LECTURE NOTES

For Environmental Health Science Students

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Water Supply II

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In collaboration with the Ethiopia Public Health Training Initiative, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education

2004

Funded under USAID Cooperative Agreement No. 663-A-00-00-0358-00.

Produced in collaboration with the Ethiopia Public Health Training Initiative, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education.

Preface

The principal risk associated with community water supply is from waterborne diseases related to fecal, toxic chemical and mineral substance contamination as a result of natural, human and animal activities.

When people consume water from a contaminated source, they will be exposed to infectious and other related diseases, risking possible death and disability. Therefore, it is important to make the water safe for human consumption through the utilization of different methods of protection and treatment.

For this reason, this lecture note is developed for environmental health students on how to treat water at household, small scale and large scale levels, to make the water safe for human consumption. This lecture note also includes information on water quality control for the assessment of hygienic quality of the drinking water using physical, chemical and bacteriological analysis and the principle of water pumps to lift and distribute water from shallow and deep wells for individual and community utilization.

In this lecture note, each chapter has its own learning objectives, review questions, and note for the teachers, which will help the teachers to do cognitive and summative evaluation for their students.

Acknowledgments

I express my sincere thanks to Professor Dennis Carlson and Carla A. Gale, Resident Technical Advisor at The Carter Center, for their encouraging and honorable advice in organizing teaching material development.

I am grateful to The Carter Center for its overall financial and material support and Ato Aklilu Mulugeta of The Carter Center for facilitating the lecture note preparation process.

I also thank senior reviewer Dr. Mengesha Admassu from Gondar College of Medical Sciences and the teaching staff of the Environmental Health Department for giving valuable comments and suggestions for improving this lecture note.

Finally, I wish to thank W/ro Zinash Ayalew, who single-handedly organized, edited, and provided the secretarial assistance that made each edition of this lecture note better than the last.

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List of Abbreviations and Acronyms

BOD	Biochemical Oxygen Demand
cm^3	Cubic Centimeter
COD	Chemical Oxygen Demand
CFU	Colony Forming Unit
d	Day
^0C	Degree Celsius
DO	Dissolved Oxygen
FC	Fecal Coliform
FS	Fecal Streptococci
ft	Feet
gm/l	Gram per Liter
HPC	Heterotrophic Plate Count
HP	Horsepower
Kg	Kilogram
MAC	Maximum Allowable Concentration
MF	Member Filter
m	Meter
m/h	Meter per Hour
m^3	Cubic Meter
m^3/d	Cubic Meters per Day
$m^3/c/d$	Cubic Meters per Capita per Day
µ	Micron
mg/l	Milligram per Liter
ml	Milliliter
MPN	Most Probable Number
NTU	Normal Turbidity Unit
ppm	Part Per Million
%	Percentage
PCA	Plate Count Agar
ppt	Precipitate
SS	Suspended Solid
TC	Total Coliform
^OH	Unit of Color
US	United States
w	Weight
WHO	World Health Organization

CHAPTER ONE

TREATMENT OF WATER ON A SMALL SCALE

1.1 Learning Objectives

At the end of this chapter students will be able to:

1. Mention methods of treating household water supplies
2. Describe the principal health risk associated with household water storage
3. Design and construct different household water filtration method
4. Mention chemicals and their dosage used in water treatment at household level.

1.2 Introduction

In most rural areas and small communities in developing countries, adequate water treatment procedures are almost non-existent, mainly for economic reasons. Generally, water for human use is collected from various unprotected water holes, and is consumed without treatment.

Naturally, water-borne diseases are prevalent among communities that consume such untreated contaminated water, and such practices must be discouraged. Water must be adequately treated before consumption, even in rural areas.

Therefore, small-scale treatment of water in emergency situations, temporary settlement areas, at household level and areas where the municipality is not well organized is very important to reduce the problem of waterborne disease through the utilization of different methods of water treatment
Treatment of household water supplies may be effected by the following methods, used singly or in combination, depending on the reliability of each method.

1.3. Boiling

Boiling is one of the most reliable methods of disinfecting water at household level. Provided that water is brought to the boiling point, and is kept boiling for 15 to 20 minutes, all forms of micro-organisms, including the most resistant spores or cysts, will be destroyed.

Furthermore, boiling is effective for all kinds of raw water, unless the water contains toxic chemicals which boiling cannot destroy.

Yet although boiling is one of the most practicable methods of treating water, it may not be used if a community has not developed the habit of drinking boiled water. Boiled water has at least one disadvantage, and that is its flat taste, due to the loss of dissolved gases (carbon dioxide and oxygen) and minerals during the process of boiling. This can be remedied, however, by keeping the boiled water for a few hours in partially filled containers. The flat taste may not be a hindrance if a continuous effort is made to develop the habit of drinking boiled safe water.

Great care must be taken to avoid recontamination of the boiled water either during storage or consumption. It must be stored in a clean, firmly covered container, preferably the same container in which it was boiled.

Health caregivers should take into consideration the importance of health education to change the habit of people towards safe water supply through boiling of water to reduce the problems of waterborne disease.

1.4 Filtration

Filtration for household water supply is generally carried out by simple filtration systems, such as:

A) Homemade Sand Filters

These can be set up in individual homes, in containers such as steel barrels, drums, etc., that are locally available. An example is shown in Figure 1.1.

The components of the filter media and the basic principles of operation of a homemade sand filter are the same as those of a slow sand filter. The minimum depth of filter sand should not be less than 60 cm.

A properly constructed and carefully maintained homemade sand filter can remove most of the substances that cause turbidity, taste and odor, the cysts and ova of parasites, and other relatively larger organisms.

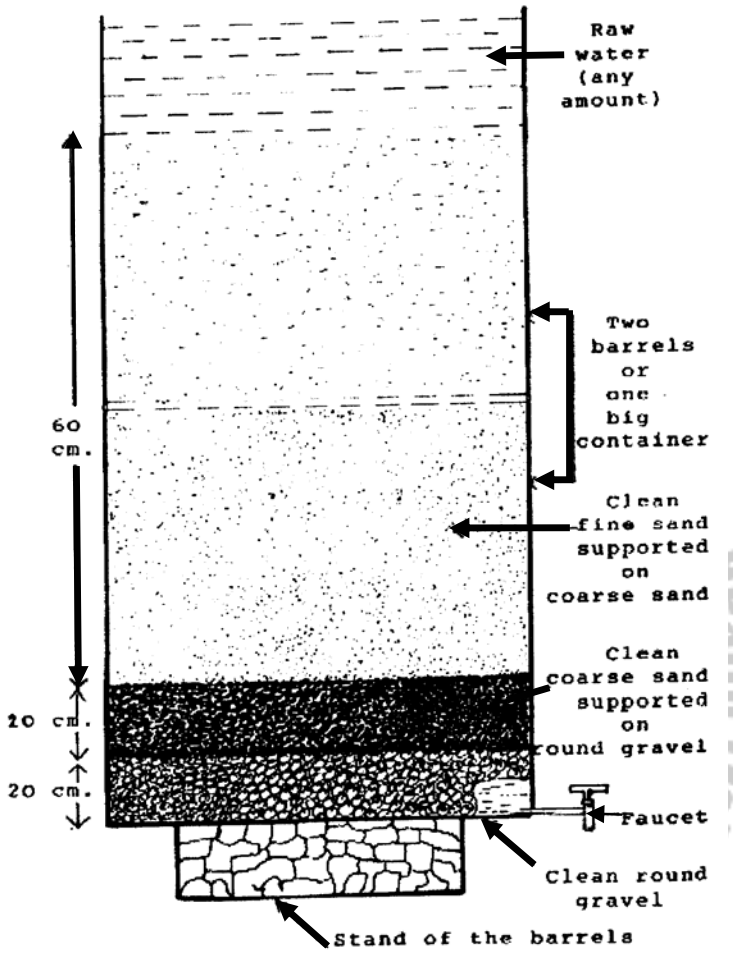

Figure 1.1. Home made sand filter

(Adapted from Gabre- Emanual Teka. Water Supply-Ethiopia: An Introduction to Environmental Health Practice, 1997.)

Some of the limitations of a homemade sand filter are:

1. It cannot be relied upon to remove all forms of pathogenic organisms, particularly the viruses and some of the very small-sized bacteria.
2. It frequently gets clogged, particularly if the raw water to be filtered is turbid.

Maintenance of a homemade sand filter

1. There must be a continuous flow of raw water over the filter bed.
2. The rate of filtration should normally be controlled to not more than 1.5 liters per minute. This rate will be achieved after the filter has been in operation for a few days.
3. The top-most layer of the sand must be scraped off, cleaned and replaced at fixed periods.

B) Home Candle Filters

There are commercially made for filtering individual water supplies. There are various types and sizes, known by different trade names.

The core of the filter is a porous cylinder (shaped like a wax candle, hence the name), made from high-quality unglazed porcelain (See Figure 1.2). The efficiency of filtration depends upon the pore size of the candle. Different manufacturers

produce candle filters of varying pore sizes, but generally the pore size varies from a maximum radius of about 50 microns to a minimum radius of 0.3 micron. (A micron is one-millionth of a meter.)

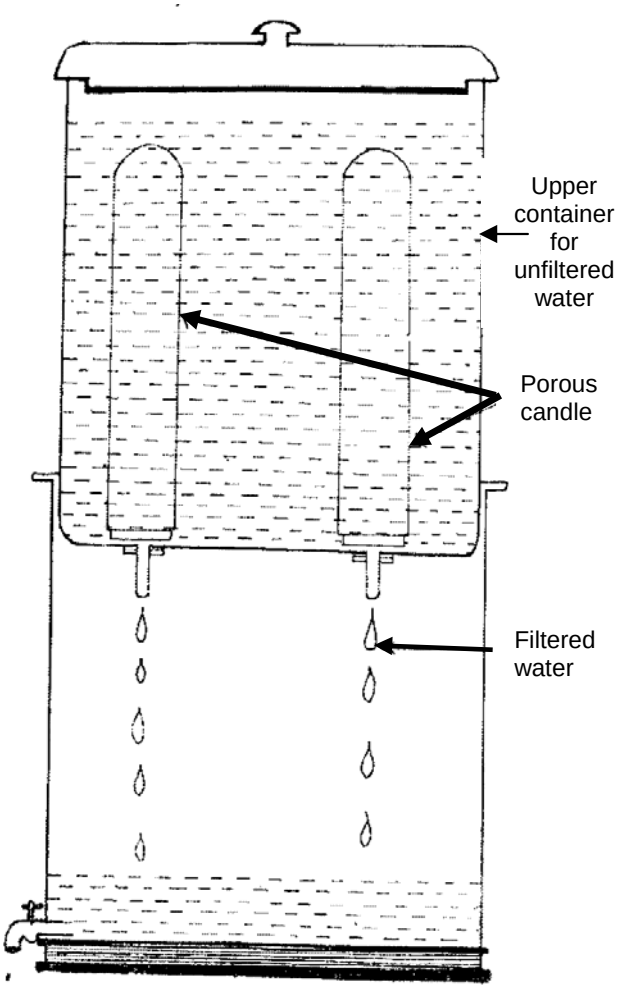

Figure- 1.2- Candle Filter

(Adapted from Gabre-Emanual Teka. Water Supply,Ethiopia, An Introduction to Environmental Health Practice, 1997.)Some of the limitations of candle filters are :-

1. The average size of a bacterium is about 1.5 microns. Thus, candle filters with a pore radius of more than 1.5 microns may not remove all the pathogenic organisms that may be present in the water. Viruses, for example, cannot be removed by a candle filter.
2. The rate of filtration of a candle filter is normally very low, although the rate can be increased by having a three-candle or four-candle filter
3. Candle filters are relatively too expensive for wide use by the general public.

Maintenance during operation

1. The raw water to be filtered must be reasonably clear, in order to reduce clogging of the candle pores.
2. The candle needs dismantling once a week, for washing and sterilizing in boiling water.

C) Stone filters

Stone filters are similar to candle filters but are carved from porous local stone (see Fig. 1.3.). They are generally difficult

to clean and heavy to lift, but have the advantage of being relatively inexpensive if they can be produced locally. If these filters were commonly used in a practical area, it would be worthwhile to test the water from a representative sample to determine the efficiency of removal of fecal contamination. This method of filtration could be possible in Ethiopia using the local “Beha” stone. But it needs research to introduce this method of filtration for individual and community use.

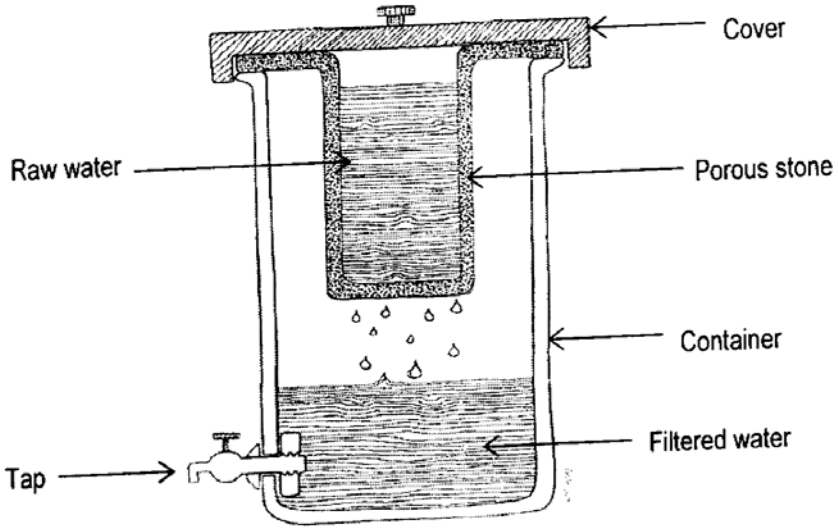

Figure –1.3- Stone filter

(Adapted from WHO’s Guidelines for Drinking Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume3, 1997.)

D) Cloth filtration to prevent guinea worm disease

Guinea-worm disease (dracunculiasis) is transmitted via contaminated drinking water (e.g. from stagnate ponds, cisterns, or step wells). The disease occurs in a number of countries in Africa and Asia and causes severe suffering and disability among the world's most deprived people. Infected individuals do not develop immunity. There is no known animal reservoir, and people can disseminate the parasite one year after infection and during 1-3 weeks after emergence of the worm. For these reasons, control of transmission, including treatment of drinking water, is simple, and global eradication of this disease is feasible.

Dramatic reductions in the prevalence of dracunculiasis have been achieved through improvement of water supplies and by promoting proper hygiene in areas where the disease is endemic. In such areas, guinea worm (Dracunculus medinensis) can be effectively eliminated by filtering all drinking water through fine cloth (see Fig. 1.4). Filtration of drinking water is thus a primary strategy for the control of guinea-worm disease.

Filters should be of mesh size less than 130 µm; this should remove all infected intermediate hosts. Monofilament synthetic cloth (nylon) is most suitable because it clogs less rapidly and is easily cleaned; it has a mesh size of 100-130

µm. Cotton cloth can be used but tends to clog rapidly. Boiling is also effective as a means of controlling the disease.

Figure 1.4. Cloth filtration

(Adapted from WHO - Guidelines for Drinking Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume3, 1997.)

1.5. Chemical Disinfection

A) Chlorine or its compounds

Chlorine or its compounds can be applied to disinfect water on a small scale, as described in the next chapter.Methods such as siphon-bottle feeders can be used easily f for household water disinfection.

When dealing in terms of liters, 3 drops of 1% chlorine stock solution applied to every liter of water can give satisfactory disinfection; the dose can be doubled if the water is turbid.

The tablet forms of chlorine, such as Halazone, may be effectively used under field conditions when camping and during travel (dose: 1 tablet per liter of clear water.)

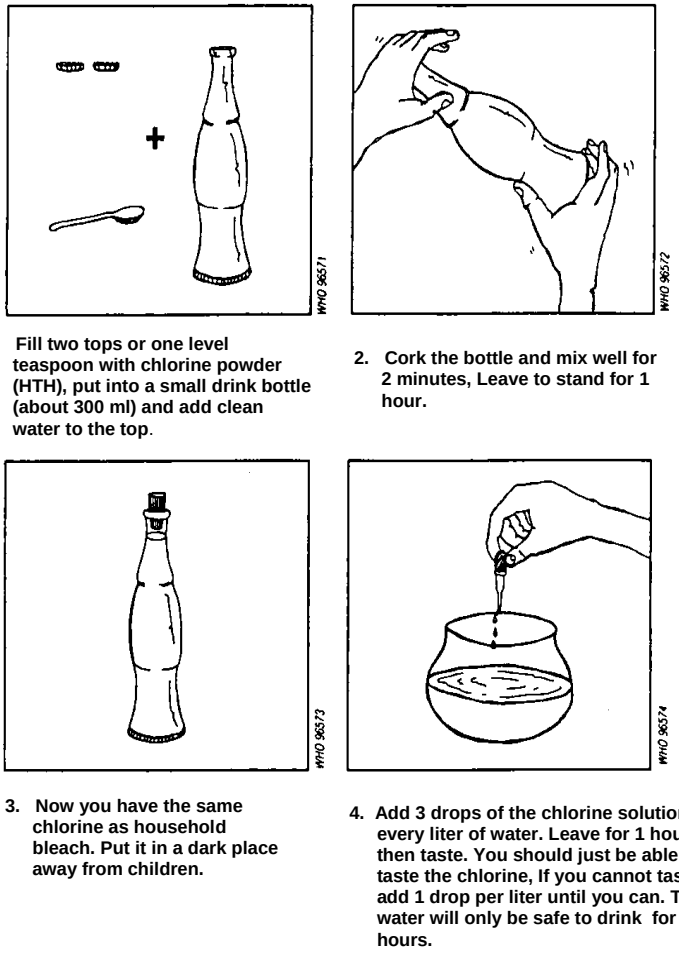

Figure-1.5.- Method of preparing chlorine solution using local material

(Adapted from WHO's Guidelines for Drinking-Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume-3, 1997.)

B) Iodine and its compounds

Iodine and its compounds have also been effectively used for individual water disinfection. In fact, iodine is believed to be a better disinfectant than chlorine. Tablets of iodine, like those of chlorine, are available under various trade names (Globaline, Potable Aqua, etc.). Tincture of iodine (2%) applied at the rate of 2 drops per liter gives satisfactory results. Iodine, however, is relatively expensive for ordinary use, and in addition imparts to the water the familiar medicinal iodine smell.

C) Silver

Colloidal silver was used by the Romans to protect the quality of water in storage jars since, at concentrations of about 0.05 mg/l, silver is toxic to most micro-organisms. It is of value for small portable filter units for field use where silver-impregnated gravel filter candles remove turbidity and provide disinfection. The cost becomes excessive for other than very small supplies.

1.6. Household Water Storage

When household storage is well practiced in the community, turbidity will be reduced, bacteria and eggs of parasites will be

sedimented, and schistosomiasis will be prevented because the chances of cercaria survival after 24 hours of water storage will be reduced.

The principal health risk associated with household water storage is the ease of recontamination during transport and storage, particularly if the members of a family or community do not all follow good hygiene practices. **Good hygienic measures include the following:**

- Careful storage of household water and regular cleaning of all household water storage facilities:
- Construction, proper use, and maintenance of latrines;
- Regular hand-washing, especially after defecation and before eating or preparing food;
- Careful storage and preparation of food.

Water that is clean from the supply or has been treated in the household needs to be protected from recontamination.

The most important elements of water storage can be summarized as follows:-

- Use a clean water source or treat the water, either at home or in a storage tank.

- Store water in an earthenware or plastic container with a lid.
- Store the water container at a height that puts it beyond the reach of children and animals.
- Fit a tap to the container for drawing clean water in order to prevent contamination by dirty cups, ladles, or hands.

Storage tanks

Where a piped water supply to the household operates intermittently, a storage tank is commonly used to ensure that there is sufficient water for the family needs throughout the day. The tank should be covered to prevent contamination of the water and to restrict access by children and animals. It may be located inside or outside the house, but a secure cover should be fitted to an outdoor tank.

If the water running into the tank is clean (i.e. comes from a protected source or a treatment plant), the tank should be inspected, cleaned, and disinfected at least once a year. Where the water supplied is not clean, the tank will require more frequent cleaning, the frequency depending on the water quality. Water of poor quality should be treated by the most appropriate means.

The pipes running from a household storage tank to the taps must not be made of lead, which is toxic; pipes made of galvanized iron, copper, or plastic (such as potable grade PVC) should be used instead. Galvanized iron pipes should not be used where the water supplied is highly acidic or alkaline because they will corrode.

A non-lead solder should be used, where possible, to join metal pipes and a nontoxic solvent cement for plastic pipes. The system should be thoroughly flushed before use to remove and traces of solvent or metal solder from the pipes.

When a household storage tank and pipes for drinking water are installed, they should ideally be filled with water containing 50 mg/liter of chlorine and left to stand overnight so that the system is disinfected before use.

Review Questions

1. What makes boiled water less attractive than the unboiled water?
2. What are the health risks associated with household water storage?
3. What are the advantages and disadvantages of homemade sand filters?
4. Justify the reason why iodine is believed to be a better disinfectant than chlorine.

Note to the teacher

In a developing country like Ethiopia, provision of adequate and safe water supply through large-scale water treatment is very difficult. The only choice to protect the community from waterborne disease is through the internalization of household water treatment methods that can be easily practiced.

Using your own local materials, arrange a practical session in developing household filtration media and show students the efficiency of filtration of fecal coliform, using bacteriological analysis.

CHAPTER TWO

CONVENTIONAL LARGE SCALE WATER TREATMENT

2.1. Learning Objectives

At the end of this chapter students will be able to:

1. Define water treatment.
2. Explain the main objective of water treatment.
3. Identify the criteria required in classifying raw water treatment.
4. Write and discuss steps in conventional large-scale water treatment.

2.2. Introduction

Water is used for many purposes associated with human activity. In its natural state it occurs in and on the ground in sub-surface and surface reservoirs. The quality and reliability of a source of water will vary considerably, both in time and space. This means that characteristics (chemical, physical, and biological) will differ greatly depending upon the location and type of source. It also means that a given source may vary over the seasons of the year.

Thus, in the selection of a water source, consideration is usually given to the use to which the water will ultimately be put, so as to minimize the cost of treatment. Simultaneously, consideration must be given to the reliability of the source to provide an accurate and constant source of supply.

Ground water supply may enjoy the benefit of requiring little or no treatment, while a surface supply such as a river, pond or lake may require considerable and perhaps seasonally varying treatment. However, a surface supply is visible and therefore more reliable whereas a ground water supply may just disappear with no warning or notice. In certain areas, fresh water is so scarce that the source must be accepted and choices are not available.

In 1854, cholera claimed the lives of 10,675 people in London, England. In 1910, the death rate from typhoid fever in the City of Toronto, Canada, was 40.8 per 100,000. By 1931 it had fallen to 0.5 per 100,000. These improvements all related to the extensive water purification and sterilization techniques that were introduced to municipal water treatment systems during that period.

We must therefore determine the significance of water quality before we examine the types of treatment that are necessary to achieve this quality. Water quality very much depends upon the use for which the water is intended. For example,

industrial boiler feed water requires a very low hardness because the hardness tends to deposit on the pipes in the boiler system and reduces the efficiency of the heat transfer. However, if the hardness of the boiler feed water is zero, the water tends to be very corrosive and this of course is also very undesirable for a boiler system.

Thus, assuming that natural water requires some kind of treatment in order to achieve certain predetermined standards, and the process of treating these waters can be subdivided into physical and chemical processes, the remainder of this section will deal with the physical and chemical methods of treating water for municipal use.

Water treatment on a large scale is utilized where the population is larger and when there is an organized municipality operating the treatment plant for the production and distribution of adequate and safe water for the community. It is different from treatment of water on a small scale; hence, it utilizes different complicated steps of water treatment units for filtration of raw water for large populations.

Water Treatment – This is defined as the process of removing all those substances, whether biological, chemical or physical, which are potentially dangerous or undesirable in water supply for human and domestic use.

Main objective of water treatment

1. To remove pathogenic organisms and consequently to prevent waterborne disease.
2. To remove substance which impart color, taste or odor to the water.
3. To remove excess or undesirable chemicals or minerals from the water.
4. To regulate essential elements or chemicals that may be in excess or lacking in a certain water supply (e.g. fluoridation or defluoridation of water, softening of water, etc.)
5. To remove excess or undesirable dissolved gasses.

In order to achieve these objectives, water treatment procedures may involve a simple physical process such as sedimentation, or complex physio-chemical and biological processes, depending upon the undesirable elements or substance present in the raw water that we need to improve.

The treatment process or processes to be used in any specific instance will depend upon the nature and quality of the raw water to be treated, which will in turn depend on the source of the raw water and its surroundings, particularly the existence of actual and potential sources of contamination. Nevertheless, treatment processes and practices have been generally standardized, and the steps applied are universally practiced.

Preliminary planning of water treatment plant work should include a comprehensive study of the catchments area in terms of:

1. Size, topography, population division and surface geology
2. Source of pollution
3. Sewage treatment facilities
4. Raw water characteristics including physical, radiological, chemical, bacteriological and biological characteristics
5. Rainfall and run-off data
6. Evaporation rate
7. Anticipated water supply requirement, (minimum, maximum and average); and
8. Other items of importance in providing a safe water supply, adequate in amount for the community in question.

For the purpose of classifying and evaluating raw water quality with respect to its treatment requirements, the United States Department of Public Health has offered the following criteria:

Group I - Water requiring no treatment, underground water without any possibilities of contamination.

Group II - Water requiring disinfections only. Water from underground and surface sources subjected to a

low degree of contamination; Clear (with out turbidity) and having an MPN of coliform organisms not exceeding 50 per 100 ml in one month.

Group III- Water requiring complete rapid sand filtration treatment or its equipment, together with continuous chlorination by pre- and/or post-chlorination. All water requiring filtration for turbidity and color removal, having a high or variable chlorine demand, or polluted by sewage so as not to be admissible to Group I or Group II and having an MPN of coliform organisms not more than 5,000 per 100 ml in 20% of samples examined in any one month.

Group IV- Water requiring auxiliary treatments in addition to complete filtration and post-chlorination; water which might require pre-sedimentation or long term storage of 30 days or more with pre-chlorination, and having an MPN more than 5,000 per 100 ml in more than 20% of sample collected but not more than 20,000 per 100 ml in more than 5 % of sample collected.

Group V- Water requiring unusual treatment measures; water requiring treatment by multiple chlorination or other provisions and not falling in to Group I-IV, but having to be used because of unusual circumstances, and having in no case an MPN exceeding 250,000 per 100 ml.

The most important factors influencing in selection of treatment processes are:

- Treated water specifications.
- Raw water quality and its variations.
- Local constraints (availability of skill, manpower and funds).
- Relative cost of different treatment processes.

2.3 Steps in Municipal (Conventional Large Scale) Water Treatment Plant

1. Preliminary water treatment
   -The source and intake of the raw water
   - Screening
2. Aeration and pre-chlorination
3. Coagulation and flocculation
4. Sedimentation
5. Filtration
6. Post-chlorination
7. Supplementary treatment

2.3.1 Preliminary Water Treatment

To protect the main units of a treatment plant and to aid in their efficient operation, it is necessary to remove any large floating and suspended solids that are often present in the inflow. These materials include leaves, twigs, paper, rags and other debris that could obstruct flow through a plant or damage equipment in the plant.

The Source and Intake of the Raw Water

The intake phase of municipal water treatment starts with a careful survey of the sanitary condition of the entire catchments basin or drainage area of the source of the raw water, whether it is river, lake or artificial pond. As a rule, the source, especially the intake area, should be fenced around or maintained in such a way that gross pollutants such as sewage and industrial waste are entirely prevented from entering it. Obviously, the better the quality of the raw water, the more the saving in treatment cost.

An appropriate size of intake pipe is installed at a carefully selected point at the source, and a pumping station, if needed, is constructed at the size of the intake. Then, depending on the presence of undesirable substances in the raw water, the treatment process is selected.

Screening

River water frequently contains suspended and floating debris varying in size from logs to small rags. These solids can clog and damage pumps or impede the hydraulic flow in open channels and pipes. Screening is the first step in treating water containing large solids (see figure 2.1).

Type of Screening

A) Coarse screening

River water intakes are commonly located in a protected area along the shore to minimize collection of floating debris. Lake water is withdrawn below the surface to preclude interference from floating materials. Coarse screens of vertical steel bars having openings of 1-3 inches are employed to exclude large materials. The clear openings should have sufficient total area so that the velocity through them is less than 3 feet per second. These screens are available with mechanical rakes to take accumulated material from the bars. A coarse screen can be installed ahead of a finer one used to remove leaves, twigs, small fish, and so on.

Whatever the source of water, it is necessary to insert some kind of screen in the system in order to prevent the passage of solids in the subsequent steps of water treatment. If the source of water is a well, the screens tend to be designed to

prevent the admission of sand from the water bearing strata in to the pumping system. Where water supply is drawn fromrivers or lakes, the intake usually has to be screened and built of corrosion-resistant materials in order to prevent the admission of fish or logs or any other undesirable solids into the system.

B) Micro-strainer (Fine Screen)

The micro-strainer is a development of the drum screen that uses a fine woven stainless steel mesh with aperture sizes of 20-60 µm to provide removal of relatively small solids. It has applications in water treatment for removal of algae and similar size particles from water of otherwise good quality.

A micro-strainer is also employed as a final tertiary stage to produce a high-quality sewage effluent. Because of the small mesh apertures, clogging occurs rapidly so that the drum is rotated at a peripheral speed of about 0.5 m/s and the mesh continually washed clean by high-pressure sprays. Straining rates in normal usage are 750-2500 m^3 /m^2/d.

The design of micro-strainer installations is based on the laboratory determination of empirical characteristics of the suspension known as the filterability index. This parameter measures the behavior of the suspension with reference to its clogging properties and can be used to determine the

allowable straining rate to prevent excessive clogging and possible physical damage to the mesh.

In some locations where it is found that seasonally algal blooms become a nuisance, micro-straining has been introduced. Micro-strainers are a very fine weave of stainless steel wire with apertures sufficiently small to prevent the passage of the microscopic algae which is normally found in an algal bloom. Such a screening system is normally only required on a seasonal basis and in certain locations where these problems are prevalent. Micro-straining is conducted at such a very small diameter orifice that it is sometimes considered to be a part of filtration.

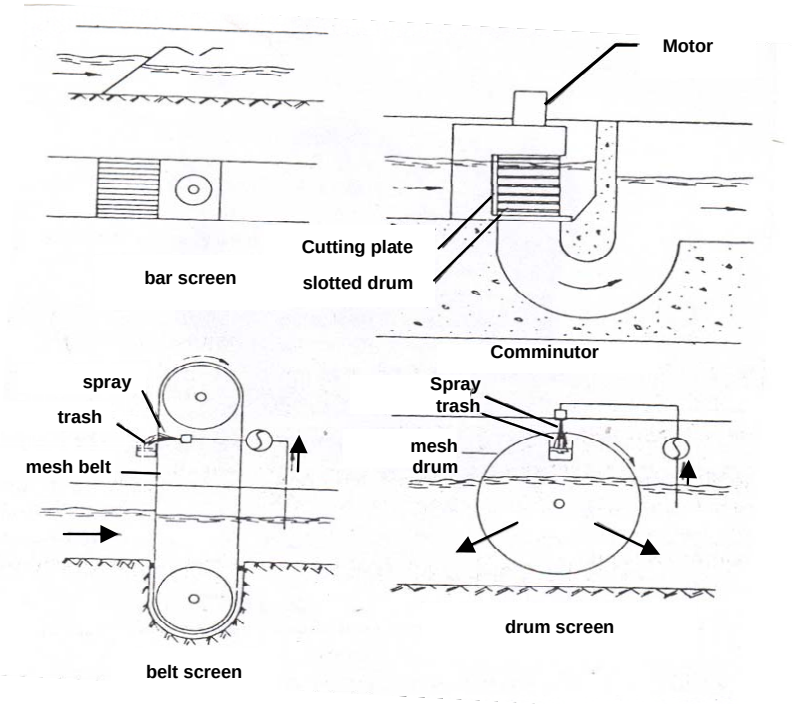

Figure 2. 1. The preliminary treatment units

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

2.3.2. Aeration and pre-chlorination.

Within the hydrological cycle, freshwater is exposed to the earth's atmosphere in falling rain and snow, and in runoff from rainfall and snowmelt gathered in the brooks and rivers, ponds, lakes, and reservoirs. In reduced volume, freshwaters are exposed also to ground air within the voids of soils through which seepage waters flow. From the free

atmosphere, surface water absorbs mainly oxygen and nitrogen in smaller amounts, and carbon dioxide, hydrogen sulfide, and other gases released to the atmosphere by:

1. household and industrial operation (mainly the combustion of fuels), and
2. the respiration of living things ranging from man and the higher animals to the saprophytes responsible for the degradation of organic matter.

From the ground air, groundwater may absorb methane, hydrogen sulfide, and large amount of carbon dioxide, all of them gases of decomposition that accumulate in the ground. When plants die, the stubble of crops is left to rot, leaves fall, and organic waste substance are destroyed by bacteria, moulds, and other micro-organisms of the teeming soil. Currently, groundwaters may surrender their dissolved oxygen to the saprophytes. If all the available oxygen disappears, decomposition becomes anaerobic. Similar change takes place also in the stagnant depths of ponds, lakes, and reservoirs and in tidal estuaries in which organic detritus is laid down in benthal deposits.

