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**TECHNOLOGY MISSION ON
DRINKING WATER IN VILLAGES AND
RELATED WATER MANAGEMENT**

**CHEMICAL CONSTITUENTS IN WATER
RELATED TREATMENT AND MANAGEMENT**



**NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
NEHRU MARG, NAGPUR-440 020 (INDIA)**

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CONTENTS

	Page No.
Introduction	1
Water Quality Parameters	2
Colour	3
Turbidity	3
Hardness	4
Alkalinity and Acidity	4
Chlorides	5
Sulphates	5
Dissolved Solids	5
Iron and Manganese	6
Fluorides	6
Nitrates	7
Toxic chemical substances	7
Standards for Drinking Water	7
General Treatment Processes	11
Storage	13
Coagulation	15
Sedimentation	16
Filtration	16
Precipitation softening	18
Removal of Toxic Inorganic Contaminants	19
Arsenic	20
Cadmium	20
Chromium	21
Nitrate	22
Iron and Manganese	22
Fluorides	23
In Conclusion	24

**HAZARDOUS CHEMICAL CONSTITUENTS IN WATER, RELATED
TREATMENT AND MANAGEMENT**

Lecture by
K.R. BULUSU*

Rainfall is the chief source of water and along with other forms of precipitation, snow and dew, it is classified by the geologists as meteoric water.

Annual rainfall over the entire country is just over 400 million hectare metre (mham) of water. Of this about 70 million is lost by evaporation and roughly 215 mham seeps into the soil, leaving 115 mham to flow into the river system. It has been estimated that only 77 mham can be used for irrigation. Of the 215 mham that seep into the soil annually, 165 mham remain in top layers and contribute to soil moisture, which is essential for growth for vegetation. The remaining 50 mham percolates into the porous strata and represent the annual enrichment of underground water. The total storage at any time may be several times this amount. The total utilisation by 2025 AD is estimated as 105 mham.

It must, however, be pointed out that the proportions of run-off, percolation and evaporation vary considerably, being influenced by the seasons and geological and topographical features. During its traverse, the water picks up various impurities and dissolves salts in varying amounts.

The salt in potable waters are few in number, and whilst some of them are found in practically all natural waters, others occur in comparatively few, yet it is upon their quality and quantity that the character of water depends.

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Practically all waters contain dissolved salts and gases taken from air. A little organic matter is invariably present, in pure waters in actual solutions, in less pure waters generally in a colloidal condition. All these natural waters can be included in the following group.

- i) Acid waters with a hydrogen ion concentration represented by pH 6.0 or less. The acidity may be due to carbonic, humic, acetic, formic, glycollic and oxalic acids. These waters may dissolve lead, may cause incrustation in pipes, and may dissolve concrete.
- ii) Alkaline waters having pH value of 8.5 or over. They are not numerous, but occur more frequently than supposed.
- iii) Neutral waters with pH value between 6 and 8. This includes the great majority of potable waters.

WATER QUALITY PARAMETERS

The analyst familiar with water quality characterisation will often select parameters to be measured based on experience and intuition. For certain uses water quality criteria have been established which include quantitative as well as qualitative information. In most case guidelines should be followed. The analyst should familiarise himself with significance of important parameters and the factors which determine the concentrations and distribution of the constituents to be measured. Although hundreds of different water quality parameters exist, in actual practice the number of analysis which are applied to an individual water sample is always quite small.

Table 1 gives the mineral constituents of natural waters in equilibrium with calcite, dolomite, apatite, Kaolinite, gibbsite, sodium and potassium feldspars, and atmospheric carbondioxide. Most natural waters are dynamic rather than static systems and may not have achieved thermodynamic equilibrium. Thermodynamics cannot predict whether a certain substance is present, but rather if a system containing a substance is stable. In addition thermodynamic calculations do not predict the time necessary to achieve equilibrium in system.

Table - I : Mineral Constituents of Natural Waters

Major Constituents	Minor Constituents
Calcium	Iron
Magnesium	Manganese
Sodium	Aluminium
Potassium	Silica
Carbonate	Phosphate
Bicarbonate	Fluoride
Sulphate	Nitrate
Chloride	

Of the various constituents found in potable water a few are objectionable even when present in very small quantity, others only, if present in such unusual quantities as to relegate the water from the 'potable' to the unusable class. Some of those relevant in the present context of water quality are dealt here briefly.

Colour : Colour like taste and odour, is properly measured by a physiologic response. It is necessary to distinguish between the true colour of water caused by substances in true solution and the apparent colour which is caused by the effects of suspended and colloidal material.

