

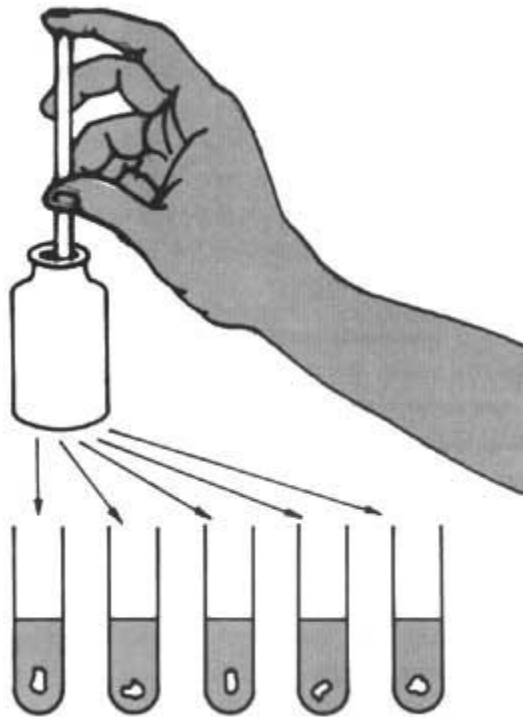
WATER QUALITY MONITORING, STANDARDS AND TREATMENT

Water sampling

Testing procedures

Investigative analysis

Water treatment methods



2.1 Water sampling

2.1.1 Borewells

2.1.2 Municipal mains

2.1.3 Water tanks and reservoirs

2.1.4 Harbour basin water

Water used for processing fish, washing fish or making ice is supposed to meet drinking water standards if it is to be considered safe. Reason: contaminated water is the main cause for pathogen-loading of fish, posing a serious health hazard to its consumer.

WHO has issued guidelines for drinking water quality, a report in three volumes. Vol. 1 deals with guideline values, Vol. 2 deals with each contaminant and Vol. 3 gives information on how to handle water supplies in small rural communities. WHO recognizes that very stringent standards cannot be used universally and so a range of guideline values for more than 60 parameters have been elaborated. Most nations have their own guidelines or standards. The control exerted by local regulatory authorities may differ from place to place depending on the local situation. So how can acceptable water quality be defined? What can the harbour-master do to ensure quality? Ensuring the quality of the harbour basin when it is contiguous with estuarine or coastal waters is perhaps beyond the scope of the harbour-master except to ensure that activities in his harbour do not add to the pollution. However, he is duty-bound to ensure that the water used for drinking, cleaning fish, ice making and fish processing meets standards of potability set in his country.

Qualitative and quantitative measurements are needed from time to time to constantly monitor the quality of water from the various sources of supply. The harbour-master should then ensure appropriate water treatment within the fishery harbour complex as well as initiate remedial measures with the suppliers when water supply from outside is polluted.

Water sampling and analysis should be done by ISO-certified laboratories. Wherever laboratories available locally are not ISO-certified, it is advisable to get their quality assessed by an ISO-certified laboratory by carrying out collaborative tests to ensure that variation in the accuracy of results is sufficiently small. Unreliable results exacerbate problems of pollution when corrective action cannot be taken in time. Sampling and monitoring tests should be carried out by qualified technicians.

Depending on the actual state of the fishing harbour infrastructure and environmental conditions in and around the harbour, monitoring should be carried out according to a specific programme for each source of water supply.

2.1.1 Borewells

Contamination may arise from pollutants entering the water table some distance from the port or from sewage entering the borehole itself in the port area through cracked or corroded casings. In cases where overdrawn is evident (water is brackish), tests should be conducted at least monthly.

2.1.2 Municipal mains

Supply could be contaminated at source or through corroded pipelines leading to the fishery harbour. Mixing with sewage lines due to defective piping has been known to occur often.

Complete tests should be carried out every half year, and the authorities should be informed when results indicate contamination.

2.1.3 Water tanks and reservoirs

Both types of structure are prone to bacterial growth if the residual chlorine levels in them are low or non-existent. Testing may not be necessary if periodic scrubbing is carried out. Bacteriological tests should be done at least half-yearly.

2.1.4 Harbour basin water

Typically, harbour basins are tested yearly. However, in areas where monsoons are very active, it may be advisable to test at the peak of the dry season when effluent point discharges tend to remain concentrated in the water body and again during the wet season when agriculture run-off may be considerable. Another critical period for harbours is the peak of the fishing season when the harbour is at its busiest and vessel-generated pollution is likely to be at its peak.

2.2 Testing procedures

2.2.1 Physical tests

2.2.2 Chemical tests

2.2.3 Bacteriological tests

While the details of sampling, testing and analysis are beyond the scope of this handbook, what follows is a general description of the significance of water quality tests usually made.

Testing procedures and parameters may be grouped into physical, chemical, bacteriological and microscopic categories.

- *Physical tests* indicate properties detectable by the senses.
- *Chemical tests* determine the amounts of mineral and organic substances that affect water quality.
- *Bacteriological tests* show the presence of bacteria, characteristic of faecal pollution.

2.2.1 Physical tests

Colour, turbidity, total solids, dissolved solids, suspended solids, odour and taste are recorded.

Colour in water may be caused by the presence of minerals such as iron and manganese or by substances of vegetable origin such as algae and weeds. Colour tests indicate the efficacy of the water treatment system.

Turbidity in water is because of suspended solids and colloidal matter. It may be due to eroded soil caused by dredging or due to the growth of micro-organisms. High turbidity makes filtration expensive. If sewage solids are present, pathogens may be encased in the particles and escape the action of chlorine during disinfection.

Odour and taste are associated with the presence of living microscopic organisms; or decaying organic matter including weeds, algae; or industrial wastes containing ammonia, phenols, halogens, hydrocarbons. This taste is imparted to fish, rendering them unpalatable. While chlorination dilutes odour and taste caused by some contaminants, it generates a foul odour itself when added to waters polluted with detergents, algae and some other wastes.