From what has been said, it is clear that the discharge of putrid or decomposable organic matter into natural water by households and industry and its entrance into these waters as

decaying or as fertilizing elements through run off from agricultural lands increase the aquatic food supply and within the general lands increases the aquatic food supply and within the generation of gases of decomposition, while draining heavily on available oxygen resources, thereby affecting the quality of water.

In most instances the engineering objective of aeration is either the removal of gases and other violet substance from the above-water source. In some instances, however, air may be injected into water slowly for purposes of agitation.

Aeration for gas exchange in simplest and the most direct form has the following aims:

1. Addition of oxygen to oxidize dissolved iron and manganese in water drawn from the ground and, in wide measure, to maintain wanted oxygen tension in waste water treatment and disposal including both natural and induced aeration of polluted water.
2. Removal of carbon dioxide to reduce corrosion and interference with lime-soda softening;
3. Removal of hydrogen sulfide to eliminate odor and taste, decrease the corrosion of metals and disintegration of cement and concrete, and lessen interference with chlorination.

4. Removal of methane to prevent fires and explosions; and
5. Removal of volatile oils and similar odor and taste producing substances released by algae and other micro-organisms.

Aerator spaces, especially enclosed spaces, should be well ventilated not only to create effective differentials in gas concentration between the two phases, but also to prevent:

1. Asphyxiation of operating or repair crews and visitors by carbon dioxide,
2. Their poisoning by hydrogen sulfide and,
3. Formation of explosive mixtures of methane with air.

Pre – chlorination

Pre-chlorination replaces aeration in some water purification plants. Pre-chlorination accomplishes a similar objective to aeration, and in addition, it helps to control the growth of algae, which cause the clogging of filter sand. Pre-chlorination should not be confused with the universal practice of chlorination or disinfecting; the latter practice is usually termed as post-chlorination

Use of Pre –chlorination will:

- Improve coagulation
- Reduce taste and odor caused by organic sludge in the sedimentation tank
- Reduce excess growth of algae and other organisms
- Reduce frequency of cleaning sand filters

Pre-chlorination is not applicable in developing country like Ethiopia where the process is uneconomical and very difficult from the practical point of view.

2.3.3. Coagulation and flocculation.

Many impurities in water and wastewater are present as colloidal solids, which will not settle. Their removal can be achieved by promoting agglomeration of such particles by flocculation with or without the use of a coagulant followed by sedimentation or flotation.

Most commonly used coagulants are:

A) Aluminum Sulphate
B) Ferrous Sulphate
C) Ferric Sulphate
D) Magnesium Carbonate
E) Polyelectrolyte
F) Copper Sulphate

The principle of chemical coagulation in terms of chemical reaction.

Most of the suspended particles in water are in colloidal form. Colloids may be defined as minute particles that exist in dispersed state in a liquid, in this case water. The average size of colloidal particles ranges from one micron (one micron is equivalent to 1/10,000 cm. ,or 10^{-3} millimeters) to 100 millimicrons.

When a solution of aluminum sulphate is added to the water, however, its molecules dissociate into Al^{3+} and SO_4^{-2}. Some of the positively charged molecules of alum (Al^{3+}) combine with the negatively charged colloids in the water; thus

$$Al^{3+} + \text{Colloid} \rightarrow \text{Al Colloid}$$

At the same time some of the Al^{3+} combines with the OH^- in water, forming aluminum hydroxides; thus

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3$$

$$Al(OH)_3 + \text{colloid} \rightarrow Al(OH)_3 \text{ colloid} .$$

The aluminum hydroxide farther interacts with the negatively charged colloids, thus forming relatively heavy flocs, which are removed during coagulation. The end result of chemical coagulation is shown in the following reaction.

$$Al_2(S0_4)_3 + 3\,Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3\,CaSO_4 + 6\,CO_2$$

Alkalinity usually in water

Floc-Forming

Natural water normally contains calcium bicarbonate alkalinity, which may be sufficient to bring about the desired result when alum is added to water. However, if the water does not contain sufficient alkalinity for the quantity of alum to be added, then lime (calcium hydroxide) or soda ash must be added, in order to adjust the alkalinity.

The reaction of lime with alum is as follows:

$$Al_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3\,CaSO_4$$

The relative proportions of alum and lime can be determined in theory from the above reaction. In practice, however, they are determined by experiment and experience. It must be remembered that, in practice, chemical coagulation is not as simple as described here. In fact, the entire process of flocculation is a very complicated one, which cannot be carried out economically under rural conditions or in small water-treatment plants. First of all, it requires special equipment and a highly skilled operator. Secondly, the efficiency of coagulation brought about by alum or any similar coagulant depends upon such variables as the availability of

the water, the nature of the suspended materials and the temperature of the water. For these reasons, coagulation with alum is routinely used before rapid sand filtration, which is normally operated by skilled person.

Colloidal Suspensions

Sedimentation can be used to remove suspended particles down to a size of about 50 µm depending on their density, but smaller particles have very low settling velocities so that removal by sedimentation is not feasible. It can be seen that the smaller particles have virtually non-existent settling velocities. If these colloidal particles can be persuaded to agglomerate, they may eventually increase in size to such a point that removal by sedimentation becomes possible.

In a quiescent liquid, fine particles collide because of Brownian movement and also when rapidly settling solids overtake more slowly settling particles. As a result larger particles, fewer in number, are produced; growth by these means is, however, slow. Collisions between particles can be improved by gentle agitation, the process of flocculation, which may be sufficient to produce settle able solids from a high concentration of colloidal particles. With low concentrations of colloids a coagulant is added to produce bulky floc particles, which enmesh the colloidal solids.

Agitation of water by hydraulic or mechanical mixing causes velocity gradients, the intensity of which controls the degree of flocculation produced. The number of collisions between particles is directly related to the velocity gradient and it is possible to determine the power input required to give a particular degree of flocculation as specified by the velocity gradient.

Flocculation of dilute colloidal suspensions provides only infrequent collisions and agglomeration does not occur to any marked extent. In such circumstances, clarification is best achieved using a chemical coagulant followed by flocculation and sedimentation. Before flocculation can take place, it is essential to disperse the coagulant, usually required in doses of 30-100 mg/l, throughout the body of water. This is carried out in a rapid mixing chamber with a high-speed turbine (see Fig. 2.2) or by adding the coagulant at a point of hydraulic turbulence (e.g. at a hydraulic jump in a measuring flume). The coagulant is a metal salt that reacts with alkalinity in the water to produce an insoluble metal hydroxide floc, which incorporates the colloidal particles. This fine precipitate is then flocculated to produce settlable solids.

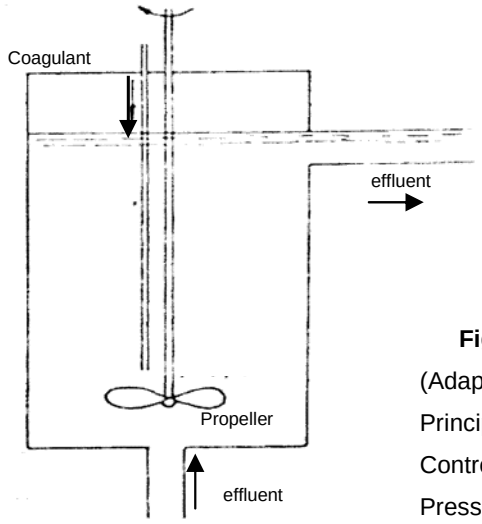

Figure 2.2 Rapid mixer
(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

With very low concentrations of colloidal matter, floc formation is difficult and coagulant aids may be required. These may be simple additives like clay particles, which form nuclei for precipitation of the hydroxide, or polyelectrolytes (heavy long-chain synthetic polymers), which when added in small amount (<1 mg/l) promote agglomeration. Because of the spongy nature of floc particles, they have a very large surface area and are thus capable of absorption of dissolved matter from solution.

The principal function of chemical coagulation is known as destabilization, aggregation, and binding together of colloids. Alum (aluminum sulphate, $Al_2 (SO_4)_3 .18H_2O$) is one of the most common coagulants that may be added to a water system. Such a coagulant possesses tiny positive charges

and therefore has the ability to link together with negatively charged color or turbidity particles by mutual coagulation. Alum also reacts with the natural alkalinity (carbonate-bicarbonate system) of the water to produce a precipitate, which is usually thought to be aluminum hydroxide. If the relation takes place with the natural alkalinity, it may be expressed as follows:-

$$Al_2(SO_4)_3 . x H_2O + 3 Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3 CaSO_4 + x H_20 + 6 C0_2$$

In the event that there is insufficient natural alkalinity for this to occur, then calcium oxide (lime) may be added to create the same effect. Because this system is poorly understood, the optimum dose required in practice has to be done by trial and error through a series of tests known as jar tests.

It is not possible to calculate the dose of coagulant required nor the results that it will produce so that laboratory tests must be carried out using the jar- test procedure. This involve setting up a series of samples of water on a special multiple stirring and dosing the samples with a range of coagulant, e.g. 0, 10, 20, 30, 40 and 50 mg/l, stirring vigorously with a glass rod. The samples are then flocculated for 30 minutes and allowed to stand in quiescent conditions for 60 minutes. The supernatant water is then examined.

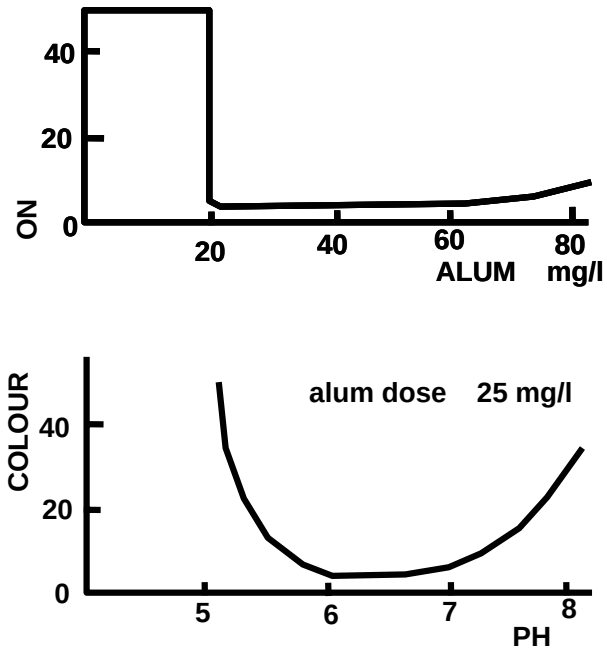

Figure 2.3. Jar- test results

(Adapted from Tebbutt. Principles of water quality control. 3rd edition, Pergamon press, 1983.)

Color and turbidity and the lowest dose of coagulant to give satisfactory removal are noted. A second set of samples is prepared with P^H adjusted over a range, for example of 5.0,6.0, 6.5, 7.0, 7.5, 8.0, and the coagulant dose determined previously added to each beaker followed by stirring, flocculation and settlement as before. It is then possible to examine the supernatant and select the optimum P^H and if necessary recheck the minimum coagulant dose required.

Figure 2.3 shows typical results from such a jar test. Because of the effect of P^H on coagulation it is normally necessary in chemical coagulation plants to make provision for the control of P^H by the addition of acid or alkali.

Coagulant aids

Coagulation may be improved by coagulant aids, that is, substances that increase the critical mass of the colloids and speed up coagulation. Kinetically, for example, water with little turbidity may not coagulate as easily as water of moderate turbidity. Coagulation may then be improved by adding colloids that carry a charge of the same sign as the normal turbidity of the water.

Examples are bentonite, anionic polyelectrolyte and activated silica. Because the critical mass of colloids interacting with coagulants is increased by additives of this kind, coagulation is accelerated; occasionally coagulant aids may reduce coagulant dosage by speeding the kinetic of the process. They may also improve the physical character of the flocs. The solution containing metal-ion coagulants for instance, some anions, polysilicate, and other ionic polyelectrolytes may produce dense agglomerates that settle fast and respond well to remove by filtration.

In the purification of municipal water supply, coagulated impurities are normally removed by gravitational settling of up flow clarification in advance of filtration. Overall efficiency depends on optional integration of component treatments. Both settling and filtration are governed, in some degree, by the compactness, size, density, sheer strength, and compressibility of the coagulates or flocs.

2.3.4. Sedimentation

In water treatment, sedimentation, or the removal by gravitational settling of suspended particles heavier than water, is perhaps the most widely useful operation. When the impurities are separated from the suspending fluid by gravitational or natural aggregation of the settling particles, the operation is called plain sedimentation. When chemical or other substance are added to induce aggregation and settling of finely divided suspended matter, colloidal substance, and the large molecule, the operation is called coagulation.

Factors that influence effective sedimentation processes are :

1. Size, shape and weight of particles, or floc (precipitate)
2. Velocity and temperature of the water
3. Effective average period available for sedimentation
4. Area of the basin of tank

5. Effective depth of the tank or basin
6. Surface overflow rate
7. Inlet and outlet position of the tank

Clarification

Many of the impurities in water and wastewater occur as suspended matter, which remains in suspension in flowing liquids but which will move vertically under the influence of gravity in quiescent or semi-quiescent conditions. Usually the particles are denser than the surrounding liquid so that sedimentation takes place, but with very small particles and with low-density particles, flotation may offer a more satisfactory clarification process. Sedimentation units have a dual role: the removal of settleable solids and the concentration of the removed solids into a smaller volume of sludge.

The Ideal Sedimentation Basin

The behavior of a sedimentation tank operating on a continuous flow basis with a discrete suspension of particles can be examined by reference to an ideal sedimentation basin (See fig. 2.4), which assumes:

1. Quiescent conditions in the settling zone
2. Uniform flow across the settling zone

3. Uniform solids concentration as flow enters the settling zone
4. Solids entering the sludge zone are not resuspended.

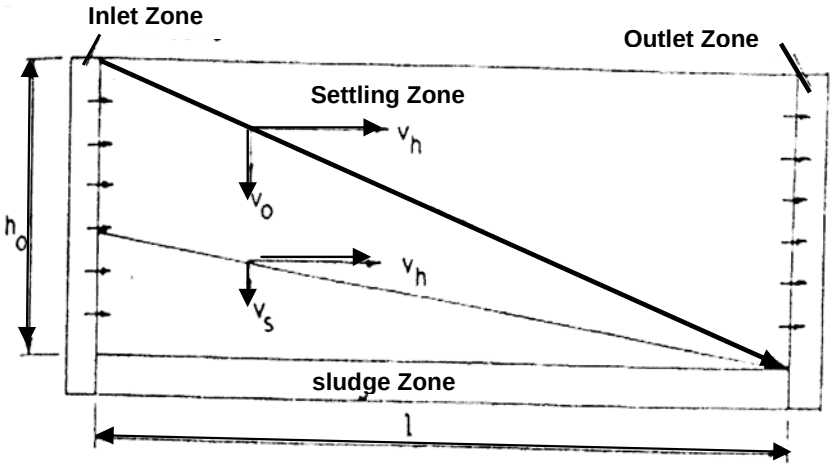

Figure.2.4. The ideal sedimentation basin

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

Efficiency of Sedimentation Tanks

The hydraulic behavior of a tank may be examined by injecting a tracer into the inlet and observing its appearance in the effluent. The flow-through curves so obtained are of infinite variety, ranging from the ideal plug flow case to that of a completely mixed tank. The flow-through curve obtained in practice is a combination of the two extremes: short- circuiting

due to density currents and mixing due to hydraulic turbulence producing a peak earlier than would be expected in an ideal tank. Thus the actual retention time is often considerably less than the theoretical value.

Since the purpose of sedimentation tanks is to remove suspended matter, the logical way of expressing their efficiency is by the percentage removal of such solids. The normal SS (suspended solids) determination records particles down to a few microns whereas floc particles smaller than 100 µm are unlikely to be removed by sedimentation. Thus a sedimentation tank will never remove all the SS from sewage and the normal range of SS removal from sewage by sedimentation is 50-60%. Research has shown that with heterogeneous suspensions such as sewage, the hydraulic loading on a tank has less influence on the removal efficiency than the influent SS concentrations.

Types of Sedimentation Tank

1. The horizontal tank
2. Circular tank
3. Hopper bottom tank

The main types of sedimentation tank found in use are shown in Fig. 2.5. The horizontal tank is compact but suffers from a restricted effluent weir length unless suspended weirs are adopted. Sludge is moved to the sump by a traveling bridge

scraper, which may serve several tanks, or by a continuousbelt system with flights. The sludge is withdrawn from the sump under hydrostatic head. Circular tanks offer advantages of long weir length and simpler scraping mechanisms but are not so compact. Hopper bottom tanks with horizontal flow are popular on small sewage works where the extra construction cost is more than offset by the absence of any scraping mechanism.

The vertical flows are popular on small sewage works where the extra construction cost is more than offset by the absence of any scraping mechanism. The vertical flow hopper bottom tank is often used in water treatment plants and operates with a sludge blanket which serves to strain out particles smaller than would be removed by sedimentation alone at the overflow rate employed.

Sedimentation tanks have two functions: the removal of settleable solids to produce an acceptable output, and the concentration of the removed solids into a smaller volume. The design of a tank must consider both of these functions and the tank should be sized on whichever of the requirements is limiting. The sludge thickening function of a tank is likely to be important when dealing with relatively high concentrations of homogeneous solids.

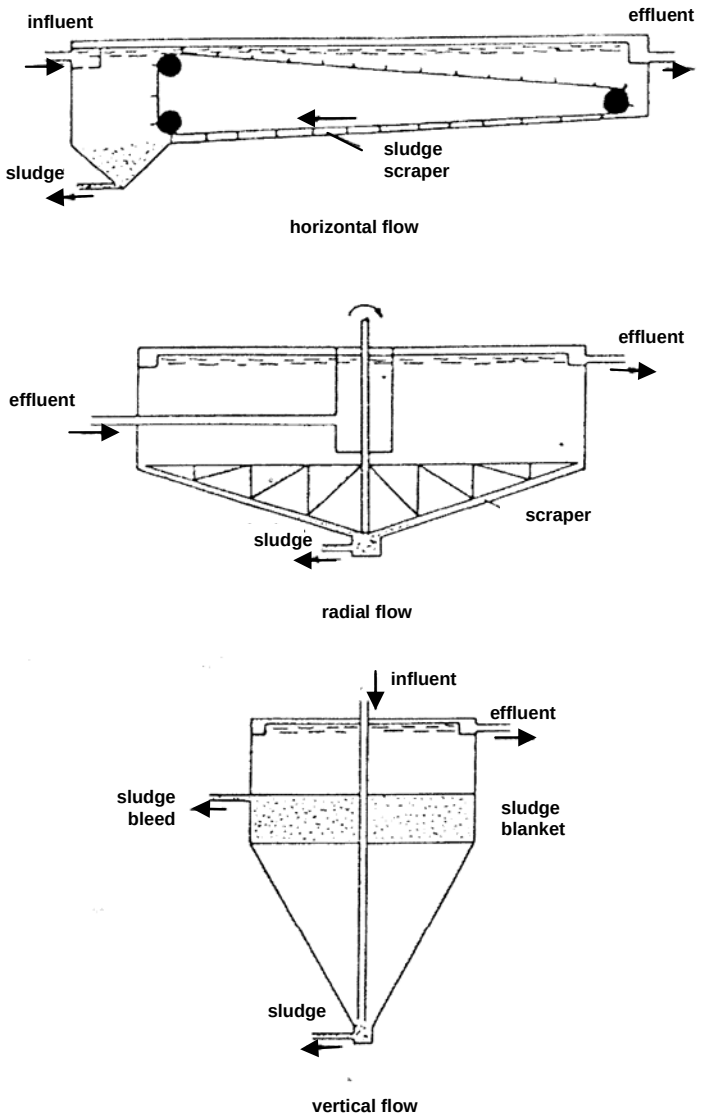

Figure.2.5. Types of sedimentation tank

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

Flotation

An alternative clarification technique, which is particularly attractive for relatively small particles and for particles with a density close to that of water, is flotation. With flotation the loading rates are not directly related to the suspension characteristics so it is usually possible to provide relatively short retention times whilst still obtaining good clarification. The process involves the addition of a flotation agent, usually fine air bubbles, which becomes associated with the suspended particles and thus provides the necessary buoyancy to carry them to the surface of the tank where they can be removed as scum.

Air flotation requires the release of a cloud of fine air bubbles at the base of the unit and this is usually achieved by saturating a portion of the treated flow (the recycle) with air at high pressure. When this pressurized liquid is returned to the main flow at atmospheric pressure, the excess air comes out of solution in the desired fine bubble form. The bubbles of air become attached to or enmeshed in the suspended particles, which then rise to the surface because of their reduced density. Figure 2.6 shows that schematic arrangement of a typical dissolved air flotation unit.

For water treatment operation recycle ratios of around 10% with pressurization up to 400 kPa have proved satisfactory,

giving rise rates of about 12 m/h with good clarification. The scum removed from the tank surface usually has significantly higher solids content than that achievable by sedimentation of the same suspension. The capital cost of flotation units is less than that of the equivalent sedimentation units but operating costs are higher.

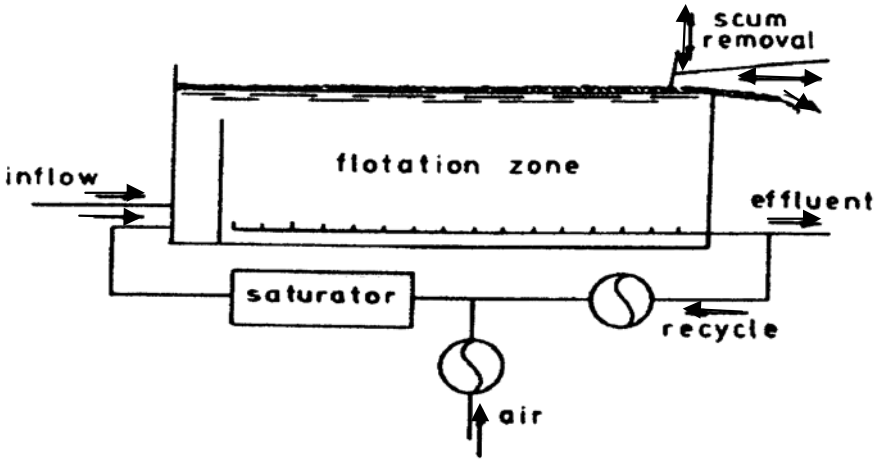

Figure 2.6. Dissolve air flotation

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

2.3.5. Filtration

It is a process where the suspended matter is separated or purified by passing it through a minute porous material or medium. This medium may be sand, diatomaceous earth, or a

finely woven fabric. When the raw water passes through a fixed depth of carefully arranged sand medium, almost all the suspended and colloidal matter in the water is trapped by the first few top layers of the sand grains, and clear water is produced at the bottom of the medium. This process is termed as **filtration**.

Filtration of water through a sand medium after sedimentation is one of the most important and oldest practices of water purification. A systematic practice of filtration of public water supply first started in about 1852, when the city of London was required by an Act of Parliament to filter its water supply from the Thames River through sand filters.

In 1892, concrete proof of the value of filtration was witnessed, when an epidemic of cholera struck the citizens of Hamburg, in Germany, who drank unfiltered water from the Elbe River. Just beyond the Elbe River, where the water supply was filtered, the residents of Altona, a suburb of Hamburg, remain healthy.

As described earlier, it has been found even in the early Egyptian days that passing water through sand resulted in a reduction in suspended and colloidal matter, and resulted in a further clarification of the water. Water that is on occasion extremely turbid should, of course, first of all be treated by

some coagulation or settling or combination of both. However, water that is normally not too turbid may be directly applied to the filter. Water that has previously been treated by sedimentation and/or coagulation may also be applied to filters to provide the final polishing and the production of clear, aesthetically acceptable water.

Settling takes place in the small settling basins that are provided between the particles. Screening takes place where particles that are larger than the interstice will be retained because they cannot pass through. Finally, a biological action takes place through bacterial growth, which may occur on the particles of the filter, and which grow at the expense of the soluble organic carbon passing through in the water. This latter phenomenon is not a very satisfactory way of removing organic carbon because it does tend to plug up the filter fairly rapidly and reduce its effectiveness. Filters have been developed through the ages through a series of steps, which are mainly related to their operating characteristics or the material that is used as filtering medium.

Objective of filtration

1. To produce clear sparkling water (reduce turbidity)
2. To reduce number of micro-organisms

3. To minimize the contaminants which cause undesirable taste and odor
4. To remove any suspended solid in water.

Types of sand filter

A) Slow sand filter

The oldest type, this type of filter has been use traditionally and has been effective in the past. However, it has certain operation disadvantages in that it cannot readily be cleaned. Some of these filters are still in use in some parts of the Far East, Europe, and North America. Where labor tends to be more costly, other types of filter have been developed. Once properly constructed, it is very well suited to rural areas, because it does not require skilled workers to construct or maintain, and the costs of operation and maintenance are reasonable.

In this filter system, the process of filtration is a combination of physical straining, (e.g. sedimentation and biological activities), such as the growth of micro-organisms which takes place in the topmost layer of the sand grains soon after filter is in operation.

This microbial growth in the sand grain forms a sticky gelatinous coat in the top layers of the filter, and is called **schmutzdecke**, a German term meaning "cover of filth".

Uninterrupted operation of the filter encourages the formation of schmutzdecke, which in turns promotes the efficiency of the filter medium. As the filter becomes more efficient, the rate of filtration become less and less, until the rate reaches a predetermined point at which the flow-through rate becomes unacceptably low and the loss of head is high (that is, the water emerging from the filter comes slowly, lacking the pressure of its own weight). At this point, filtration is stopped, the topmost layer of the sand is scraped off, and the filter put back in to operation

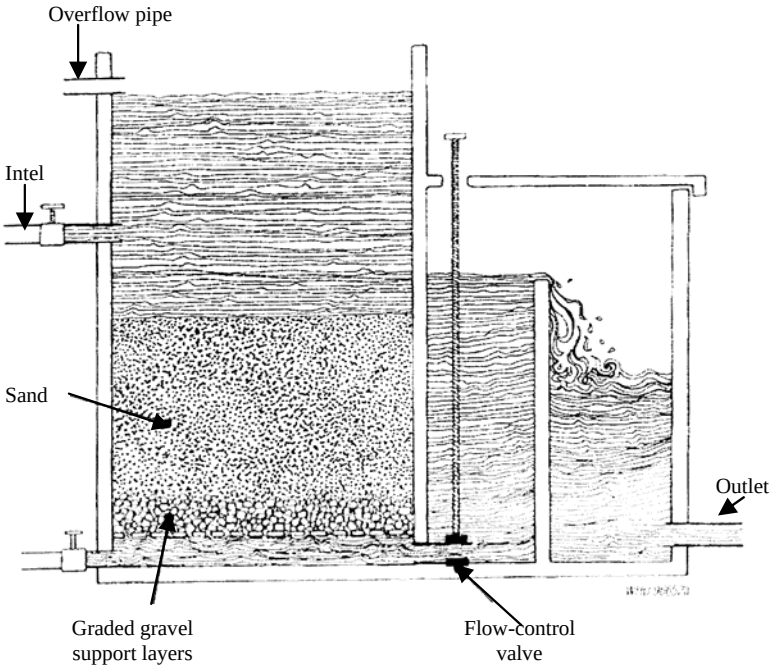

Figure 2.7. Slow sand filter.

(Adapted from WHO - Guidelines for Drinking Water Quality. Surveillance and Control of Community Supplies, 2nd edition, Volume 3, 1997.)

Main purpose of the slow sand filter

The main purpose of slow sand filtration is the removal of pathogenic organisms from the raw water, in particular the bacteria and viruses responsible for the spreading of waterborne diseases. A well-operated slow sand filter will remove protozoa such as Entamoeba histolytic and helminthes such as schistosoma haematobium and Ascaris lumbricoides. E. coli will normally be absent in a 100 ml sample of filter water, which satisfies normal drinking water standards.

B) Rapid sand filter

This is a more recently developed type, and is more or less mechanized. Both slow and rapid sand filters are sometimes called **gravity filters**, because water passes through them under the force of gravity. The major difference between the two, as their names show, is the rate of filtration.

The rapid sand filter is designed to filter a large volume of water in a very short time. The principle of operation of a rapid sand filter is basically physical straining of the water. Generally, its function is automatically controlled. It requires a very small space compared with a slow sand filter, and is very well adapted to urban areas, where highly skilled operations are normally available. The raw water to be filtered is almost always treated first with chemical coagulants and then by sedimentation.

Because the rate of filtration is 30 to 40 time higher than that of a slow sand filter, rapid sand filters will need cleaning more frequently than a slow sand filter, and because of the high frequency of cleaning involved, it is designed with what is called **back-washing system** for cleaning purpose.

The rate of filtration in both slow and rapid sand filters is controlled with two meters, which are called the rate-of-flow control gauge, and **the loss-of-head control gauge**. A well-designed and well-operated sand filter will remove from 97% to 99% of the bacteria in raw water. The turbidity can be reduced below 5 ppm, provided that the raw water is sufficiently sedimented or coagulated and sedimented, before filtration.

Design of a slow sand filter

The efficiency of the slow sand filter depends mainly on the depth, quality and size of the filter sand and the quality of the raw water to be filtered.

Constituents of a slow sand filter

1. Under Drain

Perforated pipes, or drainpipes with open joints, with side joints (laterals) connected to the main drain, are laid at the bottom of the filter bed or tank to collect filtered water.

2. Graded Gravel

Crushed round gravel of fixed sizes, varying from about 5 cm to 1.5 mm (2 inches to 1/16 inches) is laid around and over the underdrains, the largest size at the bottom and the smallest at the top. The depth of the graded gravel should be at least 30 cm (12 inches), and preferably 45 cm (18 inches).

3. Graded Filter Sand

Sand for the filter is graded or specified by:

a. Quality of Sand:
   The best possible quality is chosen (i.e. hard, durable grains, round and free from dirt, etc.)

b. Size of Sand

The size of the grains of filter sand is defined by two terms, as follows:

1. Effective size of the sand: whereby the size of grains is such that 10% of the sand grains by weight are smaller, and 90% are larger. It may also be expressed in terms of sieve size, defined as the sieve size in millimeters that permits 10% of the sand by weight to pass. Sieves for grading filter sand are usually sold in coded series known as “Standard testing sieve series”. The effective size for slow sand filter varies from about 0.2 mm to 0.4 mm, and is generally about 0.35 mm.

2. The uniformity coefficient: The uniformity coefficient means the ratio between the sieve size that will pass 60% of the sand grains by weight and the sieve size passing 10% of the sand by weight.The uniformity coefficient for slow sand filter varies from 1.70 to 2.5, and is normally about 2.00.See table 2.1 below, for a comparison between the effective size and uniformity coefficient employed in slow and rapid sand filters.

3. Depth of filter sand

The depth of the filter sand is one of the most important determinants of the efficiency of flirtation. The graded sand is laid on the top of the graded gravel to a minimum depth of 60 cm (2ft), optimum 90 cm (3ft), and a maximum depth of 1.20 meters (4ft).

4. Depth of raw water

The raw water to be filtered should be as clean as possible, and turbidity should be less than 50 mg/l. The raw water is evenly distributed over the graded sand to a depth from 90 cm to 1.20 meters (36 inches to 48 inches).

Cleaning of filter sand

Slow sand filter

The rate of filtration of a slow sand filter decreases gradually due to clogging, until the rate reaches a per-determined point indicated by the rate of flow control gauge and the loss of head control gauge, which are placed in the filter medium. When these indicate the necessity for cleaning, filtration is stopped, and the topmost layer of the sand is removed by careful scraping. Each scraping usually removes from 5 cm to 10 cm depth of sand.

The sand that has been scraped off is stored and washed several times. The cleaned sand is then replaced over the bed of the filter, to maintain the minimum depth. The cleaning interval varies from about three weeks to several months depending on the quality of the raw mater to be filtered.

Rapid sand filter

It is cleaned by means of its back-washing system. In this filter, the sand layer gets clogged quickly because of the high rate of filtration and the deposition of flocs among the sand grains. The filter is washed at intervals varying between 20 hours and 5 days, depending on the degree of turbidity of the raw water.

Washing of the filter sand is achieved by forcing clean water up through the sand, by reversing the flow of water pressure.

The forced upward flow agitates the sand layers and washes away the clogging materials to a drain system, which totally gets rid of the dirt into a final disposal drain.

The washing process is normally accomplished in five to fifteen minutes, and consumes from 4% to 5% of the filtered water. The filter is put back into operation with very little loss of time.

Table 2.1. Comparison of slow and rapid sand filter

Characteristic	Slow Filter	Rapid Filter
Space occupied	Large	Very much less
Effective size of filter sand	0.2 to 0.4 mm (usually 0.35 mm)	0.35 to 0.45 mm
Uniformity coefficient of filter sand	1.70 to 2.5 (usually 2.00)	2.00
Rate of filtration	2.8 m^3 /m^2/day	115 m^3/m^2 /day
Method of cleaning	Scraping	Back washing
Frequency of cleaning	From 3 weeks to months	From 20 hours to 5 days
Number of filter basins needed	At least two	One preferably more
Type of operators needed	Operators with less training	Highly skilled operators: effective control of the filter media is critical
Cost to build	High	Low
Cost to operate	Very low	Very high
Type of raw water for filtration	Reasonably clear, turbidity less than 50 ppm	Any water after coagulation and sedimentation can tolerate high turbidity.