Colour in water may result from the presence of material of vegetable origin, such as tannins, humic acids, peat material, plankton or weeds. Metal ions, including iron, manganese, copper and chromium, may also impart colour. Colour is objectionable for domestic water supplies and for use in many industries. Coloured waters are always objectionable, and in as much as the colour can be removed, it should be removed to such an extent that the colour is not obvious in an ordinary tumbler.

Turbidity : Turbidity is a measure of the light scattering characteristics of water caused by the presence of colloidal and particulate suspended matter. Turbid water need not be unwholesome, but they are

not pure; in any case they are objectionable to sight, and when plankton or other forms of life, are visible the appearance may be alarming and even nauseating. Obviously such waters require treatment to remove this objection.

Hardness : Waters are classified as 'hard' or 'soft' according to their action on soap. The less amount of soap consumed to produce a lather, the softer the water. Hardness is expressed in terms of calcium carbonate and the following classification is of use.

Less than 60 mg/l	Soft
61-120 mg/l	Moderately hard
121-180 mg/l	Hard
More than 180 mg/l	Very hard

While hardness is caused only by actions such as calcium and magnesium and consequently is independent of the anions in the solution, the term 'temporary hardness' and 'permanent hardness' have been used.

Hard waters have had no demonstrable harmful effects upon the health of the consumers. There is no proof that hardness causes urinary concretions or other diseases of the kidney or bladder; or biliary calculi, arteriosclerosis, dyspepsia, goitre, constipation or stomach disorders.

Alkalinity and Acidity : Alkalinity is the capacity to neutralise acids and acidity is the ability to neutralise bases. Although alkalinity of water usually is due to the presence of bicarbonate, carbonate and hydroxide ions, care should be taken in assigning the alkalinity of a sample only to these three substances. Other weak acids such as borate, silicate, phosphate, sulphide and humate will contribute to the alkalinity.

Waters contain bicarbonates in amounts which depend, among other things, on their past history, very usually they may also contain small amounts of carbonate alkalinity but caustic alkalinity is never present. In

contrast waters softened by precipitation processes, such as lime soda process, usually contain hydroxide and carbonate, but no bicarbonate.

In itself, alkalinity is not considered detrimental to human but it is generally associated with high pH values, hardness and excessive dissolved salts, all on which may be objectionable.

Chlorides : Chlorides in drinking water are generally not harmful to human beings until high concentrations are reached, although chlorides may be injurious to some people suffering from diseases of heart or kidneys. The tolerance of chlorides by human beings varies with climate and exertion, and chlorides that are lost through perspiration may be replaced by chlorides in either diet or drinking water. For drinking purposes water with chloride concentration upto 1,000 ppm is reported to be physiologically safe.

Sulphates : The limits of sulphate are not based on taste or physiological effects other than laxative effects towards new users. A review of the literature indicates that a concentration of 1,000 ppm of sulphates in water is harmless and a cathartic dose is 1 to 2 grams or a litre of water containing 1,000 to 2,000 ppm sulphates.

Dissolved Solids : Filterable residue or dissolved solids is determined by evaporating to dryness at 103-105°C or 179-181°C. Residues dried at 103-105°C may retain occluded water as well as water of hydration. Because of the difficulty in removal of occluded water at this lower temperature, attainment of constant weight may be slow. Residues dried at the higher temperature, will lose mechanically occluded water and may lose some organic matter and inorganic salts by volatilisation.

Samples which have been dried at 179-181°C in general yield residue values which conform more closely to the sum of the individually determined mineral salts than do the total residue values determined at the lower temperature.

Dissolved solids is one of the most important criteria. The limit of 500 mg/l for potable water is based primarily on taste thresholds.

The importance of dissolved solids, sulphates and chlorides as they affect water quality hinges upon their taste and laxative properties. The dissolved solids in natural water consist mainly of bicarbonates, chlorides, sulphates and possibly fluorides and nitrates of calcium, magnesium, sodium and potassium with of iron, manganese and other substances. Many communities world over use water containing 2,000 to 4,000 ppm dissolved salts, when no better water is available. Such waters are not palatable, do not quench thirst, and may have laxative effects on new users. However, no harmful physiological effects of a permanent nature have been called to the attention of health authorities.

Iron and Manganese : Both iron and manganese are objectionable constituents in water supplies for either domestic or industrial use. The taste which iron imparts to water may be described as bitter and astringent. Individuals vary in their acuity of taste perception.