2.2.2 Chemical tests

pH, hardness, presence of a selected group of chemical parameters, biocides, highly toxic chemicals, and B.O.D are estimated.

pH is a measure of hydrogen ion concentration. It is an indicator of relative acidity or alkalinity of water. Values of 9.5 and above indicate high alkalinity while values of 3 and below indicate acidity. Low pH values help in effective chlorination but cause problems with corrosion. Values below 4 generally do not support living organisms in the marine environment. Drinking water should have a pH between 6.5 and 8.5. Harbour basin water can vary between 6 and 9.

B.O.D.: It denotes the amount of oxygen needed by micro-organisms for stabilization of decomposable organic matter under aerobic conditions. High B.O.D. means that there is less of oxygen to support life and indicates organic pollution.

2.2.3 Bacteriological tests

For technical and economic reasons, analytical procedures for the detection of harmful organisms are impractical for routine water quality surveillance. It must be appreciated that all that bacteriological analysis can prove is that, at the time of examination, contamination or bacteria indicative of faecal pollution, could or could not be demonstrated in a given sample of water using specified culture methods. In addition, the results of routine bacteriological examination must always be interpreted in the light of a thorough knowledge of the water supplies, including their source, treatment, and distribution.

Whenever changes in conditions lead to deterioration in the quality of the water supplied, or even if they should suggest an increased possibility of contamination, the frequency of bacteriological examination should be increased, so that a series of samples from well chosen locations may identify the hazard and allow remedial action to be taken. Whenever a sanitary survey, including visual inspection, indicates that a water supply is obviously subject to pollution, remedial action must be taken, irrespective of the results of bacteriological examination. For unpiped rural

supplies, sanitary surveys may often be the only form of examination that can be undertaken regularly.

The recognition that microbial infections can be waterborne has led to the development of methods for routine examination to ensure that water intended for human consumption is free from excremental pollution. Although it is now possible to detect the presence of many pathogens in water, the methods of isolation and enumeration are often complex and time-consuming. It is therefore impractical to monitor drinking water for every possible microbial pathogen that might occur with contamination. A more logical approach is the detection of organisms normally present in the faeces of man and other warm-blooded animals as indicators of excremental pollution, as well as of the efficacy of water treatment and disinfection. The presence of such organisms indicates the presence of faecal material and thus of intestinal pathogens. (*The intestinal tract of man contains countless rod-shaped bacteria known as coliform organisms and each person discharges from 100 to 400 billion coliform organisms per day in addition to other kinds of bacteria*). Conversely, the absence of faecal commensal organisms indicates that pathogens are probably also absent. Search for such indicators of faecal pollution thus provides a means of quality control. The use of normal intestinal organisms as indicators of faecal pollution rather than the pathogens themselves is a universally accepted principle for monitoring and assessing the microbial safety of water supplies. Ideally, the finding of such indicator bacteria should denote the possible presence of all relevant pathogens.

Indicator organisms should be abundant in excrement but absent, or present only in small numbers, in other sources; they should be easily isolated, identified and enumerated and should be unable to grow in water. They should also survive longer than pathogens in water and be more resistant to disinfectants, such as chlorine. In practice, these criteria cannot all be met by any one organism, although many of them are fulfilled by coliform organisms, especially *Escherichia coli* as the essential indicator of pollution by faecal material of human or animal origin.

2.3 Investigative analysis

2.3.1 Test case

A harbour master's knowledge of the state of the environment in and around the fishing harbour goes a long way toward preventing outbreaks of contamination or disease with subsequent loss of resources and income. This is particularly so for the many small-to-medium fishing ports scattered around coastlines in developing countries, where, more often than not, environmental help and support from central bodies is meagre and very time-consuming.

The following is a true-life example of an investigative analysis carried out in an ASEAN country in a harbour that was experiencing problems with hygiene (coliform contaminated fish).

2.3.1 Test case

The port in question is situated in the mouth of an estuary. The town's water supply cannot provide the port with potable water and the port draws groundwater from a series of boreholes in and around the port area. The port's storage infrastructure consists of only one elevated concrete tank which cannot be taken out of service for cleaning. Ice is supplied by outside contractors.

Current laboratory test results were examined and found to be too consistent to reflect natural changes in the environment, pointing a finger of suspicion at the laboratory's Quality Assurance.

A new laboratory with I.S.O. certification was selected to carry out the new tests.

Water samples were taken by external technicians from the port's borehole, the auction hall's water taps, each and every one of the external ice suppliers and the harbour basin.

A sample report from the laboratory is shown in Table 2-1.

In this table, the first column indicates the test parameter and the last column indicates the method used to determine the test result (sometimes, more than one method may be used to determine residuals).

The second column indicates how the parameters are measured, the third column gives the actual test result which may then be compared to the values in the fourth column. The values in the fourth column are national standards or limits set by Governments and may differ from country to country. The values in the third column should not exceed those in the fourth column.

Table 2-2 shows the recommended WHO standard limits for potable water.

Table 2-1: SAMPLE WATER ANALYSIS REPORT - PORT TAP WATER

Parameter	Unit	Test Results	Requirement	Methods
Physical & Chemical *):				
• Colour	Pt. Co scale	3	15	Colorimetric
• Odour	Pt. Co scale	negative	odourless	Organoleptic
• pH	Pt. Co scale	6.50	6.5-8.5	Electrometric
• Taste	Pt. Co scale	normal	tasteless	Organoleptic
• Turbidity	FTU	1	5	Turbidity
• Aluminum	mg/l	below 0.20	0.2	AAS
• Copper	mg/l	below 0.03	1.0	AAS
• Iron Total	mg/l	below 0.04	0.3	AAS
• Manganese	mg/l	0.06	0.1	AAS
• Sodium	mg/l	96.93	200	AAS
• Zinc	mg/l	0.047	5	AAS
• Chloride	mg/l	140.41	250	Argentometric
• Flouride	mg/l	0.09	1.5	Colorimetric