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

C) Pressure filters

Whereas the rapid sand is a gravity filter, a pressure filter is somewhat the same type of system, only pressure is applied to the water to pass it through the filter. The most common household unit nowadays would be the swimming pool filter, where the water is pumped vertically through the sand and the filter, and when the head loss through the filter becomes excessive, as registered on the pressure gauge, the operator will reverse the flow through the filter, accomplishing the backwash described above.

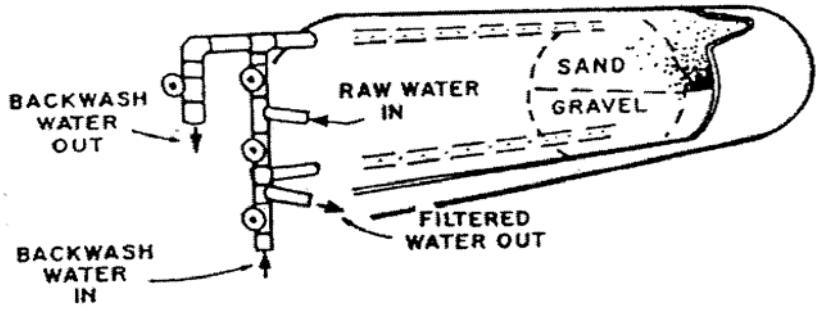

Figure 2.8. Pressure Filter cutaway

(Adapted from Pfaffin J.R. and E.N. Ziegler. Encyclopedia of Environmental Science and Engineering. 2nd edition, volume 3, Q- Z Gordon and Breach Science Publishers, 1983.)

D) Diatomaceous earth filter

Diatomaceous earth is the siliceous residue of the bodies of diatoms that were deposited in past geological ages and now

form extensive beds where they are mined. The earth is processed and ground and the silica particles are extremely irregularly shaped and thus provide a very good porous coating. The diatomaceous earth filter was developed by the army for field use to remove certain chlorine-resistant organisms responsible for dysentery.

The filter medium is supported on a fine metal screen or a porous material. There are three steps in the filtration cycle. First of all, there is a deposit of a per-coat, which is a thin layer of diatomite deposited on the filter element. The second step is the actual filtration and the body feed addition. The reason why body feed is continually added to the filter is to reduce the amount of clogging that occurs at the surface. This also permits significantly longer filter runs.

The third step, when the pressure drops or the filtration rate reaches such a low level that it becomes necessary to wash, is the removal of the filter cake, which is accomplished by reversing the flow through the filter element and the discharging the dirty filter cake to wash. Diatomaceous earth filters are frequently used for swimming pool operation, military installations in field, and for some small communities.

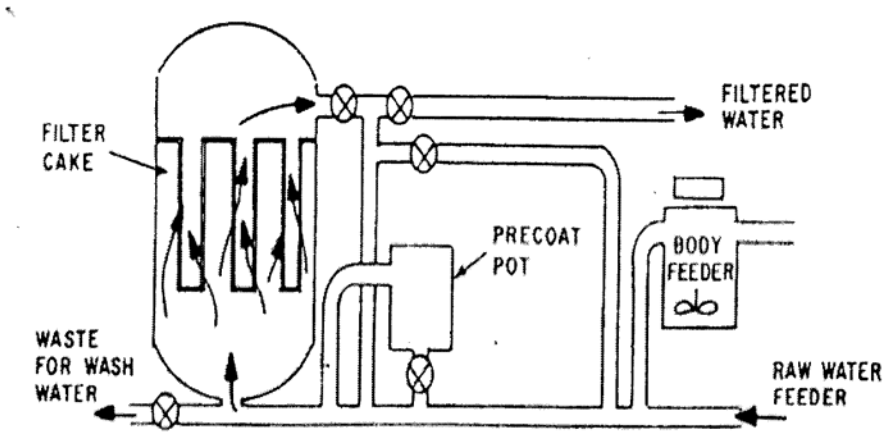

Figure-2.9-Diatomaceous earth filter

(Adapted from Pfaffin J.R. and E.N. Ziegler. Encyclopedia of Environmental Science and Engineering. 2nd edition, volume 3, Q- Z Gordon and Breach Science Publishers, 1983.)

2.3.6. Post-chlorination

The purpose of disinfecting water supplies is to prevent the spread of waterborne disease by destroying pathogenic organisms. Most of the physical and chemical treatment processes described previously will remove most of the microorganisms to some extent. However, very small numbers of microorganisms that are viable and pathogenic are all that are required to bring about disastrous epidemic. Thus, post–chlorination is considered to be a necessary final step before treated water is delivered to a municipal system.

A physical process for disinfection was described using ultra-violet irradiation. Other forms of chemical disinfectant are the halogens such as chlorine, bromine, iodine, and the powerful unstable oxidant, ozone. In North America chlorination is the most common of the disinfectant processes used, for a number of reasons. Firstly, it is fairly simple to handle and can be manufactured inexpensively in bulk and delivered to the site. It can be applied under fair controlled conditions, and can maintain a measurable residual in the water supply to indicate safety at all points on a water distribution system. The same is true for Ethiopia.

There are certain disadvantages of chlorination, in that a high residual chlorine will bring about a taste that is unacceptable to many people, and chlorine furthermore will react with certain micro- constituents of water, such as phenols, to bring about substantial odors (chlorophenole) quite out of proportion to the concentration of the causative chemical. The addition of chlorine to water releases a group of substance, all of which have some disinfecting properties.

The substances released are:

1. Hypochlorite ion (OCl)
2. Hypochlorous acid (HOCl)
3. Monochloramine (MH_2Cl)
4. Dichlormine ($NHCl_2$)
5. Nitrogen trichloride (NCl_3)
6. Organic compounds containing chloride, and
7. Chlorine dioxide.

Disinfection of water can be accomplished in many ways. For example, boiling is the easiest and the most reliable method of disinfecting water, because it sterilizes the water by completely destroying all forms of micro-organisms, including the most resistant spores. However, boiling is not practicable for large quantities of water such as municipal supplies.

Chlorine and its compound are the disinfectant of choice because:

A) They are relatively easy to handle and transport and they are readily available almost everywhere
B) They are comparatively inexpensive
C) They are effective and long lasting
D) They are simple to apply and relatively easy to detect in water, both qualitatively and quantitatively

Form of chlorine and its compounds commonly used for water disinfections

Elemental chlorine is usually available in the form of liquid chlorine. It is prepared commercially by compressing gaseous chlorine into steel cylinders, which can be transported like standard oxygen cylinders.

The most common forms of chlorine that are readily available in rural areas and small communities are calcium hypochlorite powder, Ca $(OCl)_2$, and sodium hypochlorite solution, NaOCl, variously known as chlorox (Barachina),etc, Chlorine compounds are also available in the form of tablets such as Halazone for disinfection of small amounts of water.

Other factors that influence the disinfecting power of chlorine and its compounds.

A) The quality of the water to be chlorinated

Since chlorine is a very active element, it will combine with many substances, organic or inorganic, that may be present in the water, and will then lose its effectiveness.

The water to be chlorinated must therefore be as free as possible of suspended or dissolved substances.

B) Contact time

After chlorine is added to water, adequate time must be allowed for the chlorine to react with microorganisms or other substances in water. For effective and reliable disinfection, at least 20 minutes (normally 30 minutes) of contact time must be allowed.

C) Water Temperature.

Almost all chemical reactions are accelerated with temperature increase, and temperature also affects the disinfecting power of chlorine. At higher temperatures, the disinfecting power of chlorine is higher, especially when the chlorine is used in the form of a compound.

D) Presence of Ammonia.

When chlorine is added to water which contains ammonia (NH_3), or organic nitrogenous compounds, it readily combines, forming chloramines. The types of chloramines formed as a result of the reaction of ammonia with chlorine depend mainly upon the p^H and the temperature of the water. Thus:

a) $NH_3 + HOCl \rightarrow NH_2Cl + 2H_2O$ (P^H over 7.5)

Monochloramine

b) $NH_3 + 2HOC \rightarrow NHCl_2 + 2H_2O$ (P^H 5.0 to 6.5

Dichloramine

c) $NH_3 + 3HOC \rightarrow NCl_3 + 3H_2O$ (P^H below 4.5)

Nitrogen Trichloride.

Fortunately chloramine has similar disinfecting properties to chlorine, except that it is much weaker and needs a much longer contact time. The disinfecting action is generally achieved by the monochloramines and dichloramines. Nitrogen trichloride, however, is almost inactive and useless for disinfecting purposes.

Dosage rate of chlorine

The amount of chlorine or its compounds to be added to disinfect a given quantity of water depends upon several factors, chiefly:

A) The chlorine demand of the water

The chlorine demand of the water may be defined as the difference between the initial amount or dosage of chlorine added to water supply for disinfection, and the amount of available chlorine residuals remaining at the end of a specified contact period, generally 30 minutes.

B) Residual chlorine

Residual chlorine is the amount of chlorine left over in the water in the form of Cl_2, hypochlorous acid (HOCl) or

hypochlorite ion (OCl^-), after the water is completely disinfected and the chlorine demand of the water is satisfied.

Let us assume that the dosage of chlorine applied to a certain water supply system was two parts per million. After three hours of contact the total chlorine residual was found to be 0.4 ppm. Therefore the chlorine demand of this water is 2 ppm - 0.4 ppm = 1.6 ppm. In other words, out of the initial doses 2 ppm, 1.6 ppm chlorine is consumed by the water by reaction with organic and inorganic matter, or by killing micro-organisms that may have been in the water.

In actual fact, the chlorine demand of water varies with the quality of the water, and indeed from time to time even in the same water supply system. In practice, a sufficient dose of chlorine is added to a water supply system in order to obtain a minimum residual chlorine of 0.1 to 0.5 ppm at any time and at any point throughout the system.

Residual chlorine in water may be found in the form of Cl_2, HOCl or OCl, in which case it is termed as **free available residual**. It may also be found chemically combined with ammonia, when it is termed as **combined available chlorine residual** (residual chloramines).

Dechlorination

By error, or due to a very low chlorine demand of a specific water supply, it might happen that there is in the water an undesirable excess amount of chlorine, which must be removed. This process of extracting excess amounts of chlorine from water is called **dechlorination**, which may be achieved by the following methods:

A) The reducing chemical which is routinely use in dechlorination is sodium thiosulphate ($Na_2S_2O_3$)

B) When practicable, the water in question can be passed through beds of granular activate carbon (charcoal). The granulated charcoal has the property of absorbing chlorine, and so can remove the excess.

C) Aeration .

D) Boiling the affected water.

Chlorine compounds commonly used in community water disinfection.

In most big watertreatment plants, chlorination is carried out by using compressed liquid chlorine (pure or elemental chlorine). The cylinders containing the chlorine are conveniently fitted with controls for automatic feeding into the water.

The compounds of chlorine that easily available in cities and small towns are calcium hypochlorite, 70% high-test hypochlorite crystalline powder (commonly abbreviated to HTH) and chlorinated lime (commonly known as bleaching powder).

Sodium hypochlorite solution is known under various trade names such as Chlorox, bleaching solution, Barachina and sedex bleach. The available percentage of chlorine is usually indicated in the table below

A chlorine compound is also available in the form of tablets known as Halazone. Each tablet is normally sufficient for one liter of clear water.

Table 2.2. Some chlorine compounds with their chlorine concentration (Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

	NAME	CHEMICAL FORMULA	PERCENT OF AVAILABLE Cl_2	REMARKS
1.	Liquid or elemental chlorine	Cl_2	100%	Compressed in steel cylinders
2.	Calcium hypochlorite (HTH)	$Ca(OCl)_2$	70%	Crystalline stable powder: dissolves in water with very little residue
3.	Bleaching powder (Chlorinated lime)	CaClOCl	25% to 35%	Relatively unstable available chlorine decrease with length of storage
4.	Sodium hypochlorite solution	NaOCl	2.5% to 17% (normally 4% to 5.25 %	Widely available under such name as chlorox, barachina, etc.
5.	Halazone tablets	$HOOC\text{-}C_6H_4\text{-}SO_2NCl_2$		One tablet for one liter of relatively clear water

Methods of feeding chlorine under rural conditions:

In large municipal water treatment systems, chlorine feeders are usually provided with chlorine gas tanks, which have built-in automatic controls for feeding chlorine. However, under rural conditions, the use of such complex and expensive equipment is not feasible, and some simple devices for feeding chlorine solution have to be found.

The siphon-bottle chlorinator consists of a large bottle fitted with an airtight rubber stopper with two holes. A bent glass tube passes through the first hole into the chlorine solution, well above the bottle. To the top end of the tube is attached a rubber hose, at the end of which is a glass orifice or opening with a stopcock. By loosening or tightening the stopcock, we can adjust the flow rate of the chlorine solution. The second hole in the stopper is for a glass tube that keeps the solution open to atmospheric pressure.

When the initial amount is used up, the bottle is replenished with clear hypochlorite solution. Disturbance of continuous feeding can be avoided by using a second bottle while the first is being refilled. The bottle can be set up in an inverted position, provided the siphon action is maintained.

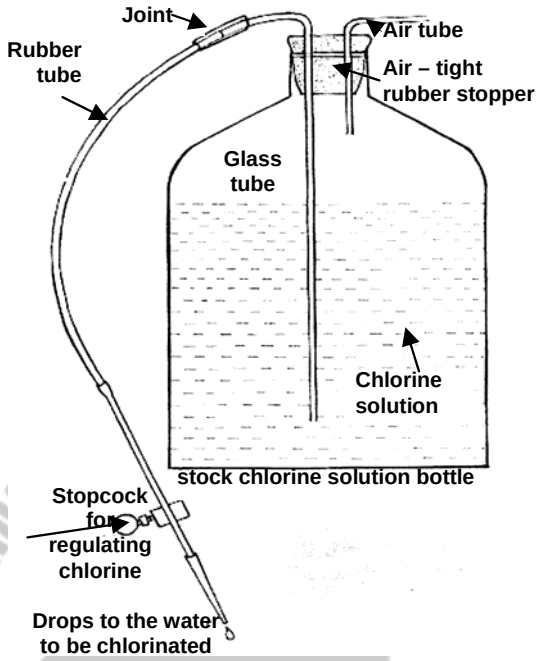

Figure-2.10- An Emergency Siphon Chlorination

(Adapted from Gabre- Emanual Teka. Water upply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Another simple but permanent type of chlorinator that can be easily constructed in rural areas is shown in figures 2.11A and 2.11B, which produces the water supply chlorinator in use at the Public Health College of Gonder. This type of chlorinator provides constant flow, regardless of the depth of chlorine solution in the tank. The concrete tank can be replaced by wooden, plastic or similar container. Interruption of the flow by clogging can be reduced if the chlorine is kept free of residues. The rate and the consistency of the flow of the chlorine solution is controlled by the stopcock on the rubber hose.

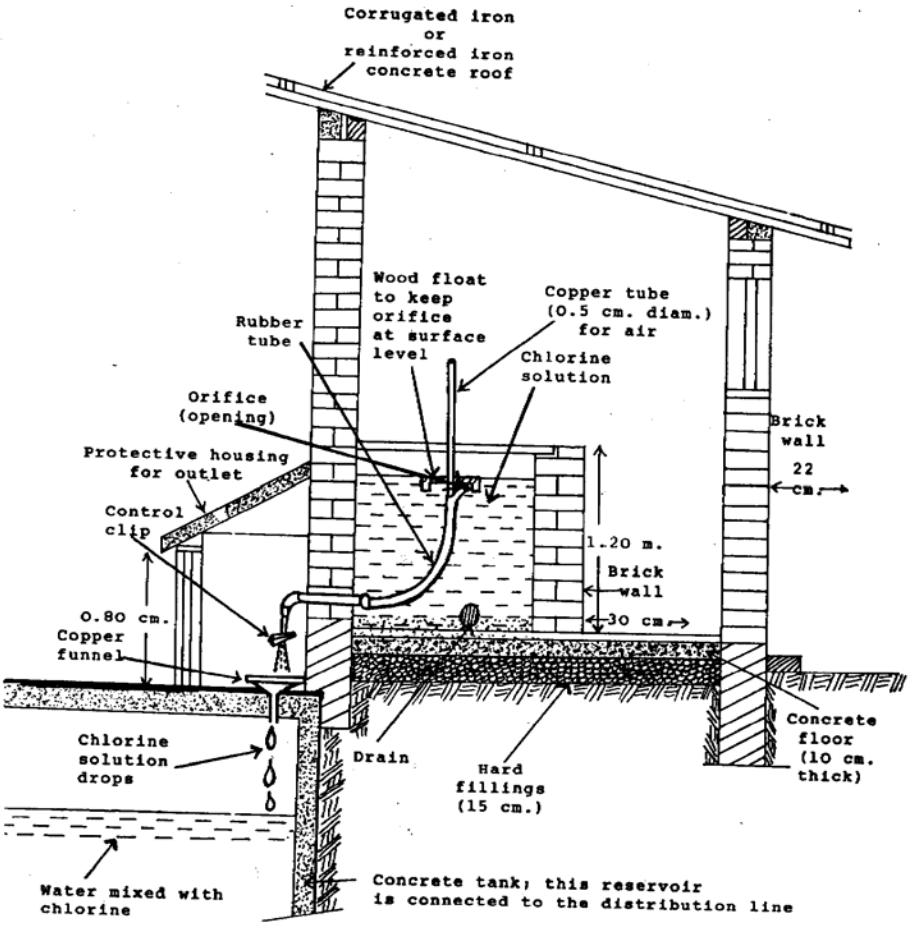

Figure 2.11 A Permanent type of hypochlorite solution feeder

(Adapted from Gabre- Emanual Teka. Water Supply - Ethiopia, An Introduction to Environmental Health Practice, 1997.)

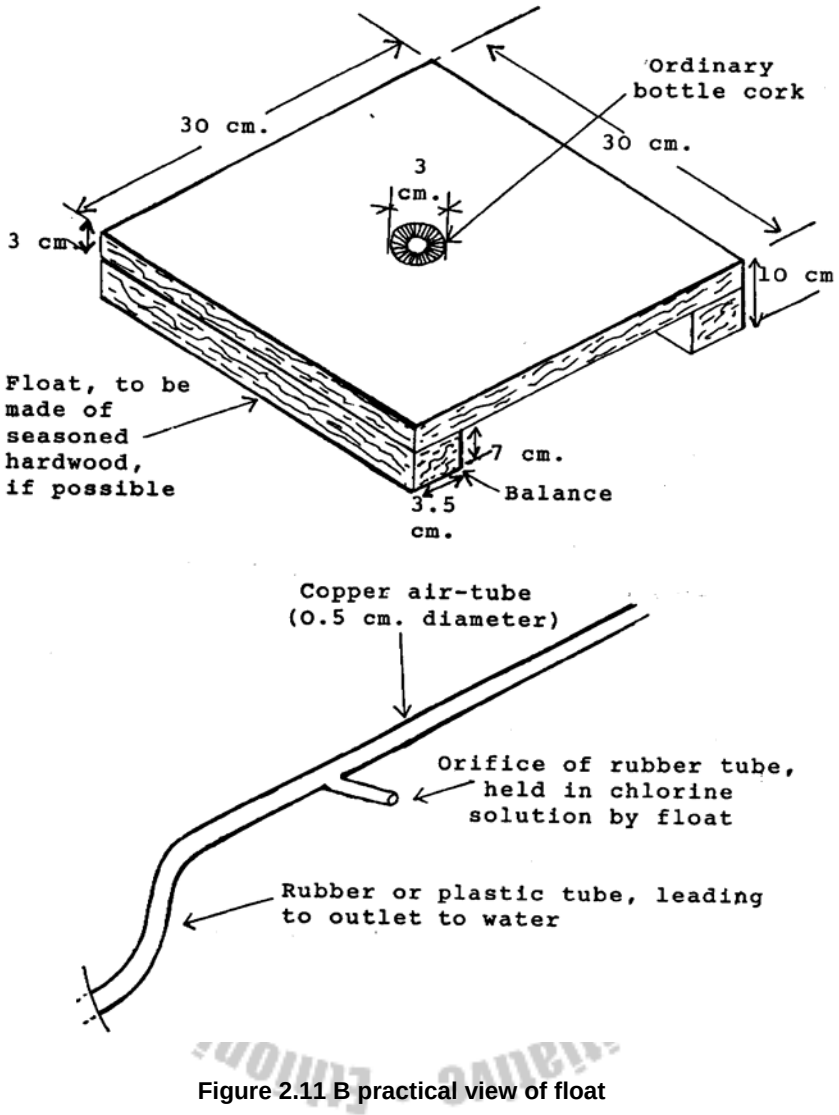

Figure 2.11 B practical view of float

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

The chlorinator should be regularly checked and refilled with stock solution for assurance of constant flow of chlorine at a pre-determined rate.

Other disinfectants

Ozone

Ozone is an allotropic form of oxygen produced by passing dry oxygen or air through an electrical discharge (5000-20,000 V, 50-500 HZ). It is unstable, highly toxic blue gas with a pungent odor. A powerful oxidizing agent, it is an efficient disinfectant and useful in bleaching color and removing tastes and odors. Like oxygen, it is only slightly soluble in water and because of its unstable form it leaves no residual.

Unless cheap energy is available, ozone treatment is much more expensive than chlorination but it does have the advantage of good color removal. In these circumstances, filtration and ozonization may give a finished water similar to that produced by a more complex coagulation, sedimentation, filtration and chlorination plant. Because of the absence of ozone residuals in the distribution system, biological growth with attendant color, taste and odor problems may result. Such growth in the distribution system can usually be prevented by adding a small dose of chlorine after ozonization.

Ozone must be manufactured on site by passing dry air through a high voltage high-frequency electrical discharge.

There are two main types of ozonizer:

a) Plate type with flat electrodes and glass dielectrics.
b) Tube type with cylindrical electrodes coaxial with glass dielectric cylinders.

The high-tension side is cooled by convection and the low–tension side by water. Air passes between the electrodes and is ozonized by the discharge across the air gap. Ozone production is usually up to about 4% by weight of the carrier air with power requirements of around 25 kHz/kg of ozone produced. Ozone will react with organic matter to form ozonides in certain conditions and the significance of the presence of these products in water is not yet fully understood.

Ultraviolet (UV) Radiation

Various forms of radiation can be effective disinfecting agents and UV radiation has been used for the treatment of small water supplies for many years. The disinfection action of UV at a wavelength of around 254 nm is quite strong, provided that the organisms are actually exposed to the radiation. It is thus necessary to ensure that turbidity is absent and that the dose is increased to allow for the absorption of UV by any organic compounds present in the flow. The water to be disinfected flows between mercury discharge tubes and

polished metal reflector tubes, which give efficient disinfection with a reflection time of a few seconds although at a rather high power requirement of 10-20 W/m^3

The advantage of UV disinfections includes:

a) no formation of taste and odor
b) minimum maintenance
c) easy automatic control with no danger from overdosing

The disadvantage of UV disinfections includes:

a) lack of residual
b) high cost
c) need for high clarity in the water

Preparation of stock solution

When chlorine compounds are used for disinfecting water supply, sewage effluent, etc., it is convenient to prepare a known concentration of chlorine solution and to feed from this solution at a desired dose. This known concentration of chlorine or any other chemical is known as a stock solution. Normally a chlorine stock solution is prepared to the strength of one percent available chlorine equivalent to 10,000 ppm.

Let us take some of the most readily available compounds of chlorine, and prepare a 1% available chlorine stock solution:

A) If we have sodium hypochlorite solution (Clorox), which contains from 4% to 5.25% available chlorine, we should take 250 milliliters (about 1 medium cup) of the Clorox solution in a one-liter jar, and fill it up with clear water, preferably distilled or boiled. The one-liter jar now contains a 1% stock solution.

B) If we have HTH, which contains 70% available chlorine, we should take 15 gm. (one tablespoon) of HTH, and fill the jar up to one liter with clean water.

C) If our chlorine compound is calcium hypochlorite powder (chlorinated lime), which generally contains about 30% available chlorine when freshly prepared, we should take 40 gms. (two-and-a-half tablespoons) of this compound, and fill the jar up to one liter with clean water.

All chlorine compounds (particularly calcium hypochlorite, HTH, etc.) should be stored in dark containers or in sealed plastic bags in dark and cool places. Freshly-opened calcium hypochlorite or HTH gradually loses available chlorine upon exposure to air and therefore should be used as soon as possible.

Methods of calculating chlorine dosage

Too much chlorine is poisonous, and too little is unreliable in disinfecting water. An exact dose must therefore be determined for chlorinating a given water supply. Generally chlorine is applied at the rate of 2 to 3 ppm, depending on the quality of the raw water.

Method No. 1

One liter of pure water weighs 1000 grams or 1,000,000 milligrams. Hence, 1 milligram/liter is normally considered to be equal to 1 ppm, even when the water is not pure. In calculating chlorine dosage, it is useful to remember:

1 ppm = 1 milligram per liter
2 ppm = 2 milligram/ liter
10 ppm = 10 mg/l

Example 1. A well is 2 meters in diameter, and contains water to a depth of 1.75 meters. It is desired to chlorinate the water in this well with 10 ppm of 70% HTH (available chlorine 70%).

Solution.

First find the volume of the water in the well, using the formula

$V = \pi r^2 h$ where v =volume
h = height
r = radius
$\pi = 22/7$

V= 22/7 x $(1)^2$ x 1.75 cubic meters

V= 22/7 x 1 x 7/4 x1000 liters

V= 5500 liters

Using the formula

$$\frac{\text{Weight of powder}}{\text{Weight of water}} = \frac{\text{ppm desired}}{\text{ppm in the powder}}$$

$$\frac{\text{Weight of powder in kg}}{\text{Weight of water in liters}} = \frac{\text{ppm desired}}{\text{ppm in the powder}}$$

$$\text{Weigh of powder} = \frac{\text{ppm desired}}{\text{Ppm in the powder}} \times \text{weight of water in liters}$$

$$= \frac{10\text{ppm}}{700{,}000\text{ppm}} \times 5500\text{litres}$$

$$= \frac{55}{700}\ \text{Kg}$$

$$\text{Weight of powder in gram} = \frac{55{,}000}{700}\ \text{gram}$$

= 78.57 grams of 70% HTH Needed.

Well water chlorination

A newly constructed well, or a well suspected to be polluted, should be disinfected with a chlorine dose from 50 to 100 ppm, and a contact period of 12 to 24 hours should be allowed for disinfection. After this, the disinfected water should be bailed out of the well until the emerging supply shows only about 0.1 ppm residual.

Example 2.

A new well has just been constructed and properly protected in the Boricha town of Sidma Zone. It is required that the well water should be disinfected with 50 ppm of chlorine before it is passed for community use. The well is circular, and its dimensions are diameter of 2m and level of water 7m.

Sodium hypochlorite solution (sedex bleach) is available at Boricha town shop at Ethiopian Birr (ETB) 0.80 per liters. The available chlorine of the sedex bleach is 5%.

Find

1. The volume of water
2. The dose of sodium hypochlorite solution needed for disinfection
3. The cost of chlorinating the water.

1. $V = \pi r^2 h$

   $= 22/7 \times (lm)^2 \times 7m$

   $= 22\ m^3$

   = 22,000 liters

2. $\frac{\text{Weight of disinfectant}}{\text{Weight of water}} = \frac{\text{ppm desired}}{\text{ppm in the disinfectant}}$

   $\text{Weight of disinfectant} = \frac{50\ ppm}{50{,}000 ppm} \times 22{,}000 \text{ liters required}$

   = 22 liters

3. One liter of sedex bleach costs ETB 0.80

   So 22 liters cost ETB 22 x 0.8

   = ETB17.6

Method 2

Table 2.3 Formula for calculating problems related to chlorination

Formula 1

Calculation of quantity of any chlorine compound needed to prepare a chlorine stock solution or to treat water, given the required dosage or strength of chlorine, the volume of water to be treated, and the chlorine content of the chlorine compound in percentage of available chlorine.:

(a).Chlorine compound (in grams) =

$$\frac{\text{(chlorine dosage or strength (ppm)) x (volume to be added or treated (liters))}}{\text{(10 x \% available chlorine of compound)}}$$

(b).Chlorine compound (in grams) =

$$\frac{\text{(chlorine dosage (ppm))x (volume of water to be treated (cu. m.) x (100)}}{\text{(\% available chlorine of compound)}}$$

Note

Using the formula given above, it is possible to calculate any desired item in the formula, by making it the subject of the

formula, and then substituting for the known values of the other variables.

Formula 2.

Calculation of the volume of a stock chlorine solution of known strength required to treat a certain volume of water with a desired chlorine dosage (chlorine residual + chlorine demand):

(a) stock chlorine solution (in liters) =

$$\frac{\text{(volume of water to be treated (liters))} \times \text{(chlorine dosage (ppm))}}{\text{(strength of chlorine solution (ppm))}}$$

(b). Stock chlorine solution (in liters) =

$$\frac{\text{(volume of water to be treated (cu. m.))} \times \text{(chlorine dosage) (ppm)} \times 1000}{\text{(strength of chlorine solution (ppm))}}$$

Note: If strength of chlorine is given in terms of percentage of available chlorine, then substitute in each of the above formula: strength of chlorine solution (% available chlorine) x 10,000 in place of strength of chlorine solution (ppm). This is because % available chlorine = 10,000 ppm.

Formula 3.

Calculation of rate of feeding a chlorine solution into flowing water that is to be treated, given the rate of flow, the dosage of chlorine (residual and demand), and the strength of the chlorine solution:

(a) Rate of feeding chlorine solution (in cubic centimeters/minute) =

$$\frac{\text{(rate of flow of water (cu. m./day)) x (chlorine dosage (ppm) x 100)}}{\text{(strength of chlorine solution (ppm))}}$$

(b) Rate of feeding of chlorine solution (in cc/minute) =

$$\frac{\text{(rate of flow of water (cu. m./day)) x (chlorine dosage (ppm)) x1}}{\text{(strength of chlorine solution (ppm))}}$$

2.3.7. Supplementary water treatment

In addition to the normal water treatment steps, some water may need supplemental treatment. The need will depend upon the nature of the source of the water, which in turn varies from locality to locality. Complete supplemental water treatment cannot be efficiently carried out under rural conditions, because it requires complex equipment, laboratory

facilities and specially trained, skilled personnel. In spite of these difficulties, however, some aspects of supplemental treatment can be attempted, if the quality of the water requires specific treatment.

Of the various types of supplemental treatments, we will discuss the principles of fluoridation, and also softening of water.

Hardness of water

Hard water may be described as water that will not readily give a lather with soap. A more comprehensive definition of hard water is water in which calcium and magnesium salts, and occasionally iron, manganese, etc., are held in solution in the form of bicarbonates, sulphates or chlorides.

Hardness that is caused by the presence of bicarbonates of calcium or magnesium is termed as **temporary hardness**, because it is readily removed by boiling. Hardness that is due to the presence of sulphates or chlorides of calcium or magnesium is known as **permanent hardness**, as it cannot be easily removed by boiling.

The degree of hardness of water is commonly expressed in terms of the amount of dissolved salts per unit volume of water (mg/1 or ppm).

Thus water which contains

- 0 -75 mg/l (0 to 75 ppm) of dissolved salts is termed as soft;
- 75 - 150 mg/l → is termed as moderately hard;
- 150 - 300 mg/l → is termed as hard;
- 300 mg/1 upwards → is termed as very hard.

However, the importance of the degree of hardness is relative, because it varies with the type of water to which the consumer has been accustomed for a prolonged period, and the purpose for which the water is to be used.

Causes of hardness

The conditions which must exist in order to render water hard are as follows:

A) The soil formation of a locality must have limestone or other hardness-causing mineral deposits.

B) The water that comes in contact with the hardness-causing mineral must contain dissolved carbon dioxide. Limestone or chalk (calcium carbonate) is one of the most widely occurring minerals in the world, and most of the hardness in nature is attributed to salts of calcium. Magnesium salts are the next most common offenders.

How does water become hard?

As rain falls, it dissolves carbon dioxide from the atmosphere. In addition, it may dissolve more CO_2 from the top layers of soil as it percolates into the ground, forming carbonic acid. Thus:

$$H_2O + CO_2 \rightarrow H_2CO_3.$$

When the water that contains dissolved carbon dioxide comes in contact with limestone formations, it transforms the insoluble calcium carbonate into soluble bicarbonate:

$$H_2CO_3 + CaCO_3 \rightarrow Ca(HCO_3)_2.$$

This reaction is reversed on heating:

$$Ca(HCO_3)_2 \xrightarrow{\text{Heat}} CaCO_3 + CO_2 + H_2O$$

Calcium carbonate can be replaced by magnesium carbonates in the above reactions.

Disadvantages of hard water

The disadvantages of hard water are more an economic problem than public health.

A) Hard water wastes soap. How does hard water waste more soap than soft water?

Soap is a sodium salt of complex fatty acids. Thus typical common soaps are sodium palmitates (C_{15} H_{3l} COONa), or sodium stearates ($C_{17}H_{35}$ COONa). Taking sodium palmitate as representative, the reaction with hard water is as follows:

$$Ca(HCO_3)_2 + H_2O + 2C_{15}H_{31}COONa \rightarrow \underset{\text{Precipitate}}{Ca(C_{15}H_{31}COO)_2} + 2NaHCO_3.$$

Since soap must precipitate all the ions causing hardness before it acts as a detergent from the reaction shown above, it is clear that soap is wasted in combining with calcium salts instead of performing its function of cleansing. The amount of soap wasted this way will depend upon the degree of hardness of the water.