The concentration of manganese should be low in drinking water : (a) to prevent aesthetic and economic damage and (b) to avoid any possible physiological effect from excessive intake. Minute amounts of manganese produces a brownish colour in laundered goods and imparts the taste to beverages including coffee and tea. The principal reason for limiting the concentration of iron and manganese is to provide water quality control and thus reduce aesthetic and economic problems.

Fluorides : Fluorides in drinking water will prevent dental caries. When the concentration is optimum, no ill effect will result and caries rates will be low.

Excessive fluoride in drinking water supplies produces objectionable dental fluorosis which increases with increasing fluoride concentration above the recommended levels. Other expected effects from excessively high intake levels are (a) bone changes when water containing 820 ppm is

consumed over a long period of time, (b) crippling fluorosis when 20 mg or more fluoride from all sources is consumed per day for 20 or more years and (c) death when 2,250-4,500 mg of fluoride is consumed in a single day.

Nitrates : In some circumstances, nitrates have been shown to be a health hazard to infants, and possibly elder children, if the concentrations in drinking water is greater than 45 mg/l (as NO_3) because, after reduction to nitrite, they may give rise to methaemoglobinaemia. In view of the small quantity of water consumed by infants directly as drinking water, or indirectly as prepared food, it should not be difficult to find an alternate source of water of low nitrate content for this vulnerable section of the population.

Toxic chemical substances : A number of chemical substances, if present in certain concentration in drinking water, may constitute a danger to health. The limits for these substances are usually related to the daily intake of drinking water and tentative limits for some toxic substances are on the basis of the available toxicological data and the body burden from other sources-food and air for example. The average daily water intake is about 1.5 litres and the total liquid intake including milk, water in solid foods etc., is in the region of 2.85 litres.

STANDARDS FOR DRINKING WATER :

Domestic water supplies should protect the health and promote the well-being of individuals and the community. Giving due regard to the conditions prevailing in India relating to the provision of drinking water supplies and the progress of the schemes under the various national and state development programmes and the need for prescribing standards of bacteriological and chemical quality which safeguard the health of the consumers and at the same time liberal enough to permit the acceptance of supplies which are satisfactory as regards their

sanitary conditions, Indian Council of Medical Research (ICMR), Ministry of Health, Government of India recommended the following standards (1975) for drinking water.

i) **Toxic Substances :**

Substances, total.	Upper limit of concentration, mg/l
Arsenic (As)	0.05
Cadmium (Cd)	0.01
Lead (Pb)	0.01
Mercury (Hg)	0.001
Selenium (Se)	0.01
Cyanide (CN)	0.05

Concentrations higher than the upper limit of concentration should not be permitted in the treated water.

ii) **Substances and characterisations affecting potability of water**

Certain chemical substances present in water and certain characterisations of the water, although not constituting a hazard to the health of the people using it, may affect its acceptability as a domestic supply. A list of such substances and characteristics is given in table, together with an indication of the undesirable effects they may produce, figures where appropriate for the highest desirable and maximum permissible levels recommended. The limits described as 'highest desirable' apply to water which will be generally acceptable to the consumers. Concentrations exceeding the limit given as 'maximum permissible level' will be unsatisfactory for drinking and domestic purposes.

Table - Substances and Characteristics Affecting the the Acceptability of Water for Domestic Use (ICMR, 1975).

Substances or characteristics	Undesirable effect that may be produced	Highest desirable level	Max. permissible level
Substances effecting the color TCU (1)	Discolouration	5 units	25 units
Substances causing odours	Odours	Unobjectionable	Unobjectionable
Substances altering the taste	Taste	- do -	-do-
Turbidity JTU (s)	Gastrointestinal irritation	5 units	25 units
Dissolved solids	Gastrointestinal irritation	500 mg/l	1500 mg/l*
pH range	Taste, corrosion, scale formation	7.0 - 8.5	6.5-9.2
Total hardness	Taste, scale formation	300 mg CaCO ₃ /l	600 mg CaCO ₃ /l
Calcium	- do -	75 mg Ca/l	200 mg Ca/l
Magnesium	Taste, scale formation, gastrointestinal irritation in presence of sulphates.	Not more than 50 mg/l Mg, if there are 200 mg/l sulphates; if there is less sulphate magnesium upto 100 mg/l Mg may be allowed at the rate of 1 mg/l Mg for every 4 mg/l decrease in sulphates	100 mg Mg/l
Copper	Astringent taste, sia-discolouration, corrosion of pipes, fittings, utensils?	0.05 mg Cu/l	1.5 mg Cu/l