• Nitrate	mg/l	below 0.11	10	Colorimetric
• Nitrite	mg/l	0.96	1	Colorimetric
• Sulphate	mg/l	below 0.94	400	Turbidimetric
• Arsenic	mg/l	below 0.001	0.05	AAS
• Barium	mg/l	below 0.10	1	AAS
• Cadmium	mg/l	below 0.005	0.005	AAS
• Cyanide	mg/l	below 0.01	0.1	Colorimetric
• Chrom Hexavalent	mg/l	below 0.006	0.05	Colorimetric
• Lead	mg/l	below 0.01	0.05	AAS
• Mercury	mg/l	below 0.001	0.001	AAS
• Selenium	mg/l	below 0.007	0.01	AAS
• Organic Matter by KMnO ₄	mg/l	3.06	10	Permanganantometric
• Dissolved Solid	mg/l	431	1000	Gravimetric
• Hydrogen Sulphide as H ₂ S	mg/l	below 0.01	0.05	Colorimetric
• Total Hardness	mg CaCO ₃	95.49	500	AAS

Bacteriological:

• Total Bacteria	per ml	6.9 x 10 ²	1.0 x 10 ²	Pour Plate
• Coliform	per 100 ml	nil	nil	Filtration
• E. Coli	per 100 ml	nil	nil	Filtration
• Salmonella sp	per 100 ml	negative	negative	Filtration

*) Standard Methods

A. Examination of the port's deep borehole test report revealed that whereas the iron and manganese levels were over the limit, indicating vegetable matter in the aquifer, the sodium and chloride levels were low, indicating that the pump was not overdrawing. Both the nitrate and nitrite levels were low indicating that sewage intrusion into the borehole casing was not a problem. The total bacterial count, however, was very high, indicating that the water has to be chlorinated to lower the count.

B. Examination of the auction hall's tap water test report (comparing them to the borehole water) indicates that the bacterial count is slightly lower but not enough to be considered sanitary and fit for drinking. The turbidity also dropped dramatically between borehole and tap, indicating deposition of solids inside the port's only storage tank. The nitrate level also drops as the nitrates are further converted to nitrites indicating bacteriological activity inside the overhead tank as well. As it turned out, chlorinating equipment was not installed.

C. Examination of the ice test reports reveals that both sodium and chlorides are over the limit indicating either leaking cans at the ice plants (dirty brine water enters the ice water during the chilling operation) or overdrawing at the plant's borehole. Closer examination also revealed that the nitrite levels are very high (indicating decomposed sewage) and that coliforms were present in the ice. This pointed a finger at the borehole of one particular plant, which in fact was found to

be overdrawing water to meet an increase in demand. The presence of the coliforms also indicated that the ice plant's own chlorinating equipment was not functioning properly.

D. A close look at the river basin water indicated heavy contamination by sewage of the water course.

The conclusions to be drawn from the above exercise are that:

- a) The most likely source of contamination was the ice supplied to the fishermen, which in turn contaminated the fish in the holds;
- b) The port's own water supply and storage system was in need of an overhaul;
- c) The port's river water was not to be used in any of the fish handling processes.

Table 2-3 gives the EU recommendations for harbour waters in general.

Harbour water is never suitable for use in fish handling processes destined for human consumption.

Table 2-2: W.H.O. DRINKING WATER STANDARDS

PARAMETER	UNIT	LIMIT
Aluminium	mg Al/l	0.2
Arsenic	mg As/l	0.05
Barium	mg Ba/l	0.05
Beryllium	ug Be/l	0.2
Cadmium	ug Cd/l	5.0
Calcium	mg Ca/l	200.0
Chromium	mg Cr/l	0.05
Copper	mg Cu/l	1.0
Iron Total	mg Fe/l	0.3
Lead	mg Pb/l	0.01
Magnesium	mg Mg/l	150.0
Manganese	mg Mn/l	0.1
Mercury	ug Hg/l	1.0
Selenium	mg Se/l	0.01
Sodium	mg Na/l	200.0
Zinc	mg Zn/l	5.0
Chlorides	mg Cl/l	250.0
Cyanide	mg Cn/l	0.1
Fluorides	mg F/l	1.5

Nitrates	mg NO ₃ /l	10.0
Nitrites	mg NO ₂ /l	-
Sulphates	mg SO ₄ /l	400.0
Suphides	mg H ₂ S/l	0
TOTAL "drins"	ug/l	0.03
TOTAL "ddt"	ug/l	1.0
Hydrocarbons	mg/l	0.1
Anionic Detergents	mg/l	0
pH		9.2
Total dissolved solids	mg/l	1500
Total hardness	mg/l	500
Alkalinity	mg/l	500
MICROBIOLOGICAL PARAMETERS		
Total Bacteria	Count/ml	100
Coliform	Count/100ml	0
E. Coli	Count/100ml	0
Salmonella	Count/100ml	0

ug = microgram or ppb

mg = milligram or ppm

Table 2-3: EU ESTUARY AND HARBOUR BASIN WATER STANDARDS

PARAMETER	UNIT	LIMIT
Mercury	ug Hg/l	0.50 (D)
Cadmium	ug Cd/l	5.00 (D)
Arsenic	mg As/l	0.50 (G)
Chromium	mg Cr/l	0.50 (G)
Copper	mg Cu/l	0.50 (G)
Iron	mg Fe/l	3.00 (G)
Lead	mg Pb/l	0.50 (G)
Nickel	mg Ni/l	0.50 (G)
Zinc	mg Zn/l	50.00 (G)
Tributyltin	ug/l	0.002
Triphenyltin	ug/l	0.008
Aldrin	ug/l	0.01
Dieldrin	ug/l	0.01
Endrin	ug/l	0.005
Isodrin	ug/l	0.005
TOTAL "drins"	ug/l	0.03

TOTAL "ddt" all 4 isomers	ug/l	0.025
para-ddt	ug/l	0.01
Hexachloro-cyclohexane	ug/l	0.02
Carbon tetrachloride	ug/l	12.0
Pentachlorophenol	ug/l	2.0
Hexachlorobenzene	ug/l	0.03
Hexachlorobutadiene	ug/l	0.10
Chloroform	ug/l	12.0
Ethylene Dichloride	ug/l	10.0
Perchloroethylene	ug/l	10.0
Trichlorobenzene	ug/l	0.40
Trichloroethylene	ug/l	10.0
Hydrocarbons	ug/l	300.0 (G)
Phenols	ug/l	50.0
Surfactants	ug/l	300.0 (G)
Dissolved Oxygen	% Saturation	80-120 (G)
pH		6-9
Sulphide	mg/l	0.04 (S)
MICROBIOLOGICAL PARAMETERS		
Faecal conforms	per 100ml	2000
Total coliforms	per 100ml	10000
Salmonella		0
Enteroviruses		0
ug = microgram		
G = Guideline		
mg = milligram		
S = Suggested		
D = Dissolved		

