment of biologically contaminated water; and

v.) The rejected contaminants from the wastewater can be collected as solid waste for proper disposal and therefore EMRION is environmentally friendly.

For a typical raw water treatment system, the key components of the custom designed EMRION based system are as follows:

i.) Pre-treatment filtration includes;

a) pressurized sand or disc filtration to eliminate particles over 150 microns in size

b) Granulated activated Carbon (GAC) filtration to reduce odour

c) EMRION treatment to reduce inorganic pollutants form raw water since patented technology does not utilize membranes, resins or chemicals the long-term maintenance costs are lesser

ii.) Post-treatment filtration includes micro - filtration to eliminate particles over 10 microns in size;

iii.) Ozone based disinfection with pulsed UV to reduce BOD and COD levels to permissible limits; and

iv.) Solid waste collection system to store the contaminants from the input effluent and to safely dispose the waste.

Contaminants that can be removed through this Technology:

i.) Fluoride

ii.) Arsenic

iii.) Iron

iv.) Hardness

v.) Heavy metals like Lead, Silver, Cadmium

vi.) TDS reduction

vii.) Complete microbial disinfection

Estimated Capital Cost (In Rs): 12 Lakh

Cost of Water Per Liter (Paise per liter): 6.00

Design Capacity: Starting from 10 KLD (10 hours) to maximum of 10 MLD is possible. Water will pass through EMRION and 3-stage filtration including Carbon, micron and pre-filtration to make water totally free of Turbidity. System will also contain state-of-the-art ultra-disinfection system with pulsed UV and Ozonation.

Pre-Treatment Protocol: Groundwater will pass through multi-grade filtration consisting of sand, pebbles and multi-port valve with backwash system.

Post-Treatment Protocol: Two stage filtration followed with double ultra-disinfection systems:

(i.) Carbon Filtration with GAC;

(ii.) Micron Filtration with 5-micron non-woven fabric;

(iii.) Pulsed UV with UV intensity meter along with lamp life indicator;

(iv.) Ozone treatment with dissolved ozone meter with display; and

(v.) Complete automation of the plant with pre-treatment and post-treatment quality parameters communication as optional at additional cost.

Operations and Maintenance Cost and Protocol: 1.5 lakh to 2.5 lakh per annum depending on the size of the plant. Periodical replacement of Carbon media and micron filters and nano material releasing patented plates.

Reject Management Cost and Protocol: The EMRION system generates 5% sludge reject water which will be recycled back passing through filter press/ decanter/ bag filter to separate out solid waste which can be safely disposed to the landfill making the entire system zero liquid discharge (ZLD).

Ease of Operations and Management:

i.) Can be operated at remote place with solar panels;

ii.) Zero liquid discharge without spoiling surrounding environment;

iii.) Pre and post treated quality parameters communication with SIM card to multiple users and regulatory stakeholders;

iv.) Double disinfected with world class pulsed UV and ozonation system which is non-recurring and chemical free disinfection system; and

v.) Mountable on a truck to make it mobile treatment plant wherever borewell is available, operates with battery.

Interference by other Contaminants: No other contaminants will be generated in the process.

Test Trailed: Input water parameters: pH up to 8.5 to 9, TDS below 1200 PPM, Fluoride 18.5 PPM, Arsenic 1.2 PPM, Hardness 450 with abnormal E. Coli and other bacterial contamination. EMRION Treated Output water: pH 6.8 to 7.2, TDS below 300 PPM, Fluoride below 1.5 PPM, Arsenic 0.01 PPM, Hardness around 100 with zero microbial traces.

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3.4.16 Bharti Nano Fluoride removal technology by online dosing

Summary of the Product: Bharti Nano Fluoride Removal Technology by online dosing SKF281164-A & SKF-281164-B. No regeneration is required, and no backwash needed for Fluoride removal. Dosing of Bharti nano SKD-281164 chemical technology has been duly approved by CSIR, Government of India.

Contaminants that can be removed through this Technology: Bharti Nano Fluoride Removal Technology can remove up to 5 PPM Fluoride.

Design Capacity: It can be hooked to both small and medium defluorination requirements including hand pump attachment.

Pre-Treatment Protocol: Not applicable.

Post-Treatment Protocol: Not applicable.

Operations and Maintenance Cost and Protocol: The systems are efficient in Fluoride removal from source. Very easy operation and practically maintenance free.

Reject Management Cost and Protocol: Not applicable.

Certification of Product: The technology is approved from CSIR, Government of India vide Ref. No. LT-05/ESD/11/17/1/85 Dated 17.11.2017.

Ease of Operations and Management: very easy operation and practically maintenance free.

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4 Iron removal methods and technologies

4.1 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 viewpoint.

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.

Acceptable limit of Iron in drinking water as per BIS 10500 is 1 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.

4.2 Techniques for removal of Iron from water

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 techniques 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 can remove 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 the solution; it can be collected or allowed to dissipate into the atmosphere.

4.3 Technologies for removal of Iron from water

4.3.1 Hand pump attachable Iron removal plant developed by CSIR-NEERI

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 can remove 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 55). 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.

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.

Figure 55: NEERI Hand Pump Attachable Iron Removal Plant

4.3.2 Iron removal plant developed by CSIR-CMERI

Central Mechanical Engineering Research Institute (CSIR- CMERI) has developed Iron removal plant. Removal of Iron from water containing Ferrous salts is done by oxidation accompanied by the dissolved Qxygen 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 are MS plate, pipe valves, consumables including limestone, MnO_2, sand and gravel.

Figure 56: CMERI Iron Removal Plant

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

4.3.3 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 Potassium Permanganate ($KMnO_4$) 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 57: Household Iron Removal - CSIR - NEERI Technology

4.3.4 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.

$$2\ Fe^{2+} + H_2O_2 + 2\ H^+ \rightarrow 2\ Fe^{3+} + H_2O$$

$$H_2O_2 \rightarrow \tfrac{1}{2}\ O_2 + H_2O$$

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

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

4.3.5 Terra filtration system for Iron removal

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 groundwater sources like dug wells, ponds, tube wells and rivers are 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. 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 rate of filtration.
- Community level filter: 1000 to 100000 LPD
- 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

Figure 58: Terafil Filter

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.

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Institute of Minerals and Materials Technology
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Council of Scientific & Industrial Research
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Telephone: +91-674-2581126, +91-674-237-9400

4.3.6 SEUF Iron removal plant

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 60. 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 to act as one 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

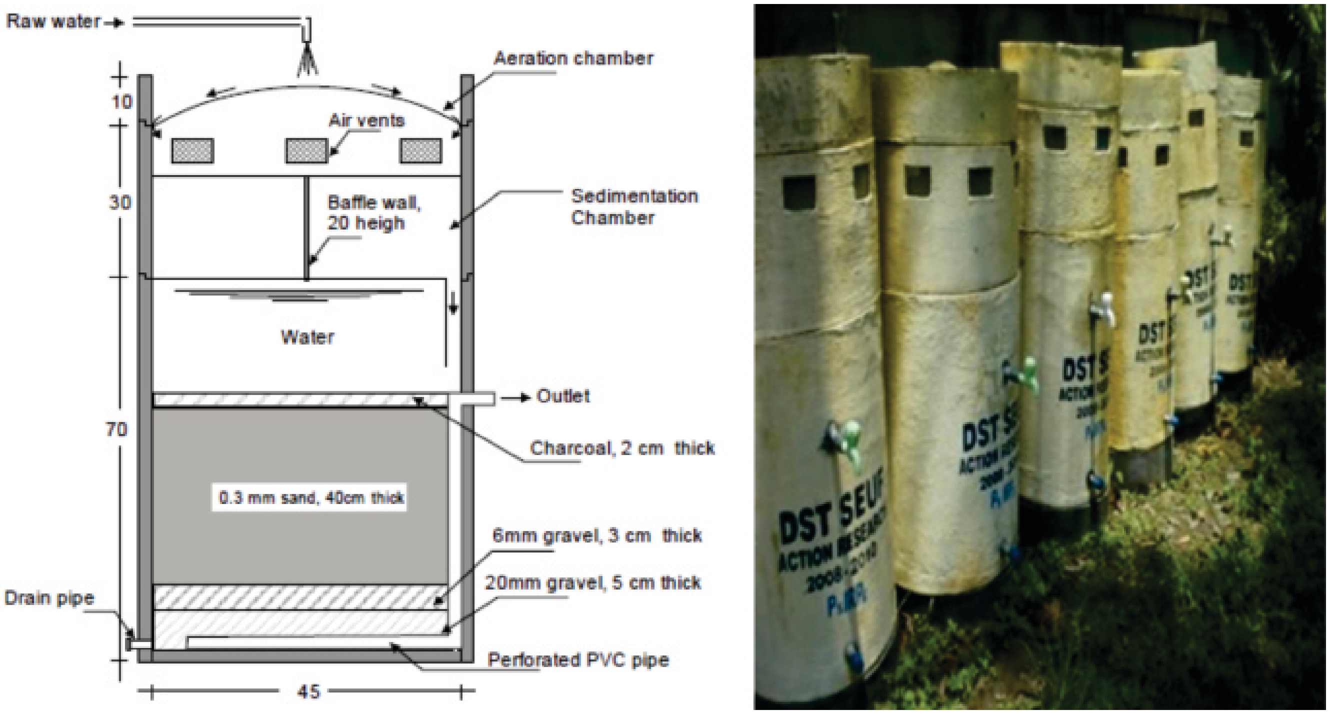

Figure 59: SEUF Iron Removal Plant (IRP)

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 into 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. The filter media used was fine river sand having an effective size of 0.25mm and uniformity coefficient of 5.6.

i.) Bottom most layer of 20 mm gravel, 5 cm thick;

ii.) 2nd layer of 6mm gravel, 3 cm thick;

iii.) 3rd layer of 0.3 mm sand, 40cm thick; and

iv.) Top layer of charcoal, 2cm thick.

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

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

4.3.7 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.

Contact details:
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4-3-140, Hill Street,
Secunderabad- 500 003.
ramakrishnak@balajicastings.com
+91 8686400530

4.3.8 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;

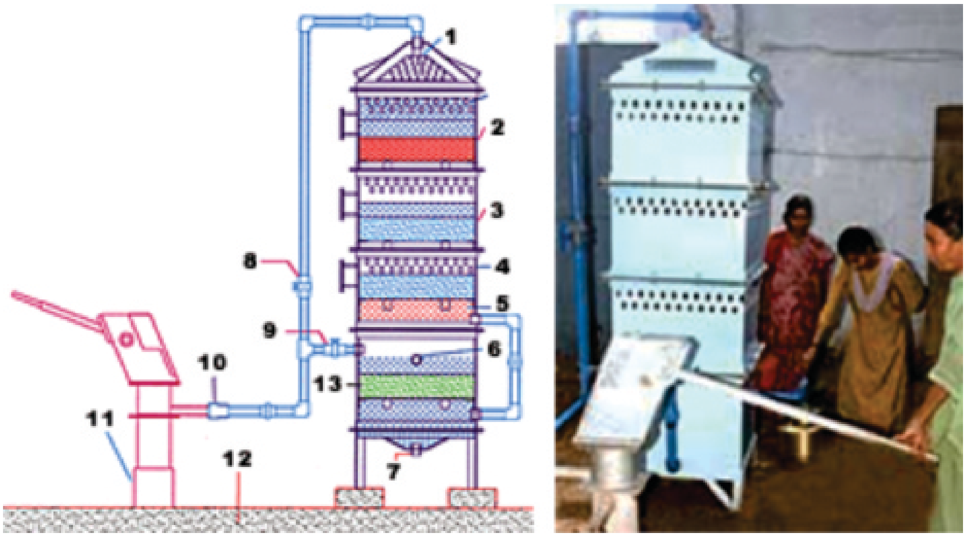

Figure 60: Iron Removal Plant of Balaji industrial and Agricultural Castings

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

(iv.) Precipitation of Ferric Iron; and

(v.) Removal of precipitated Iron by sedimentation, up flow and gravity flow filtration.

Figure 61: Water Iron Removal Unit of DRDO

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.

4.3.9 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.

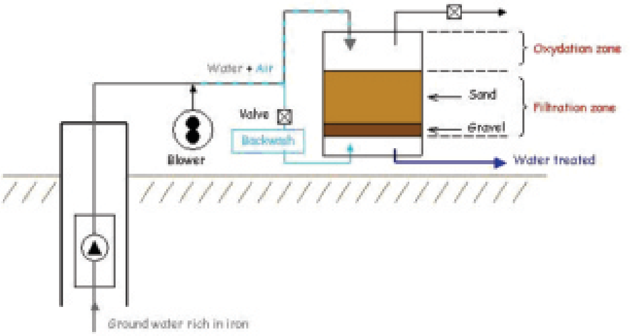

Figure 62:Schematic Diagram of Lenntech Iron Removal Plant

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The Netherlands
tel: +31 15 261 09 00 fax: +31 15 261 62 89
e-mail: info@lenntech.com

4.3.10 Iron removal unit of CREPA

This technology is designed to make Iron-rich groundwater potable, using a simple and low-cost technique. The Iron Removal Unit (Figure 63) 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 and 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 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 USD 250 to 300 per unit (Rs. 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%.

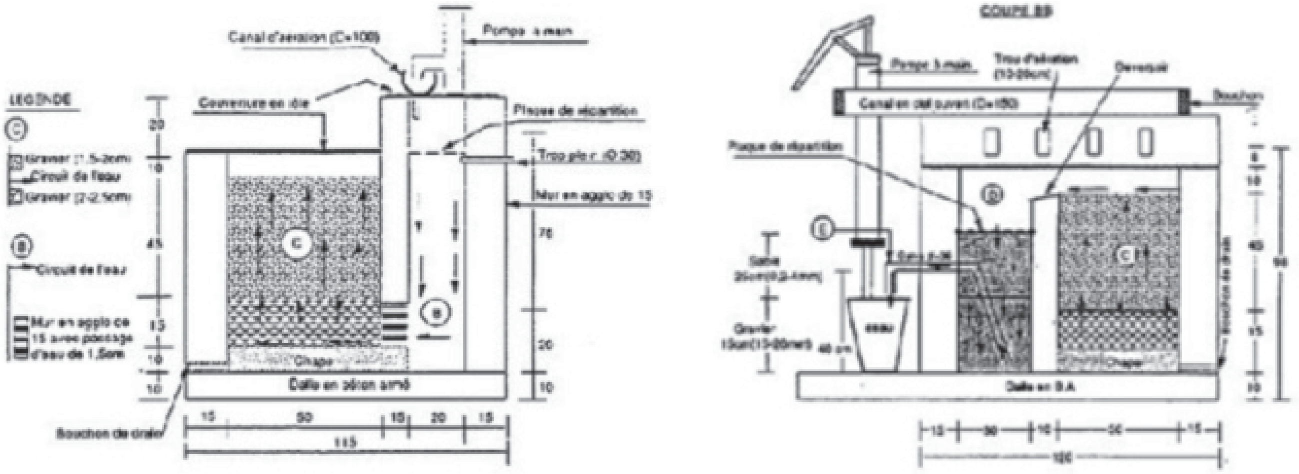

Figure 63: Schematic of a Typical Iron Removal Unit

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.

4.3.11 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. The cost of this filter is Rs. 3,500-4000/- for 25 liter/ hour capacity domestic unit.

Figure 64: Ion Specific Resin Unit (CSIR-CGCRI)

4.3.12 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 as community level and can remove 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 65). 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.

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. 3,000 and above.

Figure 65:UF Membrane Assisted Device for Removal of Iron

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Head, Technology Transfer & Collaboration Division,
Bhabha Atomic Research Centre,
Trombay, Mumbai - 400 085

4.3.13 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 salts 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 MS welded pressure vessel fitted with M S control pipe and CI diaphragm valve, strainers, sampling cock, pressure gauge, air compressor and first charge filter media (Figure 66). **The flow range is** 50 litres/ hour to 50,000 litres/ hour.

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Gujarat, India.
Phone : +91-79-30086163/66
Fax : +91-79-30086163,
Email: info@shubhamindia.com

4.3.14 Deferum Iron removal technology:

Filter Innovations has designed the Iron Stopper" Treatment System (by combining "Deferum" Iron removal technology with Filter Innovation's automated controls and separation technology.

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

- Feedwater 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;

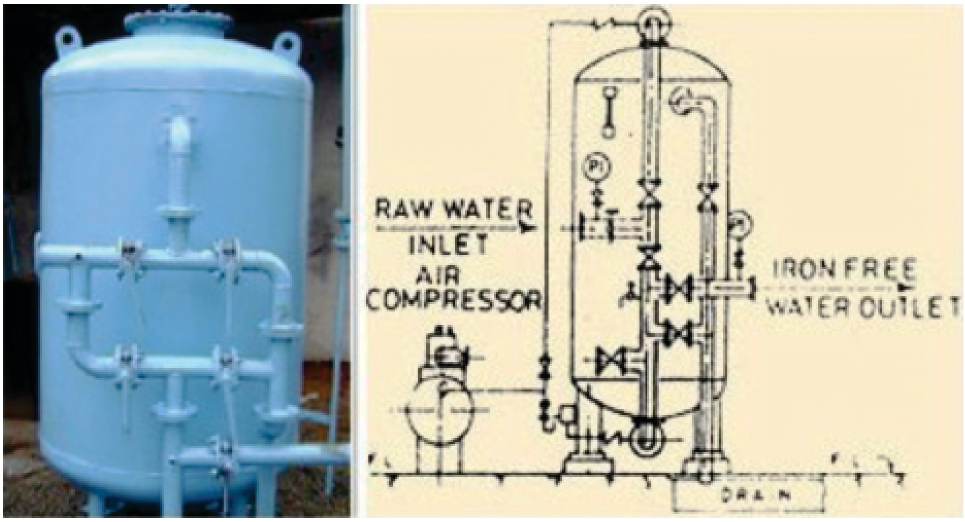

Figure 66:Iron Removal Plant (by Shubham Inc.)

Figure 67: Iron Stopper Containerized Treatment System

- 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; and
- 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

4.3.15 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. 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.

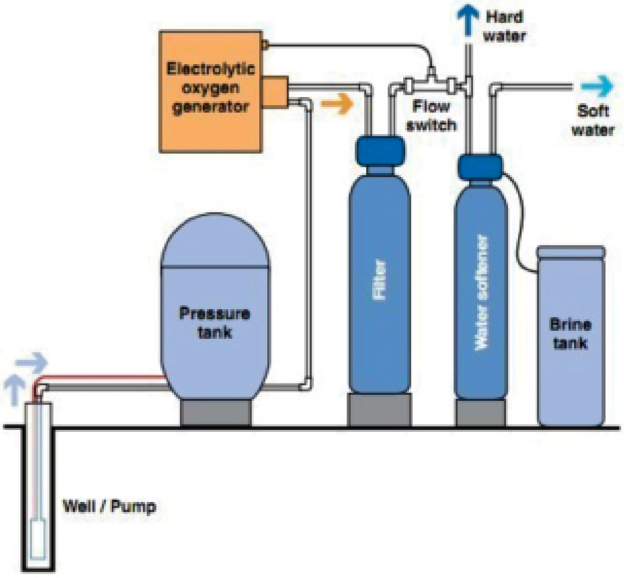

Figure 68: The WATER D.O.G. Iron Hunter HD

Contact details:
Patsy Parker-Kettle
pkettle@wcponline.com

4.3.16 Jal-TARA water filter

Background:

Sand filters commonly used for water treatment are of two types a slow sand (2 to 6m^3/m^2 /day) and rapid sand (100 to 150 m^3/m^2/day) filters. Though there are many other ways of treating water, no single process is as effective in simultaneously improving microbiological and physio- chemical qualities of water as slow sand filtration. It is for this reason that slow sand filters are very much favoured in developing countries where land and labour constraints are not pressing, and the ease of operation, maintenance and cost are most important.