B) Hard water forms incrustation (scale) in boilers and cooking utensils. Scaled boilers and cookers are poor transmitters of heat, and lead to wastage of fuel.

C) Hard water decreases the life of fabrics, and is hence undesirable in textile factories, etc.

D) Hard water, which contains an excessive amount of magnesium sulphate in certain localities, may cause disturbances of the stomach and intestine, particularly to newcomers to those localities.

It must be noted that the disadvantage of hard water varies with the degree of hardness and the purposes for which the water is needed. For drinking purposes, very soft water is undesirable, because water that contains trace amounts of certain dissolved minerals is beneficial for health.

Methods of softening water

As it has been pointed out earlier, softening of water may not be practicable in rural areas where complex equipment and trained technical personnel are not available. Nevertheless, health workers should be familiar with the principles of water softening.

1. Removing temporary hardness

A) Temporary hardness may be removed by simple boiling. Thus water that contains Ca++ or Mg++ bicarbonates is softened as follows:

$$Ca(HCO_3)_2 \rightarrow \underset{\text{Ppt}}{CaCO_3} + CO_2 + H_2O$$

B) Of course boiling is not practicable for softening water on a large scale. For this hydrated lime or calcium hydroxide $Ca(OH)_2$ is used to remove temporary hardness:

$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$ (Ppt)

$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow MgCO_3 + CaCO_3 + 2H_2O$ ($CaCO_3$: Ppt)

The amount of calcium hydroxide to be added will depend upon the degree of hardness of water.

2. Removing permanent hardness

Permanent hardness of water may be removed by one of the following methods:

Lime soda method

When sodium carbonate (soda ash, $Na_2 CO_3$) is added to water that contains non-carbonate hardness, (e.g. $CaSO_4$, $MgSO_4$, $MgCl_2$, etc.), soda precipitates the hardness-causing cations, forming non-hardness-causing sodium salts:

$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$

$MgSO_4 + Na_2 CO_3 \rightarrow MgCO_3 + Na_2SO_4$

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$

In practice, sodium carbonate is regularly used together with hydrated lime; hence the term Lime Soda Method is applied to this process. The role of the hydrated lime is to convert soluble $Ca(HCO_3)_2$ to insoluble $CaCO_3$, to facilitate fast removal of $CaSO_4$, etc., by Na_2CO_3.

The type of chemical reaction can be shown as follows:-

$$MgSO_4 + Ca(OH)_2 + Na_2CO_3 \rightarrow CaCO_3 + Mg(OH)_2 + Na_2SO_4.$$

In this reaction, both $CaCO_3$ and $Mg(OH)_2$ are precipitated, leaving soft water.

The lime soda method is usually used in large-scale water softening, and can remove both permanent and temporary hardness.

The amounts of soda ash or hydrated lime to be added are determined by titration (the EDTA method).

The degree of hardness of both carbonate and non-carbonate type is expressed in terms of calcium carbonate ($CaCO_3$). When measured by titration, the result is expressed as **total hardness**, because the titration method indicated all forms of hardness, whether calcium, magnesium, iron, aluminum, etc., as equivalent to **$CaCo_3$ hardness**. The result is expressed as

Clark's Degree of Hardness. One degree on Clark's scale is equal to one grain of $CaCO_3$ hardness in one gallon of water. One grain of hardness is equivalent to 17.1 mg/l.

Base (ion) exchange method; zeolite process

In this method, hardness-causing cations (Ca^{++}, Mg^{++}, etc.) are replaced by non-hardness-causing cations or base (Na^{+}). This is accomplished by the process called **Base (Ion) Exchange.** The ion exchanger is often a zeolite.

The zeolite used in this process consists of a stable molecule composed of aluminum, silicon, and oxygen, to which a mobile base Na^{+} is loosely attached. The chemical formula of this molecule is a very complex one, and is usually expressed as $Na_2Al_2Sl_2O_8$. For the sake of simplicity, we shall represent its stable component as " Z^{-} " then, with its mobile sodium, it will be represented as $Na^{+}Z^{-}$.

When hard water containing Ca^{++}, Mg^{++}, etc., comes in contact with the zeolite exchanger, which we now call $Na^{+}Z^{-}$, the mobile sodium (Na^{+}) in the exchanger is replaced by Ca^{++}, Mg^{++}, which are insoluble bases. Thus the water is made soft:

$$2Na^{+}Z^{-} + Ca^{++} \rightarrow Ca^{++}(Z^{-})_2 + 2Na^{+}$$

$$2Na^{+}Z^{-} + Mg^{++} \rightarrow Mg^{++}(Z^{-})_2 + 2Na^{+}$$

Once the exchanger gives up all its mobile Na^+ supply, it cannot soften water any further. The exchanger is normally regenerated by pouring through it a concentrated solution of common salt or brine:

$Z_2Ca + 2Na^+$ (from brine) → 2 ZNa.

The zeolites originally used were naturally occurring substances known as glauconite or green sand. Later, different types of synthetic exchangers, such as polystyrenes, were developed. This process is usually used to soften household water supply systems. Different portable water softeners are sold under various trade names. Some of these softeners may remove other offenders in water, such as iron and manganese, in addition to softening hard water.

Fluoridation of water

Fluoridation of water is another commonly practiced supplemental water treatment in most of the developed regions of the world. By fluoridation is meant the application of a predetermined dose of fluorides to drinking water.

Fluorides are compounds of the element fluorine, which only occurs in compound forms. Such compounds as fluorspar (CaF_2) occur naturally in rock in certain regions of the world. Fluoride is one of the normal chemicals component of the

human tissues, particularly bone tissues, and quite a large proportion of food items contain traces of fluorides. Most water contains some amount of dissolved fluorides, the amount varying from place to place. But some water may contain too little fluoride, some almost none, while some contains an excess. The objective of fluoridation is to supplement fluoride deficiencies of drinking water.

Relation of fluorides to dental caries

Tooth decay is a very widely distributed chronic disease, affecting all segments of the population, the old and the young alike. Hence tooth decay is a very important health problem all over the world.

In localities where drinking water contained an optimum amount of fluoride, the decay of teeth was observed to be much lower in children who had consumed this water from ages 1 to 16, that is, during their formative years. It was also observed that where there was an excess amount of fluoride in water, it cause mottled or spotted teeth, dental fluorisis, disfiguration or staining of the enamel of teeth.

The optimum concentration of fluoride is established to be in the range of 0.8 to 1.2 ppm (0.8-1.2 milligrams of fluoride per liter of water). Lower concentrations than this do not give

maximum protection against dental caries. Higher concentrations cause mottled teeth, and 1.7 ppm (1.7mg/l) is taken to be the upper critical limit. Still higher concentration may accumulate in the bone tissue (fluorosis) and cause skeletal damage.

Fluoridation of water is essentially an effective and relatively cheap means to ensure dental health. It helps to prevent tooth decay.

Methods of feeding fluorides

Fluoridation of water requires complex equipment and highly skilled operator. Fluorine and its compounds are poisonous in concentrated form, and thus need careful handling at every stage. Because of these difficulties, fluoridation is usually carried out only in carefully operated municipal water-treatment system.

Generally fluorides are fed in solution or powder forms. Regardless of the form of fluoride, the feeders are normally small pumps that are specially designed to feed carefully calculated doses at predetermined time intervals.

Defluoridation

In certain regions of Ethiopia, particularly in the Rift Valley, the water supply systems, especially groundwater, contain a higher concentration of fluoride than is desirable. In such regions as the Wonji and Metahara areas in the Awash Valley, cases of mottled teeth can be observed among school children in the Sugar Estate.

Fluoride concentrations of 3.9 mg /l, 6.4 mg/l and 6.8 mg/l at Dire Dawa, Wonji and Awash Valley park respectively were recorded in well water by the Environmental Health Division of the Ministry of Public Health during 1970-1972.

The excess or undesirable concentration of fluoride in such places must be removed from the water supply before the water reaches the consumers. This process of removing the undesirable amount of fluoride is known as defluoridation.

Various methods have been developed for the defluoridation of drinking water, but all are at present generally too complicated and expensive for application in small water treatment plants and in rural areas.

Home defluoridation units suitable for the use of individual families have also been developed. Yet here again the units are too complex and expensive to warrant wider application.

Some of the current defluoridation methods that can technically be used are:

1. The Ion Exchange Process
2. The Phosphate Compounds Process
3. The Aluminum Compounds (Activated Aluminum) Process.

An alternative method, when practicable, may be the dilution of high fluoride water with low fluoride water.

Water desalinization

To meet the ever-increasing demands for fresh water, especially in arid and semi-arid areas, much research has gone into finding efficient methods of removing salt from seawater and brackish water. Three of the processes involve evaporation followed by condensation of the resultant steam and are known as multiple-effect evaporation, vapor-compression distillation, and flash evaporation.

The last-named method, the most widely used, involves heating seawater and pumping it into lower pressure tanks, where the water abruptly vaporizes (flashes) into steam. The steam then condenses and is drawn off as pure water. Freezing is an alternate method, based on the

different freezing points of fresh and salt water. The ice crystals are separated from the brine, washed free of salt, and melted into fresh water.

In another process, called reverse osmosis, pressure is used to force fresh water through a thin membrane that does not allow the minerals to pass. Reverse osmosis is still undergoing intensive development.

Electrodialysis is being used to desalt brackish waters. When salt dissolves in water, it splits into positive and negative ions, which are then removed by electric current through anion and cation membranes, thus depleting the salt in the product water. Although developmental work on electrodialysis is continuing, a number of commercial plants are in operation. In any event, desalination of seawater is expensive and not applicable for community water supply.

Review Questions

1. What is the advantage of raw water intake in water treatment?
2. What is the use of fine and coarse screens?
3. In water treatment plants, what is the most important use of clarifiers?
4. Explain the use of jar test.
5. Mention the most commonly used water coagulants.
6. Write the phenomena that occur in filtration.
7. In a water treatment plant, the Jar test results show that 5 mg/l of Alum at P^H 7 is required for coagulating. What is the consumption of Alum for 5,000 m^3 of water intended for coagulation?
8. Identify the disinfectant used in water treatment.
9. In a community water supply, 10 ppm of chlorine are added for disinfection. After 30 minutes, the residual chlorine was found to be 0.3 ppm in laboratory test. What is the chlorine demand of the water?
10. The label of a chlorine powder container indicates that it contains 70% of available chlorine. How many grams of the powder must be added to $45m^3$ of water to give a dose of 2 ppm?
11. What are the conditions that lead to the formation of hardness?

12. Show the chemical reaction indicating how water becomes hard.

Note to the teachers

- After you have gone through this chapter, arrange a practical visit to a nearby conventional large scale water treatment plant and show the students the steps in treatment processes. Give them an assignment to write a report and present it.

- Arrange a practical session to an environmental health laboratory to show the students how to prepare stock solution and determine the residual chlorine concentration.

CHAPTER THREE

WATER SAMPLING AND ANALYSIS

3.1 Learning Objectives

At the end of this chapter students will be able to:

1. Define sampling and analysis of water
2. Describe the purpose of sampling and analysis
3. Mention steps involved in sampling water from different sources.

3.2 Introduction

To obtain a true indication of the nature of water or wastewater, it is first necessary to ensure that the sample is actually representative of the source. Having satisfied this requirement, the appropriate analysis must be carried out using standard procedures so that results obtained by different analyses can be directly compared.

The collection of a representative sample from a source of uniform quality poses few problems and a single grab sample will be satisfactory. A grab sample will also be sufficient if the

purpose of sampling is simply to provide a spot check to see whether particular limits have been compiled with.

However, most raw waters and wastewaters are highly variable in both quality and quantity so that a grab sample is unlikely to provide a meaningful picture of the nature of the source. To obtain an accurate assessment in this situation, it is necessary to produce a composite sample by collecting individual samples at known time intervals throughout the period and measuring the flow at the same time.

By bulking the individual samples in proportion to the appropriate flows an integrated composite sample is obtained. Similar procedures are often necessary when sampling streams and rivers and with large channel sections it may be desirable to sample at several points across the section and at several depths. Various automatic devices are available to collect composite samples and these may operate on either a time basis or on a flow-proportional basis.

3.3. Sampling

One of the objectives of sampling is to assess the quality of the water supplied by the supply agency and of that at the point of use, so that samples of both should be taken. Any

significant difference between the two has important implications for remedial measures.

Samples must be taken from locations that are representative of the water source, treatment plant, storage facilities, and distribution network, points at which water is delivered to the consumer. In selecting sampling points, each locality should be considered individually; however, the following general criteria are usually applicable:

- Sampling points should be selected such that the samples taken are representative of the different sources from which the water is obtained by the public or enters the system;
- These points should include those that yield samples representative of the conditions at the most unfavorable sources, or places in the sample system, particularly points of possible contamination;
- Sampling should be uniformly distributed throughout a piped system;
- The points chosen should generally yield samples that are representative of the system as a whole and of its main components;
- In systems with more than one water source, the locations of the sampling points should take into account the number of inhabitants served by each source, and;

- There should be at least one sampling point directly after the clean water outlet from each treatment plant.

For the general sampling procedures see Chapter Six (page 193-196).

The most important tests used in water quality surveillance or quality control in communities are those for microbiological quality and turbidity, and for free residual chlorine and P^H where chlorination is used. These tests should be carried out whenever a sample is taken, regardless of how many other physical or chemical variables are to be measured.

Situations that requiring testing:

* Change in environmental conditions
* Outbreak of waterborne diseases
* Increase in incidence of waterborne diseases

Although recommendations vary, the time between sample collection and analysis should be kept to a minimum (6-24 hours). It is assumed that the samples are immediately placed into a tight insulated box containing melting ice. If such a container is not available, the transportation time must not exceed 2 hours.

3.4. Selection of Sites and Frequency of Sampling

Samples should be taken from locations that are representative of the water sources, treatment plant, storage facilities, distribution network and household connection. Where there are several sources and a mixed distribution system, it is necessary to take account of this. Where there is a branched distribution system, samples should be taken at random points evenly spread throughout the system. Where there are main branches and remote periphery, greater attention should be given to the main branches and remote points in the nextnetwork.

For the urban populations greater than 50,000, samples should be taken from the distribution system at a minimum rate of one sample per 5,000 population per month. For smaller populations use the following scheme:

Table 3.1. Frequency of water sampling

Population	No. of samples taken at the treatment	No. of samples taken from distribution	Max. sampling interval
< 1,000	1 per quarter	4 per quarter	3 months
1,001 –2,000	1 per quarter	6 per quarter	3 months
2,001 - 3,000	1 per month	4 per month	1 month
3,001 – 5,000	1 per month	6 per month	1 month
5,001 – 10,000	1 per month	11 per month	1 month
10,001 – 20,000	2 per month	22 per month	2 weeks
20,001 – 30,000	2 per month	34 per month	2 weeks
30,001 – 50,000	4 per month	60 per month	1 week

Sampling of water for microbial examination

- The objective of sampling is to obtain information about a particular source by examination of a small portion of that source.
- Samples may be collected as:
  - Part of a quality control of surveillance systems,
  - Official samples to determine conformity to legal specification, or
  - Part of waterborne disease investigation.

Collection of water samples

- Samples of water for bacteriological testing must be collected in a sterile bottle, and care must be taken to

prevent accidental contamination of the water during its collection and transport to the laboratory.

- The laboratory results and their interpretation are only as valid as the sample submitted for examination.

Containers for samples

- Collect samples for microbiological examination preferably in a glass bottle with a capacity of at least 200 ml.
- The sample bottle should be fitted with round glass stoppers or screw caps.
- The stopper or cap and neck of the bottle should be protected from contamination by a suitable cover either of paper or thin aluminum foil.

Dechlorination of samples

- If the water to be examined is likely to contain chlorine (chloramines) or other halogens, add a reducing agent to the sample collection containers.
- Sodium thiosulphate ($Na_2s_20_3$) is a satisfactory dechlorinating agent that neutralizes any residual halogen and prevents continuation of bacteriological action during sample transit. The examination then will indicate more

accurately the true microbial content of the water at the time of sampling.

- Add 0.1-0.2 ml of $Na_2S_20_3$, 30 gm/l (3% weight per volume) to each bottle of 200 ml capacity before it is sterilized.

Sampling procedures

- When the sample is collected, leave ample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
- Collect samples that are representative of the water being tested.
- Flush or disinfect the sample parts.
- Use aseptic techniques to avoid sample contamination.
- Keep sampling bottle closed until it is to be filled. Remove stopper or cap as a unit; do not contaminate the inner surface of the stopper or cap and neck of the bottle.
- Fill container without rinsing and replace the stopper or cap immediately.

Size of sample

- The volume of sample should be sufficient to carryout all tests required, preferably not less than 100 ml.

Identification of Data

- Accompany the sample by complete and accurate identifying and descriptive data. This should include:
  - Code number of the sample.
  - Reasons for examination (for example, whether a routine sample or otherwise).
  - Source from where the water has been collected.
  - Whether the water has been filtered, chlorinated, or treated in some other way.
  - If the water is from a well, give details of depth, whether covered or uncovered, and whether recently constructed or altered.
  - If the sample is spring water, describe whether the sample was taken directly from the spring or from a collecting chamber.
  - If the water is a river or stream, mention the depth at which the sample was collected, and whether there had been heavy rainfall or flooding.
  - If the water is from a lake or reservoir, given the exact position, and the depth at which it was collected, and whether there had been heavy rainfall or flooding.
  - Indicate the temperature of the source of the sample.
  - Mention any possible sources of pollution in the area, and their approximate distance from the sampling point.

- Indicate the date and time when the sample was taken and dispatched.

Holding Time and Temperature

- Start microbiological examination of water sample promptly after collection to avoid unpredictable changes.
- If samples cannot be analyzed within one hour after collection, use an ice cooler for storage during transport to laboratory.
- Hold the temperature of samples below 10 ^{0}c during a maximum transport time of 6 hours.

When local conditions necessitate delays in delivering of samples longer than 6 hours, consider conducting a field examination, using field laboratory facilities located at the site of collection.

Review Questions

1. What is the objective of sampling?
2. What are the prerequisites taken into consideration in the handling of sample bottle for bacteriological analysis?
3. What is the importance of dechlorination of samples of water for microbiological analysis?

Note to the teacher

After you have gone through the different methods of sampling in the theoretical class, arrange a practical session for the students to show how to take samples from different sources of water.

CHAPTER FOUR

WATER QUALITY

4.1. Learning Objectives

At the end of this chapter students will be able to:

1. Define physical, chemical and bacteriological analysis of water.
2. Describe the difference method of physical, chemical and bacteriological analysis of water.
3. List laboratory apparatus used in drinking water quality analysis.
4. Identify points to be considered in sanitary surveying of water sources.
5. Explain the drinking water quality standard.

4.2. Introduction

It is estimated that 80 % of all diseases and over one-third of deaths in developing countries are caused by the consumption of contaminated water and, on average, as much as one–tenth of each person's productive time is lostto water-related disease.

The cause for these problems is contaminated water with pathogenic micro-organisms and harmful chemical substances. Therefore, provision of potable water is very important to reduce these problems, as well as developing drinking water standards with special emphasis on aesthetic, physical, chemical, bacteriological and sanitary surveying of drinking water supply so as to reduce suffering and death in the community.

4.3. Aesthetic and Physical Analysis

Aesthetic parameters are those detectable by the senses, namely turbidity, color, taste, and odor. They are important in monitoring community water supplies because they may cause the water supply to be rejected and alternative, and possibly poorer quality, sources to be adopted. Additionally, they are simple and inexpensive to monitor qualitatively in the field.

Color

Color in drinking water may be due to the presence of colored organic matter, (e.g. humic substances), metals such as iron and manganese, or highly colored industrial wastes. Drinking water should be colorless. For the purposes of surveillance of community water supplies, it is useful to note the presence or absence of observable color at the time of sampling. Changes

in the color of water and the appearance of new colors serve as indicators that further investigation is needed.

Taste and odor

Odors in water are caused mainly by the presence of organic substances. Some odors are indicative of increased biological activity; others may results from industrial pollution. Sanitary inspections should always be made to correct an odor problem. Taste problems, which are sometimes grouped with odor problems, usually account for the largest single category of consumer complaints.

Generally, the taste buds in the oral cavity detect the inorganic compounds of metals such as magnesium, calcium, sodium, copper, iron, and zinc. As water should be free of objectionable taste and odor, it should not be offensive to the majority of the consumers. If the sampling officer has reason to suspect the presence of harmful contaminates in the supply, it is advisable to avoid direct tasting and swallowing of the water. Under these circumstances, a sample should be taken for investigation to a central laboratory.

Turbidity

Turbidity is important because it affects both the acceptability of water to consumers, and the selection and efficiency of

treatment processes, particularly the efficiency of disinfection with chlorine since it exerts a chlorine demand and protects micro-organisms and may also stimulate the growth of bacteria.

In all processes in which disinfections are used, the turbidity must always be low, preferably below 1 NTU or (these units are interchangeable in practice). It is recommended that, for water to be disinfected, the turbidity should be consistently less than 5 NTU or / and ideally have a median value of less than 1 NTU.

Turbidity may change during sample transit and storage, and should therefore be measured on site at the time of sampling. This can be done by means of electronic meters, which are essential for the measurement of turbidities below 5 NTU. For the monitoring of small community water supplies, however, meters that are capable of measuring turbidities of 5 NTU and above are adequate. These rely on robust, low-cost equipment that does not require batteries and is readily transportable in the field, and are therefore generally preferred.

Environmental Significance

Turbidity is an important consideration of water supplies for three major reasons:

- Aesthetics

- Filterability
- Disinfection

Application of Turbidity Data

Turbidity measurements are of particular importance in the field of water supply. They have limited use in the field of domestic and industrial wastewater treatment.

Turbidity is used in conjunction with other information to determine whether the water supply requires special treatment by chemical coagulation and filtration before it is used for public water supply.

See procedures for measuring turbidity in the field using a simple "turbidity tube" in Chapter Six.

4.4 Chemical Analysis

Under ideal conditions, water meant for drinking and domestic uses should not contain above the maximum allowable concentration of chemicals that may be harmful, objectionable or economically undesirable. The maximum allowable concentration (MAC) or the permissible dose of a toxic substance is "a definable and measurable level of human exposure at some point above zero, below which there is no significant threat to human health".

The aim of chemical analysis of water is, therefore, to determine the quality and quantity of different types of chemicals that may be present in a water supply system. The analyses are generally expressed in terms of mg/l or ppm.

Chemical analysis of water may be divided into two types: general chemical analysis and sanitary chemical analysis.

A) General chemical analysis

General chemical analysis is concerned with the determination of acidity-alkalinity, P^H, hardness, dissolved oxygen, hydrogen sulphide (H_2S), chloride, chlorine residual, fluoride, iron, manganese, and toxic substances such as arsenic, lead, pesticides, etc.

The significance of the presence of some of these chemicals in water will be briefly discussed below.

1. Hydrogen ion concentration (P^H)

The P^H of water is a measurement of how much acid or alkali is in it, the P^H scale being marked from 0 to 14. A P^H of 0 is extremely acid, while a P^H of 14 is extremely alkaline. A scale reading of 7 indicates a neutral point. The P^H values of natural water range from slightly acidic to slightly alkaline, running from 5.5 to 8.5.

Ideally, drinking water should be neutral or slightly alkaline, P^H 7.0 to 8.5. Water that is acidic is corrosive; it affects the solubility factors of the various chemicals that might be in the water, and hence affects the process of water treatment. On the other hand, water on the alkaline side of the scale reduces the disinfection efficiency of chlorination, etc.

P^H testing

It is important to measure P^H at the same time as chlorine residual since the efficacy of disinfection with chlorine is highly P^H dependent: Where the P^H exceeds 8.0, disinfection is less effective. To check that the P^H is in the optimal range for disinfection with chlorine (less than 8.0), simple tests may be conducted in the field using comparators such as that used for chlorine residual. With some chlorine comparators, it is possible to measure P^H and chlorine residual simultaneously.

Alternatively, portable P^H electrodes and meters are available. If these are used in the laboratory, they must be calibrated against fresh P^H standards at least daily; for field use, they should be calibrated immediately before each test. Results may be inaccurate if the water has a low buffering capacity.

See procedures for measuring P^H using a comparator in Chapter Six.

Environmental significance

- Change in P^H gives valuable clues in water quality control. It can reflect decomposition of organics in the water or photosynthetic activities in surface water. It can also indicate water pollution.
- Biological processes in water, especially in ponds, lakes, and quiet waters, are indicated by P^H changes. The CO_2 produced by the respiration of animals and plants in water is sufficient to depress the P^H and the CO_2 taken up by photosynthetic process of aquatic plants is sufficient to raise P^H.

Application of P^H

- P^H measurement is important in almost every phase of water supply and wastewater treatment.
- It is a factor that must be controlled in:

- Chemical coagulation
- Disinfection
- Water softening
- Corrosion control

2. Hardness

As discussed in Chapter 2, hardness of water is divided into temporary and permanent hardness. The two hardnesses considered together are called Total Hardness. Analyses of total hardness are usually expressed in terms of $CaCO_3$ equivalent (mg/l of $CaC0_3$). Hard water wastes soap, forms scale in boilers, and may act as a laxative under extreme conditions.

3. Chlorides

Sodium chloride or common salt dissolves easily in water. The content of chloride in natural surface waters is generally insignificant, but groundwater may contain excessive amounts of chloride, particularly where the rock formation of a region contains salt deposits. In other cases, the presence of excessive concentrations of chlorides may be due to contamination of the water by sewage (urine concentration of chlorides is in the order of about 5000 mg/l), or the mixing of salty water from coastal areas with fresh water. In any case, the concentration and the source of the chlorides in water supply must be determined.

Water that contains high concentrations of chlorides has an unpleasant taste; the level at which this objectionable taste is noticeable depends on the individual.

WHO's international standards for drinking water (1971) indicate 200 mg/l as the highest desirable level, and 600 mg/l as the maximum permissible level of chlorides in drinking water.

Chlorine residual test

The disinfection of drinking water supplies constitutes an important barrier against waterborne diseases. Although various disinfectants may be used, chlorine in one form or another is the principal disinfecting agent employed in small communities in most countries.

Chlorine has a number of advantages as disinfectant, including its relative cheapness, efficacy, and ease of measurement, both in laboratories and in the field. An important additional advantage over some other disinfectants is that chlorine leaves a disinfectant residual that assists in preventing recontamination during distribution, transport, and household storage of water. The absence of a chlorine residual in the distribution system may, in certain circumstances, indicate the possibility of post-treatment contamination.

Three types of chlorine residual may be measured: **free chlorine** (the most reactive type, i.e. hypochlorous acid and the hypochlorite ion); **combined chlorine** (less reactive but

more persistent type formed by the reaction of free chlorine species with organic material and ammonia); and **total chlorine** (the sum of the free and combined chlorine residuals). Free chlorine is unstable in aqueous solution, and the chlorine content of water samples may decrease rapidly, particularly at warm temperatures. Exposure to strong light or agitation will accelerate the rate of loss of free chlorine. Water samples should therefore be analyzed for free chlorine immediately upon sampling and not stored for later testing.

The method recommended for the analysis of chlorine residual in drinking water employs N, N-diethyl P-phenylenediamine, more commonly referred to as DPD. Methods in which 0-tolidine is employed were formerly recommended, but this substance is a recognized carcinogen, and the method is inaccurate and should not be use. Analysis using starch-potassium iodide is not specific for free chlorine, but measures directly the total of free and combined chlorine; the method is not recommended except in countries where it is impossible to obtain or prepare DPD.

See procedures for the determination of free chlorine residual in Chapter Six.

4. Iron and manganese

Iron and manganese are usually considered together because they usually occur together in groundwater, and their chemical behavior is similar.

Iron and manganese, when present in excess of the optimum level of concentration, impart a brown-to-reddish color to the water, and they stain clothes washed in such water. They also affect the taste of water, and their removal to an acceptable level (MAC: iron as Fe 1.0 mg/l, and manganese as Mn 0.5 mg/l) is essential in water treatment.

5. Lead:

Lead (Pb) is one of the toxic elements that may be present in a water supply, but which is not normally found in natural waters. However, lead dissolves in water that is acidic, and will contaminate water that is conveyed through lead pipes, collected over lead-painted surfaces or stored in lead-coated containers, etc.

Lead can also reach water through industrial wastes. Lead poisoning is cumulative; that is, it increases with every addition of lead in the human system, which cannot get rid of it; and it causes various forms of paralysis. The maximum allowable concentration that can be permitted in water without ill effects is established to be less than 0.1 mg/l.

See tables for guidelines for drinking water quality in Chapter Six.

B) Sanitary chemical analysis

As the name implies, sanitary chemical analysis of water is concerned with tests intended to reveal the sanitary quality of water. The analysis usually involves the detection of nitrogenous compounds (e.g. ammonia, nitrites and nitrates). The correlation of this test with the sanitary quality of the water is based on the nitrogen cycle in nature.

Nitrogen compounds are among the main constituents of all organic matter, plants and animals. When organic matter, such as human feces, animal droppings, dead bodies, etc., decays, nitrogenous compounds are the main products given off. One of the first products of decay is ammonia, which, with the help of some nitrifying bacteria in the soil, is converted to nitrite.

The sanitary significance of this is that, if nitrogen-ammonia, nitrogen-nitrite (the intermediate stage of decay), or nitrogen-nitrate (the final stage of decay) is detected in water above the maximum allowable concentration, then this must be due to decomposition that is taking place, or that has taken place in

the recent past. Hence, this is an indication that the water is polluted with decaying organic waste

Furthermore, dissolved nitrogen-nitrates (NO_3) are a health hazard when present in water above the permissible level of concentration. The presence of more than 45 mg/l concentration of NO_3 in water supply causes a disease known as **methaemoglobinaemia ("blue babies")** in infants less than three months old.

This can happen when babies consume food or milk prepared with water that has a high nitrate concentration. The disease is restricted mainly to infants of less than three months, because only the intestinal bacterial flora of infants of this age are able to convert the nitrate. The newly formed nitrite then converts hemoglobin, the blood pigment that is responsible for the circulation of oxygen in the tissues, to methaemoglobin, which interferes with the oxygen-transporting function of the hemoglobin; the end-result is oxygen deprivation (suffocation) of the body tissues.

Although no systematic investigation has been made over the whole country, it has been found that excessive amounts of nitrates in groundwater are a serious problem in several regions of Ethiopia.

Nitrates may also reach water from other sources, such as carelessly stored fertilizers, runoff from fertilized fields, cattle-feeds enriched with nitrate compounds, etc.

Technically, nitrates can be removed or reduced to a desirable level in drinking water, but the method is generally complex, expensive and impracticable under rural or semi-rural conditions.

See tables for guideline for drinking water quality in Chapter Six.

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4.5. Bacteriological Analysis

The principal risk associated with water in community supplies is that of infectious disease related to fecal contamination. Hence, the microbiological examination of drinking water emphasizes assessment of the hygienic quality of the supply. Indicator organisms may be used to assess the efficiency of drinking water treatment plants, which is an important element of quality control. The isolation of specific pathogens in water should be undertaken for the purposes of investigating and controlling outbreaks of disease.

Bacterial indicators of fecal pollution

The use of normal intestinal organisms as indicators of fecal pollution rather than the pathogens themselves is a universally accepted principle for monitoring and assessing the microbial safety of water supplies.

Feces contain a large number of organisms including Escherichia coli, streptococcus fecalis and clostridium perfringens. These organisms form part of the normal bacterial flora of the intestinal tract. A useful way, therefore, for determining whether a water supply is fecally polluted and could possibly contain enteric pathogens dangerous to health, is to test the presence of normal fecal organisms.

Direct search for all potentially present pathogens is not practicable for routine control purposes, because:

a) The pathogens present are usually greatly outnumbered by normal intestinal microbes ($1:10^6$).
b) They tend to die off faster, and
c) Isolation of and specific tests on all possible pathogens involve complicated and lengthy procedures.

Therefore, simple and rapid tests have been developed for detection of normal intestinal bacteria that in this way are used as indicators or tracer bacteria of fecal pollution of water; their presence indicating only that pathogens might also be present. Hence, if water is found to contain fecal indicator bacteria, it is considered unsafe for human consumption.

Bacteria indicators/tracers of fecal contamination ideally should fulfill the following requirements. They must:

a) Be applicable to all types of water
b) Always be present when pathogens are present
c) Always be absent when pathogens are absent
d) Be easy to detect and count, and detectable in low densities
e) Be non-pathogenic for the safety of laboratory personnel
f) Be a normal member of intestinal flora of healthy people
g) Be exclusively intestinal inhabitants, hence exclusively facal in origin when found in the environment
h) Unable to multiply outside the intestine.

No bacterial species or group presently in use completely fulfill all these requirements. But a few come close to doing so. In conventional water bacteriology, three main groups or species of bacteria are used as fecal indicators:

1. Coliform bacteria (E. -coli, Citrobacter, Entrobacter, klebsiella)
   - Total coliform (TC)
   - Fecal coliform (FC)
   - Non-fecal coliferm (NFC)
2. Fecal streptococci (FS) or Entrococcus - e.g. streptococus fecalis
3. Clostridium perfringens (Cl. Welchi).