2.4 Water treatment methods

2.4.1 Primary treatment

2.4.2 Secondary treatment

2.4.3 Complete treatment

Treatment of raw water to produce water of potable quality can be expensive. It is advisable to determine the quantity of water needing treatment, as **not all water used in a fishery harbour**

or processing plant needs to be of potable quality. Sizing of the equipment is crucial to produce acceptable water at reasonable cost. The main point to remember is that separate systems and pipelines are required for potable and non-potable water to avoid cross contamination. Each system must be clearly identified by contrasting coloured pipelines.

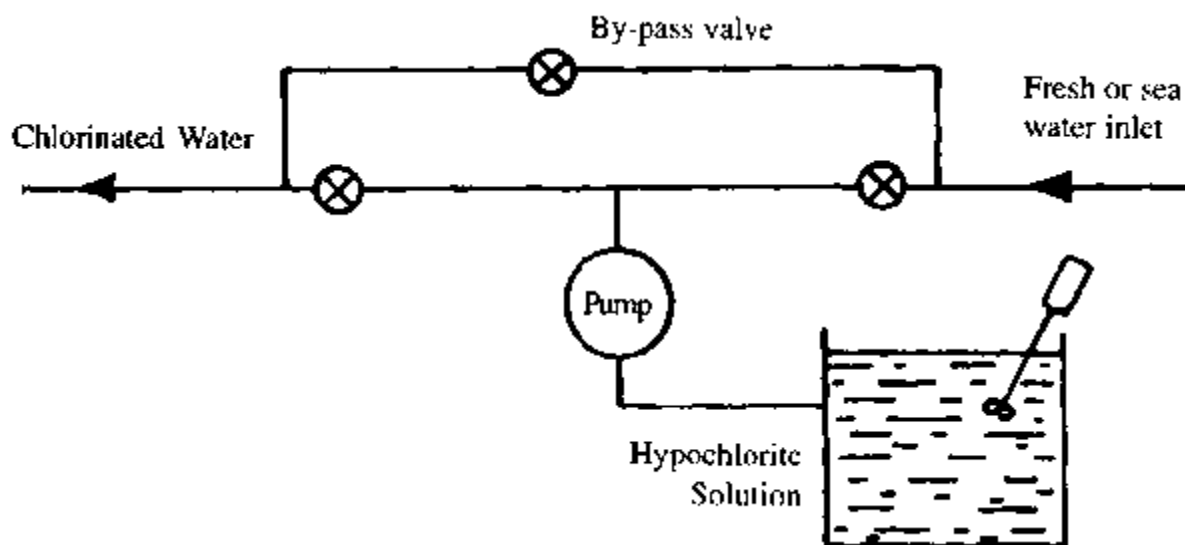
Water used for drinking, cleaning fish and ice-making must be free from pathogenic bacteria and may require secondary treatment or even complete treatment depending on chemical elements that need to be removed. Water for other needs like general cleaning may perhaps need only primary treatment.

2.4.1 Primary treatment

There are four methods of primary treatment: chlorination; ozone treatment; ultraviolet treatment; and membrane filtration.

Chlorination: Fresh or sea water can be chlorinated using either chlorine gas or hypochlorites. Chlorinated water minimizes slime development on working surfaces and helps control odour.

Figure 8: CHLORINATION TREATMENT



The main advantages of using chlorine gas are:

- It is the most efficient method of making free chlorine available to raw water.
- It lowers the pH of the water slightly.
- Control is simple; testing simple; and it is not an expensive method.

The main disadvantages are:

- Chlorine gas is toxic and can combine with other chemicals to form combustible and explosive materials.

- Automatic control systems are expensive.
- Chlorine cylinders may not be readily available at small centres.
- Chlorine expands rapidly on heating and hence the cylinders must have fusible plugs set at 70°C. It also reacts with water, releasing heat. Water should not therefore be sprayed on a leaking cylinder.

Figure 9: PERCENTAGE OF AVAILABLE CHLORINE BY WEIGHT

COMPOUND	CHEMICAL COMPOSITION	% CHLORINE BY WEIGHT
Chlorine gas	Cl ₂	100.0
Monochloramine	NH ₂ Cl	138.0
Diochloramine	NH ₄ Cl ₂	165.0
Hypochlorous Acid	HOCl	135.4
Calcium hypochlorite	Ca(OCl ₂)	99.2

Hypochlorites are generally available in two forms - sodium hypochlorite solution normally available at 10% concentration and calcium hypochlorite available as a powder.

The main disadvantages of using hypochlorites are:

- Calcium hypochlorite is not stable and must be stored in air-tight drums.
- Sodium hypochlorite is quite corrosive and cannot be stored in metal containers
- Sodium hypochlorite must be stored in light proof containers.
- It is difficult to control the rate of addition of hypochlorites in proportion to water flow.
- Hypochlorites raise the pH in water.
- They are more expensive than chlorine gas.

It is important to understand the manner in which chlorine or chlorine-releasing substances behave when added to water, depending on other substances present.

- When water contains reducing substances like ferrous salts or hydrogen sulphide, these will reduce part of the added chlorine to chloride ions.
- When water contains ammonia, organic matter, bacteria and other substances capable of reacting with chlorine, the level of free chlorine will be reduced.
- If the quantity of chlorine added is sufficiently large to ensure that it is not all reduced or combined, a portion of it will remain free in the water. This is termed as *residual free chlorine* or *free chlorine*.