Jal-TARA filter has been developed by Development Alternatives, New Delhi. These filters are now marketed by TARA Technology and Action for Rural Advancement, a social enterprise of the Development Alternatives Group. The Filter is designed to treat drinking water contamination with pathogenic bacteria, turbidity (dust, dirt and suspended material) and Iron using slow sand filtration technique. Jal-TARA filter is a community level system, which can provide 2000-3000 litres of safe drinking water per day. It doesn't require electricity and is also suitable for hilly region.

Principle:

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.

Jal-TARA filter is standardized in 1,000 litres water tank with the output water supply of 2,500- 3,000 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 photovoltaic.

Flow Rate: 2-3 m^3/ m^2/day

In Jal-TARA Filter, two types of filtration processes act together to improve the quality of water. The two filtration processes are as below:

i.) Physical filtration: The fabric filter prevents most organic matter, silt and mud particles from passing through.

ii.) Biological filtration: A biological community builds up on fabric filter and sand bed, scavenging and breaking down unwanted pathogens and organic matter in the raw water.

Jal-TARA is NABL accredited laboratory certified community based slow sand filter available commercially in the country.

Contact Details:
Development Alternatives
B-32, TARA Crescent,
Qutub Instituional Area New Delhi -110016.
Email: mail@devalt.org
Website: www.devalt.org
Ph: 011-2654-4100, 011-2654-4200

4.3.17 Iron removal by using Iron specific resin (INDION ISR)

INDION ISR Iron removal technology that is far superior to the existing technologies which find its application in hand pump, tube well and tap as source of water.

As compared to the existing technologies, this technology is robust and can handle greater Iron load per cubic feet of media used and also TDS of 2,500 ppm. It is very simple to use wherein no pretreatment is required and has zero operating cost. Being completely indigenous, this technology removes the dependence on foreign technologies and its superiority ensures tremendous potential in the foreign markets as well.

INDION ISR(Iron Specific Resin) is based on ion exchange resin technology and has manganese dioxide as a catalytic moiety. It works as a catalyst to promote Iron oxidation. Basically, Iron and oxygen are attracted to manganese dioxide, which enhances the oxidation of dissolved Iron and converts the soluble Iron (Fe^{++}) into insoluble Ferric (Fe^{+++}), which can be filtered through the media that acts as catalyst in this process and does not get consumed. In this reaction, manganese dioxide is reduced to Manganese Oxide and Ferric Hydroxide is precipitated. During backwash, the surface of this material is scoured, converting it to MnO_2, which is further used to oxidise the Iron. Simple backwash regenerates Manganese Dioxide. No chemicals are required to regenerate the resin.

Key advantages:

- Affordable;
- Treated water meets WHO drinking water standards;
- INDION ISR is WAQ Gold Seal certified;
- As hand pump attachment and tap attachment the technology does not require electricity;
- No chemicals are required to regenerate the resin; and
- Easy to maintain and operate

Contact details :
ION Exchange India LTD
Flat No.-8, Block-B, Naraina Local hopping Center,
Ring Road, Nairaina Vihar, New Delhi -110028
Mobile: 9810305509

4.3.18 Iron removal OxiMax systems

OIRM' is a granular catalytic boosting oxidation process in aqueous solutions (Water and is not a coated media. The active comments are permanently fused to the surface and are not subject to depletion through abrasion during the services and backwash portion of service run. The media acts as an oxidation catalyst in the true meaning of the world and facilitates or enhance oxidation. The process used by the media to remove the Iron and manganese is classic oxidation–preparation–filtration. The media does not require periodic regeneration for reactivation (as the greensand does) and does not display a decaying activity to do its catalytic work. The media will only require periodic backwashing to remove the collected solids. Another function of the chlorine (fed as Sodium Hypochlorite (NaOCl using electro-chlorination systems) is that it keeps the media free from bacterial or slime growth and is also used in post-treatment of filtered) water. At the same time, the NaOCl is a source of oxygen more reactive than molecular oxygen. No regeneration required, only backwash with Oximax technology which not only removes the Iron from the water, but also removes microbiological contamination from the water with the use of electro chlorination.

Contact details:
HES Water Engineers (India) Pvt. Ltd,
K-27, Fivestar Ind. Zone,
MIDC Butibori, Nagpur 441122

4.3.19 Bharti-Senco Iron removal unit

Summary of the Product: Bharti-Senco Iron removal units have been designed and developed for solving the Iron contamination problems in hand pump and tube wells water and providing safe and Iron free water in India. The different type of models are as available.

Contaminants that can be removed through this Technology: It can handle up to Iron up to 20 PPM at inlet water and outlet water is less than 0.30 PPM. It also reduces turbidity of water.

Design Capacity: Designed Iron removal systems for hand pumps (capacity up to 15 LPM) and Iron removal system for bigger water supply schemes (Tube wells & Overhead tanks) for capacities starting from 1000 LPH to 60000 LPH.

Pre-Treatment Protocol: Not Applicable

Post-Treatment Protocol: Not Applicable

Operations and Maintenance Cost and Protocol: Replacement of Iron removal media once in 3 - 4 years.

Backwash is needed depending on the Iron content in water.

Reject Management Cost and Protocol: Not Applicable

Certification of Product: Test report done by the department and ISO 9001 :2015, ISO 14001 : 2015, OSHAS 18001 : 2007 and ISO 22000 : 2005 Certification and NSIC Registration Certificate.

Ease of Operations and Management: Bharti Iron removal unit is an extremely cost effective & efficient product which can solve the problem of red Iron contamination water in hand pumps in rural India. The unit gives Iron free water. It can treat water with up to 20 PPM Iron. This unit is proprietary to Bharti Waters Pvt. Ltd. and has been developed to make it easy to use by people in rural India.

Interference by other Contaminants: Not Applicable

Test Trailed: The product has been successfully trialed & tested in Dumka district of Jharkhand and various state in India like Jharkhand, Uttarakhand, Odisha.

Contact details:

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Bharti Waters Pvt. Ltd.
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Mobile: 9810600304

Shri. Siddhartha Aggarwal
Bharti Waters Pvt. Ltd.
Email id: sidhartha@bhartiwaters.com
Mobile: 9650516070

4.3.20 Automation and remote monitoring of Iron removal plant

Brief on the technology: Automation and remote monitoring of treatment plant of Iron removal from groundwater has already been recognized and published through compendium of technologies published in the year 2015. This has been featured as solar operated standalone groundwater treatment plant for removal of dissolved Iron, Arsenic, and Fluoride present in groundwater using non-RO technology.

Other observations:

1. The technology can be retrofitted into existing system;
2. Production capacity can be easily scalable;
3. Overall life cycle cost of the technology excluding taxes is Rs. 5,75,000;
4. Semi-skilled & un-skilled persons can operate the plant using training and Standard Operating Procedures;
5. Life of the filter media is 5 years;
6. Post installation services like remote monitoring & online data transmission of operating parameters including power consumption is available;
7. Liquid sludge is generated and can be managed at site;
8. Allowable turbidity of inlet water is 5 NTU & allowable maximum TDS of inlet water is 500mg/L;
9. No pre & post treatment of inlet & outlet water is required; and
10. Completely indigenous technology.

Contact details:

Membrane Filters (I) Pvt. Ltd
101, KRUPA , 40/12, Bhonde Colony,
Off Prabhat Road, Pune
Email Id: subhashdevi@membranefilters.in

4.3.21 Self-sustained Auto Backwash Iron Removal Plant

Self-sustained auto backwashed Iron Removal Plant is the ideal solution for Iron contaminated water. It can be provided with a solar pump package and foundation structure for the overhead arrangement of a plant. The Iron removal plant is based on a hydro-automatic gravity filter. This system also removes dissolved gases such as Hydrogen Sulphide, Methane, Manganese and Carbon Dioxide. Particulate and organic matter can be removed as well, making clean and pure treated water. It can also be used for the removal of turbidity. It can deal with Iron content between 0.1 and 40 mg/l without reagent treatment. The system is low maintenance and easy to set up. Plant capacity ranges from 1,500 liters per hour to 1,00,000 liters per hour. Higher capacities are available on a requirements basis.

Process: The oxidation system is based on induced vacuum aeration. Atmospheric oxygen is introduced into the water until saturation is reached. It contains hybrid media, including non-reactive food-grade buoyant media. As the media get clogged by Iron precipitate, this slows down flow leads to an increase in backpressure. This causes the system to switch to the self-cleaning mode or self-backwash mode. The media is violently agitated, and the impurities are rinsed into the backwash collection box.

Advantages:

1. Eco friendly;
2. A small amount of water is required for backwash with stand-alone backwashing technique;
3. The backwash is based entirely on the pressure difference and water levels; and
4. System operation is self-adaptable with changing contaminant loadings.

Operation and maintenance: The system is based on the principle of self-cleaning. The system is auto 'backwash' and does not require manual interference for backwashing. This means that a small amount of water will be sent back through the filters to wash out the collected Iron floc and other debris on the filter media.

Figure 68: Self -Sustained Auto Backwash Iron Removal Plant

5 Nitrate removal methods & technologies

5.1 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 groundwater 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.

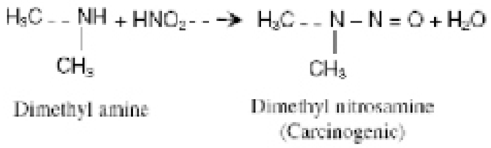
Secondary toxicity

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 months of age. Methemoglobin (MetHb) is formed when Nitrite oxidizes the Ferrous Iron in Haemoglobin (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 methaemoglobin 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.



$$\underset{\text{Dimethyl amine}}{H_3C - \underset{\displaystyle CH_3}{\underset{|}{N}}H} + HNO_2 \dashrightarrow \underset{\substack{\text{Dimethyl nitrosamine}\\ \text{(Carcinogenic)}}}{H_3C - \underset{\displaystyle CH_3}{\underset{|}{N}} - N = O} + H_2O$$

To protect consumers from the adverse effects associated with the high Nitrate intake, Nitrate consumption should be limited. BIS has stipulated acceptable limit for Nitrate in drinking water is 45 mg/l and WHO has guideline value of 50 mg/l.

Methods for removal of Nitrates from drinking water

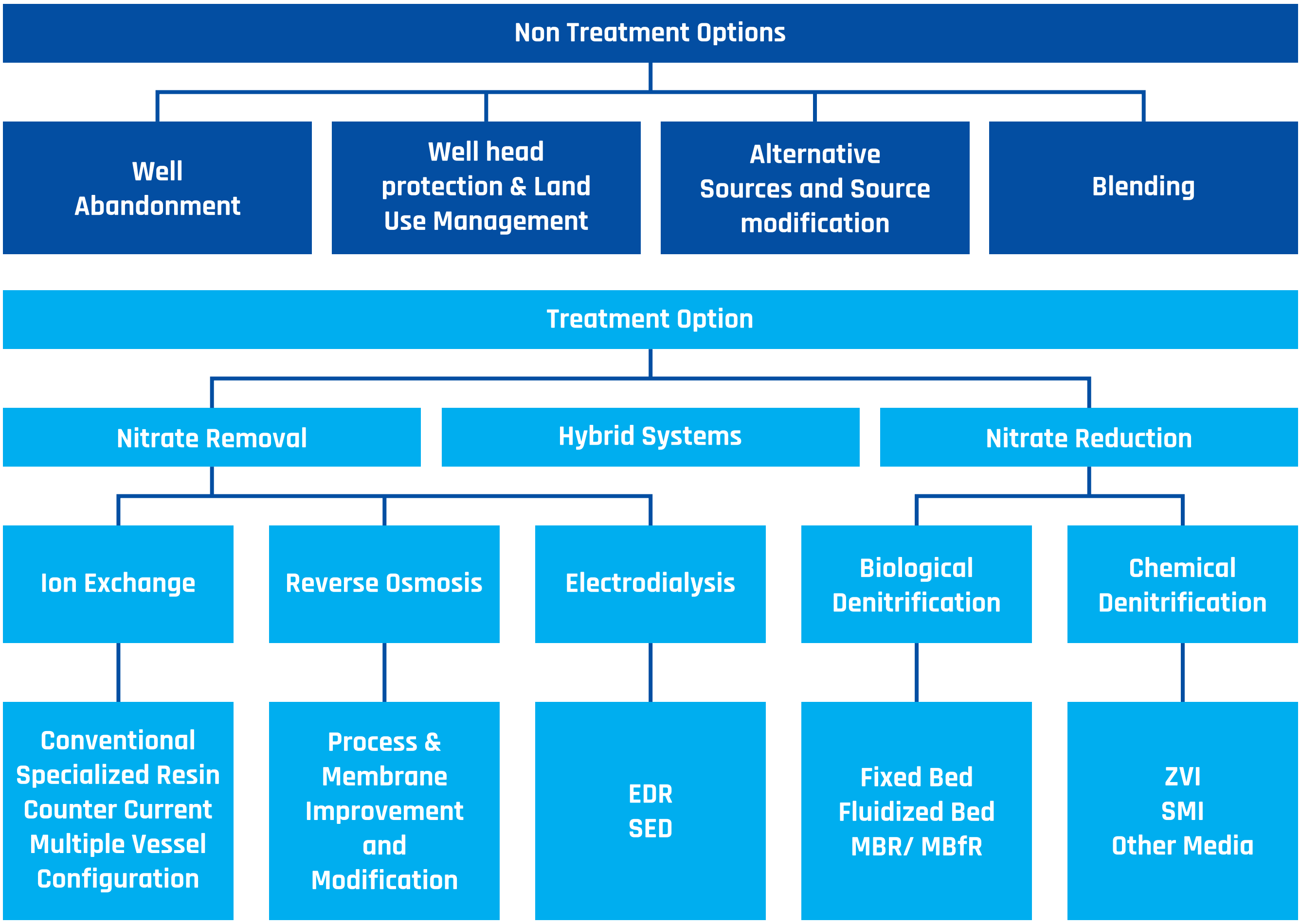
Nitrate is a stable and highly soluble ion with less potential for co-precipitation or adsorption. These properties make it difficult to be removed from water by some popular processes such as chemical coagulation, lime softening and filtration which are effective for removing most of the pollutants 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:

1. Adsorption/ Ion exchange
2. Biological denitrification
3. Catalytic reduction
4. Reverse osmosis
5. Electrodialysis
6. 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.

5.2 Techniques for removal of Nitrates from water



5.2.1 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 the popular commercially 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.

5.2.2 Biological De-nitrification

Biological de-nitrification 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 de-nitrification, the autotrophic and heterotrophic de-nitrification. Heterotrophic de-nitrification is a process that uses various Carbon compounds as energy and electron sources such as Ethanol, Methanol etc., while autotrophic de-nitrification bacteria use Hydrogen, Iron or Sulphur compounds as energy source and Carbon Dioxide or Bicarbonate as Carbon source. The main advantages of heterotrophic de-nitrification are the high denitrifying rates and treatment capacity. Biological de-nitrification 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.

5.2.3 Catalytic Reduction/ De-nitrification

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.

5.2.4 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 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.

5.2.5 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).

5.2.6 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.

5.3 Technologies for removal of Nitrates from water

5.3.1 Technology from Ion Exchange India Limited

Ion Exchange India Limited (Figure 71) 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; and

5.) Only Sodium Chloride is needed for regeneration.

Figure 69: Nitrate Removal Systems of Ion Exchange India Limited

Two Nitrate removal systems of 6 m^3/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.

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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

5.3.2 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 the Figurebelow.

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.

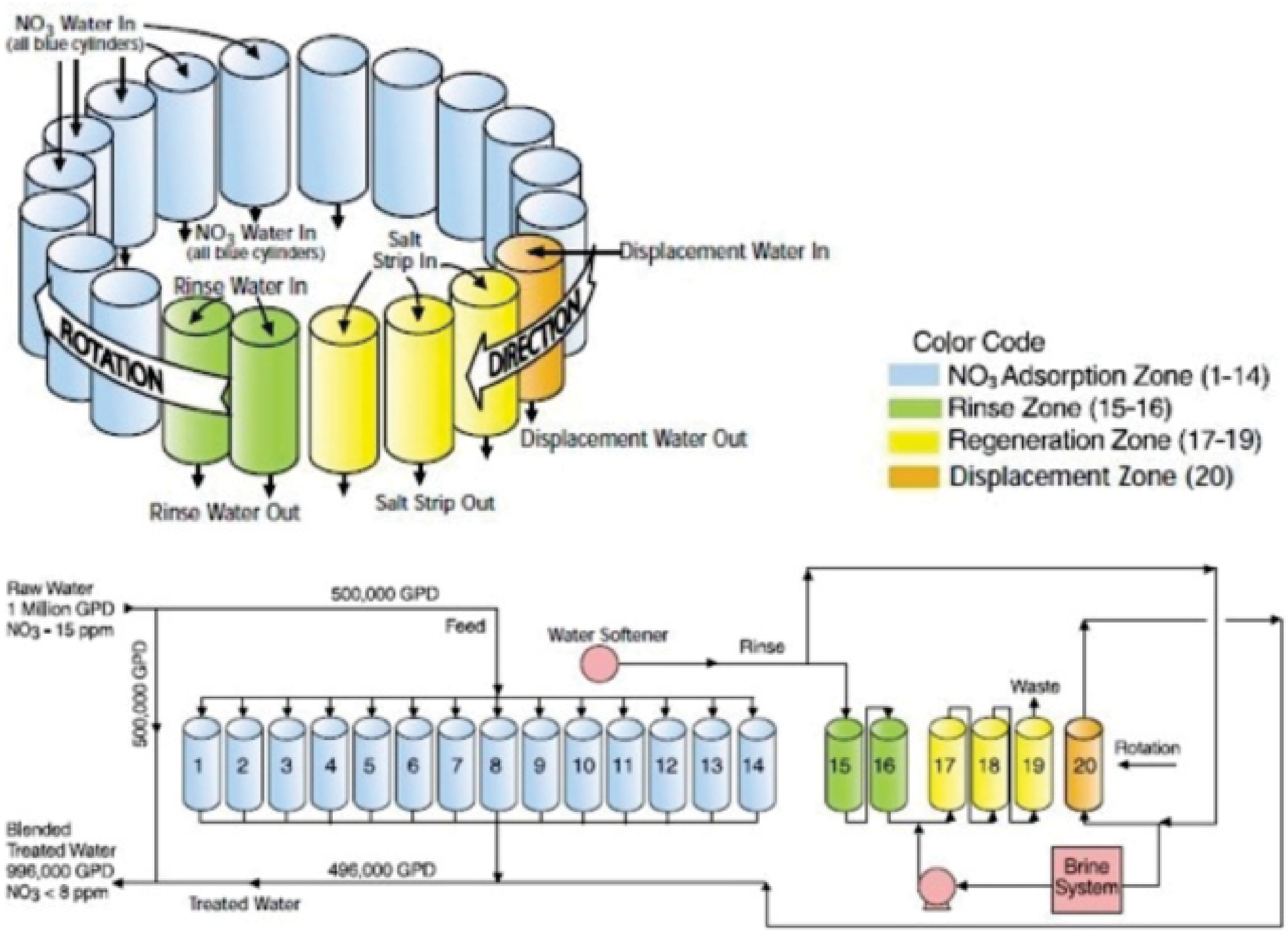

Figure 70: ISEP Nitrate Removal System

Strip Wash Zone (15-16)

A small amount of pre-softened feedwater 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.