Coliform Bacteria

1. Are present in human and animal feces; in human feces in numbers of 10^{6}-10^{9} /gm of stool
2. Are the most sensitive fecal indicator; one cell in 100 ml water is detectable.
3. Exist in two main groups; fecal and non-fecal coliforms (together forming total coliforms)
4. The term “total coliforms” refers to gram negative, rod-shaped, aerobic or faclutive bacteria capable of growth in the presence of bile salts or other surface active agents with similar growth inhibiting properties, and able to ferment lactose at either 35^{o}c or 37^{o}c with the production of acid gas and aldenyde with in 24-48 hours
5. Total coliforms include E. coli, Citrobacter, Entrobacter and klebsiella. Total coliforms are derived not only from the feces of warm-blooded animals but also from

vegetation and soil. Therefore, the detection of total coliforms only from a water sample may not indicate pollution by fecal matter.

- Fecal cloiforms are coliforms that exhibit the same properties as total coliferms at temperature of 44 ^{o}c or 44.50 ^{o}c
- Total coliforms comprise the genus E. coli and, to at certain extent, occasional strains of entrobacter, citrobacter and klebsiella. Of these organisms, only E. coli is specifically of fecal origin, being always present in the feces of humans, animals and birds in large numbers and rarely found in water or soil that has not been subject to fecal pollution.
- Complete identification of E. coli in terms of modern taxonomy would require an extensive series of tests, which would be impractical for routine water examination. Therefore, detection and identification of fecal coliforms as fecal organisms or presumptive E. coli is considered to provide sufficient information to assess the fecal nature of pollution.
- Fecal coliform organisms that ferment lactose at 44 ^{o}c or 44.5 ^{o}c with the production of acid and gas and that also form indole from tryptophan are regarded as presumptive E coli.

- Fecal (thermo-tolerant) coliforms are less reliable indicators of fecal contamination than E. coli although under most circumstances their concentrations are directly related to E. coli concentration in water. Their use for water-quality examination is, therefore, considered acceptable.

Fecal Streptococcus

Fecal streptococci are present in the human body and animal feces. Their number in humans is 10^5-10^8/gm of stool; in general, smaller than that of coliforms.

The fecal streptococcus group consists of a number of species of the genus streptococcus such as streptococcus fecalis, streptococcus faecium, streptococcus bovis, streptococcus equinus and streptococcus gallinarum.

The normal habitat of fecal streptococcus is the gastrointestinal tract of warm-blooded animals. Streptococcus fecalis and streptococcus facium are considered to be more human-specific than other streptococcus species. Other species have been observed in human feces but less frequently.

The entrococcus group is a subgroup of the fecal streptococci that includes S. fecalis, S. facium, S. gallinarum and S. avium.

The entrococci are differentiated from other streptococci by their ability to grow in 6.5% sodium chloride at p^H 9.6 and at 45 ^{0}c.

The main value of fecal streptococcus lies in assessing the significance of doubtful results from the coliform tests.

When organisms of the coliform groups but not E. coli are found in a water sample, the finding of fecal streptococcus affords important confirmatory evidence of the fecal nature of pollution.

Sometimes fecal streptococcus tests are used as an independent test in the examination of swimming pool water.

Clostridium Perfringens (Cl. Welchi)

Clostridium perfringens is anaerobic, spore forming, exclusively fecal in origin, and can also be pathogenic (gas gangrene and food poisoning)

Cl. perfringens occurs in human and animal feces. A gram of human feces may contain 10^1 –10^7 Cl. Perfringens, which is lower than fecal streptococcus and fecal coliforms.

Cl. perfringens can persist for a longer time outside the intestine, and resist chlorination. It can, therefore, be used as

an indicator of occasional or intermittent fecal contamination (example, of open wells) or of fecal pollution of a remote date, when no fecal coliforms or fecal streptococcus can be detected any more.

Methods of Examination of Water

In the interest of public health, drinking water sources should be tested regularly to confirm their freedom from fecal contamination. It is impractical to attempt directly to detect the presence of all the different kinds of water borne pathogens. Instead, reliance is placed on testing the supply for fecal indicator bacteria.

It is necessary not only to attempt to detect the presence of indicator bacteria, but also to enumerate them, for the greater their number, the greater the dangers of infection from the supply.

There are two principal methods for counting and identification of indicator organisms. These methods are:

1. Membrane Filter method;
2. Multiple Tube Fermentation or Most Probable Number (MPN) Method.

1. Membrane Filter (MF) Method

In this method, a measurable volume of the water sample is filtered through a membrane with a pore size small enough to retain the indicator bacteria to be counted. The membrane is then placed and incubated on a selective indicator medium, so that the indicator bacteria grow into colonies on the upper surface. These colonies, which are recognized by their color, morphology and ability to grow on the selective medium, are counted.

The membrane filter technique is highly reproducible, can be used to test relatively large sample volumes, and yields numerical results more rapidly than the multiple tube procedure. The membrane filter is extremely useful in monitoring drinking water. In the membrane filter technique, sample sizes will be governed by expected bacterial density. In drinking water analysis, sample size will be limited only by the degree of turbidity or by the non-coliform growth on the medium.

An ideal sample volume will yield 20 to 80 coliform colonies, and not more than 200 colonies of all types on a membrane filter surface. Analysis of drinking waters can be conducted by filtering 100 – 1000 ml or by filtering replicate smaller sample volumes.

Analysis of other water can be conducted by filtering three different volumes (diluted or undiluted), depending on the expected bacterial density.

When less than 10 ml of sample (diluted or undiluted) is to be filtered, add approximately 10 ml sterile dilution water to the funnel before filtration, or pipette the sample volume into a sterile dilution flask, and then filter the entire dilution. This increase in water volume aids in uniform dispersion of the bacterial suspension over the entire effective filtering surface.

In the membrane filtration method, a minimum volume of 10 ml of the sample (or dilution of the sample) is introduced aseptically into a sterile membrane filter. A vacuum is applied and the sample is drawn through the membrane filter. All indicator organisms are retained on or within the filter, which is then transferred to a suitable selective culture medium in a petri dish. Following a period of resuscitation, during which bacteria become acclimatized to new condition, the petri dish is transferred to an incubator at the appropriate selective temperature where it is incubated for a suitable time to allow the replication of the indicator organism.

Visually identifiable colonies are formed and counted, and the results are expressed in numbers of color formation (CFU) per 100 ml of original sample.

See Membrane Filter (MF) method and tables for guidelines for drinking water quality in Chapter Six (pages 206 – 216 and 243 – 245 respectively).

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2. Multiple Tube Fermentation or MPN Method

The multiple tube fermentation method determines the presence and number of coliform bacteria through the planting of a series of measured sample portions into tubes containing favorable culture media. The test progresses through three distinct phases:

i) The presumptive phase
ii) The confirmed phase
iii) The completed phase.

It is possible to stop the examination of a water sample at the end of any of these phases, provided the purpose of the test has been fulfilled, or the examination may proceed directly from one stage to the following stage.

The confirmed test and the completed test increase the certainty that positive results obtained in the presumptive test are due to coliform bacteria, and not to the activity of other kinds of bacteria.

The completed test is the standard test for the determination of the bacteriological safety of water. In routine practice,

bacteriological testing of most public water supplies is stopped as the end of the confirmed test. The confirmed test is also valuable in testing sample from the sources of a water supply from various parts of a water treatment plant.

When multiple tubes are used in the fermentation technique, the results of examination of triplicate tubes and dilutions are reported in terms of the most probable number, based on certain probability formulas, as an estimate of the mean density of coliforms in the sample.

MPN tables are based on the assumption of a Poisson distribution (random dispersion). However, if the sample is not adequately shaken before the portions are removed, or if clumping of bacterial cells occurs, the MPN value will be an underestimate of the factual bacterial density.

The precision of each test depends on the number of tubes used. The most satisfactory information will be obtained when the largest sample of inoculums examined shows positive reaction in some or all of the tubes, and the smallest sample of inoculums shows negative reaction in all or a majority of the tubes.

The multiple tube method is also referred to as the most probable number (MPN) method because, unlike the membrane filter method, it is based on an indirect assessment of microbial density in the water sample by reference to statistical tables to determine the MPN micro-organisms present in the original sample. It is essential for highly turbid water samples that cannot be analyzed by membrane filter.

The multiple tube methods depends on the separate analysis of a number of volumes of the same sample. Each volume is mixed with culture medium and incubated. The concentration of micro-organisms in the original sample can then be estimated from the pattern of positive results by means of statistical tables that give the MPN per 100 ml of original sample.

See multiple tube fermentation or MPN method and tables for guidelines for drinking water quality in Chapter Six (pages 216–242 and 243–245 respectively).

Hetrotrophic Plate Count (HPC)

The HPC (or standard plate count) is a procedure for estimating the number of live heterotrophic bacteria in water, and measuring changes during water treatment and distribution. Colonies may arise from pairs, chains, clusters,

or single cells; all of which are included in the term "colony-forming units" or CFU.

Even though the HPC is not of much use in ascertaining the sanitary quality of water, it is helpful in determining the bacterial removal efficiency of filtration units in water treatment plants.

There are three different methods to count hetrotrophic bacteria:

i) Pour plate method
ii) Spread plate method, and
iii) Membrane filter method.

i) Pour plate method

This method is simple to perform, and can accommodate volumes of sample or diluted samples ranging from 0.1 to 2.0 ml. The colonies produced are relatively small and compact, showing less tendency to encroach on each other than those produced by surface growth.

In this method, a significant heat shock to bacteria from the transient exposure of the sample to 45 ^{0}c to 46 ^{0}c agar may occur.

ii) Spread plate method

This method causes no heat shock to bacteria, and all colonies are on the agar surface where they can be distinguishing readily from particles and bubbles.

The spread plate method is limited by the small volume of sample or diluted sample that can be absorbed by the agar, (0.1 to 0.5 ml, depending on the degree to which the poured plate have been dried).

iii) Membrane filter method

The membrane filter method permits testing large volumes of low turbidity water, and is the method of choice for low-count waters (< 1 to 10 CFU /ml).

This method produces no heat shock, but adds the expense of the membrane filter.

Media for Hetrotrophic Bacteria

a) Plate Count Agar (PCA) – Tryptone glucose yeast agar.
   - Used for pour and spread plate methods.
   - Gives lower counts than R_2A and NWR agar.

b) M-HPC Agar
   - Used for membrane filter method only.
   - Is high nutrient medium.

c) R2A Agar

- Used for pour, spread and membrane filter methods.
- Gives higher counts than PCA .

d) NWRI Agar (HPCA)

- Used for pour, spread and membrane filter methods.
- Is a low nutrient medium, but produce higher colony counts.

Sample size

- **Pour and spread plate Method**
  - Select the dilutions so that the total number of colonies on a plate will range between 30 and 300. For example, when a hetrotrophic plate count as high as 3,000 is suspected, prepare plates with 10^{-2} dilution.

For most potable water samples:

- Plate 1ml and 0.1ml undiluted sample and 1ml of the 10^{-2} dilution in pour plate method.
- Plate 0.1 and 0.5 ml in spread plate method.

- **Membrane Filter Method**

The volume of the sample to be filtered will vary with the sample. Select a maximum sample size to give 20 to 200 CFU / filter.

Incubation

The usual incubation temperature and time for the hetrotrophic plate count is 35 ^{0}c for 48 hours.

Counting and Reporting the Results

- Count all colonies on selected plates promptly after incubation.
- In preparing plates, pipette a sample volume that will yield from 30 to 300 colonies per plate. The aim is to have at least one dilution, giving colony counts between these limits (30 – 300).
- Consider only plates having 30 to 300 colonies in determining the plate count.
- Compute bacterial count per ml by the following equation:

$$\text{CFU/ml} = \frac{\text{Colonies counted}}{\text{Actual volume of sample in dish, ml.}}$$

The term "colony forming units" (CFU) is descriptive of the methods used; therefore report all counts as colony forming units. Include in the report:

- the method used
- the incubation temperature and time and
- the medium.

For example – CFU/ml, pour plate method, 35 ^{0}c /48 hours, PCA.

Culture Media

Most bacteria can be cultured artificially if the culture medium contains:

- The required nutrients
- The proper osmotic pressure, and
- The proper pH.

The micro-organisms should be incubated in a proper temperature that suits their metabolism.

80- 90% of the living weight of a bacterial cell is water, and of the dry weight 2 – 5% phosphorus; the remainder is made up of various minerals and combinations of oxygen and hydrogen in organic compounds. Therefore, the media used for growing should contain water, and sources of phosphorus, nitrogen, carbon, minerals and essential vitamins.

Sterilization of culture media

The commonly used methods to sterilize culture media are:

1. Autoclaving

- Used to sterilize most agar and fluid medic.
- Ensuring the destruction of spores and vegetative cells.

2. Steaming

- Used to sterilize media containing ingredients that would be broken down or inactivated at temperature over 100 ^{0}c.
- Can be performed in an autoclave with the lid left loose.

3. Filtration

- Used mainly to sterilize additives that are heat sensitive and therefore cannot be autoclaved.

4.6. Sanitary Survey

A sanitary survey of a water supply system is the complete, extremely careful and detailed investigation of the entire water supply system, from the source to the consumer, in order to detect the presence of actual or potential sources of contamination. The sanitary survey report of the water supply system is the single reliable and practical source of information for ascertaining the potability of the water supply.

Sanitary survey of a water supply includes the following information:

A) Geological and topographical survey of the source: the type and nature of the rock formations of the locality, (including porosity, permeability, existence of limestone,), hydraulic gradient, depth to water table, etc.; the extent of the drainage or catchments basin of the source or other feeders of the source, the type of vegetation, and the factors that all these points may contribute to contamination.

B) Human habitation, livestock and animal population: the existence of actual or potential sources of contaminants as the result of human activities. For example, methods of excreta disposal, refuse disposal, and animal waste disposal; the distance of such sources of contaminants, latrines, cesspools, sewage, etc., from the water source; industrial or other wastes which are being drained or will be drained into the source.

C) Amount and duration of rainfall: the chances of infiltration or flooding of runoff during rainy seasons and dry seasons to the source; preventive measures against such infiltration by diversion ditches, if any or by other means.

D) Soundness of the protection technique: if the source is a well or a spring, the soundness of the casing platform and

cover to exclude the infiltration of contaminants; the possibility of contamination through the method of drawing water (water pump, sanitary bucket and rope, etc.); the gradient and distance from potential sources of contaminants, with the chance or infiltration from nearby streams, ponds, septic tank effluents, seepage pits, cesspools, oxidation ponds, etc.

Note: Fluorescein sodium solution is one of the chemicals commonly used for tracing underground infiltration of pollution.

E) Efficiency of treatment: the type of treatment used and the efficiency of each step: aeration, chemical coagulation, sedimentation filtration (slow or rapid sand filter) chlorination; storage methods and condition of the reservoir; possibilities of contamination during pumping, transport (piping), storage and distribution, including public standpipes and house connections; frequency of supervision, type of personnel and their qualification for running the treatment processes; regularity of chlorination; presence of residual chlorine at all times and at all points in the system, availability of residual chlorine records (daily, weekly, etc.); frequency of disinfection, if any; and, if the source is ground-water, type and frequency of laboratory test performed.

Sanitary Inspections

A sanitary inspection is an on-site inspection and evaluation by qualified individuals of all conditions, devices and practices in the water supply system that pose an actual or potential danger to the health and well-being of the consumer. Sanitary inspections provide a direct method of pinpointing possible problems and sources of contamination. They are also important in the prevention and control of potentially hazardous conditions, including epidemics of waterborne diseases.

Sanitary inspections are intended to provide a range of information and to locate potential problems. The data obtained may identify failures, anomalies, operator errors, and any deviations from normal that may affect the production and distribution of safe drinking water. When the inspections are properly carried out at appropriate regular intervals, and when the inspector has the knowledge necessary to detect and suggest technical solutions, the production of good quality water is ensured.

The frequency of routine sanitary inspections depends on a number of factors, such as geography, distribution of the population, access to the various localities, etc. as well as the overall development level, including facilities, number and expertise of technical staff, level of activity in programs, etc.

The two principal activities are sanitary inspection and water quality analysis. Sanitary inspection should take priority over analysis, but the two should be done together whenever possible. They are complementary activities; inspection identifies potential hazards, while analysis indicates whether contamination is occurring and if so, its intensity.

A sanitary inspection is indispensable for the adequate interpretation of laboratory results. No analytical, bacteriological or chemical survey, however carefully carried out, is a substitute for comprehensive knowledge of conditions at the water source and within the distribution system, the adequacy of water treatment, and the qualifications and performance of the operators. Samples represent conditions at a single point in time and even when there is frequent sampling and analysis, the results are reported after contamination has occurred, especially in systems without long-term storage. Micro-biological contamination is often sporadic and may not be revealed by occasional sampling.

1. Sanitary Inspection Reports

The sanitary inspection report is that part of the survey based on the on-site inspection of the water sources (i.e. a field survey). It therefore provides a direct method of identifying all the hazards that are potential and actual causes of contamination of the supply. It is concerned with the physical

structure of the supply, its operation, and external environmental factors. The hazards recorded during inspection are often tangible and observable and may be used together with analytical data to derive a risk assessment.

Sanitary inspections, thus, provide essential information about immediate and ongoing possible hazards associated with a community water supply, even in the absence of microbiological or chemical evidence of contamination.

A) Functions of sanitary inspection report forms

Inspections forms should provide a simple and rapid means of assessing and identifying hazards associated with water supply systems. The inspection form should include at least a checklist of the components of the water supply from source to distribution and incorporate all the potential points where hazards may be introduced. Any problems identified during the inspection should be highlighted so that a report may be provided directly to the community and copies forwarded to both supply agency and health authority. The specific functions of the sanitary inspection report are to:

- Identify potential sources and points of contamination of the water supply;
- Quantify the hazard (hazard score) attributable to the sources and supply;

- Provide a clear, graphical means of explaining the hazards to the operator/user;
- Provide clear guidance as to the remedial action required to protect and improve the supply, and;
- Provide the raw data for use in systematic strategic planning for improvement.

B) Design of sanitary inspection report forms

The design, evaluation and refinement of sanitary inspection forms are among the most important aspects of developing a surveillance or quality-control program. Two approaches are possible: the use of pictures and brief checklists, or the use of detailed checklists with explanatory notes. Either may be used successfully. However, the use of pictorial inspection forms should be adapted to match local circumstances; they should be suitable for the inspectors to use, and the recipients of the information should be able to understand and act on them.

2. Carrying out sanitary Inspections

Staff responsible for field sanitary inspection work should always try to notify the local community representatives in advance of the visit, especially where the presence of the latter is required in order to obtain access to certain points in the supply system and where the assistance of community members in conducting the inspection is needed.

Before visiting the community, the sanitarian should have prior knowledge of the type and number of supplies, sources and taps. This should be checked against local records and maps held by the local health post or health center. If no map is available, an attempt should be made to prepare at least a sketch map of the supply or sources.

The sanitarian should complete the sanitary inspection report onsite together with the community representatives. Opportunities to point out problems or defects in the field to community members, their representatives, or the system caretaker or operator should be taken whenever possible. It may also be appropriate to undertake simple repairs at the same time.

After completing the sanitary inspection, the sanitarian should circle each of the points of risk on the diagram. Before leaving the community, the sanitarian should discuss, agree and schedule any follow up actions and indicate the date of the next survey. The survey officer carrying out the sanitary survey should record whether or not sampling or analysis will be undertaken. Labor, and hence, time can sometimes be saved by carrying out the analysis in the field at the same time as the inspection.

Sanitary inspections should be undertaken on a regular basis. Regular or routine inspections are visits made with a defined frequency in accordance with a previously established plan. In addition, non-routine visits by the inspector will be necessary in atypical situations, such as the introduction of a new water source, and in cases of emergency. Emergency situations calling for the urgent presence of the inspector include:

a) reports of epidemics
b) high turbidity caused by floods
c) unresolved cases where bacteriological analysis repeatedly show the presence of excess levels of micro-organisms and where residual chlorine levels remain consistently low
d) the detection of any important changes that could impair drinking water quality.

Review Questions

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1. What is the environmental significance of turbidity?
2. What is the implication of high/low conductivity?
3. What are the tablets used in testing P^H and residual chlorine?
4. Discuss briefly the similarities and differences between general and chemical analysis.
5. Coliform organisms are the preferred indicators compared with pathogenic micro-organisms – Do you agree? Justify your reason of agreement.
6. Which methods of water quality test for microbiological analysis are feasible during fieldwork?
7. Write the common ingredient of culture media.
8. Write and discuss types and forms of culture media.
9. What factors are to be considered in sampling water for bacteriological examinations?
10. What factors are to be considered during sanitary inspections?

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Note to the teachers

It is difficult for the students to understand easily this chapter in the classroom teaching learning process. So, in your environmental health laboratory, arrange for the students to have a practical session on analysis of drinking water quality using different methods.

CHAPER FIVE

PUMPS AND THEIR PRINCIPLES OF OPERATION

5.1. Learning Objectives

At the end of this chapter students will be able to:

1. Define the meaning of water pumps.
2. Discuss the impact of atmospheric pressure on pumping.
3. Explain the principle of pumping water.
4. Identify the types of pumps used in drinking water supply.
5. Recognize cause of friction head.
6. Calculate power requirements of pumps.

5.2 Introduction

A water pump is a device for moving water from one location to another, using tubes or other machinery. Water pumps operate under pressures ranging from a fraction of a pound to more than 10,000 pounds per square inch. Everyday examples of water pumps range from small electric pumps that circulate and aerate water in aquariums and fountains to

sump pumps that remove water from beneath the foundations of homes.

Two types of modern pumps used to move water are the positive-displacement pump and the centrifugal pump. Positive-displacement pumps use suction created by a vacuum to draw water into a closed space. An example of this type of pump is the lift, or force, pump used commonly in the rural United States until the mid-1900s.

The lift pump is operated by raising a handle that is attached to a piston encased in a pipe. Lifting the piston creates a partial vacuum beneath it in the pipe, causing water to be drawn from a well below, through the pipe, and into a chamber in the pump. A one-way valve closes after water is pumped into the chamber, keeping the water from flowing back down into the well. Subsequent pumps of the piston pull more water into the chamber, which eventually overflows, spilling water out of a spout.

Centrifugal pumps use motor-driven propellers that create a flow of water when they rotate. The blades of the propeller are immersed in the water to be pumped. As the propeller turns, water enters the pump near the axis of the blades and is swept out toward their ends at high pressure. An alternative, early version of the centrifugal pump, the screw pump,

consists of a corkscrew-shaped mechanism in a pipe that, when rotated, pulls water upward. Screw pumps are often used in wastewater treatment plants because they can move large amounts of water without becoming clogged with debris.

5.3 Water Pumps

With the exception of favorably located gravity springs or artesian wells, water generally has to be lifted from a lower to a higher point of elevation; for example from a shallow dug well up to ground level and above, or from a deep well to a raised tank. For this purpose, pumps are used.

Pumps may be described as devices for moving water, or, more accurately, for moving liquids or gases. The branch of physics that studies the laws dealing with the pumping of liquids is known as **hydraulics**.

There are numerous types of pumps designed and made by various manufacturers throughout the world. The selection of a specific type of pump depends upon several factors, the main ones being:

A) The type of driving force (prime mover): by hand, by internal combustion (motor) engine, by electricity or wind.
B) The total head or pressure against which the pump is intended to operate, and at what frequency.

C) The volume of water to be pumped, and height to which it is to be raised.
D) The practicability of the pump as regards to installation, operation and maintenance in a given locality.

In many rural areas of developing regions, electricity is not available, and engines powered by mineral fuel (e.g. oil or petrol/benzene) can be too expensive to install and maintain. In such circumstances, the cheapest and simplest types of pumps, other than windmills, are hand-operated. However, these pumps have limitations, and the possibility of changeover to electric or mineral fuel pumps should be considered if it is economically and technically feasible. Regardless of the driving force, the basic principle of operation of most pumps is similar. As examples of the major type of pumps commonly used, we will describe the **positive-displacement type of pump** (usually manually operated) and the **centrifugal type of pump** (motor-operated).

5.4 Atmospheric Pressure

The atmosphere that surrounds the earth's crust has a definite weight, which varies with altitude. At sea level, zero altitude, the weight is 1 kg/cm^2 . The higher the altitude is, the lower the weight of the atmosphere becomes, because air is denser at sea level and thins as elevation increases. Atmospheric

pressure, which is the weight of the atmosphere per unit area, decreases accordingly with the rise in altitude.

Atmospheric pressure is normally measured by an instrument called a **barometer**. Under ideal conditions, atmospheric pressure at sea level is equal to a column of mercury of 760 mm or 30 inches.

So far we have been dealing with atmospheric pressure. What about the relative weight (head) of water? We have already stated that the atmospheric pressure at sea level is 1 kg/cm^2 or equal to a head of 760 mm of mercury.

Since mercury is 13.6 times heavier than an equal volume of water, the equivalent head of water is 13.6 x 0.76, or 10.34 m. (34 ft.). This means that when a perfect vacuum is created in a tube, atmospheric pressure can raise water to a height of 10.34 m.

Let us look at Figure 5.1. The tube shown at A is open at both ends. Atmospheric pressure exerts equal weight at all points, so there is no difference in the water level.

In the second tube B, there is a plunger, which can be raised by applying an external upward force. If we assume that the plunger fits the tube perfectly and can therefore create a

perfect vacuum by driving out the air in the tube, the water level will rise to a maximum height of 10.34 m due to the atmospheric pressure. Tube B is a simple diagram of the suction pipe of a hand-operated pump.

In practice, however, under normal conditions, an ordinary pump plunger cannot bring about absolute zero atmospheric pressure, creating a perfect vacuum. The practical height to which atmospheric pressure can lift water at sea level varies from about 6.60 m to 8.1 m (from 22 to 27 ft).

5.5. Principles of Pumping Water

To reduce pressure below atmospheric level, a pump consisting of a cylinder with valves and plunger rod, etc., is used. (See Figure 5.2.)

The height to which atmospheric pressure can lift water depends on several factors, the main ones being:

A) The capacity of the pump to create a "perfect" vacuum

In practice, ordinary pumps cannot create a perfect vacuum; hence, it is usual to express pump efficiency in terms of a percentage. Most ordinary pumps used in water supplies have efficiencies from 50% to 80%. Accordingly, the relative

theoretical height of 10.34 m of water at sea level is in practice roughly equivalent to 7.5 m (25 ft) known as the practical height.

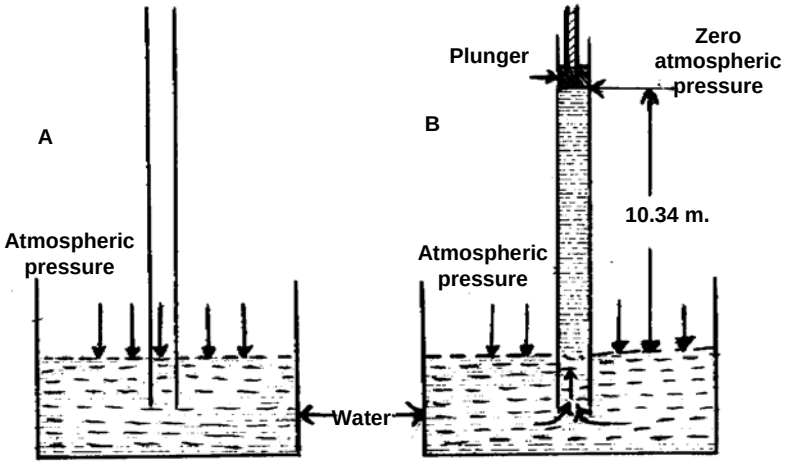


Figure 5.1 Pressure exerted by the Atmosphere

(Adapted from Gabre- Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

B) The altitude of a locality

Atmospheric pressure decreases with increase in elevation above sea level, because the air gets thinner as altitude increases, and hence its weight per unit area (pressure) also decreases accordingly. Therefore, both the theoretical and practical height to which atmospheric pressure can lift water varies with elevation above sea level. This decrease is

equivalent to about 0.4 m (1.3 ft) for every 300 m (1000 ft.) rise in altitude.

To illustrate this point, let us take Addis Ababa, which is about 2800 m (8400 ft) above sea level. The theoretical head of water that can be raised by atmospheric pressure in Addis Ababa is:

$$10.34 - \left(\frac{2800 \times 0.4}{300}\right) = 6.61 \text{ m}$$

The practical suction height is

$$7.5 - \left(\frac{2800 \times 0.4}{300}\right) = 4 \text{ m}$$

This is without considering the depth of the well from which the water is to be lifted. If we assume that the average depth of the water table is about 10 meters in Addis Ababa, then the type of pump that depends on atmospheric pressure is of little practical value in the city. Because the height to which this type of pump can lift water is limited, the pump is sometimes called a **shallow well pump**. As a rule shallow well pumps should not be considered for areas where the water table is deep or the average elevation is high.

Principles of operation of the positive displacement type of pump

The principles of operation of the positive displacement type of pump may be illustrated by using a typical lift pump as an example.

This type of pump is known by several other names, such as pitcher pump, spout pump, single-action displacement pump, reciprocating or alternating lift pump, etc.

All of them work on the same principle, but for this discussion we shall take the example of the **pitcher pump**. The pitcher pump consists of the following main parts (as in Figure 5.2):

A) A cylinder.
B) A plunger or piston connected to a handle.
C) Two valves:
   (1) The plunger valve or piston valve, and
   (2) The foot valve or check valve.
D) A suction pipe or drop-pipe which extends down into the level of the static water

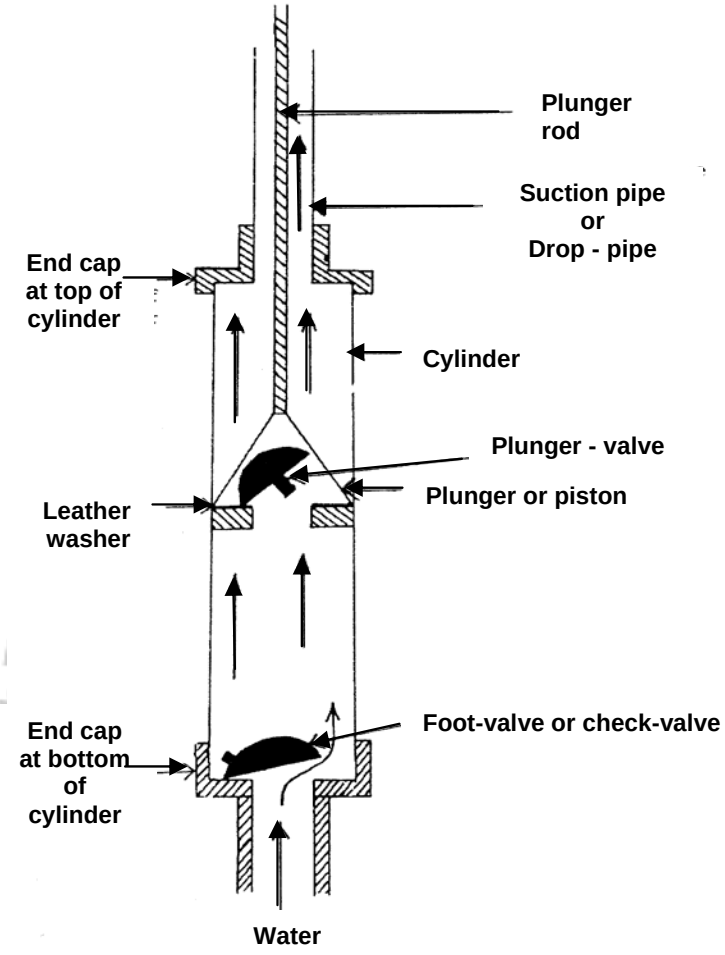


Figure 5.2 A typical single – action pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Steps of operation

Step 1: The pump has to be primed with water from an outside source. The purpose of priming is to wet the plunger and the valves, particularly the washers, etc., in order to

render them airtight. (See Figure 5.3 in which the plunger is shown in the upward position.)

Step 2: With the pump primed, on the first upstroke and with the plunger rod moving upwards, the check-valve (2) opens, because of the partial vacuum created by the plunger as it moves upward. The plunger-valve (1) closes because of the weight of the priming water above it (Figure 5.3).

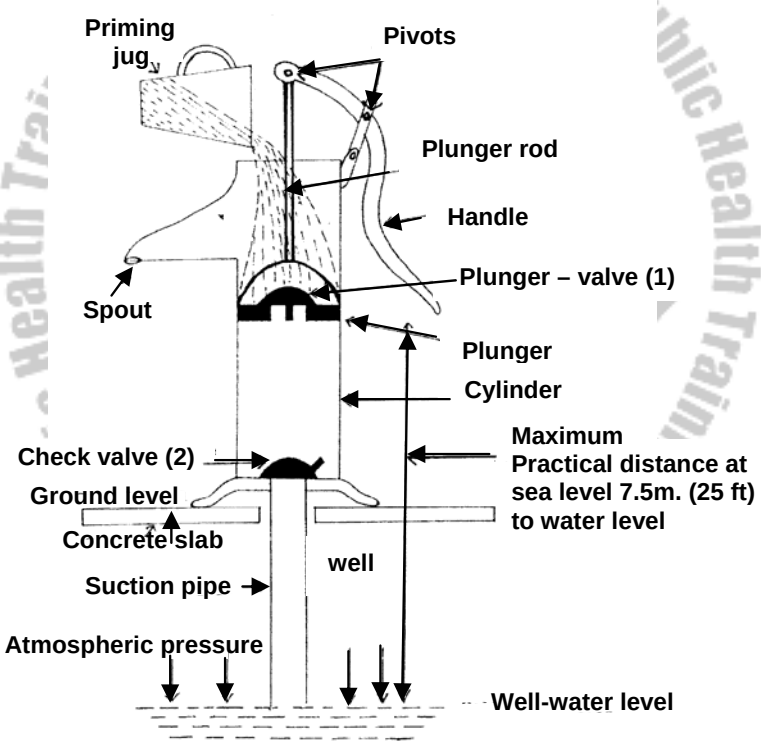


Figure 5.3. A typical pitcher pump being primed

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Step 3: On the first downward stroke, the check-valve (2) closes due to the weight of compressed air in the cylinder. The plunger- valve (1) opens, because of the compressed air pushing on it, and consequently the compressed air escapes through the priming water (Figure 5.4). Steps 2 and 3 are repeated until air is exhausted between the static water level, the suction pipe and the cylinder.