Substances or characteristics	Undesirable effect that may be produced	Highest desirable level	Max. permissible level
Iron	Astringest taste, discolouration, turbidity deposits, growth of iron, bacteria in pipes	0.1 mg Fe/l	1.0 mg Fe/l
Manganese	Astringent taste, discolouration, turbidity, deposits, in pipes	0.1 mg Mn/l	0.5 mg Mn/l
Chloride	Taste, corrosion in hot water systems	200 mg Cl/l	1000 mg Cl/l
Sulphates	Gastrointestinal irritation when combined with magnesium or sodium.	200 mg SO ₄ /l	400 mg SO ₄ /l
Nitrate	Danger of infantile methaemoglobinaemia, if the water is consume by infants	20 mg NO ₃ /l	**
Fluoride	Fluorosis ***	1.0 mg F/l	1.5 mg F/l
Phenolic compound	Taste, particularly chlorinated water	0.001 mg phenol/l	0.002 mg phenol/l

The values prescribed are to be considered individually and may not bear correlation with each other.

1. True colour unit, platinumcobalt scale.
2. Jackson Turbidity Unit.

* Dissolved solids relaxable upto 3000 mg/l in cases where alternate sources are not available within reach.

** More information is required to prescribe a value but in no circumstances should the level exceed 100 mg NO₃/l.

Excessive nitrates in drinking water may cause methaemoglobinaemia in some young infants. No simple or economical method for removing nitrates from water is available. Hence, it is recommended that in case of water supplies containing nitrate in excess of the limiting concentrations, the consumers should be advised as to the potential danger of using the water for infant feeding.

Treatment Process

The treatment deals specifically with processes designed to produce water suitable for domestic purposes; it does not deal with the treatment of water for industrial purposes, though some of the information given will also be applicable to other purposes also.

The authorities who supply water for domestic purposes secure that the water for domestic purposes is pure and wholesome. Water taken from properly protected source and subject to adequate system of purification can be rightly designated as pure and wholesome, if it is free from visible suspended matter colour, odour, taste, from all objectionable bacteria indicative of the presence of disease producing organisms, and contains no dissolved matter of mineral or organic origin which in quality or quantity renders it dangerous to health, and with dissolved substances injurious to health.

Broadly speaking, little treatment would be required, if pure and wholesome water is available for domestic purposes. No natural water supplies are wholesome and pure, however, not even rain water; they always contain dissolved gases and solids, and often suspended matter and living organisms. If these natural waters are used untreated for potable purposes various complications and disease will follow.

All surface waters from rivers, lakes and impounding reservoirs and well waters requires treatment for one or more of the following reasons.

1. To remove colour, turbidity and bacteria.
2. To remove hardness.
3. To remove metals, for example iron and manganese
4. To remove fluorides
5. To neutralise acidity and correct corrosive activity and plumbo solvency.
6. To remove dissolved solids by desalination techniques.

Water treatment involves physical, chemical and biological changes to transform raw waters into potable waters. The treatment processes used in any specific instance must depend on the quality and nature of the raw water. Thus many well waters are of satisfactory physical and chemical quality and require treatment only by chlorination to protect against known or potential bacteriological pollution. At the other extreme are those mineralised raw waters subject to pollution, which require all the resources of water treatment to yield an attractive water of safe quality.

By employing available processes of treatment, a great many otherwise unsatisfactory waters can readily be made suitable for drinking and domestic purposes. Some ground waters contain, however, so much mineral matter that treatment is impracticable. A number of ground waters are unusable owing to the presence of an excess of salts, a few contain excess nitrates, and no simple means to remove these constituents are available.

In India, river waters invariably require treatment and most of the public supplies to large towns are of this character. Owing to the inability of underground waters to meet increasing demands of the population and industries, greater resort will have to be made to rivers in the future also.

The first line of treatment of water supplies is prevention of pollution so far as practicable. The subsequent lines of treatment vary according

to the individual circumstances and the efficiency of the methods employed is ascertained by the laboratory examination of samples of the water before and after treatment.

Some of the treatment methods employed in this country to obtain safe water are storage, coagulation, sedimentation, filtration, disinfection, iron and manganese removal and defluoridation. If hard, the water may be softened by lime, lime-soda or base exchange process.

These treatment processes are dealt briefly in the following paragraphs.

STORAGE

The raw water storage reservoirs serve two main purposes (i) collect sufficient water from streams and rivers during rainy season for use throughout the year and during years of drought and (ii) to equalise the water and tide over periods of unusually heavy rainfall, when the river waters may become too turbid or impure for efficient treatment by normal processes. Some purification also takes place during storage, the principal effects being the removal of suspended matter by sedimentation and destruction of pathogenic and other intestinal bacteria.