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 1-800-422-7266 • Fax 412-787-6713,
www.calgoncarbon.com

5.3.3 Heterotrophic De-nitrification

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.

$$6NO_3 + 2CH_3OH \quad \text{®} \quad 5CO_2 + 3N_2 + 7H_2O + 6OH^-$$

Autotrophic denitrification using hydrogen gas

$$NO_3^- + 5H_2 + 2H^{+\text{®}}\ 2\,N_2 + 6H_2O$$

Or

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

Features of this technology are given below:

(I.) High efficiency, low Carbon footprint Nitrate removal from groundwater;

(ii.) Treatment to drinking water standards;

(iii.) Achieved through Autotrophic de-nitrification; and

(iv.) Scalable technology.

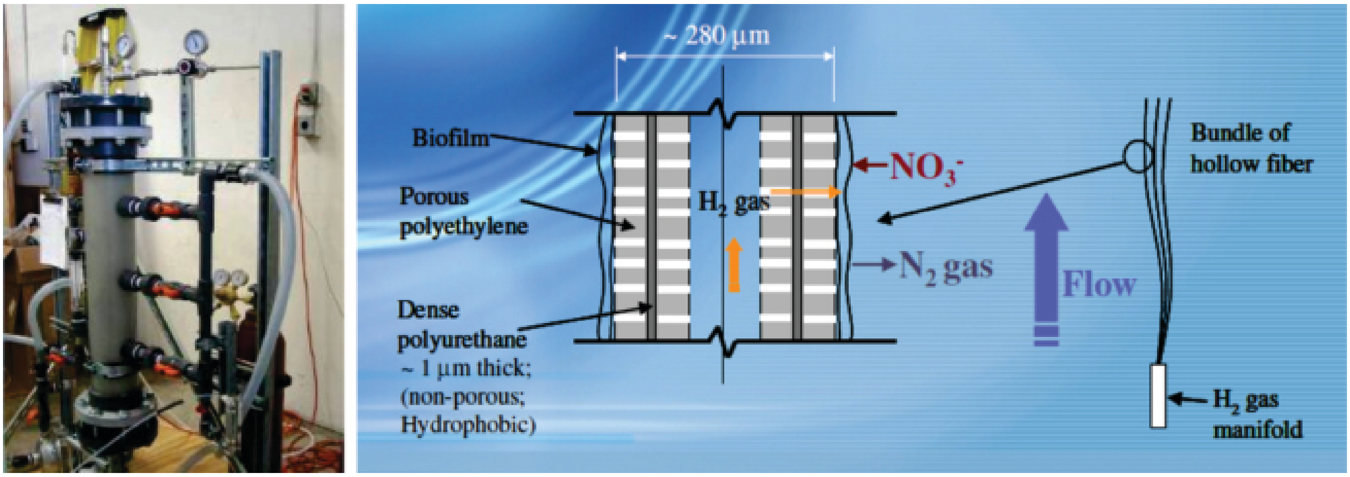

Figure 71: Advanced Nitrate Reduction Hollow-Fibre Membrane Bio-Reactor

1.3.4 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 .

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 throughout), these systems can provide an environmentally friendly solution to the increasing need for Nitrate removal.

Figure 72: MIEX Treatment Systems

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

5.3.5 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 73: Siemens Nitrate Removal System

Contact details:
Siemens Water Technologies
2430 Rose Place, Roseville, MN 55113, USA

5.3.6 Nitrate removal plant based on Nitrate selective ion exchange technology

Summary of the Product: Rite Waters Nitrate removal system offers a perfect solution to this problem. Nitrate removal system works on the phenomena of Nitrate selective ion exchange. This system uses a polymer resin which has Chloride ions adhered to its surface. When the water containing Nitrates passes over the resin the Nitrate ions get adsorbed onto the surface and Chloride ions are released into the water. Along with the Nitrate ions, Sulphate ions also get removed in this system due to the affinity of the Sulphate ions to the resin. The recharging of the resin needs to be done using concentrated brine solution. During regeneration the Chloride from the salt displaces the Nitrate and Sulphate Ions. The regeneration frequency depends on the concentration of the Nitrates and Sulphates in water as well as on the volume of the resin. The technology for this plant used a media which is selective to Nitrate and has little effect of competing ions like Sulphates in groundwater. This results in high Nitrate removal capacity and low changes of Nitrate breakage. This media requires only common salt for regeneration which is freely available in every corner of India. This makes it highly feasible for use in remote rural habitations. This also makes the technology highly user friendly and low cost. In conventional Ion Exchange Technology, like DM Plants for Nitrate removal, the media has to be regenerated by chemicals like acid and alkali which are difficult to handle and not easily available in villages leading to plant being dysfunctional. However, in Nitrate selective Ion exchange method, the media can be regenerated by common salt which is easily available in villages thereby making the technology highly suitable for rural environment. Reverse Osmosis can be used for Nitrate Removal. However, this technology requires energy and there is almost 50% of water which is rejected. As compared to this, using the Nitrate Selective Ion Exchange method almost 100% water is recovered, and the plant can be connected online to existing water supply scheme or to existing open well/ borewell submersible pump. In case of villages without electricity, a solar submersible pump can be used to provide Nitrate free safe water to the consumers.

Contaminants that can be removed through this Technology: Nitrate

Design Capacity: 500 LPH to 10 m3/hr.

Pre-Treatment Protocol: Not required. However, in case of water with suspended solids a dual media filter is recommended.

Post-Treatment Protocol: Not applicable.

Operations and Maintenance Cost and Protocol: O&M is very crucial for success of these community-based plants.

The O&M protocol shall be as below:

1.) The unit shall be operated & maintained by the manufacturer for period of 5-7 years;

2.) through automation, the operator intervention shall be minimal;

Certification of Product: The product is empanelled by State Level technical committee of Govt. of Maharashtra.

Ease of Operations and Management: This is extremely operator friendly and can be operated by local villager after proper training.

Interference by other Contaminants: The Nitrate Selective Ion Exchange technology for this plant used a media which is selective to Nitrate and has little effect of competing ions like Sulphates in groundwater. This results in high Nitrate removal capacity and low changes of Nitrate breakage.

Test Trailed: 1000-2000 LPH systems have been set up in 2 villages of Maharashtra which are running successfully for last 1 year.

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Email Id: abhijeet@ritewater.in
Tel: 9370078182

6 Salinity removal methods and technologies

6.1 Techniques for removal of salinity from water

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

Membrane processes

a.) Reverse osmosis

b.) Electrodialysis

Distillation processes

a.) Multi-Stage Flash Distillation

b.) Multiple Effect Distillation

c.) Vapour Compression Distillation

Alternative processes

a.) Solar Humidification

b.) Freezing

c.) Membrane distillation

6.1.1 Membrane processes

6.1.1.1 Reverse Osmosis (RO)

Reverse osmosis (RO) is currently one of the fastest growing techniques for desalination of different types of water. In RO, the feedwater is pumped at high pressure through permeable membranes, separating salts from the water. The feedwater has to be pre treated to remove biofouling and scaling. The quality of water produced depends upon the pressure, the concentration of salts in the feedwater 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. In India, plants of capacity 10 m^3 to 50 m^3 per day have been installed. Several large size desalination plants up to 100 million litres per day (MLD) are operating in the coastal cities of the country. Worldwide, 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 has TDS levels ranging between 30 to 500 mg/L. The conversion rate of the product water from feedwater varies between 30-50%. 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 capacity) to only 3 paise per litre in case of large RO plants.

6.1.1.2 Electrodialysis

Electrodialysis (ED) is an electro-membrane process in which transport of ions present in contaminated or brackish water is accelerated due to an electric potential difference applied externally. An electrodialysis cell consists of a large number of narrow compartments through which the feedwater for desalination is pumped. These compartments are separated by alternatively placed cation and anion-selective membranes in a parallel fashion across the current path to form an ED cell. Using a direct current (DC) electrical field, cations and anions migrate through the appropriate membranes, forming compartments of electrolyte enriched wastewater 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 problems in a basic electrodialysis unit have been overcome by recent advancements in the ED technology in the form of Electrodialysis Reversal (EDR), a process which 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 pre-treatment chemicals, thereby optimizing the cost.

The ED/EDR process is usually only suitable for brackish feedwater with total dissolved solids (TDS) up to 12,000 mg/L. 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 1 kWH is required to extract 1 kg additional salt using ED/EDR.

6.1.2 Distillation processes

Distillation is one of the oldest and most 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 freshwater. 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 1950s. Distillation processes such as Multistage-flash (MSF), MED and Vapour Compression (VC) have led to the widespread use of distillation to desalinate seawater.

6.1.2.1 Single/ Multi-Stage Flash Distillation (SSF/ MSF)

Multistage flash distillation (MSF) is still the most used technique, particularly where energy is still not an issue or inexpensive. In a MSF plant, a stream of heated brine flows through a vessel consisting 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 blowdown. MSF operating temperatures range from 100 to 110 ºC and they produce 6 to 11 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 but for scaling of production in an economical manner MSF may be preferred. The unit cost of production varies between 3.5 paise per litre to 8.3 paise per litre of water/ distillate produced.

6.1.2.2 Multi-Effect Evaporation (MEE)/ Multi-Effect Distillation (MED)

Multi-effect distillation has a great 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 - 70ºC. The unit cost of production of MEE systems varies from 3.9 paise to 8.9 paise per litre of water/ distillate produced.

6.1.2.3 Vapour Compression Distillation (VCD)

Vapour Compression Distillation (VCD) is a distillation process where the evaporation of 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 prerequisite for the system. TVC is used in conjuncation with MEE system for large scale plants for better economics. 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 (MVC) 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 MVC, 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 feedwater using heat exchangers from the brine blowdown 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 in commercial sites.

Low Cost Vertical Tube Evaporators (VTE)

VTE technology,devised on a pilot scale by IIT,Delhi, 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 feedwater 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 julif*lora 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.

6.1.3 Alternative processes

6.1.3.1 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 of saline water (about 10 cm deep) spread over a large surface area and covered with a glass cover. 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 since no power is required, but 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 freshwater 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 andits ability to use a renewable energy source, sunlight making it an economical option for producing potable waterfrom various feedwater sources like sea water, brackish water or treated wastewater.

6.1.3.2 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 freshwater 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 other distillation methods such as lower theoretical energy requirement, minimal potential for corrosion, and little scaling or precipitation.

6.1.3.3 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 only passes water vapour and 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 feedwater.

Inquest of integrated approach (Hybrid systems)

Selection of desalination technology should 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 rainwater 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/ groundwater 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.

6.2 Technologies for removal of Salinity from water

6.2.1 Desalination related activities at Ministry of Earth Science

Introduction: Low temperature thermal desalination (LTTD) is one process that uses the availability of a temperature gradient between two water bodies or flows to evaporate the warmer seawater at low pressures and condense the resultant vapour with the colder seawater to obtain freshwater. The 12-13°C cold water available at about 400 m depth within 1000 m from the island is used along with the surface water at about 28°C to produce potable water in the Lakshadweep Islands, shown in Figure 76.1. Temperature profile collected from Argo floats near Lakshadweep Islands in Arabian sea is shown in Figure 76. The simplicity of the LTTD process also enables to control the quality of product water to provide potable drinking water.

MoES-NIOT, pursuant to its laboratory studies since 2000 and field trials off Tuticorin in 2004, established the first LTTD plant of 1Lakh liters per day capacity in Kavaratti during July, 2005 and after the initial maintenance and training for about one year, handed over the plant to UT administration in 2006. Since then, the following are some of the projects handled by MoES-NIOT.

1. Establishment of LTTD Plants in the islands of UT Lakshadweep - Kavaratti (2005), Minicoy and Agatti (2011), Kalpeni (2020) and Androth, Amini, Chetlat, Kadamat and Kiltan (in Progress), OTEC Based Self Powered Desalination Plant at Kavaratti (in Progress);
2. Demonstration of Offshore LTTD plant (1 Million Liters per Day Capacity - 2007) and Preparation of DPR for 10 MLD capacity Plant (2016);

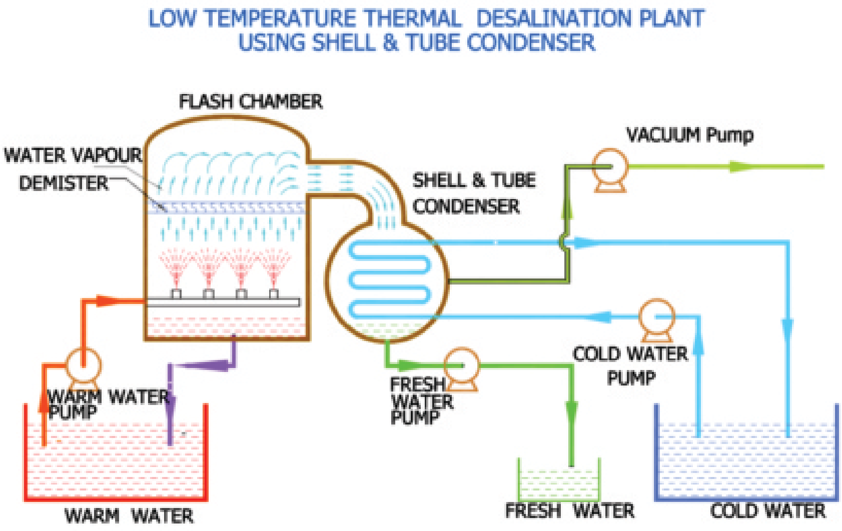


Figure 74.1: LTTD process

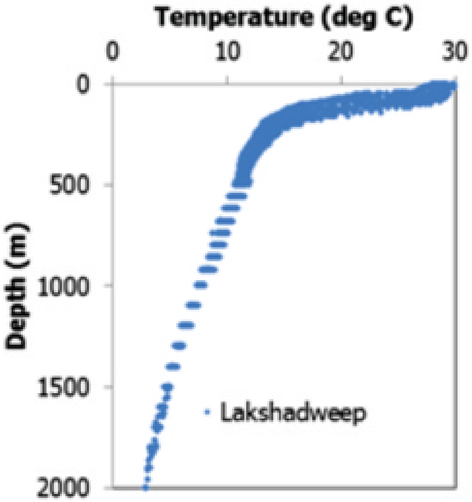


Figure 74.2: Temperature Profile in Indian Waters

3. Demonstration of Condenser Reject Based LTTD Plant in North Chennai Thermal Power Station (1.5 Lakh Liter per Day Capacity - 2009) and in Tuticorin Thermal Power Station (in Progress); and
4. Establishment of Solar based Multi Effect Distillation Plant in Ramanathapuram (1.4 lakh liter per day capacity in 2012) and in Kanyakumari (10,000 liters per day capacity in 2018)

The Details of these plants are provided in the following sections.

(a.) Establishment of LTTD Plants in the islands of UT Lakshadweep

About 10 of the Lakshadweep Islands, located along the west coast of India are inhabited. These islands have a lagoon on the western side and a steep coast on the eastern side, with availability of 400m depth within 1000m distance. MoES-NIOT established the first LTTD plant of 1 Lakh liters per day capacity in Kavaratti during July, 2005 and after the initial maintenance and training for about one year, handed over the plant to UT administration in 2006. A layout of the Plant is shown in Fig. 3, heat balance for a 1 Lakh LPD capacity plant is provided in Fig. 4 and the major process equipment are shown in Fig 5. Based on the functioning of the plant, Administration approached MoES-NIOT to put up plants in other islands of the region Minicoy (April, 2011) and Agatti (July, 2011) plants. All the three plants are being maintained by the Public Works Department of the UT Administration using the local manpower. At present work is in progress for establishing LTTD plants of 1.5 Lakh liters per day capacity in the islands of Androth, Amini, Kadamat, Kiltan, Kalpeni and Chetlat of UT Lakshadweep. The view of LTTD plants at the Islands are shown in Figure 80.

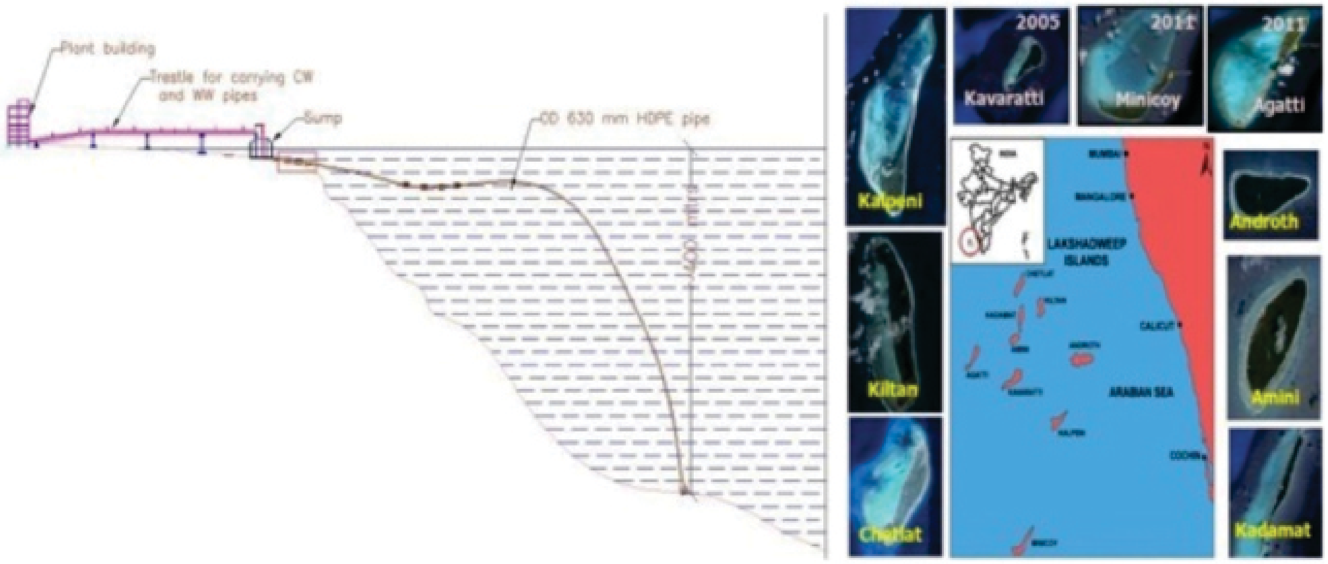


Figure 75: Layout for shore based LTTD plant (inset figure showing Lakshadweep Islands)

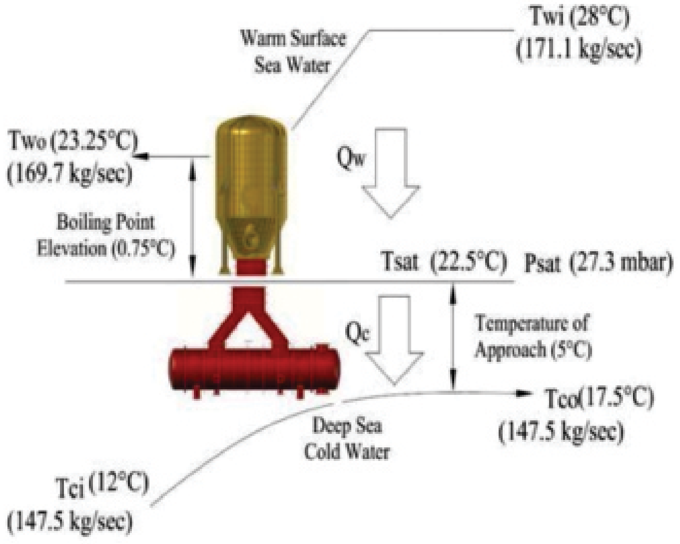


Figure 76: Heat and Mass balance for 1Lakh LPD Island based plant

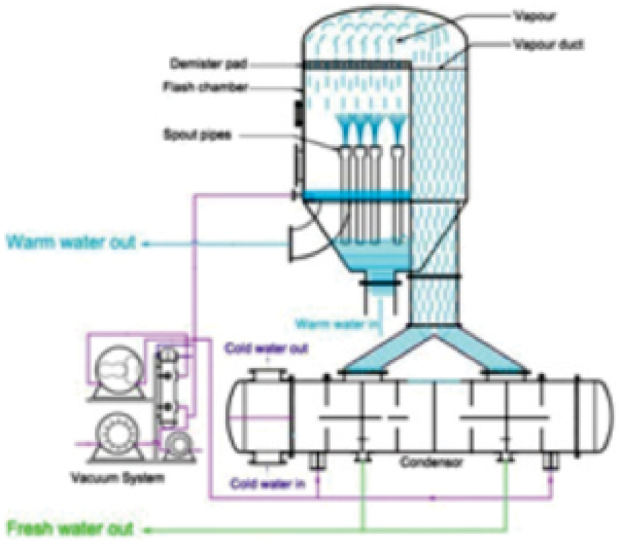


***Figure 77:** Process component*

Since the LTTD plants work with the available heat between various streams of water, they are environmentally friendly. The successful demonstration of LTTD plants in various configurations has provided MoES-NIOT with critical design experience. The continuous operation of these LTTD plants has proved the simplicity of the process. The island based plants provide the means for potable water in remote islands where applicable. Thus, a technology which is environmentally friendly, completely indigenous, with low operation and maintenance issues and with long term sustainability has been demonstrated and now needs to be scaled up with industry participation.