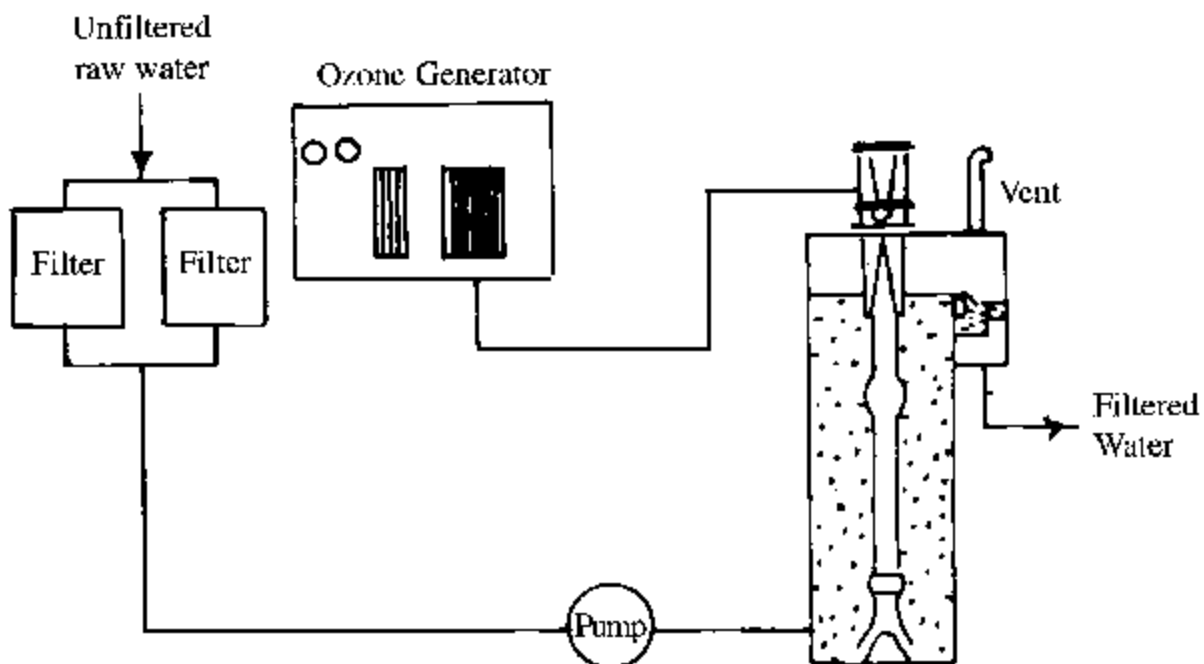
When chlorine reacts chemically as in the first two cases, it loses its oxidising power and consequently its disinfecting properties. Some ammoniacal chlorides however still retain some

disinfecting properties. Chlorine present in this form is termed *residual combined chlorine or combined chlorine*.

From the standpoint of disinfection, the most important form is free chlorine. Routine analysis always aims at determining at least the free chlorine level.

Ozone treatment: Though the principle is relatively simple, this method needs special equipment, supply of pure oxygen and trained operators. Ozone is generated by passing pure oxygen through an ozone generator. It is then bubbled through a gas diffuser at the bottom of an absorption column, in a direction opposite to the flow of raw water. Retention or contact time is critical and the size of the absorption column depends on the water flow.

Figure 10: OZONE TREATMENT



The main advantages of ozone treatment are:

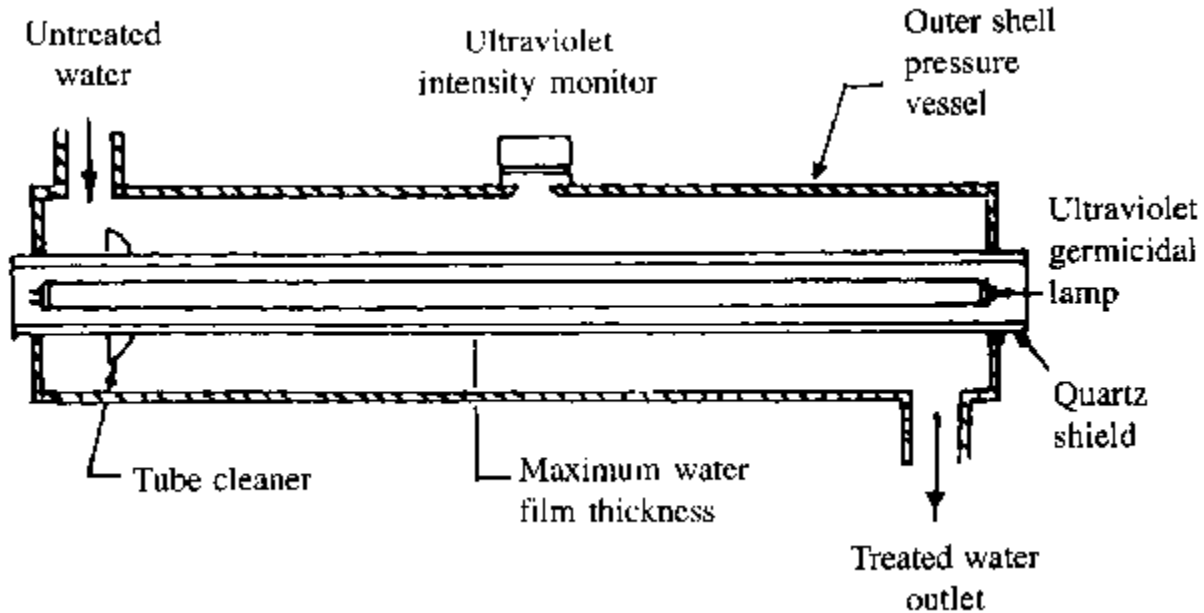
- Ozone is a much more powerful germicide than chlorine especially for faecal bacteria.
- It reduces turbidity of water by breaking down organic constituents.
- The process is easily controlled.

The disadvantages are:

- Pure oxygen may not be readily available locally.
- Ozonized water is corrosive to metal piping.
- Ozone decomposes rapidly into oxygen.
- Water has to be aerated prior to use to remove the ozone.

Ultraviolet irradiation treatment: This method is often used to treat drinking water. Successful commercial installations have been made to purify sea water in large fish processing plants.

Figure 11: ULTRAVIOLET IRRADIATION TREATMENT



The main advantages of U-V treatment are:

- U-V rays in the range of 2500-2600 Angstrom units are lethal to all types of bacteria.
- There is no organoleptic, chemical or physical change to the water quality.
- Overexposure does not have any ill effects.

