NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: EHS 409

COURSE TITLE: SEWAGE AND WASTE WATER TREATEMENT

MAIN COURSE

CONTENTS PAGE

COURSE GUIDE

EHS 409
SEWAGE AND WASTE-WATER TREATMENT

Course Team J.O. Okwa (Course Developer/Course Writer)- Ministry of Environment and Mineral Resources, Enugu, Enugu State
Prof. A. Adebanjo (Programme Leader) - NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
14/16 Ahmadu Bello Way
Victoria Island, Lagos.

Abuja Office
5 Dar es Salaam Street
Off Aminu Kano Crescent
Wuse II, Abuja

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

Published by
National Open University of Nigeria

Printed 2011

Re-Printed 2014

ISBN: 978-058-060-3

CONTENTS **PAGE**

INTRODUCTION

Sewage and Waste-water treatment is a one- semester course and a two-credits -unit course available to all students of Bachelor of Science (B. Sc) in Environmental Health. Sewage is the collective name for the liquid waste of a community. It consists of the following:

- excreta that are faeces and urine
- bathroom or bath waste-water
- wash-hand basin and sink waste-water
- kitchen waste-water
- laundry waste-water
- rain run-off waste-water
- and industrial waste-water.

From the above, it is clear that the term 'sewage' could be used synonymously as waste-water because none of its content is good or useful unless they are treated. When treated, the waste-water which could have been a curse can turn into a blessing, hence the need for such treatment and therefore the need for this course.

WHAT YOU WILL LEARN IN THIS COURSE

This Course Guide explains to you what to expect from reading the course material, what course materials you need and how to work with them. In the material, you will learn about sewage and sewerage systems, waste-water sources, components and characterisation as well as flow rates. Also to be learnt includes principles of applied microbiology, waste-water treatment, screening, use of comminutor and grit removal processes, flow equalisation processes, sedimentation and flotation processes, tricking filters, rotating biological discs, activated sludge and oxidation pond, etc. Tutor-marked assignments are expected to be done by you. Finally, it is expected that the course will prepare you for challenges you are likely to meet in the field of environmental health.

COURSE AIM

The aim of this course is to provide you with a good understanding of sewage and waste-water treatment processes with the view to making our waste-water not only harmless to man, animals and plants in the environment but even useful for some purposes in the world.

COURSE OBJECTIVES

On successful completion of the course, you should be able to:

- explain the concepts of sewage and sewerage system
- enumerate the types and sources of waste-water
- discuss characteristics and flow rates of waste-water
- explain the impacts of waste-water on the environment, treatment objectives and disposal regulations of waste-water
- discuss all the principles of applied microbiology
- explain the waste-water treatment introduction: screening, use of comminutor and grit removal processes
- discuss flow equalisation, sedimentation and flotation processes
- explain the tricking filters, rotating biological discs, activated sludge and oxidation pond
- discuss advanced waste-water treatment
- explain ultra filtration and reverse osmosis processes
- discuss activated carbon filter and UV sterilisation processes
- explain treatment of sludge-disinfection and disposal on land/water
- discuss sewer corrosion and design of waste-water treatment units.

WORKING THROUGH THIS COURSE

This course has been carefully put together bearing in mind that you might be new to the discipline. However efforts have been made to ensure that adequate explanation and illustrations were made to enhance better understanding of the course. You are therefore advised to spend quality time to study this course and ensure that you attend tutorial sessions where you can ask questions and compare your knowledge with that of your classmates. Each unit contains self assessment exercise. In the course you would be required also to submit assignment for assessment. This course should take about 15 weeks to complete.

COURSE MATERIALS

The main components of the course material are:

i. A Course Guide
ii. Study Units
iii. References/ Further Reading: these are recommended for you to buy and read if you can, so as to have more insight into the various topics discussed
iv. Assignments: to assess how you understand the topics
v. In-built sketches /plates for more elucidation.

STUDY UNITS

This course is divided into 15 units discussed under 3 modules as given below.

Module 1 Introduction to Sewage and Waste-Water Treatment

Unit 1 Definitions and Concepts of Sewage and Sewerage
Unit 2 Types and Sources of Waste-water
Unit 3 Characteristics and Flow Rates of Waste-water
Unit 4 Impacts of Waste-water on the Environment, Treatment Objectives and Disposal Regulations
Unit 5 Principles of Applied Microbiology

Module 2 Primary and Secondary Waste-Water Treatment

Unit 1 Waste-water Treatment Introduction: Screening, Use of Comminutor and Grit Removal Processes
Unit 2 Flow Equalisation Processes
Unit 3 Sedimentation and Flotation Processes
Unit 4 Tricking filters, Rotating Biological Discs, Activated Sludge and Oxidation Pond
Unit 5 Physic-Chemical Treatment Processes

Module 3 Advanced Waste-Water Treatment

Unit 1 Ultra Filtration Process
Unit 2 Reverse Osmosis Process
Unit 3 Activated Carbon Filter and UV Sterilisation Processes
Unit 4 Treatment of Sludge- Disinfection and Disposal on Land/Water
Unit 5 Sewer Corrosion and Design of Waste-water Treatment Units

TEXTBOOKS AND REFERENCES

You are advised to consult as many textbooks, journals and internet sources contained at the end of every unit for your enrichment.