DISINFECTION

Disinfection is a necessary step in the process of insuring a safe water supply. Water from surface supplies may be disinfected before filtration and sometimes before coagulation and sedimentation to prevent growth of organisms. It must also be disinfected after filtration to kill organisms that still remain and to provide a safeguard against recontamination.

Chlorination is the disinfectant normally used. It is presently the only widely accepted agent that destroys organisms in the water and leaves an easily detectable residual that serves as a tracer element.

Its sudden disappearance may signal contamination in the system. Its activity as a disinfectant depends on the temperature and pH of the water to which it is added. Disinfecting action is faster at higher temperatures but is retarded by high pH. If pH is above 8.5 the rate of disinfection decreases sharply. Effectiveness of free chlorine is highest at pH 7.0 and lower. At pH 8.5, it is one-sixth as effective and at pH 9.8, it may require 10-100 times as long for a 99% kill of bacteria as at pH 7.0.

Bacteriological effectiveness of chlorine depends on the following factors.

- Chlorine residual
- Contact period
- Temperature
- pH
- Point of application

Chlorine disinfectants are available in a number of different forms viz., liquid chlorine, calcium hypochlorite, sodium hypochlorite, chlorinated lime (bleaching powder), NEERI developed chlorine tablets and ampoules.

For disinfection of open dug wells, NEERI had carried out studies using 'pot chlorinators'. The systems studied and evaluated include 'single pot with holes in the bottom', 'single pot with holes in the middle' and 'double pot'. The double pot system is said to work satisfactorily giving a chlorine residual in the range of 0.15 to 0.50 ppm for two to three weeks in the small household wells containing nearly 4,500 litres of water and having a draw-off rate of 360 to 450 litres per day. For community wells of 4,000 to 13,000 litres content and daily draw-off rate of 900 to 1300 litres (40-60 people/day), the single pot with holes at the bottom is recommended to be enough to give required chlorination (0.2 to 1.0 ppm) for two weeks.

COAGULANTS AND COAGULATION

For the purposes of this paper, the term 'coagulation' is to include the addition of chemical coagulants and the mixing and flocculation processes. Most water sources and especially surface waters contain enough finely divided material and colloidal matter in suspension to require coagulation for its removal before filtration even though it may have been previously subjected to plain sedimentation. In addition, influxes of certain forms of algae and micro-organisms are removed through the process of coagulation, flocculation and subsequent settling in sedimentation basins.

Coagulation is accomplished through the addition of a chemical called a coagulant, which reacts with alkalinity in the water to produce a precipitate or floc. The gradual growth of this by a slow mixing process is called flocculation. During the growth process, the floc increases in size, absorbs colour, enmeshes particles causing turbidity, bacteria, plankton and other suspended matter, and with its increased weight settles to the bottom of a sedimentation basin provided for this purpose.

The chemicals used as coagulants are aluminium sulphate, sodium aluminate, ferrous sulphate, ferric sulphate, ferric chloride and chlorinated copperas.

The kind of chemicals which are suitable for coagulation of the particular raw water can be determined by the use of the results of the control tests in the laboratory and the following information on the optimum pH samples for common coagulants.

<u>Coagulant</u>	<u>Optimum pH range</u>
Aluminium sulphate	5.0 to 7.0
Ferrous sulphate	9.5 and above
Ferric sulphate	4.0 to 10.0
Ferric chloride	4.0 to 6.0 & above 9.5
Chlorinated copperas	- do -

Ferrous sulphate and ferric chloride are deliquescent salts, and the latter is very corrosive. Neither is seldom used in water treatment in India. Ferric sulphate is not available in this country and chlorinated copperas requires to be prepared immediately before use by adding chlorine to ferrous sulphate (copperas) solution. It is very corrosive solution and is not in use in India.

SEDIMENTATION

It has previously been stated that one of the benefits of storage of water is the reduction of suspended matter. Sedimentation is a good and economical method for removing that suspended matter which deposits quickly but the remainder, which requires many days of storage to reduce, is best removed by prior coagulation and flocculation. When successful coagulation of a water has been obtained, the coarse must be so collected that it can be removed as a sludge, while the comparatively clear supernatant water is drawn off for filtration.

The main items in the operation of settling basins are (a) control of quantity of water flowing through the basin, (b) removal of sludge from basin and (c) cleaning the basins and the sludge collecting equipment.