The main disadvantages are:

- Electricity supply should be reliable.
- Turbidity reduces efficiency.
- Water may require prior treatment like filtration.
- The unit requires regular inspection and maintenance.
- Thickness of the water film should not exceed 7.5 cm.

Membrane filtration: Osmotic membrane treatment methods are generally expensive for commercial scale installations. Combinations of membrane treatment with U-V treatment units are available for domestic use.

2.4.2 Secondary treatment

Secondary treatment of water consists of sedimentation and filtration followed by chlorination. Sedimentation can be carried out by holding the raw water in ponds or tanks. The four basic

types of filtration are cartridge filtration, rapid sand filtration, multimedia sand filtration, and up-flow filtration.

Cartridge filtration: This system is designed to handle waters of low turbidity and will remove solids in the 5 to 100 micron range.

The main advantages are:

- Low cost and 'in-line' installation.
- Change of cartridge is simple.
- Operation is fool-proof. Once the cartridge is clogged, flow simply stops.

The main disadvantages are:

- Sudden increase in turbidity overloads the system.
- Cartridges may not be readily available and large stocks may be required.

Rapid sand filtration: This system consists of a layer of gravel with layers of sand of decreasing coarseness above the gravel. As solids build up on top, flow decreases until it stops. This is corrected by back-flushing the system to remove the solid build up on top, Figure 12.

The main advantages are:

- Cost of filtration media is negligible.
- Operation is simple.

The main disadvantages are:

- A holding tank for filtered water is required to provide clear water back flushing.
- Pumping loads increase as sediments build up.