Salient Features of LTTD plants

Three sets of major rotating equipment - easy maintenance and operational simplicity;

- Plants designed for the prevalent ocean wave and current climate, for installation with locally available infrastructure;
- Zero environmental pollution (Brine concentration < 1%); protects the coral islands; and
- Nutrient-rich deep seawater rejected from the plants attracts marine life.

Minimal Infrastructure

- Main Equipment:
- Process Equipment: Flash chamber, condenser, seawater pumps, vacuum system, plant piping;
- Submarine cold water pipe: 700 – 1500 m long HDPE pipeline with attachments; and
- Marine Structures: Sump, approach bridge and plant building.

Critical activities in installation:

- Design/ deployment of cold water pipe;
- Design/ construction of marine structures for islands; and
- Optimization of the process for available temperature gradient.

Minimal Maintenance:

- Seawater pumps and vacuum system are the only running equipment.

Costing: The cost of water is about Rs. 0.75 per litre, for a 1.5 lakh liter per day capacity plant installed at the Island.

Criteria for Site selection Shore based LTTD plants:

- Minimum distance of 5 m depth from the coast to locate plant intake sump for accommodating sea water pumps;
- Minimum distance of 400 m contour (depth) to draw cold water by HDPE pipeline;
- Draft availability in lagoon and berths to receive plant equipment;
- Loading and unloading facilities; and
- Continuous power supply with diesel generator.

Land Area:

Plant area: 15mx15m, Bridge: 3m wide, ~200m long

a. Kavaratti (2005)

b. Minicoy (2011)

c. Agatti (2011)

d. Kalpeni (2020)

Figure 78: Views of the Commissioned Island Based LTTD Plants

(b) Ocean Thermal Energy Conversion (OTEC) Based Desalination Plant at Kavaratti

NIOT's OTEC powered desalination plant will be set up at Kavaratti Island in U.T. Lakshadweep. The plant with desalination capacity of 1 lakh litres per day will work on the principle of Open Cycle (OC)OTEC that utilizes temperature difference between surface seawater and cold deep seawater for desalination and electricity. The plant is similar in construction to a low temperature thermal desalination plant with an addition of a turbine-generator and with a longer cold water pipe. The turbine-generator will generate adequate electricity for running of this plant and no electricity will be drawn from the island grid except for the start-up. Minimum temperature difference needed is 20°C for the system to be viable. Cold water at 7-8°C available at about 1000 m depth within 3.1 km from Kavaratti Island will be used along with the surface water at about 28°C to operate this system. A 3.5 km long cold water pipe, significantly longer than a typical LTTD plant, will be deployed in order to reach 1000 m water depth. The plant will offer all the benefits of existing low temperature thermal desalination plants in Lakshadweep and in addition to that it will not draw any electricity from the already stressed island power grid. This project will be the country's first attempt in employing OC OTEC for seawater desalination.

In OC OTEC, warm seawater stream is partially vaporized inside a flash chamber kept under vacuum. This vapour, in desalinated state, expands inside a turbine and generates mechanical power. The expanded vapour is condensed using cold seawater. The condenser is kept at lower pressure than the flash chamber using vacuum compressor. Fig. 81 shows a schematic of the OC OTEC process whereas Fig. 82 shows heat and mass balance for 1 Lakh LPD seawater desalination plant working principle of OC OTEC. The turbine required for this plant has to work at ultra-low operating pressures of water vapor. The power generated by this turbine will be sufficient to power all the internal consumers in the plant namely seawater pumps, vacuum pumps, plant lighting etc. Feasibility of self-powering a desalination plant has been established developing a small-scale open cycle turbine and successfully demonstrating power generation in the laboratory.

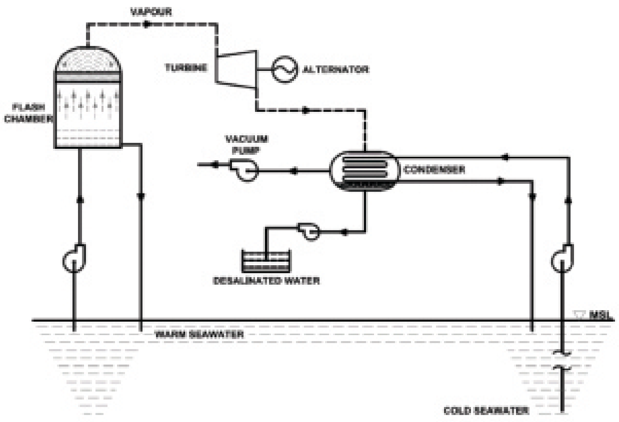


Figure 79: Schematic of OC OTEC based desalination

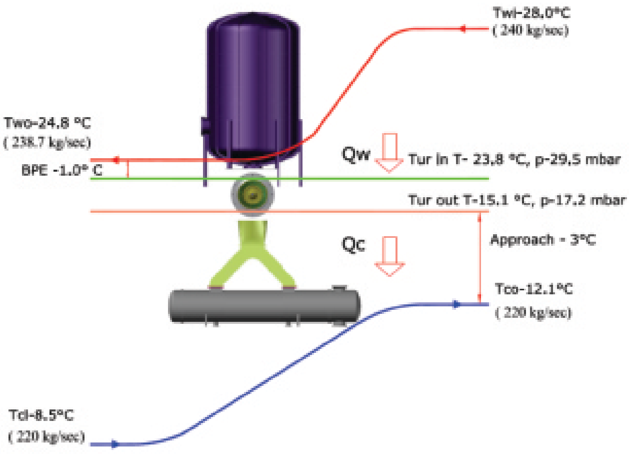


Figure 80: Heat and Mass balance for 1 Lakh LPD OTEC based desalination plant

Salient Features of an LTTD plant

- o No power drawn by the plant from island grid for its operation, which is a significant contribution to the diesel displacement drive by island administration;
- o Plant designed for the prevalent ocean wave and current climate, for installation with locally available infrastructure;
- o Zero Environmental Pollution (Brine Concentration < 1%); Protects the coral islands; and
- o Nutrient rich deep sea water rejected from the plants attracts marine life.

Minimal Infrastructure

- Main Equipment:

1. Process Equipment: Flash Chamber, Turbine-Generator, Condenser, Seawater Pumps, Vacuum System, Plant Piping;
2. Submarine cold water pipe: 3.5 km long HDPE pipeline; and
3. The plant will not have offshore sump and bridge. Plant Building and seawater sumps will be located onshore making construction easier.

- Critical activities in Installation:

1. Design / Deployment of Cold water pipe;
2. Design of ultra low pressure turbine; and
3. Optimization of the process for self sufficient operation.

Operation and Maintenance:

- o Rotating equipment includes turbine-generator, sea water pumps and vacuum systems; and
- o Regular plant operation can be done by local manpower trained for this purpose.

Costing: OTEC powered desalination plant at Kavaratti is country's first life-size prototype being built for demonstration of technology developed by NIOT. Costing of this technology has not yet been finalized.

Criteria for Site selection Shore-based LTTD plants:

- Criteria same as LTTD plant except for the minimum distance of 1000 m contour (depth) to draw cold water by HDPE pipeline;
- Draft availability in lagoon and berths to receive plant equipment; and
- Loading and unloading facilities.

Land Area: Plant area: Plant area: 19 m × 13 m, Sumps: 10 m × 8 m

©. Condenser Waste Heat Based LTTD Plants

The LTTD technology can be utilized for generation of freshwater by utilizing the waste heat available in the power plant's condenser reject water and a pilot project with a capacity of 1.5 lakh liters per day was successfully demonstrated at North Chennai Thermal Power Station (NCTPS)using their condenser reject water. The view of LTTD plant at the NCTPS is shown in Figure 83. A small temperature gradient of about 8°-10°C available between the power plant condenser reject water and the nearby surface seawater was utilized in this plant. Water was generated for long periods when all units were up and was supplied in the NCTPS premises.

NIOT is now attempting to scale up the LTTD technology at coastal thermal plants. Towards this, it is proposed to install two LTTD modules each of 1 Million Liters per Day (MLD) capacity using power plant condenser reject at Tuticorin Thermal Power Station (TTPS). Out of two modules, one module will be producing freshwater of TDS less than 200 ppm suitable for drinking and the other module will be producing industrial-quality water of TDS less than 30 ppm. The heat and mass balance for 1 MLD capacity plant is provided in Figure 84.

Figure 81 : View of the Commissioned LTTD Plant at NCTPS

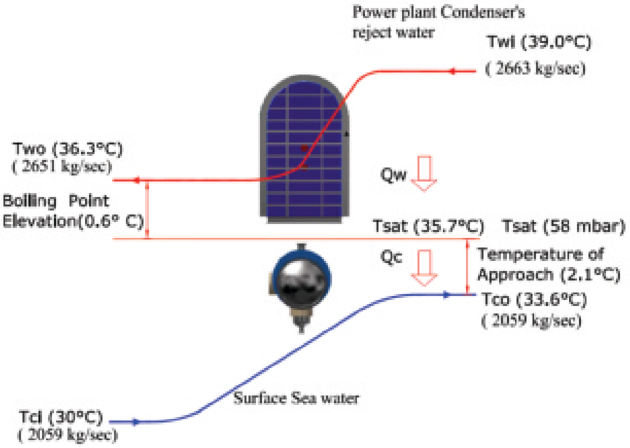


Figure 82: Heat and Mass balance for 1MLD capacity plant at TTPS

Salient Features of power plant based LTTD plant

- An efficient way to utilize the heat available in the power plant condenser's reject water which would reduce the load on the cooling towers and in turn the resultant thermal pollution; and

- o The quality of the product water could also be controlled to attain low Total Dissolved Solids (TDS) levels, so that it could be used as Industrial quality water in the power plant.

Minimal Infrastructure

- Main Equipment:

- o Process Equipment: Flash Chamber, Condenser, Seawater Pumps, Vacuum System, Plant Piping; and
- o Intake sumps for supplying warm & cold seawater to the LTTD plant and HDPE pipeline for brine discharge.

Minimal Maintenance:

Seawater pumps, freshwater pumps and vacuum systems are the only running equipment.

Commercial aspects:

If LTTD plant is employed in the design stage of a future coastal thermal power plant, the cost involved for civil structures, seawater intake and outfall arrangement including requirement of separate seawater pumps and other related accessories of the plant including piping can be eliminated as it will be taken care of in the power plant design itself. Hence, the cost of the LTTD plant components such as the flash chamber, condenser, direct contact condenser and vacuum system alone is required for the establishment of the plant.

Presently, the cost of establishment of a complete coastal thermal power plant project is around Rs. 7 Crore per MW. The percentage of cost increment if an LTTD plant is implemented in the design stage of any new or future coastal thermal power plant for the generation of 2 MLD of fresh or industrial quality water is around 0.50 % of the total power plant cost. Thus, implementation of LTTD in new power plants looks promising and such plants also have a low footprint.

(d). Offshore Low-Temperature Thermal Desalination Plant

The pipeline is the most challenging part of the system when using the ocean temperature gradient. In an onshore plant as in the case of islands, the deep water is very close to the shore. This is a special feature in the Lakshadweep group of islands. Thus, the pipe has been designed to be in a novel configuration with one end in shallow waters near the shore and the other end held by a weight in deep waters. The inverted catenary configuration is possible due to the inherent buoyancy of the material of the pipeline.

For mainland application of this technology, the drawing of the cold water is a challenge since the distance to the deep water is about 40-50 km from the east coast of India. This necessitates that the plant be located on a platform which is kept in position using moorings at a deep water location. To demonstrate that this technology can work offshore, a barge mounted desalination plant with capacity of 1 MLD was taken up. It was successfully demonstrated by NIOT at 40 km off Chennai coast in deep water for mainland applications in 2007 and shown in Figure 85. The thermal process is similar to that LTTD process implemented in the plants at UT Lakshadweep where deep sea cold water is used, two modules, each with a fresh water generation capacity of 500 m^3/day, were used.

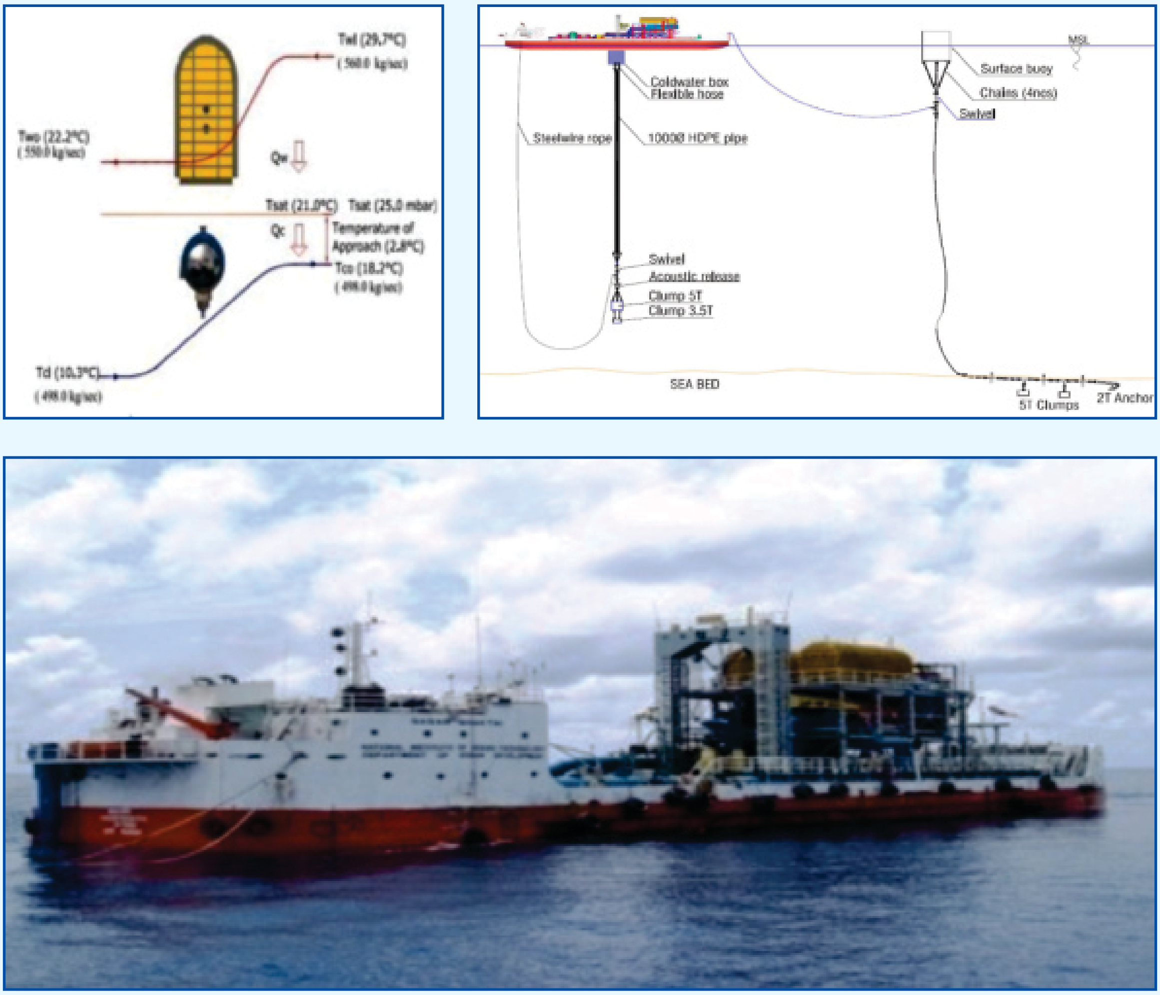


Figure 83: Details of the barge mounted 1 MLD Demonstration LTTD plant

The challenges included design, installation and maintenance of plant moored in deep water and transport of product water to the coast. For the first time in the world, a 1 m diameter and 750 m long HDPE pipe was towed, upended and connected to the bottom of a barge to pump deep sea cold water at around 10°C. The deepest single point mooring in Asia (i.e. at 1000m water depth) was designed in-house and also fabricated indigenously for mooring the 1 MLD plant. This mooring performed very well and kept the barge moored during the demonstrations trials. The barge used for the 1 MLD plant had a central moon pool through which the 1 m diameter cold water pipe was suspended vertically to draw the cold water. 1 MLD offshore LTTD plant successfully generated fresh water for several weeks.

The following were the outcomes of this plant:

1. The objective of a short demonstration of the concept of producing freshwater on a barge moored offshore was achieved and quality of water generated was excellent;

2. Within a year a long 1m diameter pipe could be assembled, towed and connected many times successfully albeit with some effort due to paucity of offshore handling equipment;
3. Single point mooring in 1000m water depth was demonstrated successfully;
4. The experience gained and success in pipe deployment and installation is an indication that pipelines for future larger plants also can be handled by NIOT; and
5. Offshore experience derived from the efforts at deployment, connection and operation has led to capacity building for future plants.

With the confidence gained, NIOT felt it is prudent to design and install a unit for 10 MLD offshore. The 10 MLD offshore platform mounted desalination plant is proposed to be installed at around 1000 m water depth nearly 40 km off the coast of Chennai.