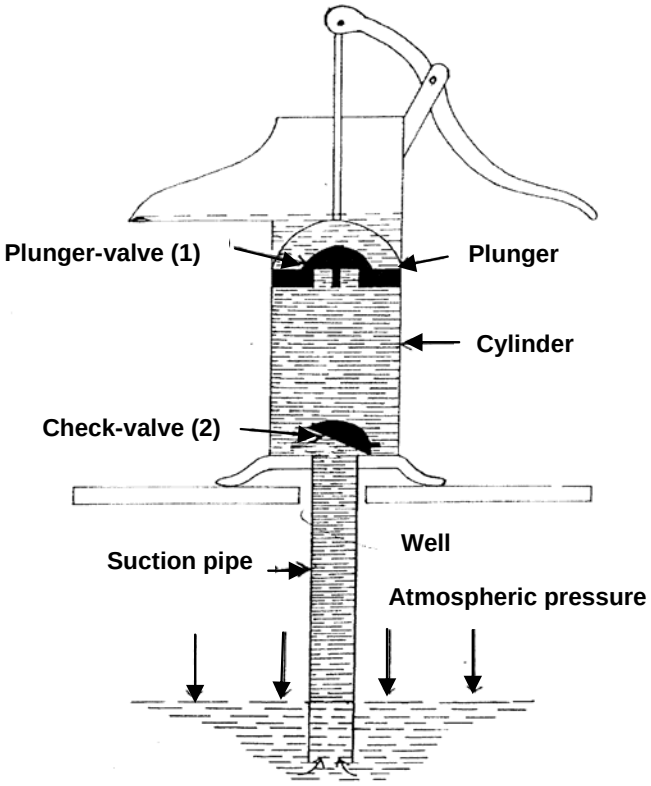


Figure 5.4 Pitcher pump during downward stroke of plunger
(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Step 4: On the successive upstrokes, the check–valve (2) opens, and water fills the suction pipe and the cylinder, due to the partial vacuum created by the upward-moving plunger. The plunger-valve (1) closes, due to its own weight and the weight of the water above it (Figure 5.5).

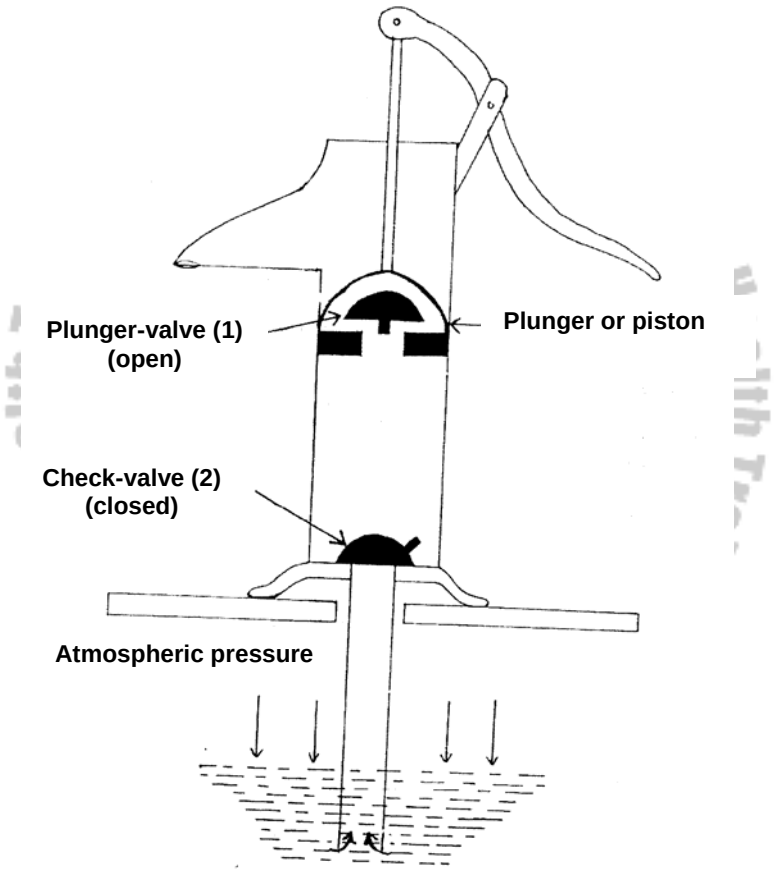


Figure 5.5 The pitcher pump with plunger rod at upward stroke
(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Step 5: On subsequent downward strokes, the check-valve (2) closes, and the plunger-valve (1) opens. As valve (1) opens, the water now filling the cylinder escapes through the open plunger-valve and is discharged at the spout (Figure 5.6). Thus, with every downward stroke, water fills the cylinder, and with every upstroke it is discharged at the spout.

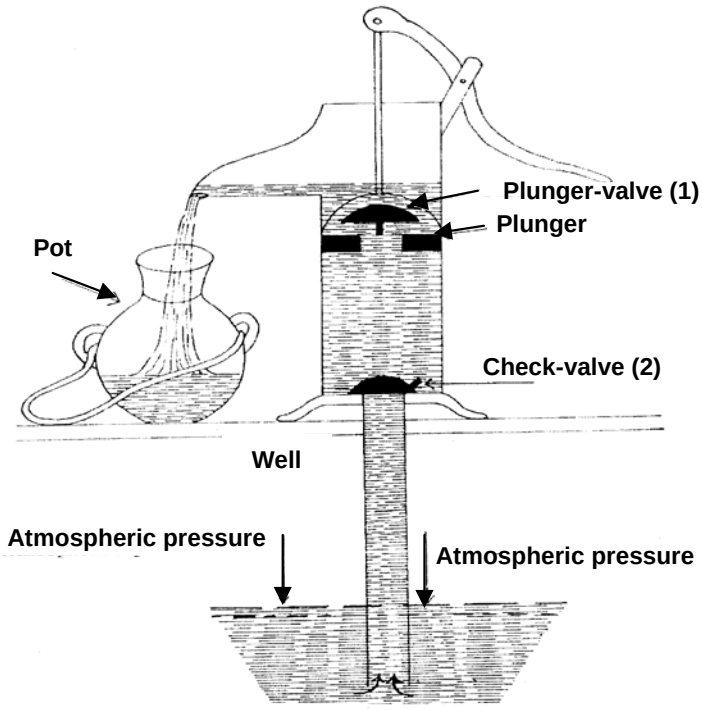


Figure 5.6 Pitcher pump delivering water at spout

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Single-action force pump

The principle of operation of the single-action force pump is the same as that of the pitcher pump or lift pump (Figure 5.3), except that the force pump is airtight at the top, for the purpose of delivering water under pressure at another outlet, as well as at the spout. (See Figure 5.7). The force pump can deliver water at the spout when the faucet valve (a) is open, and the gate-valve (b) is closed. When the faucet-valve (a) is closed and the gate-valve (b) is open, it can pump water, against pressure, to an elevated tank.

Note that this pump is about 3 meters above water level. In Addis Ababa (altitude 2800 m.), the pump must not be more than from 4 to 5 m. above water level, because of the fall in atmospheric pressure due to altitude.

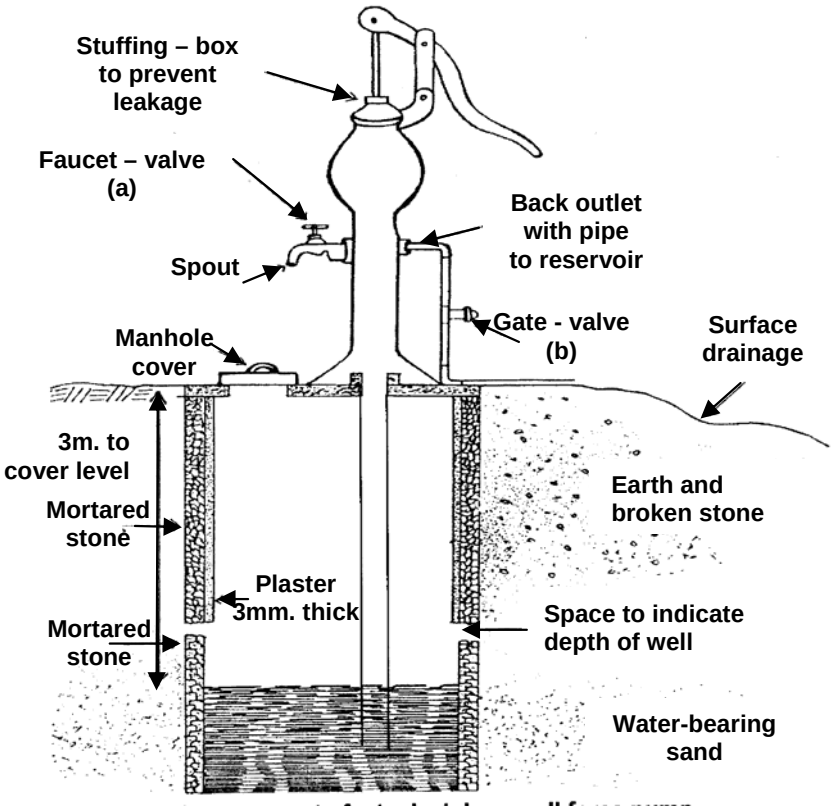


Figure 5.7. Arrangement of a typical deep well force pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

The Deep-Well Pump

To overcome the problem of the limited height to which the so-called shallow-well pump can raise water, we use a force, pitcher or lift pump whose cylinder assembly is installed below the static water level in the well.

When this is done, the height to which water can be lifted does not depend on atmospheric pressure; hence this type of

pump is sometimes called a **deep-well pump** (Figure 5.8). This pump does not need priming, because the cylinder assemblies are installed in the water of the well, and also contamination that may arise by using priming-water from suspicious sources is prevented.

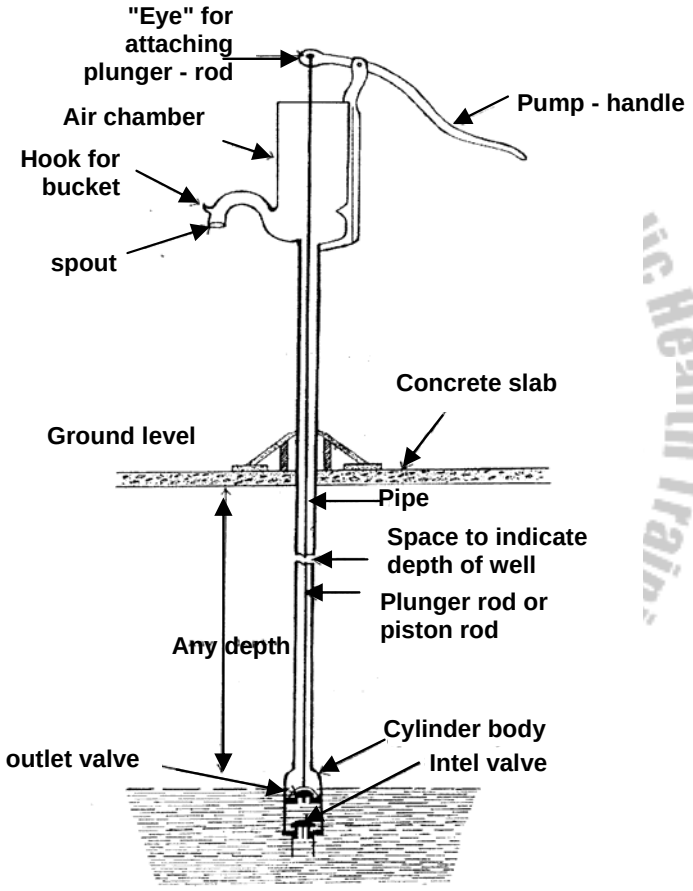


Figure 5.8 Arrangement of a typical deep-well lift pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Positive displacement pumps

Good examples of positive displacement pumps include the India Mark II and the now popular Afridev. Lifting and lowering the pump handle produces vertical displacement of the pump rod. The discharge valve (plunger) attached to the lower end of the pump rod closes as it moves to open and refill the cylinder.

As the pump handle is lowered, the foot valve closes as the discharge valve opens, moving through the water without pumping. Water is raised through the main and spout. The Afridev pump rods have mechanical linkages rather than screwed connectors. The discharge valve and foot valve can be removed for maintenance without having to remove the cylinder and main.

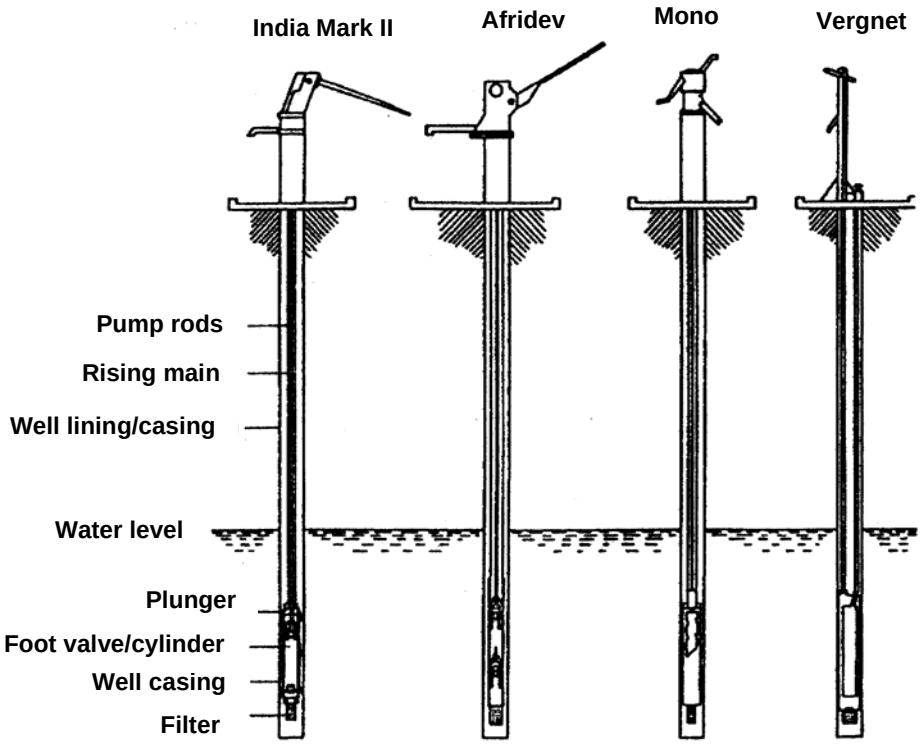


Figure 5.9 Deep well pumps

Double-action lift pump

Instead of having a plunger designed so that only one pair of valves works, as in a single-action pump, it is possible to use a pump designed with two pairs of valves that work alternately. Such a pump is known as a **double-action** or **double-acting pump**, because it delivers water at every stroke, up and down or forward and backward.

If we look at Figure 5.10A, we can see how, at every forward stroke of the piston, valves 1 and 4 are opened, so that water is drawn in through the inlet valve 1 from the suction pipe, and at the same time water is discharged through the outlet valve 4. At every backward stroke of the piston, as in Figure 5.10.B, valves 2 and 3 are opened, and water is drawn through inlet valve 2 and simultaneously discharged through outlet valve 3

This type of pump is used as a shallow-well pump. It can raise water only to a limited head; that is, to a maximum of about 7.5 m (25 ft) at sea level. It is normally used to pump water from a cistern or reservoir to an elevated tank.

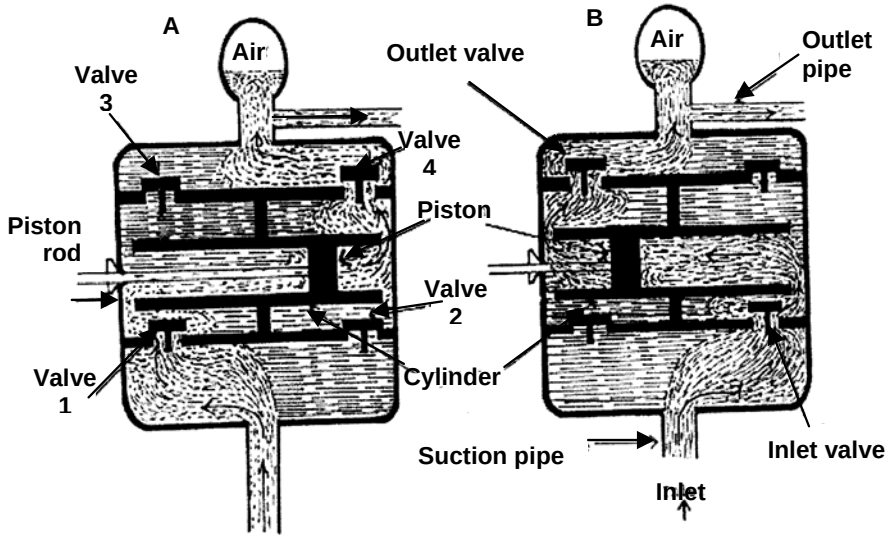


Figure 5.10 A double- action displacement shallow well pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Centrifugal force pumps (power pumps)

The pumps that are shown in Figures 5.3 to 5.9 are manually operated. They are very simple in design, and their work output is very limited. By far the most common types of pumps used in water works are power pumps; that is, pumps driven by various power sources such as benzene/petrol or diesel motors, electricity or wind power.

As a typical example of these pumps, we will describe the basic principles of operation of a centrifugal force pump, which may be defined as a pump that works on the principle of centrifugal force. The basic principle of operation of the centrifugal force pump may be illustrated by the following example:

If we take a bucket full of water and whirl it fast enough around us at arm's length, the water in the bucket does not spill out, because it is held in place by centrifugal force. On the other hand, if we make a small hole in the bottom of our bucket and rotate it again at a high speed, water will be thrown out at a high pressure through the hole. What has caused the water to be squirted out is again the effect of centrifugal force.

As another example, if we take several bottomless buckets and rotate them around inside a large diameter suction pipe, assuming there is one hole where water can leave the suction pipe, then each bucket will throw some of its water out as it passes the center or hub. This is the method by which a centrifugal force pump works.

The centrifugal force pump consists of two main parts:

A) **The impeller or rotor:** the revolving part with several blades or vanes. The impeller unit is linked to a prime mover (the initial source of power), driven by electricity or a diesel or other motor.
B) **The housing or volute:** which is the case surrounding the impeller.

The remaining unit of the pump consists of a suction pipe extending to the static water level, and an outlet pipe or discharge pipe for pumping the water to the desired location.

Figure 5.11 shows one of the typical designs of a centrifugal force pump. The revolving blades - the impeller - create a vacuum at the hub, into which water is pulled from the well through the suction pipe. The water rotates with the blades, and is then forced out through the discharge pipe by centrifugal force.

Although this simple example explains the principle of operation of a centrifugal force pump, yet the mathematical and mechanical aspects of the pump design are much more complicated than it would appear.

Depending on the design and arrangement of the impeller, there are several varieties of centrifugal force pumps. The selection of a specific type depends on such things as the volume of water to be pumped, the pumping depth and distance, the pressure and speed at which the pump is required to perform, and the type of available power for the prime mover.

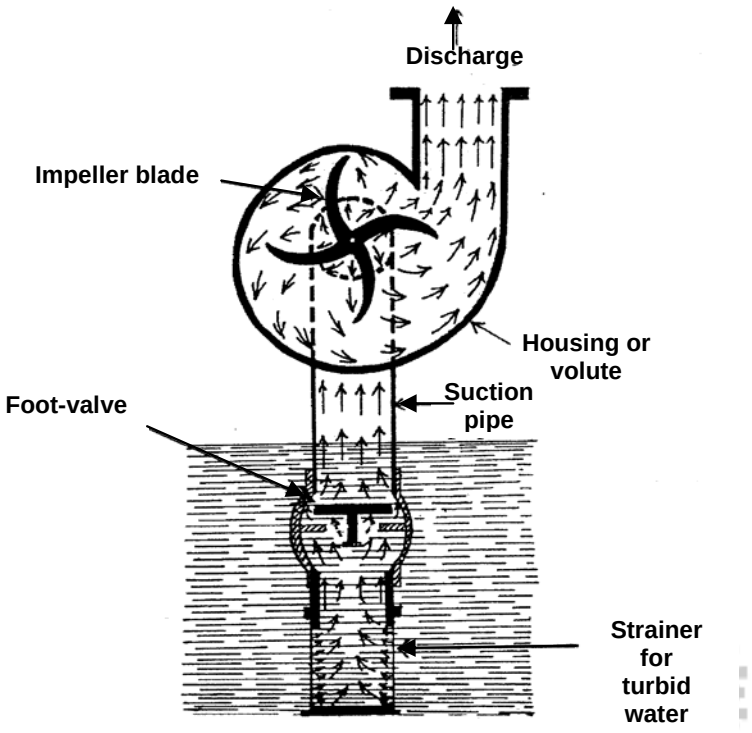


Figure 5.11 A centrifugal force pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

There are many other types of power pump: positive displacement (reciprocating), rotary, turbine, jet, hydraulic ram, and several others. However, the centrifugal force pump has the advantage over other types of pump in having no valve or piston. For this reason, it can pump sewage or any turbid liquid, as well as water.

The Windmill

One of the least used but cheapest sources of power for pumping water in Ethiopia is the wind. A machine such as a pump that uses the wind as its prime mover or power source is called a **windmill**.

Windmills have been in use for many centuries in different parts of the world for grinding corn, pumping water, and, more recently, for generating electricity for charging storage batteries. Windmills can provide a very cheap form of power for pumping water in many parts of rural Ethiopia. Windmills of this type consist mainly of:

A) A wheel or propeller, designed with a number of vanes or blades that are set at a specific angle, mounted on a horizontal shaft, in order to make most efficient use of the force of the wind.
B) A tail-vane to keep the rotor facing into the wind.
C) A tower especially designed for raising the wheel well above any obstructions in the immediate surroundings. (See Figures 5.12 and 5.13.)

After the windmill is installed in a selected spot, its operation depends upon the regularity and speed of the wind for revolving the wheel, which is linked by various methods to the pump (for example by the well-rod shown in Figure 5.12). When the breeze strikes the faces of the vanes, it causes the

wheel to revolve, consequently activating the attached pump. Windmills are generally designed to pump water from unlimited depths.

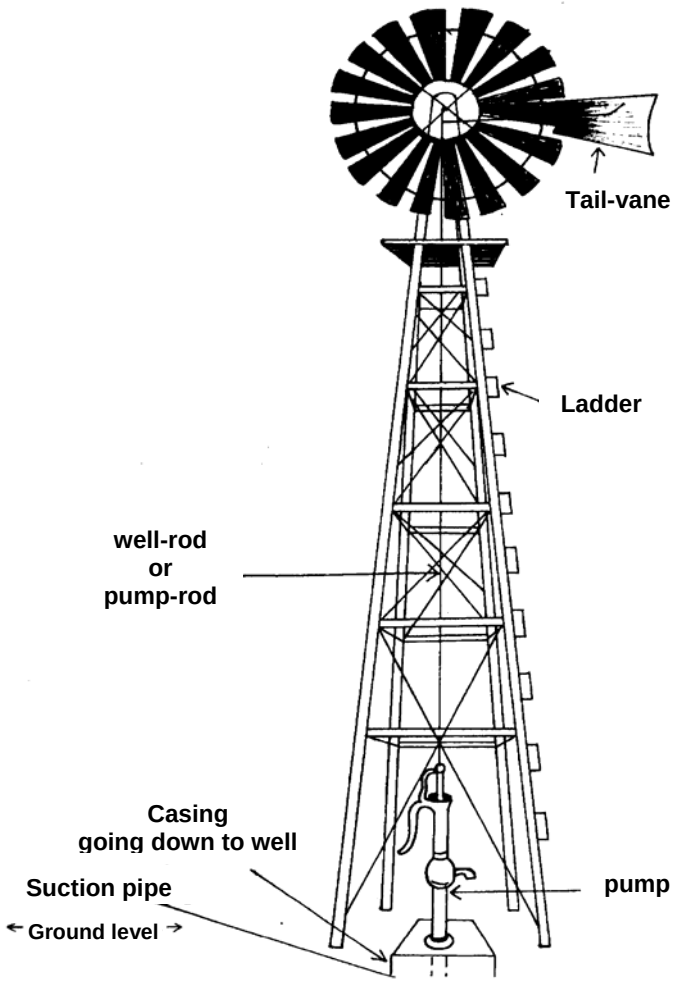


Figure 5.12 A typical arrangement of part of windmill tower and well
(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

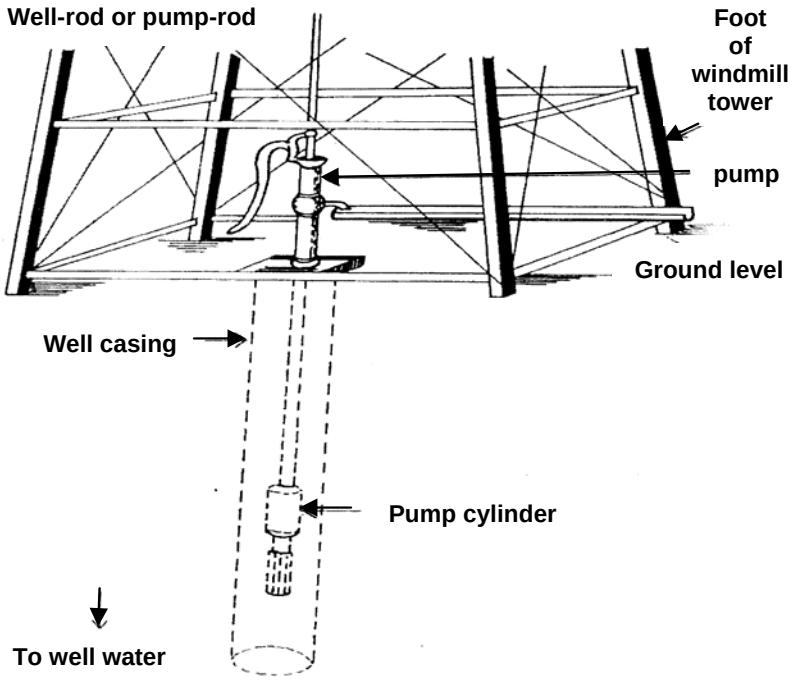


Figure 5.13 A windmill tower and pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

There are different types of windmills made by various manufacturers in the world. The cost and hence the efficiency of the windmill depend chiefly upon the quality of the materials from which it is made, the diameter of the wheel and the height of the tower.

It is important to have the following information before undertaking the installation of a windmill in any locality:

A) The regularity and average daily velocity of the wind there.

B) The nature of the terrain: for example, flat open countryside is generally a favorable area for installing a windmill.

C) The absence of obstructing objects in the immediate surrounding, in general within a 50-meter to a 100-meter radius of the well to be pumped. This will determine the height of the windmill tower.

D) The average depth of the water table of the locality, the yield of the well and total pumping head.

E) The volume and rate at which water is to be pumped. Normally windmills are installed with adequate storage facilities to compensate for times when the wind has dropped. In addition, some manufacturers make provision for pumping by hand during long periods of relative calm.

After these and other relevant data are known, the selection of a specific make of windmill becomes an easy matter. It is to be remembered that, once installed, a windmill has very small running costs. Moreover, it can easily be adapted to rural areas where electricity is unavailable, and where petrol-driven or diesel-driven motor pumps are too expensive to install and maintain.

Windmills have been installed in a few places in Ethiopia, and so far their performance has proved satisfactory.

Problems of head and pressure involved in pumping

Water flows through a pipe because the pressure at one end of the pipe is greater than the pressure at the other end. This pressure can be caused by gravity acting on water at a higher elevation, such as water flowing from a gravity spring or water flowing from an elevated tank, or by a pump discharging water into the distribution line. Whether the pressure is caused by gravity or a pump, it can be expressed as an equivalent height of water and is called the **head**. Similarly the pressure lost due to friction within the pipeline retarding the flow is also expressed in terms of head, and is called **friction head**, or **head loss**.

Since the friction head is also dependent upon the velocity of the water flowing through the pipe system, the friction loss is zero when there is no flow in the lines. There is then a static condition, and the pressure at any point in the line is equal to the original pressure applied.

As pressure head and friction head are very important factors in determining pump capacity, we will examine each a little more closely.

Water pressure

In an open system such as a storage tank, pressure due to the weight of water is equivalent to the height (head) of the water above the reference point. Thus pressure on a given surface area (e.g. on one square centimeter or on square inch) may be determined as follows:

One cubic meter ($1m^3$) of water weighs 1000 kg

One cubic centimeter ($1cm^3$) of water weighs 1 gm

One meter head of water on 1 cm^2 weighs 1 x 100 = 100 gm
= 0.1 kg

Therefore, in order to produce one kg pressure on one cm^2, it takes $\frac{1}{0.1}$ or 10 m head of water.

Expressing this in another way, we can say that for every 10 m of head, a pressure is produced of 1 kg per square cm; or we can say that 1 kg pressure can force water to a height of 10 m.

From this, we can devise a simple rule for converting pressure into head and vice versa:

A). To convert water head in meters to kg pressure, multiply by 0.1

B). To convert kg pressure to water head in meters, multiply by 10

Friction head

Friction head is defined as the head required for overcoming friction between flowing water and pipes. In order to have any flow of water in a piping system, pump pressure must overcome the **total vertical lift** or **head** plus **friction head**. Over and above this, the pump has also to lift water vertically or horizontally, or in both directions, to the desired location. Therefore, in determining the total pumping head, friction head is an important factor. The amount of head lost due to friction depends mainly upon:

A) The diameter of the pipe

Normally loss of head due to friction increases as pipe diameter decreases. In selecting pipe size, one has to consider first the cost of the pipe, which increases in direct ratio to the diameter of the pipe (that is, the larger the diameter, the more one has to pay for a similar length of pipe).

It is worth noting at this point that for uniformity and for economic reasons, pipes and their fittings are marketed in standard sizes (diameter). These pipes are generally made of galvanized iron. Pipes and their fittings should be of the largest possible size for minimizing head loss due to friction.

B) Length of pipe

Other variables being constant, the longer the pipeline, the greater the loss of head due to friction.

C) The smoothness of the interior surface of the pipe and type of material

The amount of loss of head due to friction is directly proportional to the smoothness of the interior surface of the pipe. Older pipes have rougher internal surfaces than newly manufactured pipes; hence the age of the pipe is normally quoted in the standard friction head loss tables. The interior condition of the pipe depends also on the type of material (e.g. PVC and plastic pipes) from which the pipes and their fittings may also be made.

D) Rate of flow

Other variables remaining constant, the higher the rate of flow, the greater the loss of head due to friction.

E) The type and number of fittings in the pipeline

Loss of head due to friction increases as the number of fittings increases, so the fewer the fittings, the smaller the loss of head.

Pipe fittings include elbows, tees (elbow-shaped and T-shaped joints), valves, faucets, etc. Fittings are usually available in the same sizes and materials as pipes.

Power requirements for pumping

Power is the amount of work that can be done in a specified time; that is, the work input required per unit of time. The amount of power required by a pump to raise water under certain specific conditions is generally expressed in terms of horsepower (HP).

One horsepower equals 76 kilogram-meter per second (or 33,000 foot-pounds per minute). This, divided by the weight of 1 gallon of water, or 8.33461, is usually calculated as 3960. Horsepower required for pumping is usually expressed as:

A) Water Horsepower: This is horsepower required to pump water at a definite rate to a given distance, assuming 100% pump efficiency.

Water HP equals

$$\frac{\text{Liters per second} \times \text{total pumping head (in meters)}}{76}$$

or

$$\frac{\text{Gallons per minute} \times \text{total pumping head (in feet)}}{3960}$$

B) Brake Horsepower: This is the power usually given in manufacturers' bulletins or catalogues. It is the horsepower required by a pump to lift water at a definite rate to a given

distance at practical pump efficiency. It is expressed in these ways:

$$\text{Brake HP equals} = \frac{\text{Water HP}}{\text{Pump efficiency}}$$

or

$$\frac{\text{Liters per second} \times \text{total pumping head (in meters)}}{76 \times \text{pump efficiency}}$$

or

$$\frac{\text{Gallons per minute} \times \text{total pumping head (in feet)}}{3960 \times \text{pump efficiency}}$$

Normally no pump is 100% efficient, and the actual head that can be raised (pump efficiency) varies from 50% to 85%. All pump manufacturers provide a bulletin which contains "pump characteristic curves", showing the relationship between the quantity of water pumped and the total pumping head for any given pump speed. By total pumping head is meant the combination of total suction head and total discharge head.