FILTRATION

Water from the sedimentation basin is brought on to the filters as the next step in the purification process. This water contains very finely divided suspended matter such as minutes particles of floc, clay and mud that have not coalesced and bacteria and microscopic organisms that have not been removed by sedimentation. The purpose of the filter is to remove this suspended matter and give the water a clear, sparkling, and attractive appearance. Filters are usually of two types viz., slow sand filter and rapid gravity sand filter.

SLOW SAND FILTERS

Slow sand filters contain fine grain sand (should not be less than 0.2 mm or greater than 0.4 mm, and usually should be about 0.3 mm) and have low filtration rates. They are usually used when coagulation is not included in the treatment process and the raw water is of low turbidity (below 30 units). Plain sedimentation prior to filtration may reduce the turbidities of many raw waters to below this level. Their capacity of filtration is about 2.5 m/d (2-5 million gallons per day per acre).

RAPID SAND FILTERS

Rapid sand filters are now universally used in modern water treatment plants. There are two types, gravity and pressure. These are filters designed to operate at a much higher rate than slow sand filters.

Filters of this type are usually open structure and water flows through the sand by gravity, hence another name 'gravity filters'. Other filter units are enclosed in steel tanks and may be operated under pressure, hence the name 'pressure filters'.

The rate of filtration is 4.8 m/h of filter area. A filter sand of 0.40-0.50 mm effective size range would secure reliable filtration with reasonable filter runs.

After a filter has been in service for some time foreign material will have accumulated on the surface and in the top sand to an extent that the pressure drop across the filter bed become excessive. It is then necessary that the filter be washed or, as often called 'backwashed' to clean the sand bed. It is usually practice to wash filter when the pressure drop (loss of head) has reached a point of 2.0 - 2.5 meters or after 50 hours of service. The bed is washed by reversing the flow, forcing filtered water up through the filter bed. This loosens the bed, agitating the sand grain against each other and washing accumulated

foreign matter of the grain surfaces. The wash water rises into wash trough and flows to waste.

DIATOMACEOUS EARTH FILTERS

Advances in the clarification of liquids in the chemical industry through the use of powdered filtering material have led to the development of filters in which diatomaceous earth is used as the filter medium. The two chief advantages are that these filters require much less space than sand filters of equal capacity and produce relatively clear water without prior coagulation and/or sedimentation.

Diatomaceous earth is composed of skeletons of countless tiny one celled animals called diatoms. It must be specially prepared and graded for filter use. When used as a filter medium, diatomaceous earth, which looks like a powdered chalk, is fed to water passing through a filter septum too fine to allow the diatomaceous earth through. A cake of the material is built up on the element in this manner and since the pores between the particles thus retained are very fine, the cake filters the water that passes through it under pressure. This type of filter is especially adapted to the clarification waters of low turbidity.

Diatomaceous earth is not available in India and NEERI had developed an indigenous substitute, 'Filter Aid' (FA-5) from wood charcoal.

WATER SOFTENING BY LIME SODA PROCESS

Chemical precipitation is widely used in softening municipal water supplies. Hardness in water is caused by the ions of calcium, magnesium, iron, manganese and aluminium. Practically all of these hardness producing elements can be found in natural waters in some concentration. However, in most waters only ions of calcium and magnesium are present in sizeable concentration and, hence, are of major concern in the majority of the softening processes.

The lime-soda process consists in adding hydrated lime and sodium carbonate to the water. Most of the calcium and magnesium are precipitated and alkalinity is reduced. The lime soda process is not very effective in the cold with waters containing less than 100 - 150 ppm of hardness, unless a sludge blanket or sludge recirculation type of plant is employed and such waters can be softened more conveniently by ion exchange. There is no upper limit for the hardness of water which can be softened by the lime-soda process. The residual hardness on a filtered sample of softened water is as a rule in the range 15 - 30 ppm with the cold process.

Lime-soda process plants are essentially the same as water filtration plants. Lime and soda are added to raw water, and the softening reactions occur during mixing and flocculation; the precipitation of calcium and magnesium are removed during sedimentation. An additional step called re-carbonation is frequently provided just prior to filtration. If the raw water has a high turbidity, the turbidity is partially removed by plain sedimentation prior to the softening process.

TREATMENT TECHNIQUES FOR REMOVAL OF TOXIC INORGANIC CONTAMINANTS

Most of the treatment information and data available for the removal of arsenic, barium, cadmium, chromium, lead, mercury and selenium are on conventional coagulation or lime soda softening treatment. These treatment methods are commonly used by large water supplies. Research is underway in NEERI to fill the need for information on treatment technology for rural water system.