The requirement for offshore desalination is a stable all weather platform to house the plant, a large cold water conduit/pipeline and station keeping/ mooring for the platform and an inter connecting mechanism between conduit and platform to withstand the differential loads as well as to provide ease of disconnection if required. The 10 MLD plant platform will have to be a vessel with higher displacement due to the large quantities of water being handled by large plant equipment. For an all-weather large platform, the design considerations are different. Several designs and analyses have been carried out with several configurations. A DPR is now ready with the help of an industry, for further implementation.

Building such an offshore plant will have several firsts for the country. One is the plant platform itself which will boost the Indian shipbuilding and port industry by creating new jobs. This technology if demonstrated has the potential to ameliorate the problem of water scarcity in the coastal areas of the Indian peninsula. Implementing such a technology will lead to a lot of capacity building for offshore desalination and energy generation in deep waters.

(e) Solar based Multi Effect Distillation Plants

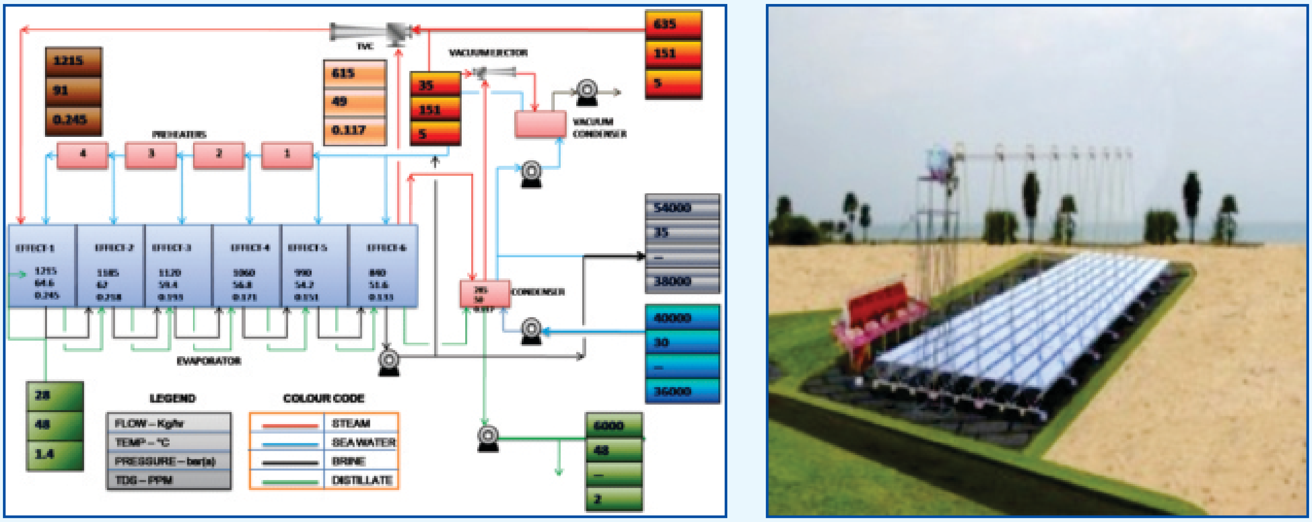
India, with its location in the temperate climatic zone, receives considerable solar insolation, ranging from 4-6 kW/m^2. It is therefore possible for any coastal location to utilize the solar heat in raising the water temperature for a Thermal desalination. Two joint projects of Solar based Multi Effect Distillation plant were undertaken by MoES NIOT, namely,

(i.) 1,44,000 LPD capacity plant at Ramanathapuram (2012), with the funding from the Department of Science and Technology (DST) Govt. of India.

(ii.) 10,000 LPD capacity plant at Kanyakumari (2018), with funding from MoES, design and execution of the plant by IIT Madras and execution of intake structure by MoES-NIOT.

(I.) Solar-based MED plant of 1,44,000 LPD capacity at Ramanathapuram

A solar energy-driven MED project with six effects, with bio-mass boiler steam support for non-sunshine hours, for generating 6 m^3/hr was developed by Empereal-KGDS Renewable Energy Pvt. Ltd., Coimbatore with technical support from NIOT, Chennai, SWS & GB Saline Water Specialists Pvt Ltd, Trichy, and Tamil Nadu Water and Drainage Board. The project was funded and guided by the DST Govt. of India. The commissioning of the plant was done during November 2012 and March 2013 at the coastal village of Narippeyyur, Ramanathapuram district in southern Tamil Nadu, plant details are shown in Figure 86. The location is a drought prone and faces a drinking water crisis in most months of the year. The region has plenty of biomass available for boiler operation. Hence, simultaneous operation of the solar and biomass system was carried out with switching over from one system to another. Linear Fresnel reflector of area 1404 m^2 was used in the solar field in this plant for concentrating the insolation on the absorber tube for converting the water into steam. A steam accumulator with a volume of 12 m^3 was used as buffer storage to store the steam also delivered steam at constant pressure and constant flow rate to the process. The plant was able to meet the design conditions of 6 m^3/hr freshwater at 2 ppm water quality.



a. Process Details of the Plant

b. Solar MED Plant Layout

c. A view of the MED Plant

d. A view of the Sea water intake system

Figure 84: Details and views of the plant at Narippeyyur

The criteria for selection of a site for the desalination plant:

- Suitability for locating a simple cost-effective seawater intake and brine discharge system;
- Clear land without any shadow from all around should be available for the solar concentrating system; and
- 8 hours operation can be considered for the design.

Costing: Project value was around Rs. 8 crore.

Land Area: Plant area: 50mx50m

(ii.) Solar-based MED plant of 10,000 LPD capacity at Kanyakumari

Solar thermal distillation plant of 10 m^3/day capacity has been commissioned by IIT, Madras under Technology Research Board (TRB) programme supported by MoES and the intake water system for the plant is provided by MoES-NIOT, plant details are shown in

Figure 87. The plant works on the MED, an ejector type vacuum system maintains the required pressures in the flash evaporator, MED evaporation distillation system and the condenser.

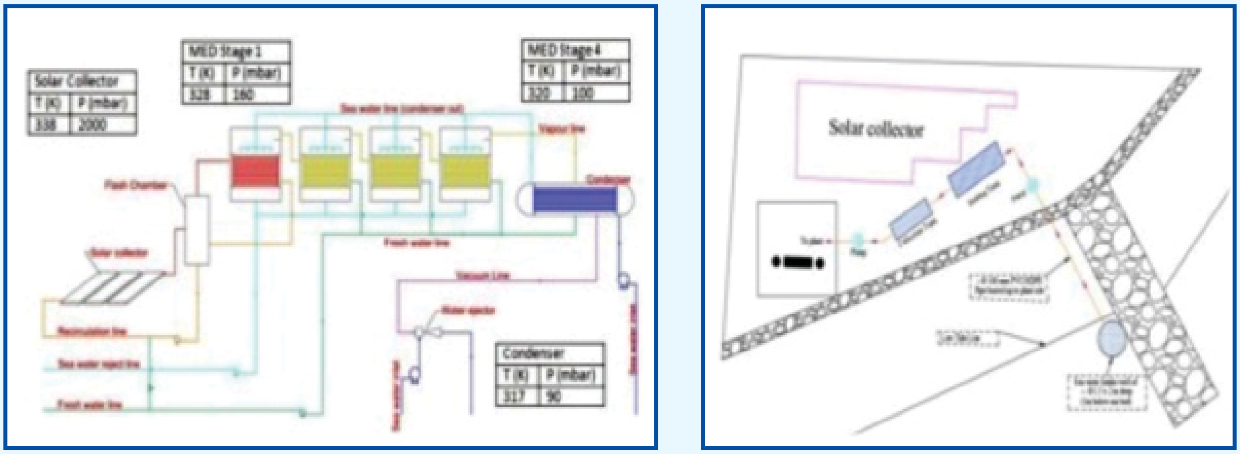
Suitability of solar MED for remote coastal villages

Coastal villages having scarce drinking water resources due to insufficient monsoon, seawater intrusion, storm surges etc., thereby, the drinking water requirement of the coastal villages can be addressed by solar thermal desalination process.

The process has the following advantages compared to the conventional technologies particularly for coastal communities; the intake water is available from the sea, the operational and maintenance challenges are negligible compared to other desalination processes, and, the process is cost effective, involving minimal operational equipment.

The criteria for Selection of site for desalination plant:

- Minimum distance of 200 m from the shore for seawater intake;



a. Process Details of the Plant

b. Solar MED Plant Layout

c. A view of the MED Plant

d. A view of the Sea water intake system

Figure 85: Details and Views of the Plant at Kanyakumari

- Suitability for locating simple cost-effective seawater intake and brine discharge system;
- Clear land without any shadow from all around should be available for the solar panels; and
- Hours operation shall be considered for the design.

Costing: The unit cost of water produced from the solar MED plant in a coastal village is about Rs. 0.5/ liter

Land Area: Plant area was 50m x 50m

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6.2.2 Desalination unit developed at BARC

The process involved 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 followed by a simple assembly of this membrane filter in appropriate housing. All the raw materials like polysulfone polymers, additives and solvents are produced within the country and are available locally.

A small room with a window air-conditioner/ dehumidifier is needed to coat the ultrafiltration membrane unit. All the steps in the presented technology are manual in nature and hence, do not require any electrical power. A constant source of water is needed to produce and test the membrane device. A single unit capacity varies from 1,000-7,000 LPD depending on the dimensions and the cost varies from Rs. 6,000 – 40,000 depending upon the size.

Figure 86: Demonstration Unit developed at BARC

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Phone: +91-22-25593897
E-mail: headttcd@barc.gov.in

6.2.3 Membrane reverse osmosis and microfiltration

The GeoPure treatment process is a combination of pretreatment, 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 feedwater, 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 5,000lpd Lires Per Day and cost is $0.94 Bbl (based on costs reported in the Barnett Shale study).

Contact details:

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

6.2.4 Siemens Water Technologies

Siemens Water Technologies developed an automatic blending valve purposely to blend RO permeate with 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 (gallon per minute) and is ideal for temporary use. A mobile RO 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 87: 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

6.2.5 TERI - Solar desalination unit

Desalination processes have been used for many a decade but they arehighly energy intensive 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 Solar Energy Centre (SEC) of the Ministry of New and Renewable Energy (MNRE), 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 SEC 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 90.1 & 90.2).

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.

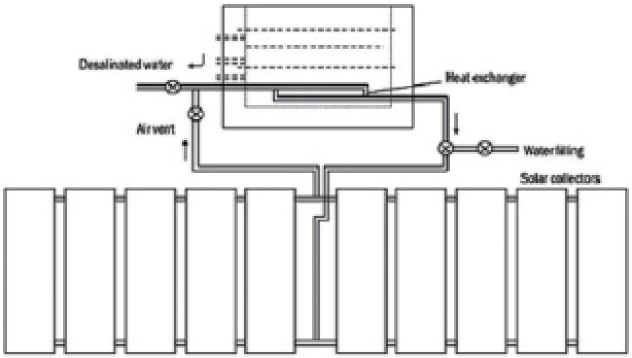

Figure 88.1: Schematic assembly arrangement of TERI's solar desalination unit

Figure 88.2: Flat-plate-collector-based solar desalination system installed at the SEC, 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 freshwater to those condemned to drink saline water.

Contact details:

The Energy and Resources Institute
Darbari Seth Block, IHC Complex,
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Tel. (+91 11) 2468 2100 and 41504900
Fax (+91 11) 2468 2144 and 2468 2145
For general inquires contact
mailbox@teri.res.in

6.2.6 Dolphin De-salinators

Dolphin de-salinators offer large capacity desalination units under rental agreements. They 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 can be freighted to the project location and 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)

6.2.7 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 may lead to small-scale or portable desalination devices that could provide vital drinking water in disaster and drought prone zones. Using modern semi-permeable membranes to convert seawater into freshwater is increasingly popular as a solution to global water shortages. Two common techniques are RO, 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

Figure 89: Dolphin Desalinators

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.

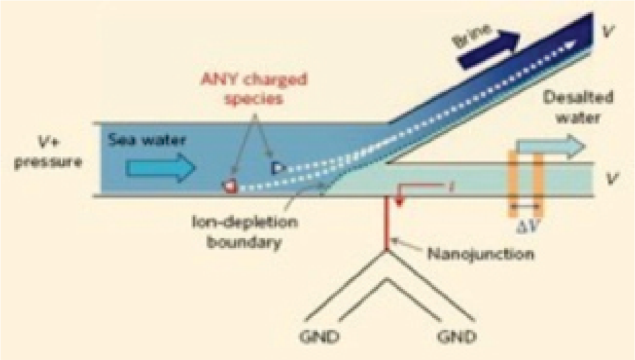

Figure 90: Salt and other charged Particles are diverted off, leaving Desalted water to flow down a separate channel

Han's team developed a microchip-sized device that funnels a stream of water down to a fork and then 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 include 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 several 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 challenges to overcome. Gold and titanium electrodes are currently used, so there is a need to find cheaper alternative materials to scale the technology up into devices. Secondly, some non-charged particles may cause fouling of the membrane, so a system of pre-treatment may be required.

6.2.8 A&M mobile desalination unit

A mobile desalination unit was constructed by the The Texas A&M University to test both pretreatment by membranes and RO desalination at field sites. Different types of membranes may be tested and RO salt rejection efficiency can be determined directly. The unit 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 93 in Washington County, Texas in 2006.

Figure 91: 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.

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:

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Desalination is a process that removes dissolved minerals (not only limited to salts) from various feedwater sources like seawater, brackish water or treated wastewater. There are more than 10,000 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 RO process, but 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:

(I.) Salinity of feedwater – lower salinity levels like in in-land brackish water could produce higher conversion/ product rates;

(ii.) Plant capacity – larger plants reduce the cost per unit product;

(iii.) Site conditions – environmental considerations for brine disposal and cost/ availability of land for infrastructure;

(iv.) Qualified labour – some of the technologies require at least semi-skilled and trained labour;

(v.) Energy costs – low-cost electric system and heating steam have a strong impact on the unit cost of production;

(vi.) Availability/ easy access to membranes, chemicals and spares;

(vii.) Ease and expenditure for operation and maintenance; and

(viii.) Provision for enhancement of designed plant capacity.

7 Chromium removal methods or technologies

7.1 Preamble

Chromium is the seventh most abundant element on the earth and twenty-first in the crystal rocks. Chromium abundance in Earth's crust ranges from 100 to 300 µg/g and concentration in soils ranges from 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 and 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.

7.2 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)].

7.2.1 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.

7.2.2 Chromium (VI)

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

7.2.3 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.

7.2.4 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.

7.3 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.,

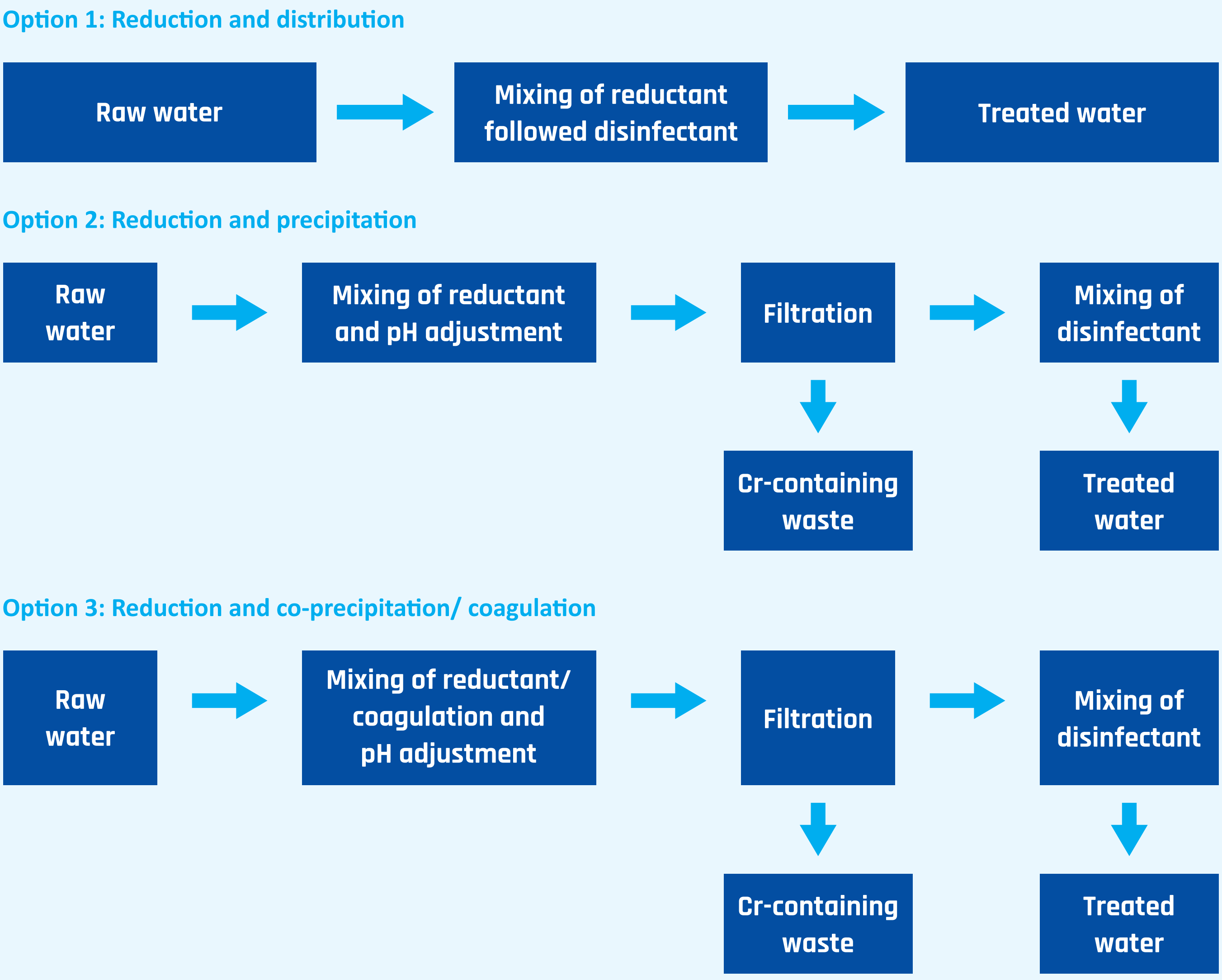


Figure 92: Treatment options involving the reduction of Chromium (VI) to Chromium (III)

and 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

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

Stannous Chloride

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

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.

7.4 Techniques for removal of Chromium from water

7.4.1 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 $Fe(OH)_3$.

Aluminum Sulphate $[Al_2\ (SO_4)_3]$ is the 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; and
- Effective for Chromium (III) removal

Demerits

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

7.4.2 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:

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

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 complex 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 most conditions, Chromium (III) is removed from solution as $Cr\,(OH)_3$ (s) precipitated phase, or as a Chromium-Iron hydroxide 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; and
- 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; and
- Long-term environmental impacts of sludge disposal.

7.4.3 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 they are presented below:

7.4.3.1 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.

7.4.3.2 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.

7.4.3.3 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. ILM 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 RO 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.