Review Questions

1. What is hydraulics?
2. What are points to be considered in selection of a specific type of pump for community water supply?
3. What is the theoretical and practical suction height to which atmospheric pressure can lift water for a locality that is 2000 m above sea level?
4. Taking a typical example of hand pump in your locality, explain the principle of operation.
5. What is the difference between a positive displacement type of pump and a centrifugal force pump?
6. What needs to be considered before installation of windmill as a source of power supply in the groundwater supply?
7. In a rural village having 10,000 people, a bore hole well was dug at 200 m depth, with a yield of 4.5 liters per second, and having 81 m^3 water reservoir tank with 210 m total pumping head and 85% pump efficiency.

Find :

A) The time required to fill the reservoir using a motor pump.

B) The length of time required for the motor to operate daily in order to fill the reservoir, if 18 liters per day per person is used in this community.

C) Calculate the water and brake horsepower.

Note to the teacher

After you have gone through this chapter, arrange a practical session to show different parts of the pump and principles of operation in your environmental health workshop, together with a field visit to show the already installed pump giving service to the community.

CHAPTER SIX

LABORATORY TECHNIQUES

6.1. Learning Objectives

At the end of this chapter students will be able to:

1. Identify different methods of sampling.
2. Perform different tests for drinking water quality.
3. Describe guidelines for value for drinking water quality.

6.2. Introduction

Water that is used for human consumption should be free from pathogenic micro-organisms and harmful chemical substances to protect the health of individuals and community from waterborne diseases. Therefore it is very important to ensure quality control for the potability of the drinking water supply, using different laboratory techniques and procedures.

6.3. Sampling methods for bacteriological testing

When water samples are collected for analysis, care should be taken to ensure that there is no external contamination of

the samples. Unless valid samples are collected the results of the subsequent analysis may be misleading.

Several types of bottle may be used for sampling, but glass bottles are best. These should have securely fitting stoppers or caps with nontoxic liners, and both bottles and stoppers should be sterilized. Each cap should have a metal sleeve clear of the screw thread to ensure that the risk of contaminating the water sample is minimized. Cotton wool plugs and paper caps should be avoided as they tend to fall off during and after sampling and increase the risk of contamination. The bottles should hold at least 200ml of water.

Whenever chlorine is used for disinfection, residual may be present in the water after sampling and will continue to act on any bacteria in the sample. The results of the micro-biological analysis therefore may not be indicative of the true bacteriological content of the water. To overcome this difficulty, it is common procedure to add sodium thiosulfate to the sample, which immediately inactivates any residual chlorine but does not affect the micro-organisms that may be present. The sodium thiosulfate should be added to the sample bottles before they are sterilized. For 200-ml samples, four or five drops of aqueous sodium thiosulfate solution (100gm/litre) should be added to each clean sample bottle.

The stopper is loosely inserted into the bottle, and a brown paper or aluminum foil cover is tied to the neck of the bottle to prevent dust from entering. The bottle is then sterilized in a hot air oven for 1 hour at 160 or 170 ^{o}C for 40 minutes or in an autoclave at 121 ^{o}C for 20 minutes. If no other facilities are available, a portable sterilizer or pressure cooker can be used, but sterilization will then take 30-45 minutes. To prevent the stopper from getting stuck during sterilization, a strip of brown paper (75 X 10 mm) should be inserted between the stopper and the neck of the bottle.

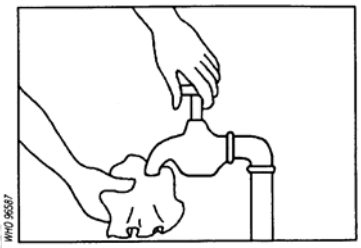
For reasons of cost, bottles should be reused. After the samples have been analyzed in the regional or central laboratory, bottles should be resterilized and if possible, returned to the sender.

Water can be divided into three basic types for the purpose of sampling:

- Water from a tap in a distribution system or from a fixed pump outlet, etc.
- Water from a water course (river, lake, etc.) or a tank
- Water from a dug well, etc.,.

1. Sampling from a tap or pump outlet

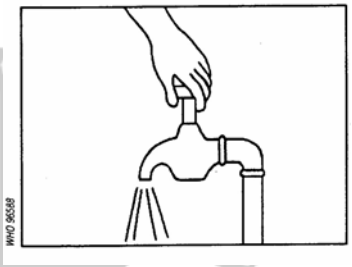
A) Clean the tap



Remove from the tap any attachment that may cause splashing. Using a clean cloth, wipe the outlet to remove any dirt.

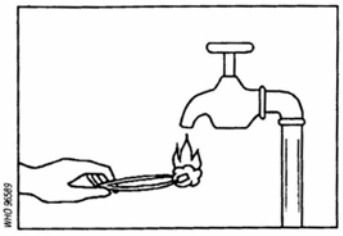
B) Open the tap

Turn on the tap at maximum flow and let the water run for 1-2 minutes.



Note: some investigators do not continue to stages C and D but take the sample at this stage. In this case, the tap should not be adjusted or turned off, but left to run at maximum flow. The results obtained in this way will provide information on the quality of the water as consumed. If the procedure is continued to stages C and D, however, the results represent the quality of the water excluding contamination by the tap.

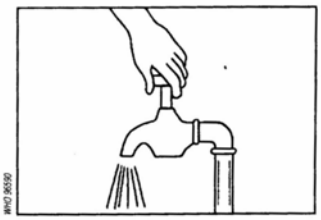
C) Sterilize the tap



Sterilize the tap for a minute with the flame from a gas burner, cigarette lighter, or an ignited alcohol-soaked cotton wool swab.

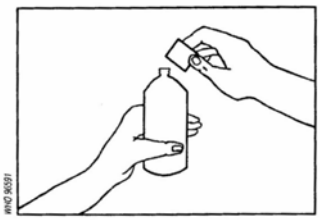
D) Open the tap before sampling

Carefully turn on the tap and allow the water to flow for 1-2 minutes at a medium flow rate. Do not adjust the flow after it has been set.



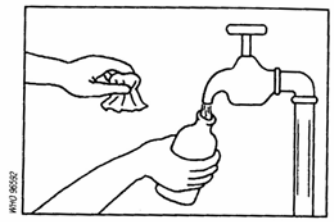
E) Open the sterilized bottle

Take out a bottle and carefully unscrew the cap or pull out the stopper.

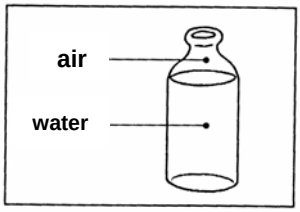


F) Fill the bottle

While holding the cap and protective cover face downwards (to prevent entry of dust, which may contaminate the sample), immediately hold the bottle under the water jet, and fill.

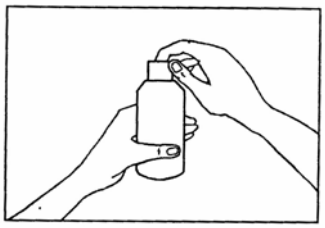


A small air space should be left to make shaking before analysis easier.



G) Stopper or cap the bottle

Place the stopper in the bottle or screw on the cap and fix the brown paper protective cover in place with the string.

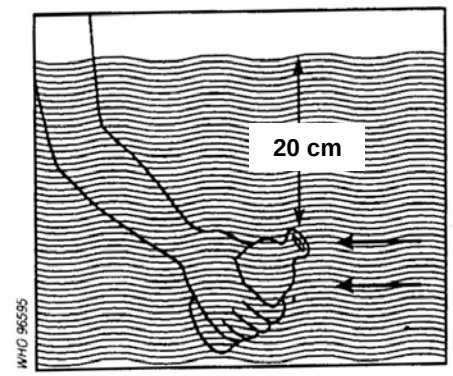


2. Sampling from a watercourse or reservoir

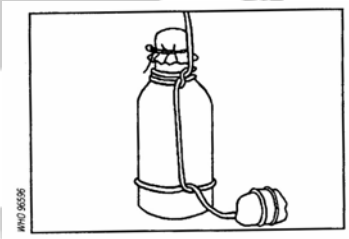
Open the sterilized bottle as described in section 1.

A) Fill the bottle

Holding the bottle by the lower part, submerge it to a depth of about 20 cm, with the mouth facing slightly upwards. If there is a current, the bottle mouth should face towards the current. The bottle should then be capped or stoppered as described previously.

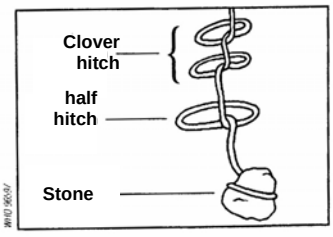


3. Sampling from dug wells and similar sources



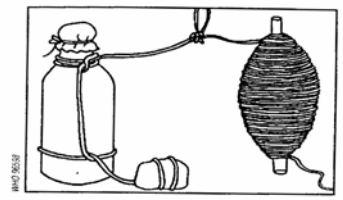
A) Prepare the bottle

With a piece of string, attach a clean weight to the sampling bottle.



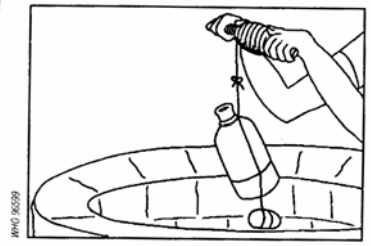
B) Attach the bottle to the string

Take a 20-m length of clean string rolled around a stick and tie it to the bottle string. Open the bottle as described in section 1.



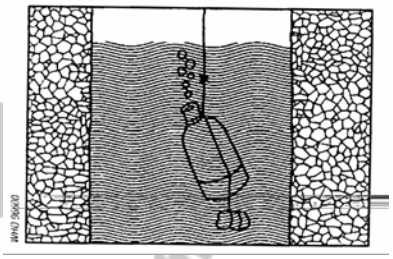
C) Lower the bottle

Lower the bottle, weighed down by the weight, into the well, unwinding the string slowly. Do not allow the bottle to touch the sides of the well.



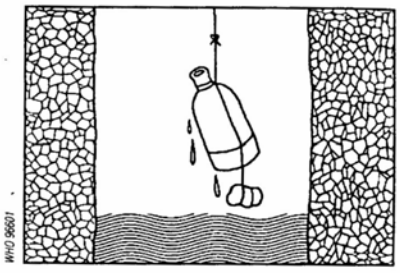
D) Fill the bottle

Immerse the bottle completely in the water and lower it well below the surface without hitting the bottom or disturbing any sediment.



E) Raise the bottle

Once the bottle is judged to be full, rewind the string on the stick to bring up the bottle. If the bottle is completely full, discard some water to provide an air space. Stopper or cap the bottle as described previously.



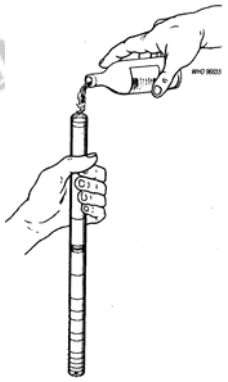
6.4. Turbidity and PH

1. Measurement of turbidity

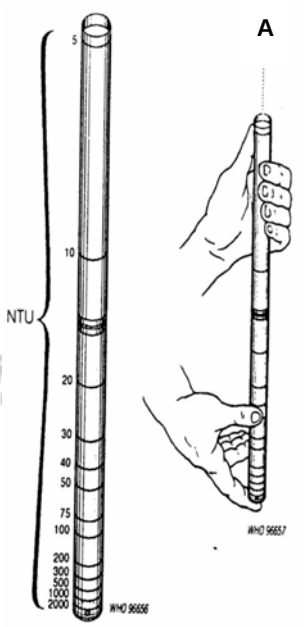
High levels of turbidity can protect micro-organisms from the effects of disinfection, stimulate the growth of bacteria, and exert a significant chlorine demand. Where disinfection is practiced, the turbidity must always be low, e.g. below 5 NTU, and ideally below 1 NTU for effective disinfection. Measurement of turbidities lower than 5 NTU will generally require electronic meters.

However, turbidities of 5 NTU upwards can be measured by simple extinction methods, which are far cheaper and require no consumables. In the monitoring of small community supplies in developing countries, such methods may be preferable. The sequence of steps involved in turbidity determination by an extinction method is shown below.

A) Add water slowly to the turbidity tube, taking care not to form bubbles. Fill until the mark at the bottom of the tube just disappears.



B) Read the turbidity from the scale marked on the side of the tube. The value is that corresponding to the line nearest to the level of the water in the tube. The scale is not linear, and extrapolation of values between the lines is therefore not recommended.



2. Measurement of P^H

Electronic P^H method

The electronic method of measuring P^H requires an electronic P^H instrument and electrode, and P^H buffer solutions at P^H 4.0, 7.0 and 9.0

A wide variety of P^H instruments is available; the less expensive tend to be “disposable” and have a life span of approximately 1 year when used in the field. The more expensive portable models generally have replaceable electrodes, and some may have rechargeable batteries to save recurrent cost.

The most common cause of failure of a P^H meter is a damaged electrode. This is generally due to poor storage and maintenance of the electrode when it is not in use. The electrode must not be allowed to dry out and must be stored

in P^H 4.0 buffer solution. It must also be protected from impact and vibrations that could crack the glass bulb.

The method of calibration is as follows:

a) Switch on the P^H meter and select P^H (if the meter has several functions)
b) Make sure that the electrode is connected
c) Using ready-prepared P^H buffer solutions (P^H buffer powder mixed with distilled water according to the manufacturer's instructions), place the P^H electrode in a P^H 7.0 buffer and adjust the meter if necessary
d) Rinse the electrode in distilled water and transfer it to P^H 4.0 buffer; adjust the meter if necessary
e) Rinse the electrode in P^H 9.0 buffer and adjust the meter if necessary
f) Check the meter in all three buffer solutions. If it does not read true, repeat the above process. If it cannot be adjusted to read correctly in all buffers, suspect a faulty or damaged electrode.

The meter is now ready for use in testing the water sample. Calibration of the meter must be carried out daily.

Comparator disc method

The comparator disc method for measuring P^H requires a comparator, color discs depending on the range required (see below) and the following reagents:-

Universal	P^H 4-11
Phenol red	P^H 6.8-8.4
Bromothymol blue	P^H 6.0 –7.6
Bromothymol purple	P^H 2-6.8
Thymol blue	P^H 8.0-9.6

For most natural water; the universal reagent and phenol red will be sufficient. Where greater accuracy in a particular range is required, the appropriate disc and reagents should be purchased.

The comparator unit is generally suitable for all the discs and so only one such unit is required. The method of use is similar for all p^H ranges:-

a) Place a water sample in the glass or plastic cuvettes provided
b) Add the reagent tablets, powders, or drops according to the manufacturer's instructions
c) Select the appropriate color disc and place it in the comparator unit
d) Place the cuvettes in the comparator unit

e) Hold the comparator unit up to the eye, facing good daylight (but not direct sunlight)
f) Rotate the disc and observe until the color matches that of the water sample
g) Read the p^H value from the disc.

If the p^H is not within the range of the disc, select the appropriate reagents and disc and repeat the above procedure.

6.5. Residual free chlorine test

The method recommended for the determination of chlorine residual in drinking water employs N,N-diethyl-p-phenylenediamine, more commonly referred to as DPD. Methods employing orthotolidiene and starch-potassium iodide were formerly also recommended.

The first of these reagents is a recognized carcinogen and the method is not reliable. The method based on the use of starch-potassium iodide is not specific for free chlorine, but measures directly the total of free and combined chlorine. It is not recommended except in countries where DPD cannot be obtained or prepared. In this chapter, therefore, only the DPD method is considered.

In the laboratory, photocolorometry or spectrophotometry may both be used for the determination of chlorine by means of DPD. However, it is common practice and highly recommended for field measurements using simple color match comparators to be done on site. The color is generated following the addition of DPD to the water sample and is matched against standard colored discs or tubes.

The method can be used by staff without extensive specialized training. The reagent may be solid (e.g. individually wrapped tablets) or in the form of a solution; the former is more stable. If the solution is used, it should be stored in a brown bottle and discarded as soon as it starts to become discolored.

1. Commercial visual comparator technique

Equipment

Commercial comparators are of two basic types: the disc type, containing a wheel of small colored glasses, and the slide type, containing liquid standards in glass ampoules. However, both consist of the same components: a box with an eyepiece in front and two cells, the whole arranged so that both cells are in the field of vision of the eyepiece.

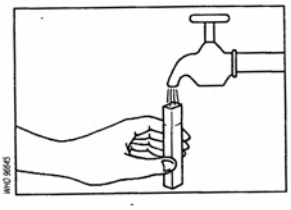
One cell, containing a water sample without the reagents, is placed in line with the rotating colored glasses or the ampoules containing the standards. The water sample containing the reagent is placed in another cell. If free chlorine is present, a color will develop. The concentration of chlorine is estimated by matching the colors in both cells, as seen through the eyepiece. Each color of the disc or ampoule corresponds to a certain quantity of chlorine in the water; different calibration discs or ampoules are needed for each of the reagents specified.

Reagents

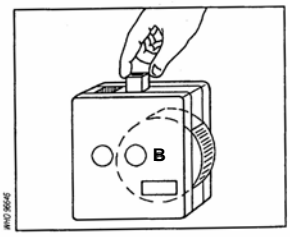
Most comparators are intended for use with the manufacturer's own reagents, and care must therefore be taken to keep a good stock of these. This is a disadvantage, since it involves dependence on the local supplier, and importation problems may occasionally arise. On the other hand, it is not necessary to prepare solutions of standards, which makes the technique very easy to use.

Method

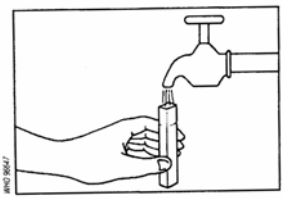
A) Rinse a comparator cell two or three times, and then fill up to the mark with the water sample.



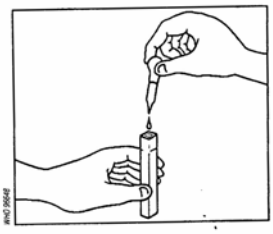
B) Place the cell in the cell carrier of the comparator, which is in line with the colored standards (B)



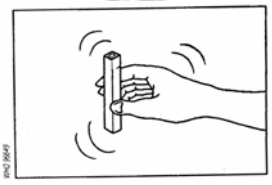
C) Rinse the second cell and fill it with the same water.



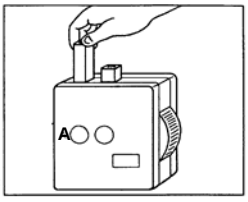
D) Add reagent to the second cell, in accordance with the manufacturer's instructions.



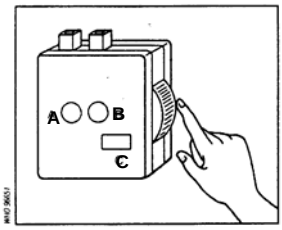
E) Shake the cell (for not more than 3-5 seconds) to mix the reagent.



F) Place the cell in the comparator (A)



G) While holding the comparator facing good natural light, rotate the disc until the color of a standard (B) is the same as that developed by the reagent (A). Immediately (i.e. in less than 20 seconds) read at C the value of free chlorine in mg/liter.

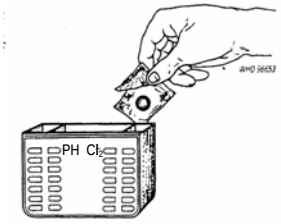


2. Color match comparator method

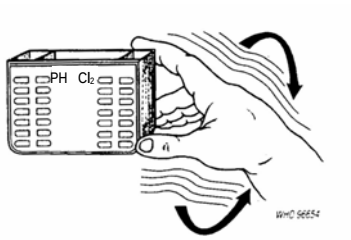
The procedure employed when a color-match comparator is used is summarized below. Some comparators employ tubes or discs or discs with the standard colors; the procedure is similar in all cases.

A) Rinse the comparator thoroughly in the water to be tested and then fill to the specified lines on the test and control tubes.

B) Add tablet or liquid reagent and mix thoroughly to dissolve. This may require the crushing of the tablet with a clean glass rod.



C) Compare the pink color in the test compartment with the standards in the control compartment by viewing the comparator in good, transmitted natural light. Express the result as mg/liter of free residual chlorine.



6.6. Membrane filtration method for thermo-tolerant (fecal) coliforms

1. Principle

In contrast to the multiple-tube method, the membrane-filtration method gives a direct count of total coliforms and thermo-tolerant coliforms present in a given sample of water. The method is based on the filtration of a known volume of water through a membrane filter consisting of a cellulose compound with a uniform pore diameter of 0.45 or 0.2 µm; the bacteria are retained on the surface of the membrane filter. When the membrane containing the bacteria is incubated in a sterile container at an appropriate temperature with a selective differential culture medium, characteristic colonies of thermo-tolerant coliforms develop, which can be counted directly.

2. Volume of water sample for filtration

Since the filtration area is relatively small, it can support the growth of only a limited number of colonies: the optimum number is between 20 and 80, with a maximum of 200. If this figure is exceeded, very small atypical colonies or superimposed colonies may develop, or there may be growth inhibition due to overpopulation. The choice of the volume of sample to be filtered will depend on the type of water.

3. Equipment and glassware

In addition to the basic equipment and glassware used in the multiple-tube method (see section 6.7), the following items are needed for the membrane filtration technique:

- Membrane-filtration apparatus: Including an electric or hand-powered vacuum pump, a vacuum flask (e.g. and Erlenmeyer side-arm flask), and a filter support
- Reusable petri dishes: made from glass or metal (disposable plastic Petri dishes may also be used)
- Blunt-ended forceps: for picking up membrane filters
- Reusable (autoclavable) bottles: for culture media (e.g. 25-ml polypropylene bottles)
- A magnifying lens: with 4-times or 5-times magnification for examining and counting the colonies on the membrane filters

- A boiling bath/pan: if filtration apparatus is to be disinfected in boiling water between analyses
- Sterile pipettes: 1 ml and 10 ml
- A graduated cylinder: 100 ml.

In addition to the consumables needed for the MPN, the following are required:

- Membrane filters: 47-50 mm in diameter, with a pore diameter of 0.45 µm. Singly packed, pre-sterilized membrane filters are very convenient. Unsterilized membrane filters can also be used, however, and should be wrapped in paper packets in convenient numbers (depending on the number of water samples to tested). These can then be sterilized in the autoclave and dried by rapid exhaustion of the steam.
- Nutrient absorbent pads: filter paper discs about 1 mm thick, with the same diameter as the membrane filters.
- Culture media: different types are available
- Wax pencils: for labeling petri dishes
- Polythene bags: for wrapping petri dishes if a dry incubator is used, to prevent drying of the sample and media.

4. Culture media and dilution water

Various media can be used for the examination of coliform organisms by the membrane-filtration method. Of these, lactose Tergitol agar, lactose TTC Tergitol agar, and membrane laurl sulfate lactose broth may be used for coliform organisms at 35 or 37^{o}C and for thermo-tolerant coliform organisms at 44^{o}C or 44.5^{o}C. Membrane fecal coliform (MFC) broth should be used only at 44 or 44.5 ^{O}C for thermo-tolerant coliform counts.

Although it is possible to prepare the media from the basic ingredients, this may be impractical in a small laboratory. The use of dehydrated media is therefore recommended. The media can be prepared as a broth and used together with nutrient absorption pads, or as solid agar plates. The broths may be solidified by the addition of 1.2-1.5% agar before boiling.

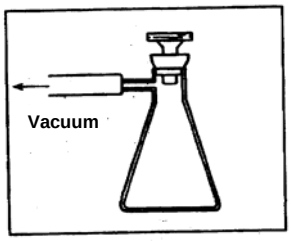
5. Procedure

The procedure generally used is described here, but different types of filtration units and equipment exist.

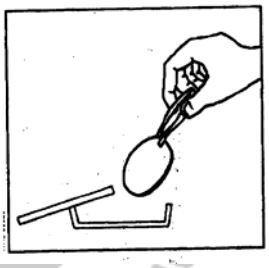
Table 6.1 Colony characteristics following analysis by the membrane-filtration method

Medium	Colony characteristics	
	Total coliforms at 35/37°C	Thermo-tolerant coliforms at 44/45.5°C
Lactose TTC[c] agar with Tergitol 7	Yellow, orange or brick-red coloration with yellow Central halo in the medium under the membrane	As for total coliforms at 35/37°C
Lactose agar with Tergitol 7	Yellow central halo in the medium under the membrane	As for total colifoms at 35/37°C
Membrane-enriched Teepol broth	Yellow color extending on to the membrane	As for total coliforms at 35/37°C
Membrane lauryl sulfate broth	Yellow color extending on to the membrane	As for total coliforms at 35/37°C
Endo agar or broth	Dark red color with golden-green metallic sheen	---
LES-Endo agar	Dark red color with golden-metallic sheen	---
Membrane fecal coliform (MFC) Broth.	____	Blue colonies

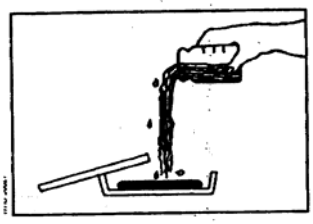
A) Connect the Erlenmeyer (side-arm) flask to the vacuum source (turned off) and place the porous support in position. If an electric pump is used, it is advisable to put a second flask between the Erlenmeyer flask and the vacuum source; this second flask acts as a water trap, and thus protects the electric pump.



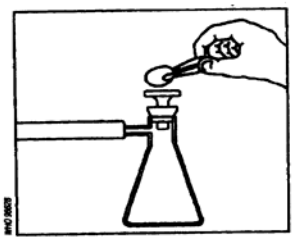
B) Open a sterile Petri dish and place a sterile absorbent pad in it.



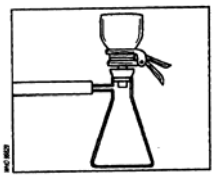
C) Add broth medium to saturate the pad; remove excess broth.



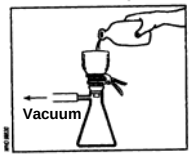
D) Assemble the filtration unit by placing a sterile membrane filter on the porous support, using forceps sterilized by flaming.



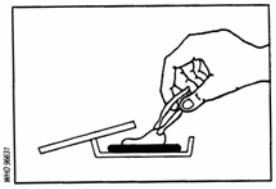
E) Place the upper container in position and secure it. (the type of clamp used will depend on the type of equipment.)



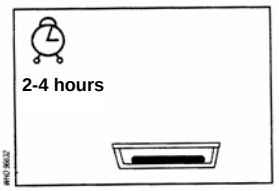
F) Pour the volume of sample chosen as optimal for the type of water into the upper container. If the test sample is less than 10ml, at least 20 ml of sterile dilution water should be added to the top container before filtration. Apply the vacuum.



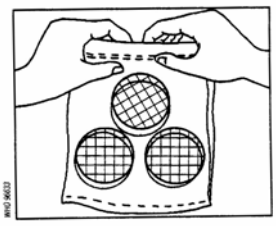
G) Take the filtration unit apart and, using the sterile forceps place the membrane filter in the petri dish on the pad with the grid side up. Make sure that no air bubbles are trapped between the pad and the filter.



H) Leave the Petri dish at room temperature or at 35 or 37 ^{O}C for 2-4 hours, for resuscitation of stressed microbes.

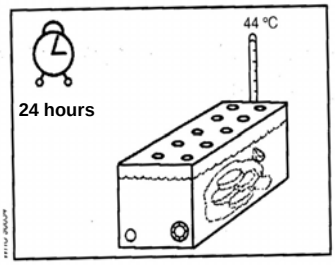


I) Place the dishes in an incubator at 44 $\pm$ 0.5 ^{o}C for 18-24 hours with 100% humidity. Alternatively, tight-fitting or



sealed petri dishes may be place in waterproof plastic bags for incubation.

J) Submerge the bags in a water bath maintained at 44 (0.5oC for 18-24 hours. The plastic bags must be below the surface of the water throughout the incubation period. They can be held down by means of a suitable weight, e.g. a metal rack.



The colonies of thermo-tolerant coliform bacteria should be identified from their characteristics on the medium used. The number of thermo-tolerant coliforms per 100 ml is then given by:

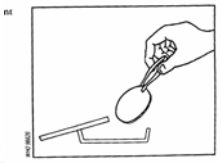
$$= \frac{\text{no. of thermo-tolerant coliform colonies counted x 100}}{\text{no. of ml of sample filtered}}$$

Field test method for thermo-tolerant coliforms

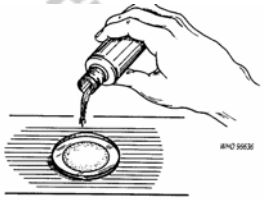
The field test method for thermo-tolerant colifroms involves the following:

A) Flame-sterilize the tip of blunt-ended forceps and allow to cool between successive manipulations of the filters.

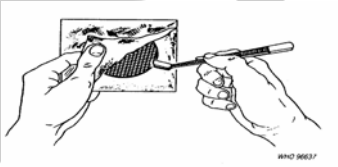
B) Place a sterile absorbent pad in a sterile petri dish.



C) Add broth medium to saturate the pad and remove the excess broth.

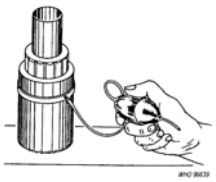


D) Sterilize the filter apparatus and assemble by placing a sterile filter membrane on the membrane support.

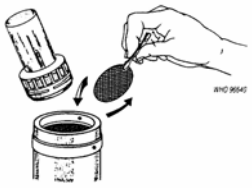


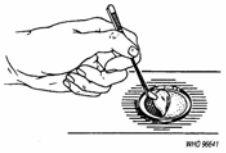
E) Mix the sample thoroughly by inverting the sample bottle several times, and put the volume to be tested into the previously sterilized filtration apparatus. The appropriate volume of sample should be selected in accordance with the type of water being tested

F) Apply a vacuum to the filter apparatus to draw the sample through the filter membrane. Disconnect the vacuum and dismantle the apparatus.



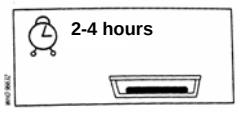
G) Using sterile forceps, remove the membrane filter from the filter apparatus and transfer it to the nutrient pad in the petri dish. Lower the membrane, grid side uppermost, carefully onto the nutrient pad, making sure that no air bubbles are trapped between the pad and the filter.



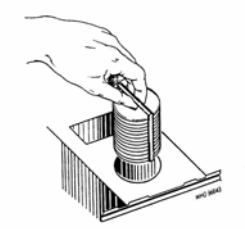


H) Replace the lid on the petri dish and label with the sample identification code using a wax pencil or waterproof pen.

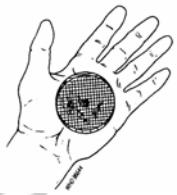
I) Incubate the petri dish at ambient temperature for 2-4 hours to allow stressed bacteria to resuscitate.



J) Incubate the petri dish at the selected temperature for 18-24 hours.



K) Following incubation, count all colonies with a morphology typical of the bacterium and the medium used. Calculate and express the result in colony-forming units (CFU) per 100 ml of sample.



6.7. Multiple-tube Fermentation or MPN method

In the multiple-tube method, a series of tubes containing a suitable selective broth culture medium is inoculated with test portions of a water sample. After a specified incubation time at a given temperature, each tube showing gas formation is regarded as "presumptive positive" since the gas indicates the possible presence of coliforms. However, gas may also be produced by other organisms, and so a subsequent confirmatory test is essential. The two test are known respectively as the presumptive test and the confirmatory test.

For the confirmatory test, a more selective culture medium is inoculated with material taken from the positive tubes. After an appropriate incubation time, the tubes are examined for gas

formation as before. The most probable number (MPN) of bacteria present can then be estimated from the number of tubes inoculated and the number of positive tubes obtained in the confirmatory test, using specially devised statistical tables. This technique is known as the **MPN method**.

1. Inoculation

Different test portions to provide tenfold serial dilution steps may be used, the dilutions being based on the anticipated number of coliform bacteria in the water sample being tested. The reliability of the result obtained depends on the number of tubes inoculated with each test portion; in certain instances, the number can be reduced to three in each dilution step. Each combination of inoculated tubes will have its own table of MPN values.

Typical volume for analysis are given in table 6.2.

Table 6.2. Typical sample volumes and numbers of tubes for the multiple-tube method

Sample	Number of tubes for the multiple-tube				
	50 ml	10 ml	1 ml	0.1 ml	0.01 ml
• Treated drinking water	1	5	-	-	-
• Partial treated drinking water	-	5	5	5	-
• Protected source of water	-	5	5	5	-
• Surface water or water from open wells	-	-	5	5	5

2. Unpolluted and treated water

Water in or entering the distribution system may generally be assumed to contain little or no pollution. In this case, it is recommended that one 50-ml plus five 10-ml volumes of water sample should be inoculated into the tubes; five tubes should each contain 10 ml and one tube 50 ml of double-strength medium.

3. Polluted water

Water suspected to be more highly contaminated (e.g. untreated water from certain raw water sources), should be examined using different inoculation volumes in ten-fold dilution steps. The following inoculations are normally made:

- 10 ml of sample to each of five tubes containing 10 ml of double-strength medium
- 1.0 ml of sample to each of five tubes containing 10 ml of single-strength medium
- 1.0 ml of a 1:10 dilution of sample (i.e. 0.1 ml of sample) to each of five tubes containing 10 ml of single-strength medium.

If the sample is expected to be highly contaminated, aliquots of 1.0 ml of ten-fold serial dilution from each dilution step are

inoculated into five tubes that each contains 10 ml of single-strength medium.