Figure 12: RAPID SAND FILTRATION

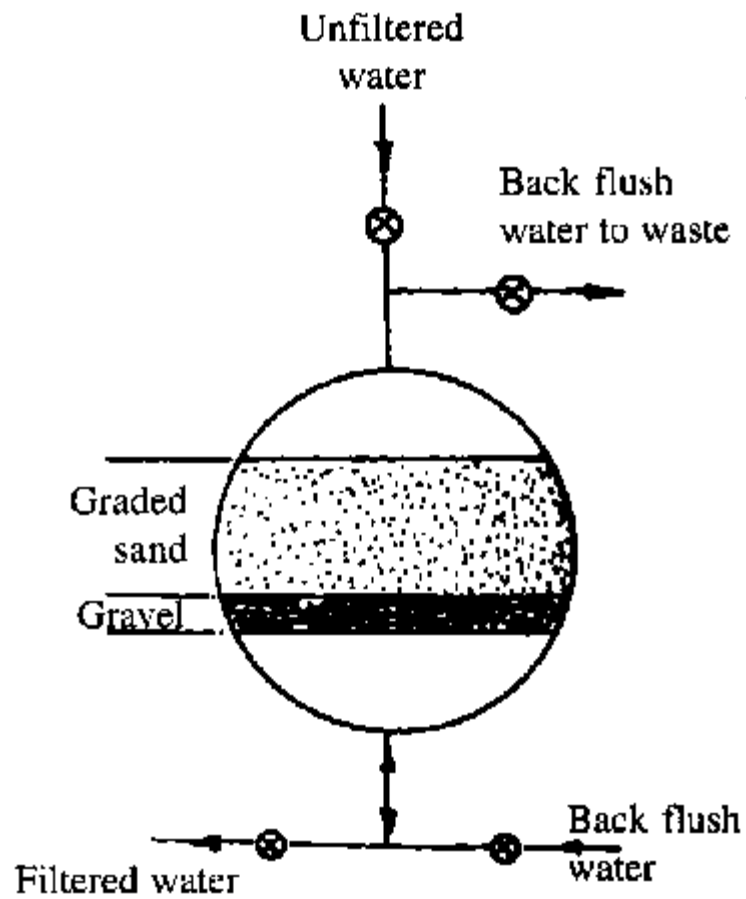
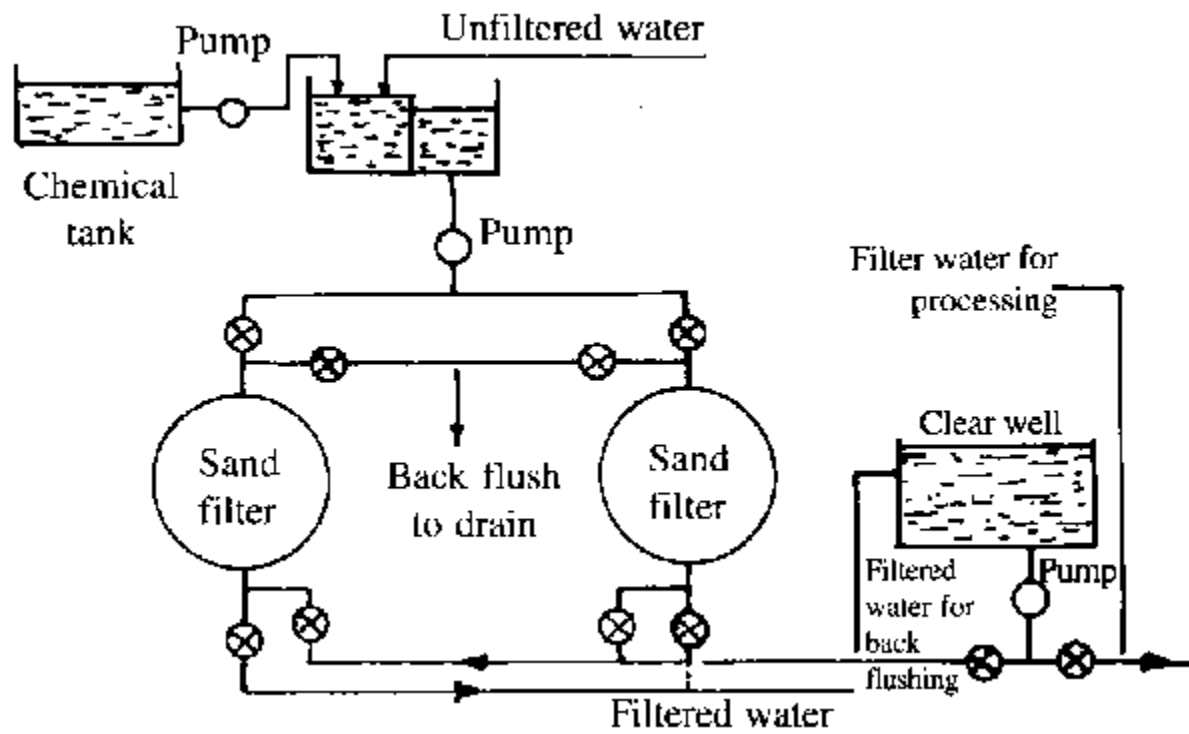
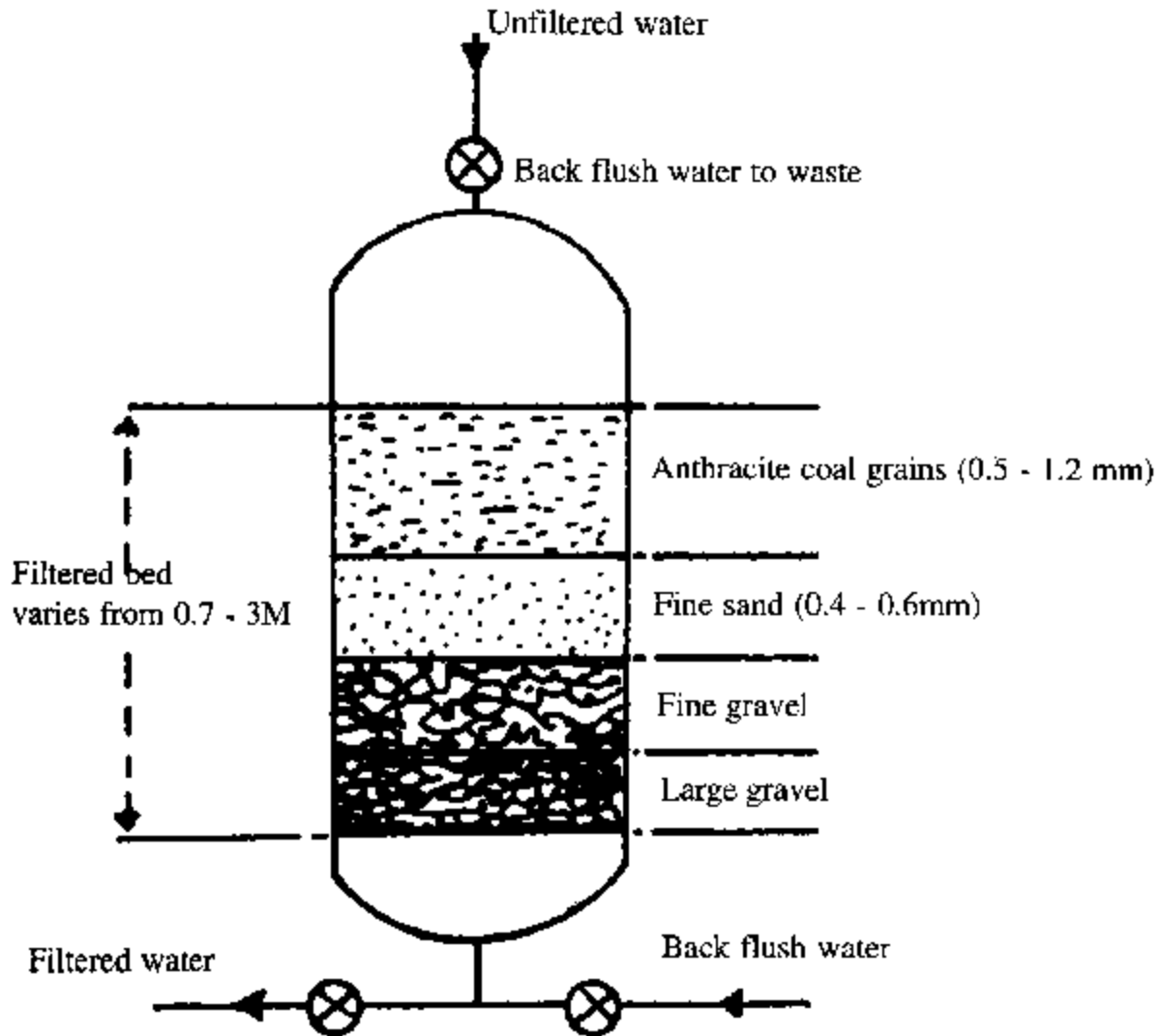


Figure 13: CONVENTIONAL SAND FILTRATION



Multimedia sand filtration: This system is similar to the rapid sand filtration method.

Figure 14: MULTI-MEDIA SAND FILTRATION



Up-flow filtration: Filtration can be at atmospheric pressure or by using a pressurised system, Figures 15a and 15b.

The main advantages are:

- High flow rates are easily attained.
- Water with turbidity up to 1500 ppm can be handled.
- Degree of filtration can be easily adjusted.
- The filter bed can be easily cleaned using the filtered water.