7.4.4 Ion Exchange

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

Table 6.2: Uptake of Chromium Cr (VI) using various membranes from synthetic wastewater

S. No.	Type of membrane	Initial Cr (VI) Conc.	Removal system	Rejection Rates	Reference
1.)	Carbon Membrane	1000mg/L	Batch	96%	Pugazhenthi et al., (2005)
2.)	Nitrate Carbon membrane	1000mg/L	Batch	84%	Pugazhenthi et al., (2005)
3.)	Aminated Carbon membrane	1000mg/L	Batch	88%	Pugazhenthi et al., (2005)
4.)	Polymer enhanced ultrafiltration	10mg/L	Continuous	30%	Aroua et al. (2007)
5.)	Composite polyamide membranes (NFI)	1000mg/L	Continuous	99%	Muthukrishnan and Guha (2008)
6.)	Composite polyamide membranes (NFII)	1000mg/L	Continuous	94%	Muthukrishnan and Guha (2008)
7.)	Polyacrylonitrile fibre	0.2mg/L	Continuous	90%	Bohdziewiez (2000)
8.)	Polymide thin-filmmembrane	--------	Continuous	77%	Hafiane (2000)

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 6.3. 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; and
- Suitable for small and large installations.

Demerits

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

7.4.5 Electrochemical treatment techniques

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

7.4.5.1 Membrane Electrolysis

Membrane electrolysis is one of the upcoming techniques useful for the removal of Chromium (VI) from wastewater. Membrane electrolysis is a chemical

Table 6.3: Chromium (VI) uptake using various ion exchange resins

S. No	Ion-exchange	Nature of resin	Capacity (mg/g)	Removal efficiency	Reference
1	Dower 2-X4	Strongly basic resin with trimethylbenzylammonium as the active group	------	100.0	Sapari et al., (1996)
2	Ambersep 132	Strongly basic (H-type)	92.1	------	Lin and Kiang (2003)
3	Solvent impregnated resin with aliquat 336	An acid resin based on hydrophilic polymer	38.0	99.5	Kabay et al., (2003)

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:

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

$2H^+ + 2e^- \leftrightarrow H_2\,(g)$

"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.

7.4.5.2 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.

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

Table 6.4: Electrochemical treatment technologies used for the removal of Chromium

S. No.	Cathode	Anode	Electrical current (A/m^2)	Power consumption (KWh/ m^3)	Initial metal conc. (mg/L)	P^H	Removal efficiency	Reference
1.)	Carbon arogel	Carbon arogel	0.8	------	8	2.0	98.5	Rana et al., (2004)
2.)	Iron rotary	Iron rotary	113.0	$7.9x10^3$	130	8.5	99.6	Martinez et al., (2004)
3.)	Fe2 O_3	------	1.7	12	-----	10-11	77.0-100.0	Kongsricharoen and Polprasert (1995)
4.)	Fe2 O_3	------	6.7	20	2100	10-11	85.1	Kongsricharoen and Polprasert (1996)

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; and
- 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 un-complexed cationic metals;
- Removal of inorganically and organically complex metal;
- Adsorption filter media can be regenerated and reused;
- Considerably less sludge production; and
- Relatively less expensive.

Demerits

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

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, being an 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:

7.4.5.3 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 micro porosity 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 6.5 summarizes the Chromium (VI) adsorption capacities for different activated carbons based on their size and shape.

Table 6.5: 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	P^H	Adsorption system	Reference
1.)	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)
2.)	Granular activated Carbon (GAC-Filtrasorb 400)	0.18	-----	----	Batch	Han et al., (2000)
		53.19	832	2.0	Batch	Hamadi et al., (2001)
3.)	Activated Carbon fibrous (ACF)	40.00	------	----	Batch	Park and Jung (2001)

Table 6.6: Adsorption capacities (mg/g) for activated carbons prepared from different sources from Synthetic Chromium wastewater

	Sources	Mg Cr^{6+}/g	P^H	Initial Conc. (mg/L)	Adsorption system	Reference
1.)	Bituminous coal	7.0	5.0-8.0	25	Batch	Natale et al., (2007)
2.)	Coconut shell	6.0	3.0-4.0	120	Batch	Selomulya et al., (1999)
3.)	Wood	5.1	2.0	120	Batch	Selomulya et al., (1999)
4.)	Dust coal	4.4	3.0-4.0	120	Batch	Selomulya et al., (1999)
5.)	Hazelnut shell	170.00	1.0	1000	Batch	Kobya (2004)
6.)	Coconut shell	20.00	2.5	50	Batch	Alaerts et al., (1989)
7.)	Hazelnut shell	17.7	2.0	30	Batch	Cimino et al., (2000)
8.)	Terminalia arjuna nuts	28.4	1.0	10	Batch	Mohanty et al., (2005)
9.)	Rubber wood sawdust	44.1	2.0	……	Batch	Karthikeyan et al., (2005)

7.4.5.4 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 extensive investigated for removing Chromium(VI) from wastewater. Table 6.7 summarizes the Chromium (VI) adsorption capacities of different industrial waste adsorbent.

Table 6.7: Adsorption capacities (mg/g) of different industrial waste adsorbents from Synthetic Chromium wastewater

S. No	Adsorbent	Mg Cr6+/g	PH	Adsorption system	Reference
1.)	Iron (III) Hydroxide	0.5	5.6	Batch	Namasivayum & Ranganathan (1993)
2.)	Waste slurry	640.00	.....	Batch	Srivastava et al., (1989)
3.)	Blast- furnace slag	7.5	......	Batch	Srivastava et al., (1997)
4.)	Bagasse fly ash	260.00	1.0	Batch	Gupta et al., (1999)
5.)	Red mud	1.60	......	Batch	Pradhan et al., (1999)

7.4.5.5 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 a 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 6.8 summarizes the Chromium (VI) adsorption capacities of different Chitosan adsorbent.

Table 6.8: Adsorption capacities (mg/g) of different types of chitosan adsorbents from synthetic Chromium wastewater

	Adsorbent	Mg Cr6+/g	PH	Adsorption system	Reference
1.)	Chitosan	273	4	Batch	Udaybhaskar et al., (1990)
2.)	Non-crosslinked chitosan	80	5	Batch	Schmuhl et al., (2001)
3.)	Crosslinked Chitosan	50	5	Batch	Schmuhl et al., (2001)
4.)	Chitosan based polymeric surfactants	180	5.3	Batch	Lee et al., (2005)
5.)	Chemically modified Chitosan beads	625	3	Batch	Sankararamakrishan et al., (2006)
6.)	Chemically modified Chitosan flakes	256	3	Batch	Sankararamakrishan et al., (2006)
7.)	Quaternary Chitosan salt	68	4.5	Batch	Spinelli et al., (2004)

7.4.6 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; and
- Possibility of metal recovery.

The Chromium (VI) removal method from wastewater using biological materials have been used for a long time. Several authors have investigated the adsorption of Chromium (VI) from aqueous solution using cellulosic, lignocellulose and agricultural waste materials briefly reported in the Table below.

7.4.6.1 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 wastewater because of their small size, their ubiquity and their ability to grow under wide range of environmental situations. The complexity of microorganism's 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, extracellular precipitation, intracellular accumulation, oxidation and reduction and methylation/ demethylation.

Table 3: Biosorption of Cr (VI) using various agricultural waste materials

Biosorbent	Reactor/ condition	Initial Cr (VI) Conc.	Maximum Cr (VI) removal	Reference
Plataneus Orientalis leaves	Batch reactor, PH =3.0-9.0, Dose=2.0, g/L,20o -30°C , 300rpm,30-240min	2.0-4.0 mg/L	5.01mg/g	Mahvi et al., (2007)
Plant Ulmus leaves	Batch reactor, PH =3.0-9.0, Dose=1.0, g/L,20o -30°C , 300rpm,30-240min	2.0-4.0 mg/L	5.0mg/g	Gholami et al., (2006)
Lignocellulosic material peat	Batch reactor, pH =2.0-7.0, Dose=2.0, g/L,30°C	10-200 mg/L	30.16mg/g	Dean and Tobin (1999)
Plant water hyacinth (Eichhornia Crassipes)	Batch reactor, PH =2.0-6.0, 30oC, 8h	10mg/L	6.0 mg/g	Lytle et al., (1998)
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 , 100rpm	10-1000 mg/L	13.4 mg/g 39.7 mg/g 17.2 mg/g 13.8 mg/g	Sharma & Forster (1994)
Rice hulls	Batch reactor, pH=2.0-8.0, 30°C	20-200 mg/L	99-38%	Cici and Keles, 1990

Table 6.10: Biosorption of Cr (VI) using various bacterial biomass

S. No.	Biosorbent	Reactor/conditions	Initial Cr (VI) Conc.	Maximum Cr (VI) removal	Reference
1.	Bacillus Circulnas biofilm	Batch adsorption non-living cells, pH=2.0-7.0, 30°C, 24-96h, 120rpm	50-500 mg/L	48% pH=7.0, 96h	Khanfari et al., (2008)
2.	Distillery sludge	Batch reactor non-living cells, dose =1-20g/L , pH =3.0-10.0, 30°C, 24-96h, 120rpm	10-40 mg/L	64% PH =3, 5g/L	Selvraj et al., (2003)
3.	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)
4.	Bacillus circulan, Bacillus megaterium, Bacillus coaglans	Batch reactor resting cells, pH=2.5, 30°C, 150 rpm, 24h, 28°C	0-100 mg/L	34.5 mg/g 32 mg/g 23.8 mg/g	Srinath et al., (2002)
5.	Bacillus coaglans or Bacillus megaterium	Batch reactor non-living cells, dose =1-20g/L , pH=2.5, 28°C, 120rpm, 24h	100 mg/L	39.9 mg/g 30.7 mg/g	Srinath et al., (2002)
6.	Microbacterium liquuefaciens MP 30	Batch reactor resting cells immobilized in (PVA) alginate beads, 30^{0}C, 100 rpm,4d continuous flow bioreactor, flow rate=0, 95 mL/h,20 d	100 µm 50 µm	Complete removal (90% removal)	Pattanapipit paisa, et al., (2001)
7.	Dried activated sludge	Batch reactor non-living cells, pH =1.0-6.0, 25°C, dose= 0.5 g/L, 150rpm, 24h	25-500mg/L	27.7 mg/g	Aks et al., (2001)
8.	Bacillus sp. QCI-2	Batch reactor resting cells, 30°C, 20h, cell conc=1x 109 cells/mL	0.3 mM	Complete removal	Campos et al., (1995)
9.	Zoogloea ramigera	Batch reactor non living cells, pH =2.0, 25°C, 100rpm, 30 min.	0-75mg/L	3.40 mg/g	Nourbaksh et al., (1994)
10.	Agrobacterium 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)

7.4.6.2 Algae

Algae 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 6.11.

7.4.6.3 Fungi

Fungi and yeasts are the eukaryotic organisms which are used as bio-sorbents 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 wastewater. 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 Dold in substantial amounts. The fungi and yeasts (A. Niger, T. Reessii, R. Arrhizus, R. Nigricans, and 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 conditions have been studied by different researchers for Chromium (VI) removal from wastewater. 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

Table 6.11: Biosorption of Cr (VI) using various algal biomass

S. No.	Biosorbent	Reactor/conditions	Initial Cr (VI) Conc.	Maximum Cr (VI) removal	Reference
1	Sargassum Seaweed (marine algae)	Batch reactor non-living cells, dose = 2.5g/L , pH=3.5, 10-60 min.	10-100 mg/L	60 mg/L	Barkhordar and Ghaiseddin, 2004
2	Sptrogyra species (green Filamentous algae)	Batch reactor non-living cells, dose = 1-15g/L, pH =1.0-6.0, 25-35°C, 180 min.	1-25 mg/L	90%	Gupta et al., (2001)
3	Chlorella Vulgaris Scenedesmus Accutus (Filamentous algae)	Fluidized bed Packed bed Kappacarragenan (natural biopolymer) Polyurethane foam (cells immobilized in columns)	50 mg/L	48% 34% 36% 31%	Travieso et al., (1999)
4	Chlorella Vulgaris 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	Nourbhaksh et al. (1994)

inorganic compounds. Table 6.12 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.

7.5 Technologies for removal of Chromium from water

7.5.1 Full scale Chromium (VI) removal technology

The Lawrence Liverpool National Laboratory (LLNL) designed and constructed an ion exchange unit to treat hexavalent Chromium in the groundwater which is operated for the Department of Energy by the University of California. In this treatment unit, groundwater is filtered to remove particulate matter and sediment to a nominal 5µm, then passed through two tank-type air strippers in series, where the volatile organic compounds (VOCs) are removed and collected onto vapor phase 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 groundwater 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 1,50,000 USD including the initial resin. The estimated yearly cost to operate the unit is: salt 1,000 USD; resin replacement 6,000 USD; filter, valve, pump maintenance, 2,000 USD and waste disposal, 1,900 USD.

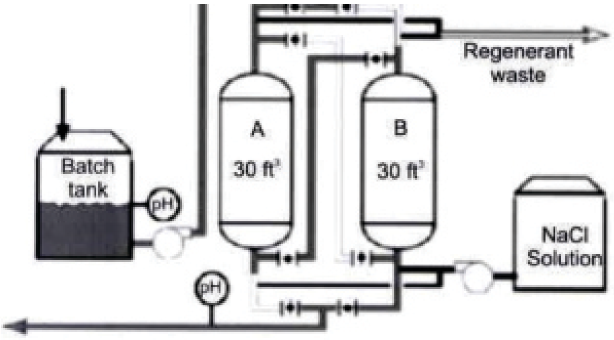


Figure 93: Schematic diagram of Lawrence Liverpool National Laboratory's hexavalent Chromium removal unit

7.5.1.2 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 portable 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*

Figure 94: Siemens Ion Exchange Resin Canister

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.

7.5.2 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 Global Environment Facility Small Grants Programme (GEF-SGP) came forward to support the pilot for a small experiment to learn, document and find alternative strategies that may be considered as possible solutionsfor 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 groundwater and soil affected by tannery effluents containing Cr VI' was implemented under the sponsorship of UNDPGEF-SGP. Initial studies have demonstrated very exciting results as the developed domestic filter has been able to completely remediate Chromium from groundwater.

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.

Figure 95: 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:

S. No.	Items	Cost in Rupees
1.)	Cost of Polypropylene filter	150.00
2.)	Zeolite (50 gms)	180.00
3.)	Activated Charcoal (75 gms)	35.00
	Total	365.00

8 Uranium removal methods or technologies

8.1 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 groundwater. 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, $UO2^{2+.}$ 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, and 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.

8.2 Health effects of Uranium

Naturally occurring Uranium has very low levels of radioactivity. However, the chemical properties of Uranium in drinking water are of a greater concern than its radioactivity, as a small amount it is absorbed and carried 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.

8.3 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 7.1.

8.4 Analytical methods for measuring uranium

Following analytical methods can be used for the measurement of Uranium in water:

(i.) Uranium in water is most 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 0.03 µg/L while Atomic Energy Regulatory Board (AERB) limit is 0.06 mg/l for uranium in water. The main demerit of this method is sample preparation

Table 7.1 Guideline values for maximum Uranium concentration in drinking water

S. No.	Agencies	Maximum permissible limit (µg/L)	Reference
1.)	World Health Organisation (WHO)	30	WHO (2011)
2.)	Environmental Protection Agency, United States of America (USEPA)	30	T.E. Milja et al., (2011)
3.)	Health Canada	20	A.P. Gillman et al., (1998)
4.)	Australia	20	A.P. Gillman et al., (1998)

which is tedious and there is also an interference from other metals;

(ii.) Uranium can also be determined by inductively coupled plasma mass spectrometry with the detection limit of 0.1 µg/L and between — run precision of less than 6%; and

(iii.) 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.

*Toxicity of the media is required to be confirmed by the firm, in case of media used in adsorption technologies.

8.5 Techniques for control of uranium from water

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: 7.2

Table 7.2A review of control methods for Uranium removal from water and their technical achievability

Treatment Methods	Technical achievability (%)	Reference
Coagulation/filtration at high pH(10+)	>95	Aieta et al., (1987)
Lime softening	85-99	Aieta et al., (1987)
Anion exchange	99	Aieta et al., (1987)
Reverse osmosis	>95	Aieta et al., (1987)
Coagulation/filtration	80-89	Lowry & Lowry (1988)
Lime softening	85-99	Lowry & Lowry (1988)
Anion exchange	90-100	Lowry & Lowry (1988)
Reverse osmosis	90-99	Lowry & Lowry (1988)
Activated alumina	90	Lowry & Lowry (1988)

9 Other treatment technologies developed by DST-WTI

9.1 Iron mitigation

Prototype: Design of highly compact, vertical modular Nanofiltration membrane systems for removal of heavy metals from groundwater.

An efficient nano-filtration based technology established with DST-WTI support by IIT Kharagpur has ensured safe and potable water which is free of heavy metals for 25,000 people in three different sites in the states of Telangana and Andhra Pradesh. The prototype has been developed by CSIR -IICT which is a highly compact vertical modular nanofiltration membrane system that has been designed for removal of heavy metals from the groundwater. It has a capacity of 100 - 300 (L/h) and removes heavy metals such as Iron and Arsenic from groundwater. Ultraviolet light is used for disinfection.

In another field intervention access to clean drinking water has been provided from a water treatment plant (300 L/h) developed by IIT Guwahati which is installed in the Lathiabagicha Primary School, Guwahati, Assam. This plant has been fabricated with support of DST-WTI and is based on chemical less electrocoagulation technology which is capable of treating Total Soluble Solvent, BOD, Iron, COD and Arsenic from contaminated drinking water. More than 120 students of the school and the villagers of Lathiabagicha (more than 500) are benefitting from this field intervention.

Treatment unit within room in the school

Water reservoir behind school

Figure 96: Prototype :installed in Lathiabagicha Primary School in North Guwahati, Assam

9.2 Fluoride mitigation

At IIT Kanpur through a DST supported project, Calcium-based Fluoride treatment technology has been developed which also works in-situ at the infested sites. Fluoride is up taken on Calcite in the presence of phosphate, through the formation of Hydroxyapatite- coated Calcite or via other Calcium Phosphate solids.

A research group at IIT Kharagpur has developed a novel adsorbent based on carbonized bone meal (CBM) and chemically treated carbonized bone meal (CTBM) for Fluoride removal having capacity of 14 mg/g and 150 mg/g respectively. The work has also designed a composite bed to meet the domestic drinking water needs at the rate of 100 liter/day using the developed technology to remove coliform and Iron along with Fluoride. After the Fluoride removal capacity is saturated, the used material can be mixed with coal and reused as fuel.

9.3 Arsenic treatment technology

Agharkar Research Institute (ARI) with the support of DST has developed a unique, cost-effective 'integrated microbial oxidation system' wherein Arsenic becomes free from groundwater rendering it completely safe. It is based on the process that Microbacterium Lacticum can oxidize As(III) in groundwater rapidly to arsenate (As5+). Bacterium has a natural isolate possessing high arsenic tolerance; non-pathogenic to humans, cattle etc. The filter also removes any odor, color or sloughed off cells from water. The treatment capacity of the filter is 1,000 L/ day which can be easily scalable upto 10,000 L/day. The filter can be operated and maintained by unskilled workers. The system is developed after rigorous third party evaluation and is demonstrated at 5 locations in the state of Chhattisgarh. The salient features of this filter are given below:

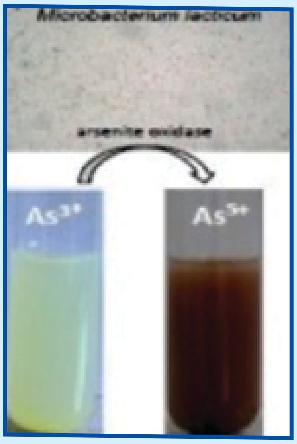
Efficient under widely varying conditions of:

- pH (6.0 – 8.0)
- Temperature (10 – 45 °C)
- Groundwater Arsenic concentration (0.025 mg/L to > 5.0 mg/L)
- Presence of Iron, Sulfate, Chlorides, Phosphates etc.