Information on the chemistry and occurrence of inorganic contaminants in water indicates that normally the reduced form of a contaminant is found in ground water, and the oxidised form in surface water. Furthermore, the more naturally occurring substances are generally found in ground water, and those occurring from industrial pollution are usually found in surface waters. This type of information is also useful and can serve as a guide in selecting the proper treatment technique.

Arsenic

Most likely occurrence and source of contaminants

+3 (arsenite) - ground water - natural occurrence.

+5 (arsenate) - ground water - natural occurrence

As⁺⁵ Removal : Alum and ferric sulphate coagulation (20-30 mg/l) achieved over 90% removal between pH 5.0 and 7.5. About pH 7.5, As⁺⁵ removals decreased as the concentration increased above 1.0 mg/l particularly with alum coagulation. Lime softening was also found very effective for As⁺⁵ removal. At pH 10.8 and above, 95% removals are possible with raw water concentration of 0.1 to 10.0 mg/l. Below pH 10.8 removal efficiency decreased to about 30% at pH 8.5.

As⁺³ Removal : This is not removed as effectively from water as As⁺³ either by iron or alum coagulation or by lime soda softening processes. In the pH range of 5.5-9.0 alum coagulation (30 mg/l) removed less than 20% and ferric sulphate (30 mg/l) 60% or less of 0.3 mg/l. Lime softening was shown to be only slightly more effective, removing 70% of 0.3 mg/l of As⁺³ at pH 10.8 and above.

Cadmium

Lime softening achieved removals of greater than 98% in the 8.5-11.3 pH range on waters containing 0.3 mg/l of cadmium. Removals equally as good were obtained at pH 11.2-11.3 when the initial cadmium concentration was increased upto 10 mg/l.

Cadmium removals by ferric sulphate and alum coagulation were lower than those of lime softening. Cadmium hydroxide and carbonate are reported to be extremely soluble below pH 7. Ferric sulphate increased cadmium removals from 20% at pH 7.2 to above 90% at pH 8 and above.

Chromium

Most likely occurrence and source of contaminant

+3 - ground water - natural occurrence

+6 - surface water - industrial pollutant

Cr⁺³ Removal

Alum coagulation, iron coagulation and lime softening are all very effective methods for removing Cr⁺³ from water. Lime softening achieved about 98% removal of Cr⁺³ (0.15 mg/l) in water in the pH range of 10.6-11.3. Below pH 10.6 removals decreased as the pH decreased, to a low of 70% at pH 9.21. Ferric sulphate achieved excellent Cr⁺³ removals greater than 98% through out the 6.5-9.3 pH range. Alum coagulation was not so effective as ferric sulphate, but did obtain 90% removal in the 6.7-8.5 pH range. Above 8.5 pH, removals decreased. When the Cr⁺³ concentration was increased upto 10 mg/l ferric sulphate and alum coagulation achieved removals greater than 98%. The same excellent results were also obtained with lime softening when the Cr⁺³ concentration was increased upto 10 mg/l.

Cr⁺⁶ Removal

Ferric sulphate achieved the best results removing 35% at the low pH of 5.5 on river water containing 0.15 mg/l of Cr⁺⁶. Alum coagulation and lime softening could do no better than 10% removal through the entire pH range 7-11. Ferrous sulphate coagulation was capable of achieving 98% removals in the pH range 6.5-9.3 at 0.15 mg/l of Cr⁺⁶ initial concentration. With its higher concentrations, removals depended upon the time of pH adjustment. When the pH was adjusted before coagulation, Cr⁺⁶ removals decreased with increasing concentrations of Cr⁺⁶ in the water. If the pH of the water is adjusted several minutes after the coagulation, removals greater than 99% are achieved with Cr⁺⁶ concentrations of 10 mg/l. This procedure of adjusting pH after coagulation is necessary to provide time to reduce Cr⁺⁶ to Cr⁺³ before floc formation.

Nitrate (NO₃)

Ion exchange is currently the only method in use to remove nitrate from water. Conventional coagulation and lime-soda softening are not effective methods for the removal of this contaminant.

Some strong base and weak base ion exchange resins are nitrate selective and can reduce nitrate concentration from as high as 50 mg/l (as N) to 0.5 mg/l. Studies are necessary to evaluate nitrate removal efficiency of ion exchange resins.