If the workload is very heavy and the time available is limited, the number of tubes can be reduced to three in each series. Statistically, however, inoculation of five tubes with each sample volume produces a more reliable MPN result.

4. Equipment and supplies

The following laboratory equipment and glassware are essential:

- **Autoclave**:- required for sterilizing the culture media. Its size should be determined by the number and type of samples to be taken. Operation of the autoclave should be strictly in accordance with the manufacturer's instructions and should ensure that all the air in the chamber is replaced by steam. Sterilization should be achieved in not more than 30 minutes. Strict adherence to recommended sterilization temperatures and times for different types of culture media is essential. Racks are needed to hold tubes and bottles of prepared culture media in the autoclave.

- **Incubator(s) or water baths**: These must be fitted with a temperature control and should be capable of maintaining a uniform temperature correct to 35 or 37 ± 0.5 ^{o}C and/or 44 or 44.5± O.25 ^{O}C. The choice of temperature depends on the indicator bacteria and the medium used. The temperature of incubators and water baths fitted with thermometers placed at representative points should be monitored periodically (preferably daily). Stainless steel racks should be fitted to hold sample tubes.

- **Balance**: This is needed for weighing powdered culture medium. It should have an accuracy of 0.05 g. A weighing scoop is also required. No balance is required if culture media are available in suitable pre-weighed quantities.

- **Water distillation apparatus, hose, and container:** These are required to produce non-toxic water (i.e. water free from any substances that can interfere with bacterial growth). The container for the distilled water should have a volume of at least 5 liters and be fitted with a tap.

- **Pipettes**: Sizes of 1ml and 10 ml, with cotton plugs at the mouthpiece, are required. The 1-ml pipettes should be graduated in 0.1-ml increments and are used for preparing dilutions; the 10-ml pipettes are used for the

addition of samples to tubes containing media. Any pipettes with chipped or broken tips should be discarded. Glass pipettes can be conveniently stored in a sterilizable metal container. Alternatively, disposable plastic pipettes can be used. A separate container should be employed for each size of pipette. Pipettes may also be wrapped individually in paper and heat-sterilized. Pipette canisters and bulbs are also needed, as is a container for discarded pipettes.

- **Test tubes and racks:** Test tubes can be 20 X 150 mm in size for 10-ml sample volumes plus 10 ml of culture medium (screw caps are not recommended for fermentation media). The racks should be large enough to accommodate culture tubes of the larger diameter used.

- **Bottles:** These are used for the larger volumes consisting of 50 ml of sample and 50 ml of culture medium. They should have loose-fitting caps and ideally be calibrated with 50-ml and 100- ml marks.

- **Media preparation equipment:** Glass or stainless steel containers (usually flasks) are required. Any heating equipment and stirrers used in the preparation of media should be clean and free from soluble toxic materials.

- **Gas burner:** A Bunsen or similar burner is adequate.
- **Culture tubes containing inverted vials (Durham tubes):** Each tube should be large enough for a vial, completely fill with medium, to be submerged in it.

- **Inoculation loop and holder:** Lengths of 24- or 26-gauge wire (7.5-10 cm) should be used. Nichrome wire is acceptable, but platinum-iridium is better. The wire is set in a handle made of metal or glass, of diameter similar to that of a pencil. To make the inoculation loop, the wire is bent to form a circle 3-4 mm in diameter.

- **Dispenser:** This is needed for sodium thiosulfate solution.

- **Cleaning and maintenance equipment:** Items such as brushes for cleaning tubes, bottles, etc., a waste bin, and a tool kit are required.

- **Safety equipment:** There should be an adequate first-aid kit and a fire extinguisher or other means of fire control in every laboratory.

- **General laboratory equipment:** Various sizes of round and Erlenmeyer flasks, beakers, stands, glass or unbreakable plastic measuring flasks, spatulas, etc., are required.

The following equipment is also desirable in a laboratory:

- **Refrigerator**: for the storage of prepared culture media.
- **Hot air sterilizer**: for sterilizing pipettes.

The following consumable items are required:

- **Culture medium:** Table 6.3 describes the uses for the various media.
- **Laboratory disinfectant:** for cleaning laboratory surfaces and the pipette discard bin.
- **Detergent:** for washing glassware, etc.
- **Sodium thiosulfate solution:** required when chlorinated supplies are tested. Sodium thiosulfate neutralizes any residual chlorine in samples at the time of collection, preventing it from acting on any micro-organisms present in water samples.

- **Autoclave tape**
- **Dilutents**: typical dilutents include Ringer's solution and phosphate-buffered saline.

Table 6.3 Culture media for MPN

Medium	Uses	Incubator temperature	Remarks
MacConke Broth	presumptive isolation of coliform bacteria	35± 0.5 ^{o}C or 37 ± 0.5 ^{o}C	Traditional medium for the presumptive isolation of coliform bacteria by MPN. The quality of bile salts can vary and may affect the result.
Lauryl typtose (lactose) broth	Presumptive isolation of coliform bacteria	35 ± 0.5 ^{o}C or 37 ± 0.5 ^{o}C	_____
	Confirmation of thermo-tolerant coliform bacteria.	44 ^{o}C	_____
Improved fromate lactose glutamate medium	Presumptive isolation of coliform bacteria.	35 ± 0.5 ^{o}C or 37 ± 0.5 ^{o}C	This is a selective medium because it contains chemically defined nutrients that can be utilized only by a limited number of bacterial species. The composition of the medium is complex and special care is required during preparation
Brilliant green lactose (bile) broth: EC	Confirmation of coliform bacteria	35 ± 0.5 ^{o}C or 37 ± 0.5 ^{o}C	Media for gas production
	Confirmation of thermotolerant coliform bacteria.	44^{o}C	
Tryptone water	Production of indole for confirmation of Escherichia coli.	44 ^{o}C	The formation of indole, detected by the addition of Kovacs reagent to tryptone water after incubation, with gas production from lactose at 44 ^{o}C indicates the presence of E. coli.

5. Culture media and dilution water.

Commercially available dehydrated media simplify the preparation of culture broths and are therefore recommended for laboratory work. Various manufacturers produce these media as powders, which can then be easily weighed out, dissolved in distilled water, and dispensed into culture tubes before sterilization.

Preparation of media

Media should be prepared in accordance with the manufacture's instructions, as follows:

a) Dissolve the stated amount of the dehydrated medium in distilled water to obtain the double-strength or single-strength presumptive medium (for confirmatory analysis, only single-strength medium is used).

b) Dispense the requisite volume into culture tubes containing an inverted Durham tube, and cap the culture tubes.

c) Sterilize in an autoclave or pressure cooker at 115 ^{0}C for 10 minutes (or in accordance with the manufacturer's specifications). It is particularly important that media containing disaccharides, e.g. lactose, are not autoclaved at higher temperatures.

d) The sterilized medium may be stored at room temperature (approximately 25 ^{0}C) or, ideally, at 2-8 ^{o}C. Media should in any case be warmed to room temperature before use to ensure that all components have redissolved. In addition, since several dyes are light-sensitive, the solution should be protected from exposure to light.

Preparation of dilution water

A special buffered, sterilized water is used to make sample dilutions for inoculation into the culture medium. It is prepared from a concentrated stock solution of phosphate buffer. To make the stock solution, dissolve 34g of potassium dihydrogen phosphate (KH_2PO_4) in 500 ml of distilled water. The P^H should be checked with a P^H-meter; it should be 7.2. It can be increased if necessary by adding a few drops of sodium hydroxide solution (4.0g dissolved in 1000 ml of distilled water). Then add sufficient distilled water to make up to 1 liter. When the stock solution is not in use, it should be stored in a tightly closed bottle at 4-10 ^{0}C, to prevent microbial growth.

When using the dilution water, add 1.25 ml of stock phosphate solution to 1 liter of distilled water and dispense into bottles for sterilization in the autoclave. Before sterilization, loosen the stoppers of the bottles. Sterilize for 15 minutes at 121 ^{o}C. Tighten the stoppers after sterilization and store the dilution water in a clean place until needed.

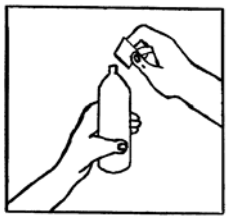
An alternative dilution water can be prepared by the addition of magnesium chloride and has been shown to give a slightly higher recovery rate. Other alternatives include a 0.1% solution of peptone in distilled water (final P^H 6.8), Ringer's solution, and physiological saline (9 g of sodium chloride per liter). These should be sterilized after dispensing into bottles, as described above.

6. Application to unpolluted water.

Procedure

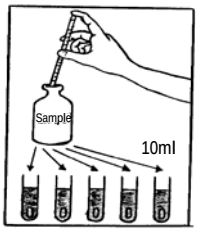
The procedure to be used for testing relatively unpolluted water, such as treated water from waterworks, is described below.

A) Remove the cap from the sample bottle.

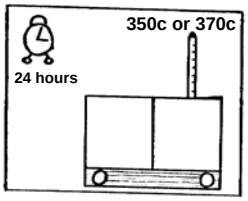


B) With the stopper in position, shake the bottle vigorously to achieve a homogeneous dispersion of bacteria. (if the bottle is completely full, remove the stopper and discard about 20-30 ml of water; then replace the stopper and shake. This ensures thorough mixing.)

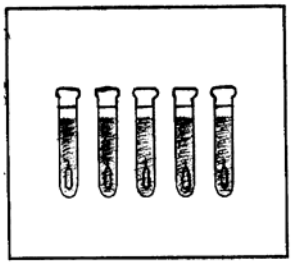
C) With a sterile 10-ml pipette, inoculate 10 ml of the sample into each of five tubes containing 10 ml of presumptive broth (double strength). Add 50 ml of sample to a tube containing 50 ml of presumptive broth. It is advisable to shake the tubes gently to distribute the sample uniformly throughout the medium.



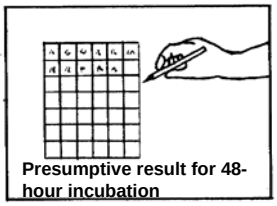
D) Incubate the tubes at 35 ^{o}C or 37 ^{o}C for 24 hours.



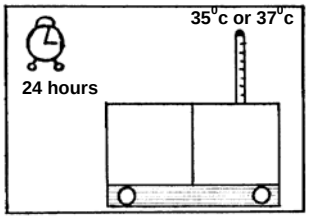
E) At the end of the 24-hour incubation period, examine each tube for the presence of gas. If present, gas can be seen in the Durham tube. If none is visible gently shake the tube; if any effervescence (streams of tiny bubbles) is observed, the tube should be considered positive.



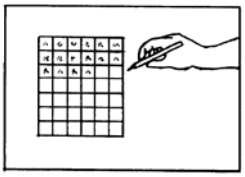
F) Using a table like the one shown here, record the number of positive tubes after 24 hours.


Presumptive result for 48-hour incubation

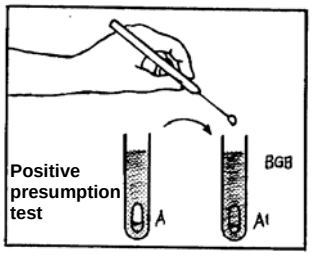
G) Re-incubate negative tubes for a further 24-hour period. At the end of this period, check the tubes again for gas production as in F above. Gas production at the end of either 24 or 48 hours' incubation is presumed to be due to the presence of coliforms in the sample.



H) Record the number of positive tubes after 48 hours.

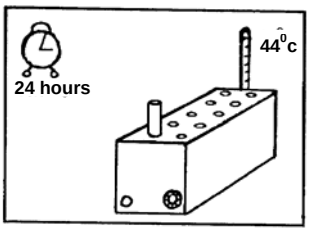


I) The confirmatory test should be carried out at the end of both the 24-hour and the 48-hour incubation. Using a sterile loop, transfer one or two drops from each presumptive positive tube into two tubes containing

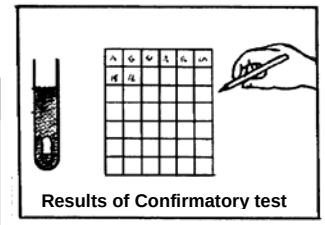


respectively confirmatory broth and tryptone water. (Sterilize the inoculation loop before each transfer by flaming and allow cooling.)

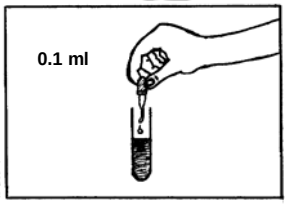
J) To confirm the presence of thermo-tolerant coliforms, incubate the subculture tubes from each presumptive positive tube for 24 hours at 44 $\pm$ 0.5 ^{O}C



K) At the end of 24 hours' incubation, examine each broth tube for growth and the presence of gas in the Durham tube. Enter the results on the table as shown.



L) To each tube of typtone water, add approximately 0.1ml of Kovacs reagent (see Table 6.3) and mix gently. The presence of indole is indicated by a red color in the Kovacs reagent, forming a film over the aqueous phase of the medium.



M) Confirmatory tests positive for indole, growth, and gas production show the presence of E. coli. Growth and gas production in the absence of indole confirm thermo-tolerant coliforms.

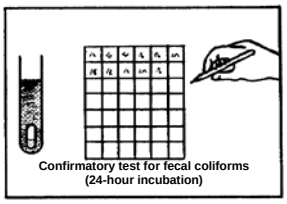

Confirmatory test for fecal coliforms
(24-hour incubation)

Table 6.4. MPN values per 100 ml of sample and 95% confidence limits for various combinations of positive and negative results (when one 50-ml and five 10-ml test portions are used)

No of tubes giving a positive reaction		NPN (per 100ml)	95% confidence limits	
1 of 50 ml	5 of 10 ml		Lower	Upper
0	0	<1	___	___
0	1	1	<1	4
0	2	2	<1	6
0	3	4	<1	11
0	4	5	1	13
0	5	7	2	17
1	0	2	<1	6
1	1	3	<1	9
1	2	6	1	15
1	3	9	2	21
1	4	16	4	40
1	5	>18	__	___

Determination of MPN

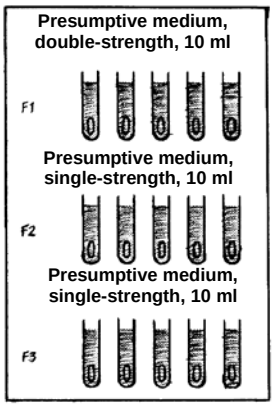
For treated water, where one 50-ml and five 10 ml portions are inoculated, the MPN can be found from the test results by means of Table 6.4.

7. Application to polluted water (full method)

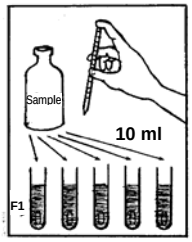
Procedure

The procedure to be used for the testing of water that is expected to be polluted, even though it may have been treated, is shown below and is essentially similar to that described in section 6.7, with the exception that several dilutions are used.

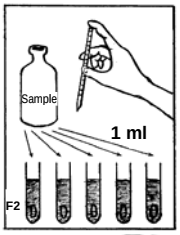
A) Arrange three rows of five tubes each in a test-tube rack. The tubes in the first row (F1) hold 10 ml of double-strength presumptive medium while the tubes in the second and third rows (F2, F3) contain 10 ml of single-strength presumptive medium.



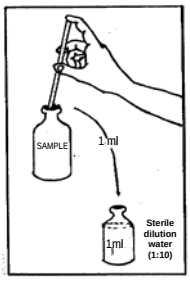
B) With a sterile pipette add 10 ml of sample to each of the five tubes in row F1.



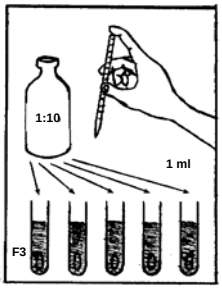
C) With a sterile pipette, add 1 ml of sample to each of the five tubes in row F2.



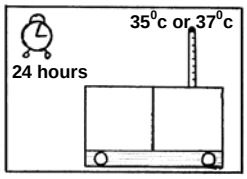
D) Prepare a 1:10 dilution of the sample by adding 1 ml of sample to 9 ml of dilution water (use a 1-ml sterile pipette). Recap the bottle containing the diluted sample and shake it vigorously.



E) With another sterile pipette add 1 ml of the 1:10 dilution to each of the five tubes in row F3.



F) After gently shaking the tubes to mix the contents, incubate the rack with the 15 tubes at 35 ^{o}C or 37 ^{o}C for 24 hours. Then proceed in the same way as for unpolluted water.



Determination of MPN

The MPN is found in a similar way to that described in pervious section but, because of the large number of tubes involved, a more complicated table must be used (see Table 6.5).

The following example shows how the results are obtained:
Suppose that, after confirmation of the presence of thermo-tolerant (fecal) coliforms, the following results are obtained:

- 5 positive tubes in row F1(sample volume inoculated, 10 ml)
- 3 positive tubes in row F2(sample volume inoculated, 1 ml)
- 1 positive tube in row F3(sample volume inoculated, 0.1 ml).

Table 6.5 NPN values per 100 ml of sample and 95% confidence limits for various combinations of positive and negative results (when five 10-ml, five 1-ml and five 0.1 ml test portions are used)

No. of tubes giving a positive reaction:			MPN (per 100m)	95% confidence limits	
5 of 10 ml	5 of 1 ml	5 of 0.1 ml		Lower	Upper
0	0	0	<2	<1	7
0	1	0	2	<1	7
0	2	0	4	<1	11
1	0	0	2	<1	7
1	0	1	4	<1	11
1	1	0	4	<1	11
1	1	1	6	<1	15
2	0	0	5	<1	13
2	0	1	7	1	17
2	1	0	7	1	17
2	1	1	9	2	21
2	2	0	9	2	21
2	3	0	12	3	28
3	0	0	8	1	19
3	0	1	11	2	25
3	1	0	11	2	25
3	1	1	14	4	34
3	2	0	14	4	34
3	2	1	17	5	46
3	3	0	17	5	46
4	0	0	13	3	31
4	0	1	17	5	46
4	1	0	17	5	46
4	1	1	21	7	63
4	1	2	26	9	78
4	2	0	22	7	67
4	2	1	26	9	78
4	3	0	27	9	80
4	3	1	33	11	93
4	4	0	34	12	93
5	0	0	23	7	70
5	0	1	311	11	89
5	0	2	432	15	110
5	1	0	332	11	93
5	1	1	463	16	120
5	1	2	613	21	150

5	2	0	49	17	130
5	2	1	70	23	170
5	2	2	94	28	220
5	3	0	79	25	190
5	3	1	110	31	250
5	3	2	140	37	340
5	3	3	180	44	500
5	4	0	130	35	300
5	4	1	170	43	490
5	4	2	220	57	700
5	4	3	280	90	850
5	4	4	350	120	1000
5	5	0	240	68	750
5	5	1	350	120	1000
5	5	2	540	180	1400
5	5	3	920	300	3200
5	5	4	1600	640	5800
5	5	5	>1800	—	—

The results can thus be coded as section 6.7; they represent the confirmatory test for thermo-tolerant coliforms. Table 6.5 indicates that coded result of section 6.7 (5x10 ml positive, 3 X 1 ml positive, 1X 0.1 ml positive) gives an MPN value of 110, meaning that the water sample contains an estimated 110 coliforms per 100 ml.

Next, consider an example of heavily polluted water. The procedure outlined above may give a coded result of 5-5-5. Such a result does not give a definite MPN valve. When such heavy contamination is suspected it is usual to inoculate more than three dilutions in a series of factors of 10. This series of 10-fold dilutions should be made in such a way that a negative result is likely for at least the highest dilution incubated. If 5 X 1.0 ml, 5 X 0.1 ml, 5 X 0.01 ml, and 5X 0.001 ml are initially

inoculated and a confirmed coded result of 5-5-1 is obtained, only three of these results should then be used to obtain the MPN value from Table 6.5. These should be selected by choosing the smallest sample volume (in this case, 0.1 ml) for which all the tubes give a positive result, and the two next succeeding higher dilutions. The coded result of these three volumes is then used to obtain the MPN value from Table 6.5. In the above example, the result 5-4-1 would be chosen, representing volumes of 0.1, 0.01, and 0.001 ml of the sample. The MPN value obtained from Table 6.5. should be multiplied by 100 to obtain the MPN for this particular sample (see below); in this case, the result is 1,700 per 100 ml.

Sometimes the laboratory worker may find it difficult to determine the multiplying factor to be used to obtain the appropriate MPN for the sample tested. A simple way to determine the MPN is to divide the MPN value obtained from Table 6.5 by the sample volume represented by the middle number in the chosen code. For example, consider a chosen code of 5-2-0, in which the 2 represents a sample volume of 0.01 ml (see Table 6.6). From Table 6.5, MPN for a code of 5-2-0 is 49. The MPN value for the sample tested will therefore be:

(49/0.O1) = 49 X100= 4900.

Table 6.6. Example of multiplying factors for determination of MPN for different dilutions of sample.

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No. of tubes giving a positive reaction:						Coded result chosen	Multiplying factor for MPN
Example	5 of 1 ml	5 of 0.1 ml	5 of 0.01	5 of 0.001 ml	5 of 0.0001 ml		
1	5	5	2	0	0	5-2-0	100
2	5	5	4	1	0	5-4-1	100
3	5	3	0	0	0	5-3-0	10
4	5	5	5	3	1	5-3-1	1000
5	0	1	0	0	0	0-1-0	10

Table 6.7. MPN values per 100ml of sample and 95% confidence limits for various combinations of positive and negative result (when three 10-ml, three 1-ml, and three 0.1-ml test portions are used)

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No. of tubes giving a positive reaction			MPN (per 100m)	95% confidence limits	
3 of 10 ml	3 of 1 ml	3 of 0.1 ml		Lower	Upper
0	0	1	3	<1	9
0	1	0	3	<1	13
0	0	0	4	<1	20
1	0	1	7	1	21
1	1	0	7	1	23
1	1	1	11	3	36
1	2	0	11	3	36
2	0	0	9	1	36
2	0	1	14	3	37
2	1	0	15	3	44
2	1	1	20	7	49

2	2	0	21	4	47
2	2	1	28	10	149
3	0	0	23	4	120
3	0	1	39	7	130
3	0	2	64	15	379
3	1	0	48	7	210
3	1	1	75	14	230
3	1	2	120	30	380
3	2	0	93	15	380
3	2	1	150	30	440
3	2	2	210	35	470
3	3	0	240	36	1300
3	3	1	460	71	2400
3	3	2	1100	150	4800

Examples are given in Table 6.6 of the factors to be used to multiply the MPN value found in order to obtain the appropriate MPN for different dilutions.

8. Application to polluted water "shorter method"

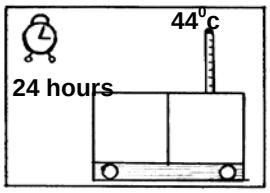
The procedure for the shorter method is almost identical to that described in section 6.7, with the single difference that only three tubes of each sample volume are inoculated, instead of five. This requires the use of a different table- Table 6.7- for determining the MPN.

9. Direct thermo-tolerant coliform method

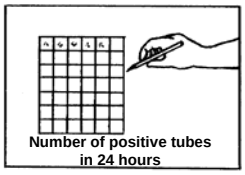
If unchlorinated water from small community water supplies is tested and only the number of thermo-tolerant coliforms is of interest, a direct multiple-tube method can be used. This is recommended for use where the total coliform result is not of great significance, (e.g. in small-community supplies in developing countries or where space, time, or facilities are limited). The method is based on the normal MPN procedure, but the tubes are incubated directly in a water bath at 44.5 ± 0.2 ^{0}C, without previously incubating at 35 or 37 ^{0}C for 24 hours and testing for total coliforms.

The procedure is similar to that described for the examination of polluted water, except that MacConkey broth is used as the presumptive medium. Prepare 15 tubes of sample and medium, as described in the procedure and then proceed as shown below:

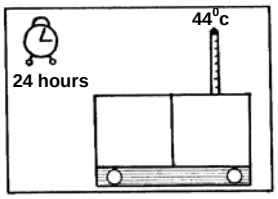
A) After gently shaking the tubes to mix the contents, incubate the 15 tubes at 44 ^{o}C for 24 hours.



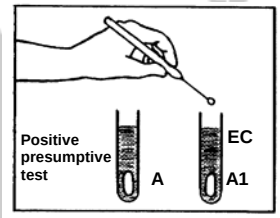
B) Observe each tube for the presence of gas and enter the number of positive tubes after 24 hours in the appropriate table.



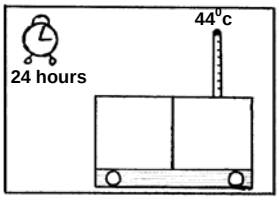
C) Negative tubes should be reincubated for a further 24-hour period, after which they should be observed for the presence of gas.



D) Confirm the presumptive results after 24 and 48 hours by transferring a loopful of broth to a confirmatory broth and incubating at 44 ^{o}C for 24 hours



E) The presence of thermo-tolerant coliforms is confirmed if gas is present in the confirmatory broth after 24 hours at 44 ^{O}C. Determine the MPN from Table 6.5 as before.



10. Selection of tubes for confirmatory test

Any bacteriological analysis should always include the confirmatory test. If only five 10-ml portions are tested, the confirmatory test for coliforms and thermo-tolerant coliforms must be carried out on all tubes showing gas production. However, if the inoculation involved five (or three) tubes for each of, or more than, three sample volumes (e.g. 10, 1.0, 0.1, 0.01 and 0.001 ml), it is not necessary to carry out confirmatory tests on all the positive tubes.

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If all five (or three) tubes of two or more consecutive dilution are positive, the set of tubes should be selected that presents the smallest sample volume for which all the tubes are positive. The confirmatory test should be carried out on all these tubes and on all the positive tubes corresponding to subsequent and lower volumes. The following example should help to illustrate this procedure:

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After 24 hours incubation, five tubes with 10 ml, five with 1.0 ml, five with 0.1 ml, four with 0.01 ml, and one with 10 ml, five with 1.0 ml, five with 0.1 ml, four with 0.01 ml, and one with 0.001 ml gave positive results. Thus the confirmatory test should be carried out on the positive tubes initially inoculated with 0.1, 0.01, and 0.001, ml of sample.

(Source, WHO - Guidelines for Drinking Water Quality. Surveillance and Control of Community Supplies, 2nd edition, volume 3, Geneva, 1997.)

6.8. Guidelines for Drinking Water Quality

Table 6.8. Drinking water quality regulation for municipal (treated) water system.

Constituent	WHO Guideline value: X/Y*	Parameter	Guideline value
Organoleptic	-----	Manganese, mg/l	0.05/0.5
Color, pt/l	5.0	Sodium, mg/l	200.0
Color, TCU	15.0/50	Sulfate, mg/l	200/400.0
Odor	No 0dor	Zinc, mg/l	5.0/15
Taste	Tasteless	Magnesium, mg/l	50/150
Turbidity, NTU	5.0/25	Calcium, mg/l	75/200
P^H	7.0-8.5/6.5-9.2	Silver, mg/l	0.05
TDS, mg /l	1000/1500	Temperature	7 - 12
Aluminum, mg/l	0.2	**Radioactive materials**	------
Chlorides, mg/l	250/600	Gross alpha activity, Bq/l	0.1
Copper, mg/l	1.0/1.5	Gross beta activity, Bq/l	1.0
Hardness as $CaCO_3$	500.0/1000		
Iron, mg/l	0.1/1.0		
Chemical toxicity	------	Nitrate mg/l	45.0
Cadmium, mg/l	0.005/0.01	Nitrite, mg/l	1.5
Chromium, mg/l	0.05 max	Fluoride, mg/l	1.5
Arsenic, mg/l	0.01/0.05	Ammonia, mg/l	0.05/0.1
Lead, mg/l	0.05	CCl_4, micg/l	3.0
Selenium, mg/l	0.01	Cyanide, mg/l	0.05/0.1
Mercury, mg/l	0.001	Flouride, mg/l	1.5
Barium, mg/l	1.0	Benzene, micg/l	10.0
Aldrin/dieldrin, micg/l**	0.03	Trichloroethane, micg/l	200.0
Benzo(a)pyrene, micg/l	0.01	Pentachlorophenol, micg/l	10.0
Lindane, micg/l	4.0	2,4,6-trichlorophenol, micg/l	10.0
DDT, micg/l	1.0	Methoxyechlor, micg/l	1.0
1,2-dichlroethene, micg/l	10.0	2,4-D, micg/l	100.0
1,1-dichlroethene, micg/l	3.0	Hexachlorobenzene, micg/l	5.0
Chloroform, micg/l	60.0	Heptachlorepoxide, micg/l	0.1
Chlordane, micg/l	0.30		

NB: *X/Y= Highest desirable level/Maximum permissible level.
**micg/l= microgram per liter.

Source: Morgan P. Rural Water Supplies and Sanitation. Blair Research Laboratory, Ministry of Health, Harare and Hong Kong, Macmillan Publishers Limited, 1990.

Table 6.9. WHO Guidelines for bacteriological quality in drinking water

Water quality	Chlorinated piped water per 100 ml		Unchlorinated piped water per 100 ml		Drinking water: wells, river, springs per 100 ml	
	Presumptive coliforms MPN per 100 ml	E. coli type I	Presumptive coliforms MPN per 100 ml	E. coli type I	Presumptive coliforms MPN per 100 ml	E. coli type I
Good quality	Nil	Nil	1 – 3	Nil	1 - 30	Nil
Suspect	1 - 3	Nil	4 – 10	Nil	30 - 50	0 – 1
Unfit	> 3	Present	> 10	Present	> 50	> 1

Source: WHO. Guidelines for Drinking Water Quality, Volumes 1 – 3, Geneva, 1984 &1985.

Table 6.10. Drinking water quality for rural areas (small scale untreated water system)

Water quality parameter	Highest desirable level	Maximum permissible level
Coliform, # / 100 ml	10	NA
E. coli, # / 100 ml	2.5	NA
Total dissolved solids, mg/l	500	2000
Turbidity, FTU	5	25
Color, mg/l	5	50
Iron, mg/l	0.1	1
Manganese, mg/l	0.05	0.5
Nitrate, mg/l	50	100
Nitrite, mg/l	1	2
Sulphate, mg/l	200	400
Fluoride, mg/l	1	2
Sodium, mg/l	120	400
Arsenic, mg/l	0.05	0.1
Chromium, mg/l	0.05	0.1
Cyanide, mg/l	0.1	0.2
Lead, mg/l	0.05	0.10
Mercury, mg/l	0.001	0.005
Cadmium, mg/l	0.005	0.01

Source: Morgan P. Rural Water Supplies and Sanitation. Blair Research Laboratory, Ministry of Health, Harare and Hong Kong, Macmillan Publishers Limited, 1990.

Glossary

Aeration - supply with air

Agar - an extract from algae, used to grow bacteria, etc.

Air washing - Cleaning by using aeration

Algae - a simple form of plant life

Alkali - a substance that combines with an acid to form a salt

Alkalinity - the state of being alkaline

Altitude - height

Asphyxiate - to stop life or consciousness because of lack of oxygen

Atmosphere - the mass of air surrounding the earth

Atmospheric pressure - pressure or thrust caused by the weight of air

BOD - the amount of oxygen needed to stabilize organic matter through the action of bacteria

Brake horsepower - power of a motor estimated from the force operated on the friction brake

Centrifugal - moving away from the center

Centrifugal force - the power that causes an object or substance on a curve or rotating surface to move outward from the axis or center

Chlorination - treatment with chlorine or with hypochlorite

Clogging - prevention of movement because of dirt or other substances.

Coagulant - a substance that makes other substances clog

Coefficient - a number that measures a quality or characteristic.

Colloid - a substance in such small particles that it does not easily settle in a liquid.

Contact time - the time needed for a reaction between two or more substance placed together.

Dechlorination - removal of chlorine or a chlorine compound

Defluoridation - the removal of fluoride

Disinffection - destruction of agents of infection

Feces - discharged body waste, excrement

Fluoridation - addition of fluoride

Friction - resistance caused by the motion of, for example, water against another substance or a wheel against a brake

Gate valve - a valve with a control that can close or open a pipe

Head - the difference in height between two points in a body of liquid; the resulting pressure of the liquid at the lower point, expressed as the height

Horsepower - a unit of power

Impeller - the driving part of a machine

Loss of head - the decrease in head between two points, i.e. the difference in pressure between a higher and lower point; loss of energy

Nozzle - a tube forming the opening of a pipe, used to control the quantity or direction of a fluid

Orifice - an opening

P^H - potential of hydrogen

Piston - a sliding cylindrical piece of equipment that moves within a hollow cylinder

Plunger - a piece of equipment made to slide up and down in a cylinder piston

Prime mover - original or initial source of power

Pre-chlorination - addition of chlorine compounds to water before it is filtered

Precipitate - solid that can usually be separated from a liquid by filtration

Sedimentation - the action of setting down or depositing matter in a liquid

Siphon - a method of continuously transferring a liquid to a lower point by air pressure forcing it up the shorter end of a bent tube

Specific Gravity - the ratio of one substance's density to another density

Spout - the part of the pipe through which fluid comes out

Suction Head - the part of the total that exists on the intake or suction part of a pump

Ultra-Violet Ray - short wave radiation beyond the violet end of the visible spectrum. Used to treat some diseases and to kill microbes

Valve - a movable piece of equipment designed to open, close or control the opening of a pipe or other piece of equipment

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