Cost-effective (treatment cost 10 paise/L)
Treated water characteristics:

- Arsenic concentration <0.010 mg/L
- Coliform count – nil
- pH – same as inlet
- No odour

Sr. No.	Features	Description
1	**Product Definition**	
	a. Product Name	ARI groundwater arsenic treatment plant
	b. Type of Product	Community Filter
	c. Cost of Unit	Rs.74,000
	d. Technology Used	Multiple stage (assembled single integrated unit) **1st stage:** Microbial oxidation (Bio-oxidation of As3+ to As5+ using a bacterium Microbacterium Lacticum immobilized on brick pieces) **2nd stage:** Adsorption of arsenate (As5+) on Alumina. **3rd stage:** Filtration using charcoal to remove odour, color, microbial cells. **4th stage:** Ultraviolet radiation for disinfection
	e. Flow rate	600-700 mL/min i.e. ~40 lph
	f. Cost of delivered water	Rs. 10 per cubic meter
	g. Electricity needs	Yes, 90 units per month
	h. Does filter water meet BIS no: 10500 of 2012?	Yes
2	**Contaminants Removed**	Arsenic
3	**Reject Management**	
	The wash water from the columns is collected in a separate container and 3% Ferric Chloride is added to it to form an Arsenic Iron complex (indicated by the formation of a red precipitate). The resulting sludge is then disposed off in the concrete pit after drying.	
4	**Uniqueness of the Product**	
	The technology uses a unique process, viz. "Integrated Microbialoxidation-Alumina Adsorption Process" for arsenic removal. Oxidation of arsenic (As3+) is a pre-requirement for its removal by adsorption. Conventional methods rely on chemical oxidation of trivalent arsenic to its penta-valent form. Owing to microbial oxidation, ARI process is eco-friendly.	
5	**Achievements**	
	• Use of Microbacterium Lacticum to oxidize Arsenite (AsIII) rapidly to arsenate (AsV). • Developed a unique ‘integrated microbial oxidation alumina adsorption process for the removal of arsenic from groundwater rendering it completely safe. • Feasibility on applicability of flat sheet liquid membrane-based separation process for removal of Arsenic from groundwater.	
6	Publication/ Patents	
	Not patented	

<table>
<tr><th>Sr. No.</th><th>Features</th><th>Description</th></tr>
<tr><td>7</td><td colspan="2">Relevance of the output of project</td></tr>
<tr><td></td><td colspan="2">• 5 systems have been installed in Koudikasa and Muraithitola villages in Chhattisgarh
• Evaluated by Bhilai Institute of Technology, Bhilai and Pt.Ravishankar Shukla University Raipur
• Oxidation of As3+ is a pre-requirement for its removal by adsorption. Conventional methods rely on chemical oxidation of trivalent arsenic to its pentavalent form. Owing to microbial oxidation, ARI process is eco-friendly. Expected life of the unit is 5 years.</td></tr>
<tr><td>8</td><td colspan="2">Location of Field Trials</td></tr>
<tr><td></td><td colspan="2">5 systems installed for community use in Koudikasa and Muraithitola villages inChhattisgarh</td></tr>
<tr><td>9</td><td colspan="2">Contact Details of Principal Investigator</td></tr>
<tr><td></td><td colspan="2">Dr. K.M. Paknikar, Director (Officiating)
Agharkar Research Institute, GG Agarkar Road Pune 411004,
Phone: +91-20-25654831
Email: kpaknikar@gmail.com, director@aripune.org</td></tr>
<tr><td>10</td><td colspan="2">
ARI groundwater Arsenic removal unit oxidizing arsenite (As3+)

Microbacterium lacticum to arsenate (As5+)</td></tr>
</table>

9.4 Forward osmosis (FO) technology

Commissioning of first of its kind desalination plant in the country through which FO technology has been demonstrated coupled with solar energy source.

Setting up of a desalination test bed at Narippaiyur, Tamil Nadu has been supported by DST-WTI to provide renewable integrated MED and FO desalination system to produce potable water. It includes demonstration of FO and MED based seawater desalination system, solar thermal energy storage system for round-the-clock plant operation and sea water intake and reject facility to produce 20 m3/day potable water. The customized convergent water solution through Forward Osmosis (FO) will supply two liters of good quality drinking water per person per day for 10,000 people in the village, and successfully overcoming a major drinking water shortage in the village. The FO system facilitates high recovery, low thermal energy consumption, lowelectric power consumption, potential for resource recovery, less fouling of the membrane because of low pressure operation.

Forward Osmosis system installed at Narippaiyur Village

LFR based Solar Thermal System

Solar hot water system installed

10 Technologies used by States for removal of Arsenic & Fluoride

10.1 Punjab

10.1.1 Adsorption on Nano Materials developed by IIT Madras (AMRIT)

Brief on the technology: Nano materials technology works on the principle of adsorption on nano-structured surface having high adsorption capacity for Iron and Arsenic and very low backwash requirement due to high surface area of Nano-structured material.

Treatment process comprises of following steps: Oxidation with compressed air, Iron removal by filtration / adsorption, Arsenic removal by adsorption, polisher unit for residual Arsenic removal and taste improvement.

Other observations:

1.) The technology can be retro-fitted into existing system. Retrofitting can be done at existing hand pumps (for 8 LPCD) as well as water supply schemes for piped supply of treated water @ 70 LPCD;

2.) Production capacity can be easily scalable;

3.) Cost of O&M per annum for 1 KLD unit is Rs. 7,500 per year;

4.) Semi-skilled person like a pump operator can operate the plant using training and standard operating procedures;

5.) Cost of treated water is around to Rs. 2.5 paisa per liter including both opex & capex;

6.) Life of filter media is 36 months and used media is non-hazardous, it will be disposed at waste management facility set up by Punjab Pollution Control Board;

7.) Pretreatment using micron cloth filter & post-treatment using chlorination are required;

8.) It is 100% indigenous technology and can be adapted to Indian market needs;

9.) Production facility is available in India and it takes 2 to 3 days to manufacture one unit; and

10.) Remote monitoring of unit is also possible.

Contact details:

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10.1.2 Ground Water Treatment Solutions_Ion Exchange adopted in Punjab State

a) INDION ® Iron Removal System

The Iron removal systems consist of ***INDION*®ISR (Iron specific resin)** which catalyzes the oxidation of dissolved inorganic Iron to insoluble Ferric precipitate. The precipitate is removed during backwash and the surface of resin is scoured restoring its catalytic property. Hence, no chemical regeneration is required.

The resin effectively removes Iron <0.3 ppm in treated water which is as per BIS drinking water standard 10500:2012. The resin can tolerate Iron upto 10 ppm and TDS < 2500 ppm

Certifications: The ***INDION®*****ISR (Iron specific resin) has NSF-61 Gold Seal Certification by WQA & it is CSIR approved.**

Ion Exchange (I) Ltd. Standard Systems:
Completely Indigenous developed Standard Systems as;

Hand Pump Attachment:

- No electricity required
- No chemicals required for regeneration
- Sturdy, easy to operate, maintenance free
- 500-600 LPH flow rate
- Compact & Economical
- User Friendly

Tube Well Attachment:

- Can be directly attached to Tube well
- No chemicals required for regeneration
- Sturdy, easy to operate, maintenance free
- Compact & Economical
- User Friendly
- Standard Systems from 1 -10 m^3/hr
- The Tube Well attachment system of 2 m^3/hr has been listed as Innovative Technology under Jal Jeevan Mission 2020 by Ministry of Jal Shakti

Commercialization: More than 2000 Units have been sold across India

b) *INDION* ®Arsenic Removal System

The Arsenic removal Systems consist of ***INDION®*** **ASM (Arsenic Selective Media) which reduces Arsenic to <10 ppb as per Drinking Water Standards from 3 ppm of Arsenic in the Inlet.**

Certifications:

- The ***INDION®*****ASM has NSF-61 Gold Seal Certification by WQA.**
- **Media is CSIR approved & Certified 'Nanoadsorbent' by INST (Institute of Nano Science and Technology, Punjab)**

Ion Exchange (I) Ltd. Standard Systems:
Completely Indigenous developed Standard Systems as;

Hand Pump Attachment:

- No electricity required
- No chemicals required for regeneration,
- backwash with treated water is sufficient
- Sturdy, easy to operate, maintenance free
- 500-600 LPH flow rate
- Compact & Economical
- User Friendly

Tube Well Attachment:

- Can be directly attached to tube well
- No chemicals required for regeneration
- backwash with treated water is sufficient
- Sturdy, easy to operate, maintenance free
- Compact & Economical
- Systems can be designed on & off grid
- User Friendly
- Standard Systems from 2 -10 m^3/hr
- The Tube-well attachment system of $2m^3$/hr has been listed as innovative technology under Jal Jeevan Mission 2020 by Ministry of Jal Shakti

Commercialization: More than 400 hand pump attachments & 10 units of tube-well attachment units have been sold across India

c) *INDION* ® Fluoride Removal System

The Fluoride removal systems consist of ***INDION®*** **RS-F (Resin Selective for Fluoride) which reduces Fluoride to <1 ppm as per Drinking Water Standards from 10 ppm of Fluoride in the Inlet.**

INDION R-SF selectively removes Fluoride from water. It performs well, even in the presence of common anions such as Chlorides and Sulphates. Treated water quality passed oral toxicity test as per US pharmacopeia at FDA approved laboratory.

Certifications: The ***INDION®*****RS-F is CSIR approved. Ion Exchange (I) Ltd. Standard Systems:**

Completely Indigenous developed Standard Systems as;

Hand Pump Attachment:

- Sturdy, Economical
- Does not require electricity
- Easy to operate
- Poly Aluminium Chloride required for recharge
- Ideal for rural applications
- Long life
- Flow of unit is 8-10 lpm
- Directly attached to hand pump

Tube-well Attachment:

- Sturdy
- Easy to operate
- System can be designed on grid or off grid
- Poly Aluminum chloride required for recharge
- Ideal for rural applications
- Long life of the media
- Directly attached to the tube well
- Standard systems from 2 -10m^3/hr
- The Tube well attachment system of 2m^3/hr (Solar-powered with remote monitoring) has been listed as Innovative Technology under Jal Jeevan Mission 2020 by Ministry of Jal Shakti.

Commercialization: More than 2500 Units of Hand Pump and 400 units of Tube well have been sold across India

d) *INDION* ® Nitrate Removal System

The Nitrate removal systems consist of ***INDION*® NSSR (Nitrate selective resin) which reduces** Nitrate to <45 ppm as per Drinking Water Standards from 200 ppm of Nitrate in the Inlet. INDION NSSR has high selectivity for nitrate. Excellent hydraulics and fast kinetics make the exchange process faster.

The resin can be regenerated and reused hence it has a long operating life. It can perform even in the presence of competing ions such as Sulphate and has excellent adaptability to be used in conventional filters, community, and POE units.

Certifications: The ***INDION*®NSSR has NSF-61 Gold Seal Certification by WQA**

Ion Exchange (I) Ltd. Standard Systems:

Completely Indigenous developed Standard Systems as;

Hand Pump Attachment:

- Activation of resin is with common salt and activation Can be scheduled once in a week
- Sturdy, easy to operate, maintenance free
- 500-600 LPH flow rate.

- No Electricity is required.
- User Friendly.

Tube-well attachment:

- Sturdy
- Easy to operate
- System can be designed on grid or off grid
- Sodium Chloride required for recharge

- Ideal for rural applications
- Directly attached to the tube well
- Standard Systems from 1 -10m3/hr

Commercialization: More than 10 Units have been sold across India

e) *INDION* ® Heavy Metal removal Systems

The heavy metal removal systems consist of ***INDION*® HMR (Heavy Metal Removal Resin) which reduces** heavy metal concentration to drinking water standards for each contaminant. Excellent hydraulics and fast kinetics make the adsorption process faster. The resin can be regenerated and reused hence it has a long operating life. It can perform even in the presence of competing ions such as Sulphate and has excellent adaptability to be used in conventional filters, community and POE units.

Ion Exchange (I) Ltd. Standard Systems:

Completely Indigenous developed Standard Systems as;

Hand Pump Attachment:

- Activation of resin is with caustic followed by common salt
- Sturdy, easy to operate, maintenance free

- 500-600 LPH flow rate.
- No electricity is required.
- User friendly.

Tube Well Attachment:

- Sturdy
- Easy to operate
- System can be designed on grid or off grid
- Ideal for rural applications
- Directly attached to the tube well
- Standard Systems from 1 -10 m^3/hr

f) INDION ® Uranium removal System

The Uranium removal systems consist of ***INDION®* USR (Uranium Selective Resin) which reduces** Uranium concentration to <30 ppb as per WHO drinking water standards. The resin selectively adsorbs Uranium without changing the feedwater characteristics.

Excellent hydraulics and fast kinetics make the adsorption process faster.

Power Pump Attachment:

- Sturdy
- Easy to operate
- System can be designed on grid or off grid
- Ideal for rural applications
- Standard systems from 1 -10 m^3/hr
- High Capacity for Uranium adsorption

Commercialization:

The INDION® Uranium removal pilot plant is operational at Badla Village, Punjab since 2019 and has continuously provided 700 m^3 of treated water with Uranium <30 ppb and is still in operating conditions. The performance of the pilot plant is monitored by the PHED Laboratory, Punjab through analysis of the treated water from the pilot plant.

Plant Capacity: 1 m^3/hr

Additional Image: Fluoride Removal-Solar powered Systems

10.2 Karnataka

10.2.1 Reverse osmosis for removal of Fluoride

Brief on the Technology: The technology employs thin film composite membranes placed in a spiral configuration inside cylindrical vessel operating at high pressure. The hardness and Fluoride contents are reduced by 85% and bacterial load by 99%. The technology is modular; providing scope to enhance capacity by adding membrane elements.

Other observations:

1.) The technology can be retro-fitted into an existing system;

2.) Production capacity can be easily scaled up;

3.) Cost of O&M is Rs. 1.5 lakh per year;

4.) Skilled or semi-skilled person can operate the plant;

5.) Cost of treated water is around to Rs. 0.35/L for the plant capacity of 1500 L/ Day;

6.) Life of filter media is 30 months and used media is non-hazardous. It can be disposed in the landfill;

7.) Pre-treatment & post-treatment UV and chlorination are required;

8.) Production facility is available in India and it takes 1 to 2 days for installation & commissioning of one unit; and

9.) Remote monitoring of unit is also possible.

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10.3 Rajasthan

10.3.1 Solar powered de-fluoridation units

Absorption based -Bio-F media

Brief on the Technology: Bio-F is a biological adsorbent using natural shell as raw material. Porous in nature. Bio-F is insoluble in water. Bio-F has high temperature tolerance. Bio-F has the capability to remove Fluoride.

Other observations:

1.) Input water quality requirement: Fluoride content should be more than 1.5 PPM and TDS should not be more than 1500 PPM;

2.) The technology can be retrofitted into the existing system;

3.) Production capacity can be easily scaled up;

4.) Cost of O&M is Rs. 54,000 per year;

5.) Semi-skilled person can operate the plant;

6.) Filter media to be replaced annually or after treating 10 lakh liter of water;;

7.) Backwash is done after the regeneration process by passing raw water through the vessel. The outlet of regeneration and backwash goes into the soakpit and the same is diluted using raw water. When the life of the media has been completed, it is collected from each site and disposed in landfills as per standard norms of disposal by CPCB.

8.) No pre-treatment or post-treatment is required;

9.) Production facility is available in India & it takes 10 days to manufacture one unit & 3 days for installation & commissioning;

10.) Remote monitoring of unit is also possible; and

11.) Regeneration/ treatment of media is easy as compared to other media like activated alumina and disposal of media is non-hazardous, can also be used in manufacturing of bricks.

Contact details:

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Jaipur, Rajasthan
Email Id: pmsc@gainfra.com

10.3.2 Reverse Osmosis Plants

Brief on the Technology: Reverse Osmosis (RO) is a water treatment process that removes contaminants from water by using pressure to force water molecules through a semi permeable membrane. During this process, the contaminants are filtered out and flushed away, leaving clean, drinking water.

Other observations:

1.) Cost of treated water is 20 paisa per liter;

2.) Very flexible technology can be customized for removing wide range of contamination in water. In Rajasthan it is used where water is multi quality affected;

3.) The technology can be retrofitted into existing system;

4.) Production capacity can be easily scalable;

5.) Cost of O&M is Rs. 1,00,000 per year;

6.) Skilled & semi-skilled persons can operate the plant;

7.) Life of filter media is 1-1.5 years depends on quality of input water;

8.) When the life of the media has been completed, it is collected from each site and disposed in landfills;

9.) Pre-treatment is required if input water has Iron;

10.) Production facility is available in India & 3 days required for installation & commissioning of one unit; and

11.) Remote monitoring of unit is also possible.

10.4 West Bengal

10.4.1 Ceramic Membrane based-Arsenic Removal Technology

Brief on the technology:

(I.) Simultaneous removal of Arsenic and Iron from highly contaminated groundwater for producing sparkling quality drinking water (with Arsenic content below the WHO recommended limit (As <0.01 ppm) and negligible Iron content (Fe <0.1 ppm);

(ii.) Excellent adsorption capacity of the media (7-8 times higher than normally used granular Ferric Hydroxide);

(iii.) Modular design with flexible production capacity (500 – 20,000 LPD, 12 hours operation per day);

(iv.) Semi-automatic, user-friendly operating procedure can be operated by even the female members of the community; and

(v.) One time media addition in 3 – 6 months is sufficient for 0.5 – 1 ppm Arsenic content in raw water and continuous addition of chemicals or media regeneration is not required.

Other observations:

1.) Cost of treated water is approximately 11 paisa per liter;

2.) Cost of O&M is Rs. 1,93,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology cannot be retrofitted into existing system;

5.) Production capacity can be easily scaled up;

6.) No pre-treatment or post-treatment is required;

7.) no reject water is generated;

8.) Filter membrane replacement is not required. Filter media shall be recharged in every three months of operation;

9.) Time required for manufacturing one unit is 15 - 20 days and 7-15 days are required for installation & commissioning of one unit; and

10.) It is a unique application of hybrid technology comprising adsorption and Ceramic membranes.

Contact details:

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West Bengal - 700 032
Email Id: swachchha@cgcri.res.in

Adsorption with Granular Ferric Hydroxide- Arsenic Removal Technology

Brief on the technology: Adsorption based Technology.

Other observations:

1.) Cost of treated water is approximately 8 paisa per liter;

2.) Cost of O&M is Rs. 2,73,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retro-fitted into existing system;

5.) Production capacity is easily scalable;

6.) Pre-treatment of inlet water (Oxidation process followed by Iron removal process is required to treat Arsenic with GEH 102) is required;

7.) no reject water is generated and no chemicals used for backwash and other processes;

8.) Lift of the filter media is 60 months or 20,000 bed volumes at 0.05 mg/l As in raw water;

9.) Regeneration process is not required for this media;

10.) This media can work in gravity filters, pressure filters and even solar operated plants to make it a universally accepted one;

11.) Spent media can be used in brick field or in cement mortar as an additional reinforcement; and

12.) Time required for installation & commissioning of one unit is 2 days.