Iron and Manganese Removal

High concentrations of these minerals are associated with deep well waters from shale, sand stone and other rocks. The minerals are dissolved by ground waters containing carbondioxide but no oxygen; the insoluble being reduced and transformed to soluble bicarbonates. These same reactions occur in the lower portions of deep reservoirs that flood iron - or manganese - bearing soils or rocks. Well waters containing soluble iron or manganese are clean as pumped from the ground water strata, but exposure of the water to the air leads to the oxidation and precipitation of the minerals.

Iron and manganese removal practice is intended to ensure that the water pumped into the distribution system will be of satisfactory quality in so far as these minerals are concerned. Manganese as a ground water problem has not yet been known in India.

There are many instances in which waters require treatment solely for the removal of iron and manganese. This removal is sometimes affected by simple measures such as aeration with or without sedimentation, followed by filtration but more complicated treatment, including the use of chemicals is often required. A decision as to the method of treatment to be employed is influenced by the state of combination in which

the metals are contained in the water, and the character of the water in respect of its mineral, organic and biological constituents. Each case must be individually considered and decided. The means by which iron and manganese are removed from water consists substantially of their precipitation by oxidation and removal of free carbon dioxide, followed by separation of suspension by sedimentation and/or filtration.

The problem of iron and manganese removal in urban and industrial supplies is often handled by conventional type of plants. But, the problem of iron and manganese removal from small community water supplies is somewhat difficult, where inexpensive, simple and easily operatable methods would be needed, preferable without repumping.

To serve these needs, NEERI has developed an iron and manganese removal system for rural purposes in which aeration over a series of coke beds is followed by slow sand filtration. A catalytic oxidation bed is formed in course of time which hastens the removal. No chemicals are required. The unit can be directly worked off a hand pump on a well and iron and manganese free water obtained.

Defluoridation of water by Nalgonda Technique

Fluoride is the most exclusive bone seeking element existing, owing to its great affinity for calcium phosphate. It is, therefore accumulated in every tissue showing calcification. Investigations of toxic effects of fluoride in humans have evoked a lively interest throughout the world because public health programmes of fluoridation for the prevention of dental caries have been considered to involve some risk of cumulative intoxication. The influence of toxic levels of fluoride in drinking water on the structure of enamel during its formation results in the "mottled" enamel. The chronic toxic effects of fluoride on the skeletal system have been described where drinking water contains excessive quantities of natural fluoride. This form of chronic intoxication was first described in India as early as 1937.

Even since the toxic effects of fluoride ion became known considerable research has gone into fluorides human health and defluoridation of water to remove excess fluorides. NEERI has reviewed the many complex questions relating to the defluoridation methods and specific overall costs taking in the investment and operating cost which constitutes and appropriate figure to economic evaluation of different defluoridation technologies. The investment expenditures and the operating costs represent the major part of the defluoridation expenditure. Based on the analysis and comparison of various economic aspects of merit the large scale and extensively tested "Nalgonda Technique" which has already been technically realised provides a reliable method for defluoridation of water.

Nalgonda Technique involves adding in sequence an alkali, chlorine and aluminium sulphate or aluminium chloride or a combination of these two. Addition of these chemicals is followed by flocculation, sedimentation, and filtration. The details of the technique, doses of chemicals and combinations required for various concentrations of fluoride and alkalinity to achieve fluoride levels in treated water to permissive and excessive limits are available for fluoride concentration 2-21 mg F/l and alkalinity 200-1200 mg/l.

Nalgonda technique can be adopted on an individual or community basis.

IN CONCLUSION

The water technology mission aims to cover 2.27 lakhs residual problem villages by 1990 by supplying 40 lpcd potable water for human beings and 30 lpcd for cattle by evolving cost effective technology.

In all, 29,100 villages have chemical contamination problem. The management of these chemical contaminant villages require technology-driven projects which cut across technologies.

The technology-driven projects aim to replace the high capital and operating costs of conventional water supply with more affordable and easily maintainable systems that are acceptable to users.

NEERI has long been working on the removal of physical and chemical contaminants from surface and ground waters. The technologies available for testing include those for pretreatment of water, softening, removal of specific contaminants such as arsenic, chromium, cadmium, iron, manganese, nitrate, and fluoride. These have been discussed briefly.

The information on maximum contaminant levels for inorganic contaminants are presented and briefly discussed.

This document attempts to state technology known in NEERI that will allow users, with the assistance from NEERI, apply whatever treatment might be necessary to improve their drinking water quality such that it meets with the standards indicated.

The author hopes that this document will be helpful to all those participating in Water Technology Mission. It is recognised, however, that it will need to be updated as new information on treatment technology becomes available through research and development and experience at actual plants in rural areas.