Figure 15a: ATMOSPHERIC PRESSURE UP-FLOW FILTER

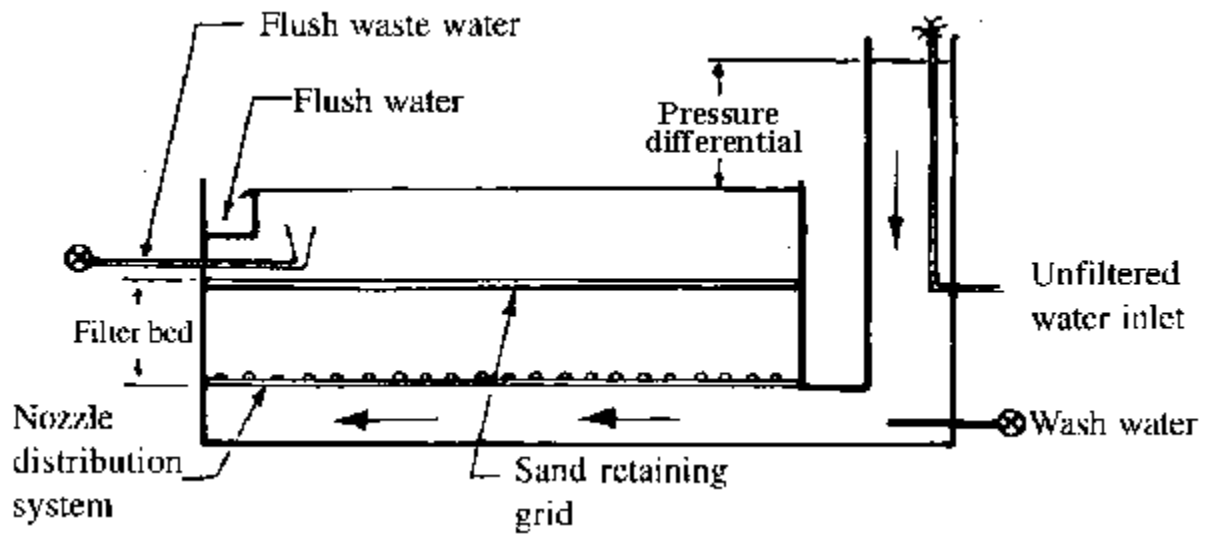
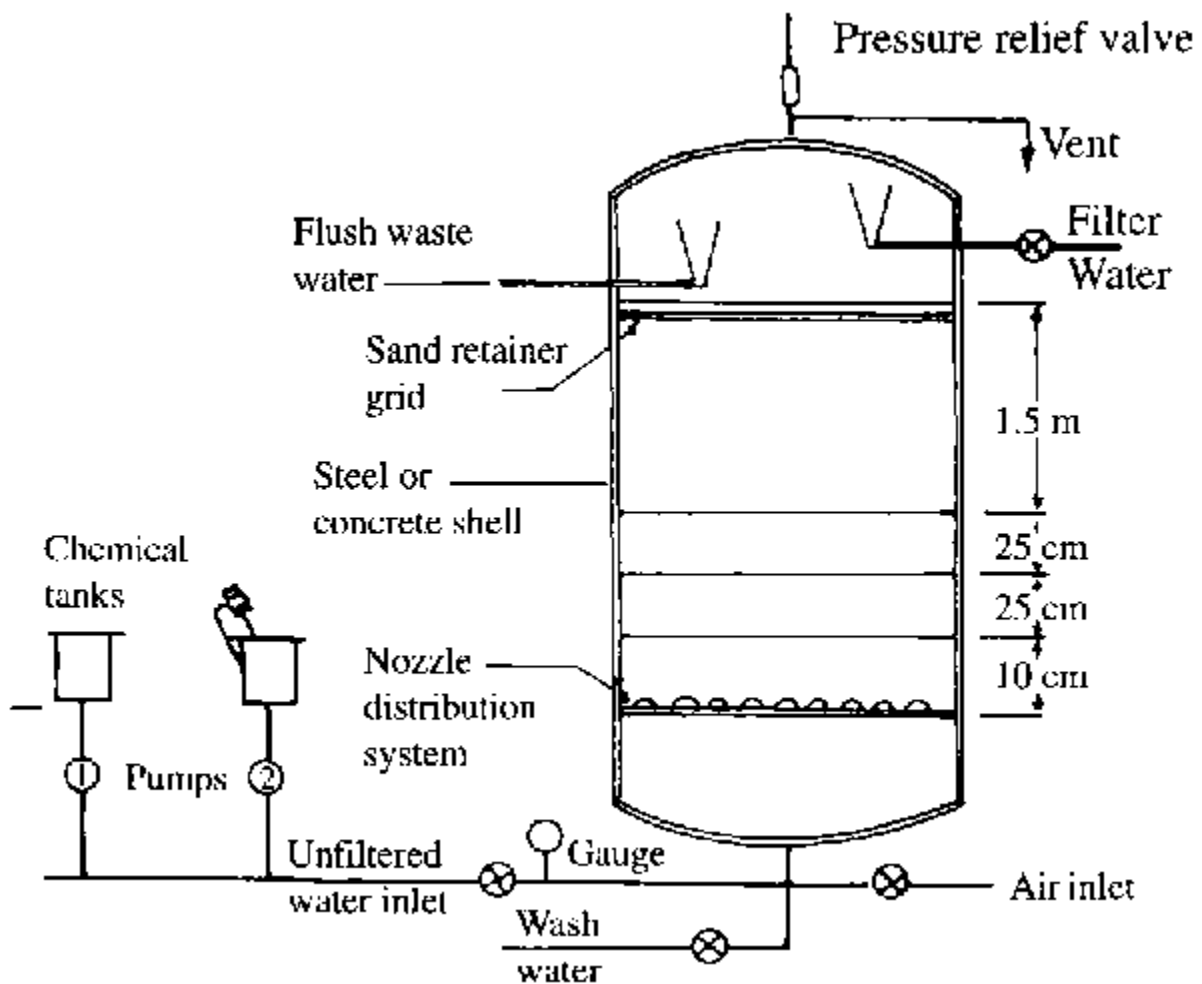


Figure 15b: PRESSURE TYPE UP-FLOW FILTER



The main disadvantage is:

- Close supervision is necessary to ensure that the filter bed does not rupture.

2.4.3 Complete treatment

Complete treatment consists of flocculation, coagulation, sedimentation and filtration followed by disinfection. Flocculation and coagulation will assist in removing contaminants in the water, causing turbidity, colour odour and taste which cannot be removed by sedimentation alone. This can be achieved by the addition of lime to make the water slightly alkaline, followed by the addition of coagulants like Alum (aluminium sulphate), ferric sulphate or ferric chloride. The resultant precipitate can be removed by sedimentation and filtration.

Chemical treatment may be required to reduce excessive levels of iron, manganese, chalk, and organic matter. Such treatment is usually followed by clarification. Iron may be removed by aeration or chlorination to produce a flocculant which can be removed by filtration. Manganese may be removed by aeration followed by adjustment of pH and up-flow filtration. Most colours can be removed by treatment with ferric sulphate to precipitate the colours.