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updates@harbauer.in

10.4.2 Gobardanga Model - Arsenic Removal Technology

Brief on the technology: Oxidation-Filtration-Coagulation-Adsorption with Activated Alumina (Gobardanga Model)

Other observations:

1.) Cost of treated water is approximately 2 paisa per liter;

2.) Cost of O&M is Rs.10,63,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) Pre-treatment of inlet water (chlorination) is required;

7.) Reject water is re-circulated;

8.) Lift of the filter media is 60 – 72 months;

9.) Regeneration process is not required for this media; and

10.) 30 days required for manufacturing one unit.

Contact details:

Public Health Engineering Department,
1, Kiran Sankar Roy Road, New Secretariat Building,
7th Floor, Kolkata-700001

10.4.3 Laterite based Arsenic Removal Adsorbent- Arsenic Removal Technology

Brief on the technology: Laterite based community water purification plants consists of a raw water OHT of 5,000 L capacity, oxidation chamber containing MnO_2 pebbles, Iron removal filter containing activated Carbon, unit for backwash & pretreatment containing raw laterite, Arsenic removal unit containing treated laterite and filtered water storage tank of 2,000 L capacity. A solar power pump is used for pumping.

The treatment process includes:

Raw Water ------àOxidizing unit------àIron removal unit------àArsenic removal unit------àBacteria removal and polishing unit ------à Treated water

Other observations:

1.) Cost of treated water is approximately 12 paisa per liter;

2.) Cost of O&M is Rs. 4,39,000 per year;

3.) Unskilled persons can operate the plant;

4.) The technology can be retro-fitted into existing system;

5.) Production capacity can be easily scalable;

6.) No pretreatment for inlet water & post treatment for output water are required;

7.) Filter media is a laterite based adsorbent treated specifically to enhance its Arsenic adsorption capacity.

8.) Life of the filter media is 60months and no treatment required for disposal of spent material in pH 3 to 10. The material meets TCLP protocol. The sludge media may be used for brick making or construction of road;

9.) 7 days required for installation & commissioning of one unit;

10.) Highest Arsenic adsorption capacity among naturally occurring materials;

11.) No regeneration in 5 years and easy maintenance; and

12.) No special sludge management.

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10.4.4 Nanostructured Surface based Adsorption-Arsenic Removal Technology

Name of the technology: Anion and Metal Removal by Indian Technology (AMRIT)

Brief on the technology:

AMRIT technology works on the principle of adsorption on nanostructured surface. These materials have very high adsorption capacity for Iron, Arsenic. Even Iron removal is done by adsorption and not filtration, leading to very low backwash requirement. Nanostructured material exhibit high surface area and have made it substantially selective for Arsenic. Contaminants are irreversibly adsorbed on the surface and leaching is less than 10 ppb. Treatment process comprises of following steps: oxidation, Iron removal by adsorption, Arsenic removal by adsorption, polisher unit for taste improvement.

Other observations:

1.) Cost of treated water is approximately 14 paisa per liter;

2.) Cost of O&M is Rs. 6,24,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) Pre-treatment of inlet water using micron cloth filter is required;

7.) Time required for manufacturing one unit is 2-3 days and 2-3 days are required for installation & commissioning of one unit;

8.) Remote monitoring of unit is possible;

9.) 100% indigenous technology and adapted to Indian market needs;

10.) Life of filter media is 5 years and saturated media can be managed on site as adsorbed contaminant does not leach into the envIronment;

11.) 1% of water is used for backwash; and

12.) Frequency of replacement of filter media is 2-5 years, depending on project requirement and quantity of media used.

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10.4.5 Oxidation, Filtration, Coagulation, Adsorption (Shujapur-Shadhipur Model)

Arsenic Removal Technology.

Brief on the technology: Oxidation-Filtration-Coagulation-Adsorption (Sujapur-Shadhipur Model) Usage of baffled flocculator, plain sedimentation tank and rapid gravity filter with or without gravity type activated alumina chamber for adsorption.

Other observations:

1.) Cost of treated water is approximately 1 paisa per liter;

2.) Cost of O&M is Rs.19,72,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) Pre-treatment of inlet water (pre-chlorination) is required;

7.) Time required for manufacturing one unit is 30 days;

8.) Reject water is re-circulated; and

9.) Frequency of replacement of filter media is 4 to 5 years.

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7th Floor, Kolkata-700001

10.4.6 Adsorption/ Contact Sorption - Arsenic Removal Technology

Brief on the technology:

Oxidation →Filtration →Adsorption Filter [by Granular Iron Hydroxide oxide for Arsenic removal] →Activated Carbon Filter (For odor removal) → UV Disinfection unit (For Bacterial disinfection).

Other observations:

1.) Cost of treated water is approximately 07 paisa per liter;

2.) Cost of O&M is Rs. 3,14,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) Post-treatment of outlet water using UV disinfection is required;

7.) Time required for manufacturing one unit is 30 days and30 days are required for installation & commissioning of one unit;

8.) Solar power operated stand alone unit; and

9.) Life of filter media is 2 and half years;

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10.4.7 Hybrid Anion Exchange Resin- Arsenic Removal Technology

Brief on the technology:

Hybrid anion exchange resin adopted with a mixture of hydrated Iron nano particles irreversibly inside resin beads.

Other observations:

1.) Cost of treated water is approximately 02 paisa per liter;

2.) Cost of O&M is Rs. 3,70,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) No pre-treatment for inlet water or post-treatment for outlet water is required;

7.) Time required for manufacturing one unit is 1 day and 1day is required for installation & commissioning of one unit; and

8.) Life of filter media is 5 years and is regenerable.

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78, Biren Roy Road West,
Kolkata, West Bengal – 700061
Email Id: sudip@drinkwell.com

10.4.8 Electrocoagulation followed by Adsorption- Fluoride Removal Technology

Brief on the technology:

Electrocoagulation followed by adsorption. Raw water Electrocoagulation → Filtration → Adsorption (if required) → Treated water.

Other observations:

1.) Cost of treated water is approximately 10 paisa per liter;

2.) Cost of O&M is Rs. 3,75,000 per year;

3.) Semi-skilled persons can operate the plant;

4.) The technology can be retrofitted into existing system;

5.) Production capacity can be easily scalable;

6.) No pre-treatment of inlet water and post-treatment of outlet water are required;

7.) Time required for manufacturing one unit is 20 days and 5-10 days are required for installation & commissioning of one unit;

8.) Life of filter media is 1 year; and

9.) Frequency of replacement of filter media: For Electrocoagulation, electrodes replacement twice a month and for filter media once in a year for regeneration or replacement.

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10.4.9 Mineralized Carbon based- Fluoride Removal Technology

Brief on the technology:

The adsorbent has been prepared from bone meal which is a source of organic fertilizer. The striking feature of this material is that it is rich in Calcium that is a potent Fluoride sorbent. A typical raw material containing Calcium to phosphate ratio exceeding 1.6 is a good substance for Fluoride removal. The mechanism of Fluoride adsorption is ion exchange with hydroxyl groups in Calcium Hydroxyapatite, Aluminium Hydroxide and Calcium Hydroxide present in MRC and TMRC. Additionally, both MRC and TMRC exhibit strong antibacterial property.

Flow Diagram:

Raw Water à Oxidising unit àIron removal unit àFluoride removal unit à Bacteria removal and polishing unità Treated Water.

Other observations:

1.) Cost of treated water is approximately 12 paisa per liter;
2.) Cost of O&M is Rs. 4,41,000 per year;
3.) Unskilled persons can operate the plant;
4.) The technology can be retrofitted into existing system;
5.) Production capacity can be easily scalable;
6.) No pre-treatment of inlet water and post-treatment of outlet water are required;
7.) Time required for installation & commissioning of one unit is 7 days;
8.) Life of filter media is 1 year and no treatment required for disposal of spent material. The sludge media may be dried and used as secondary fuel;
9.) Frequency of replacement of filter media: For electrocoagulation, electrodes replacement twice a month and for filter media once in a year for regeneration or replacement;
10.) No regeneration during service life and easy maintenance;
11.) No special sludge management; and
12.) Post installation service facility is available and turn-around time required for redressal is 1 – 3 days.

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10.4.10 Hybrid Anion Exchange Resin- Fluoride Removal Technology

Brief on the technology:

Hybrid anion exchange resin is adopted with a mixture of hydrated Zirconium/ Aluminium nanoparticles irreversibly inside resin beads.

Other observations:

1.) Cost of treated water is approximately 16 paisa per liter;
2.) Cost of O&M is Rs. 3,44,000 per year;
3.) Semi-skilled persons can operate the plant;
4.) The technology can be retrofitted into existing system;
5.) Production capacity is easily scalable;
6.) No pre-treatment of inlet water or post- treatment of outlet water is required;
7.) Time required for manufacturing, installation & commissioning of one unit is 2 days;
8.) Life of filter media is 5 years and is regenerable; and
9.) Post installation service facility is available and turn-around time required for complaint redressal is 2 days.

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78, Biren Roy Road West, Kolkata 700061
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10.4.11 Contact Sorption- Fluoride Removal Technology

Brief on the technology:

Oxidation → Coagulation → Flocculation →Adsorption → Sedimentation.

The enlarged particles of the specified contaminants are settled at the bottom of the contact tank. Sediments are periodically removed from the contact tank and directed to the sludge separation bed where water is recycled to the contact tank whereas the waste is stored for disposal as per prevailing environmental norms. Reagent 1 (metal salt) and Reagent 2 (coagulant) is injected to the main before feeding to contact tank. Reagent 1 reacts with Fluoride and converts it into metal Fluoride complexes and if Iron is also present it converts into Iron Fluoride complexes

(IFC) when are they are removed from solution. The particles are enlarged by coagulant. It is known, Fluoride can be removed more effectively as insoluble compound.

Other observation:

1. Production cost of Fluoride free treated water is very low compared to conventional systems prevalent in the market. This method also improves other water quality parameters like odour & colour resulting in ancillary health and aesthetic benefits including disinfection of microorganisms;
2. Effectively removes suspended as well as dissolved constituents of water and turbidity besides As, F, Fe, Mn, heavy metals, Phosphate etc. as well as micro-organisms, colour and odour, if any;
3. Space required by these systems is far less (1/8th) than those required by conventional systems of similar capacity. Thus, saving large pieces of agricultural land from wastage.
4. Backwash water is recycled. Minimal generation of waste and assiduous of its safe disposal.
5. O&M is easy and hassle-free with very low cost.
6. Semi-skilled persons can operate the plant.
7. Solar power operated stand-alone unit.
8. The technology can be retrofitted into existing system

Contact Details:

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10.4.12 Mixed metal oxide nano-aggregates - Fluoride removal technology

Brief on the technology:

A novel nano-adsorbent comprising of mixed metal oxides (MMOs) was developed and stands ready for attachment with rural community tube-wells for de-fluoridation of groundwater. The efficacy of this new nano-media was examined in laboratory under controlled aqueous flow conditions by batch and column studies, which gave encouraging results. The modified and unmodified sample surface was characterized by surface-sensitive techniques, namely XRD, SEM-EDAX, FTIR. The nano-crystalline nature was confirmed, and the composition resembles Iron Aluminium Oxyhydroxide (FeAlOxHy). The high porous structure and greater surface area of nano-granules favours quick sorption of Fluoride from contaminated waters. The success achieved in lab bench studies was scaled-up and translated to field through installation of domestic filters (at schools/ individual households). The innovatively designed hand tube-well attached community filters entail two-stage down-flow treatment under voluminous pumped flow conditions. The media for domestic filters continued for 6 months to 1 year, depending upon family size and Fluoride level in influent water. There is high Fluoride adsorption of 2,500-3,000 mg/Kg noted in case of domestic filter system with Fluoride nano-adsorption effective at a very low cost of 20-30 paise/liter. There was no noticeable media loss or Fluoride de-sorption during regeneration (de-clogging) procedure. The treatment is low-cost and eco-friendly, and strongly advocates the marvels of Fe(III)-Al(III) binary nano-oxide as effective commercial media for Fluoride removal from affected drinking water sources.

Other observation:

1. Cost of installation is approximately 1.25 lakh;
2. Time required for manufacturing one unit is 7 days and 1-2 days are required for installation & commissioning depending upon the location of the site;
3. Reject water management - no formal treatment will be necessary as the reject water will not contain any harmful substances; and even if any harmful substance is present, it will remain below the tolerance limits;
4. Semi-skilled persons can operate the plant;
5. No pre-treatment & post treatment are required;
6. The treatment is low-cost, efficient, environment-friendly, and strongly advocates the marvels of nanotechnology in production of effective commercial media for Fluoride removal from the affected drinking water sources;
7. The treated output water conforms to the water quality standards specified by CPCB, ICMR, APHA and other water regulatory agencies;
8. Technology can be retrofitted if required.

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10.4.13 Adsorption- Fluoride removal technology

Brief on the technology:

Tricalum Phosphate granulate is a colourless (whitish) granulate, hardly soluble in water and lye, soluble in diluted acids. Tricalum Phosphate granulate is a high purity, synthetic Tricalcium Phosphate (apatite) used for sophisticated and safe removal of Fluoride from original waters. The consistently high quality of Tricalum Phosphate granulate is certified by a certified quality according to ISO 9001: 2008 during manufacture.

Other observation:

1. Cost of O & M is Rs. 1.8 lakh;
2. Cost of treated water is Rs. 0.10 considering 5,000 liter treatment per day;
3. Semi-skilled persons are required for O&M;
4. The technology can be retro-fitted into existing system as per requirement;
5. Production capacity is easily scalable;
6. Pre-treatment is not required;
7. Life of filter media is 60 months (minimum); and
8. The adsorbent (Fluorolith) is a colourless, (whitish) granulate, insoluble in water and lyes, soluble in acids. Main components are CaO, P_2O_5 H_2O.

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11 Operation and maintenance, sustainability and utility issues

The government of various states is focusing on improving the water quantity and quality situation in the remote parts of the state through technical interventions and mitigation measures. To provide safe water to populations, various technologies were installed by various state governments. Most of the plants will become non-functional within few months of installation due to various O&M and utility issues.

The technology-specific O&M and utility challenges are discussed in detail in the following sections:

11.1 Site selection for the installation of treatment units

Site selection is a very crucial part of the entire process. It was observed during the field visit that treatment units were installed at remote locations like outside the villages, at some locations where only a few houses were in the nearby vicinity. In addition to that, installations were done at the sources that do not yield the required water quantity over the year, and the source gets dried during the summer season.

- Installation of treatment units should be the last option to provide safe water to the population residing nearby;
- The availability of a safe water source in the nearby vicinity needs to be verified before the selection of site;
- The targeted contaminant concentration in raw water also needs to be verified as per BIS standard IS-10500-2012 and its subsequent amendments;
- The utility of the installed treatment unit should be justified in terms of its benefit to the maximum population. It should not be installed just for one or two houses;
- The sufficient water yield of the selected source along the year needs to be confirmed by State PHED/ RWSS department prior to allocation of source for installation of treatment unit;
- Water quality testing for at least one complete season cycle must be undertaken prior to the installation of the water treatment unit.

11.2 Compliance of IS-10500 prior to selection of water sources for treatment units

Before allotment of water source for installation of contaminant specific treatment unit, the presence of specific contaminants in the raw water needs to be confirmed by PHED. If possible, third-party evaluation of the selected water source could be done by the authorities for the verification of the presence of contaminant concentration above the acceptable/ permissible limits. During site selection, other water quality parameters (like TDS, Nitrate, etc..) should also be taken into consideration for their presence as per IS-10500.

11.3 Adsorption based technologies - regeneration and replacement of media

The regeneration cycle of media needs to be fixed based on the contaminant type and its concentration as well as the quantity and type of adsorbent media used. In addition to that, the daily treated water requirement also needs to be considered during the calculation of regeneration cycles.

- After regeneration, it should be ensured that the used regenerant is completely removed from the adsorbent chamber by backwashing.
- pH and contaminant concentration of treated water needs to be monitored prior and after regeneration of media.
- Media should be replaced after completing its reported regeneration cycles and its performance based on adsorption capacity. The spend media disposal policy is also to be framed during the installation of treatment units.
- Standard operating procedure (SOP) must be prepared by the O&M agency defining the step-wise procedure for regeneration/ replacement of media along with its frequency.
- Plantwise records on the quantity of water treated and history of regeneration/replacement of media should be maintained and accessible to the Field Engineer during a routine inspection.
- Regulation for the environmentally safe disposal of exhausted media should be made and should be followed strictly to avoid cross-contamination of other water bodies.

11.4 Membrane-based technologies

Membrane-based technologies are more sensitive than adsorption-based technologies and require more attention towards regular O&M. Generally, these technologies come with pretreatment and conditioning of inlet water.

The general issues associated with these technologies are:

- Required highly qualified field staff for regular O&M;
- In membrane-based technologies, reject water is a serious concern. This should be minimized to avoid the loss of water during treatment;
- The big threat to these technologies is the fouling of membrane and required huge O&M cost for its replacement. This is one of the big reasons behind the non-functioning of these technologies after installation in the field;
- The energy requirement of these technologies for regular operation is relatively high and one of the big reasons behind its non-functioning. Socioeconomic audits should be done prior to its installation in the field; and,
- Mechanisms for the disposal of spent membranes need to be finalized.

11.5 Continuous monitoring of treatment units by technology provider

Presently most of the treatment units were installed with the 5-10 years O&M contract. The routine O&M is being monitored by technology provider for a pre-decided time frame. For smooth operation the installed plants, a team of ground staff is required with adequate knowledge.

- The technology provider should appoint requisite ground staff to address routine O&M issues.
- Appropriate training should be provided to the field staff regarding the regeneration and replacement of media and to handle the routine O&M related issues
- A contaminant-specific field test Kit (FTK) should be provided to field staff during a field visit.
- The records/ traceability of records needs to be maintained to ascertain the regeneration of media and its frequency.
- Schedule of regeneration and replacement should be decided based on the various deciding factors at the location. Field staff should know the regeneration cycle for each site.
- Field staff should ensure the quality of treated water as per requirement regularly;
- The mechanism for the regular reporting of treated water quality to the state government officials needs to be prepared; and
- Contact details of responsible field staff should be provided with each treatment unit.

11.6 Physical monitoring for the performance and functionality of treatment units

The compliance-related to proper installation and maintenance of the plant with the locations where the source water quality was not as per the IS-10500, needs to be monitored by the State PHED.

- Continual monitoring of installed treatment units needs to be done by field engineers to ensure the performance of the plants;
- Training for the O&M and evaluation of installed treatment units should be given to field engineers;
- The department must arrange a short practical training course on the operation and maintenance of installed treatment units;
- The protocol for physical monitoring, performance, and functionality evaluation needs to be framed by PHED; and
- A feedback mechanism should be made to periodically communicate the observations of field engineers on the overall functionality of installed treatment units to the higher authorities.

1.7 Community involvement in the routine O&M of treatment units

- The IEC campaign involving all stakeholders must be initiated;
- The operating agency should have a good presence and connects with the local community;
- The approachability of the local community to the operating agency should be well established;
- The IEC activities should be conducted at few locations initially with the community. The community should also be involved in the later stages of operation and maintenance. This will encourage them for proper utilization of treatment unit and also extend sense of ownership to the community
- This will also encourage them to maintain hygiene around the treatment unit.

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