PRESENTATION SCHEDULE

Your course materials have important dates for the early and timely completion and submission of your TMAs and attending tutorials. You are expected to submit all your assignments by the stipulated time and date and guard against falling behind in your work.

ASSESSMENT

There are three parts to the course assessment and these include self-assessment exercise, tutor-marked assignments and final examination. In tackling the assignments, you are expected to use the information, knowledge and techniques gathered during the course. The assignments must be submitted to your facilitator for formal assessment in line with the deadliness stated in the presentation schedule and assignment file. The assignment that you submit to your tutor for assessment will count for 30% of your total course work. At the end of the course you will need to sit for a final end-of-course examination of about three hours' duration. This examination will count for 70% of your total course mark.

TUTOR-MARKED ASSIGNMENT (TMA)

The TMA is a continuous component of your course. It accounts for 30% of the total score. You will be given four TMAs to answer. Three of this must be answered before you are allowed to sit for the end-of - course examination. The TMAs would be given to you by your facilitator and returned after you have done the assignment. Assignment questions for the units in this course are contained in the assignment file. You will be able to complete your assignment from the information and material contained in your reading, references and study units. However, it is desirable in all degree level of education to demonstrate that you have read and researched more into your references, which will give you a wider view point of the subject.

Make sure that each assignment reaches your facilitator on or before the deadline given in the presentation schedule and assignment file. If for any reason you cannot complete your work on time, contact your facilitator before the assignment is due to discuss the possibility of an extension. Extension will not be granted after the due date unless there are exceptional circumstances.

FINAL EXAMINATION AND GRADING

The end-of-course examination for EHS 409 will be for about 3 hours and has a value of 70% of the total course work. The examination will consist of questions, which will reflect the type of self-assessment exercises and tutor-marked assignment problems you have previously encountered. All area of the course will be assessed. Therefore, use the time between finishing the last unit and sitting for the examination to revise the whole course. You might find it useful to review your self-assessment exercises, TMAs and comments on them before the examination. The end-of-course examination covers information from all parts of the course.

COURSE MARKING SCHEME

Assignment	Marks
Assignments 1-4	Four assignments, best three marks of the four count 30% of the marks
End-of-course examination	70% of overall marks
Total	100%

COURSE OVERVIEW

This table shows the units, the number of weeks required to complete them and the assignments.

	Title of Work	Weeks Activity	Assessment (End of Unit)
	Course Guide	Week 1	
Module 1	**Introduction to Sewage and Waste-water Treatment**		
Unit 1	Definitions and Concepts of Sewage and Sewerage	Week 1	Assignment 1
Unit 2	Types and Sources of Waste-water	Week 2	Assignment 2
Unit 3	Characteristics and Flow Rates of Waste-water	Week 3	Assignment 3
Unit 4	Impacts of Waste-water on the Environment, Treatment Objectives and Disposal Regulations	Week 4	Assignment 4
Unit 5	Principles of Applied Microbiology	Week 6	Assignment 5
Module 2	**Primary and Secondary Waste-water Treatment**		
Unit 1	Waste-water Treatment Introduction: Screening, Use of Comminutor and Grit Removal Processes.	Week 7	Assignment 6
Unit 2	Flow Equalisation Processes	Week 8	Assignment 7
Unit 3	Sedimentation and Flotation Processes	Week 9	Assignment 8
Unit 4	Tricking Filters, Rotating Biological Discs, Activated Sludge and Oxidation Pond	Week 10	Assignment 9

Unit 5	Physic-Chemical Treatment Processes	Week 11	Assignment 10
Module 3	**Advanced Waste-water Treatment**		
Unit 1	Ultra Filtration Process	Week 11	Assignment 11
Unit 2	Reverse Osmosis Process	Week 12	Assignment 12
Unit 3	Activated Carbon Filter and UV Sterilisation Processes	Week 12	Assignment 13
Unit 4	Treatment of Sludge-Disinfection and Disposal on Land/Water	Week 13	Assignment 14
Unit 5	Sewer Corrosion And Design of Waste-water Treatment Units.	Week 14	Assignment 15

FACILTATORS/TUTORS AND TUTORIALS

There are 15 hours of tutorials provided in support of this course. You will be notified of the dates, times and location of the tutorials as well as the name and the phone number of your facilitator, as soon as you are allocated a tutorial group. Your facilitator will mark and comment on your assignments, keep a close watch on your progress and any difficulties you might face and provide assistance to you during the course. You are expected to mail you TMAs to your facilitator before the schedule date (at least two working days are required). They will be marked by your tutor and returned to you as soon as possible.

Do not delay to contact your facilitator by telephone or e-mail if you need assistance. The following might be circumstances in which you would find assistance necessary, hence you would have to contact your facilitator if:

- you do not understand any part of the study or the assigned readings
- you have difficulty with self-tests
- you have a question or problem with an assignment or with the grading of an assignment

You should endeavour to attend the tutorials. This is the only chance to have face-to-face contact with your course facilitator and to ask question which are answered instantly. You can raise any problem encountered in the course of your study. To gain more benefit from course tutorials prepare a question list before attending them. You will learn a lot from participating actively in discussions.

SUMMARY

This course intends to take you into an in-depth study on sewage and waste-water treatment. Sewage is the collective name for the liquid waste of a community. It consists of the following: excreta that are faeces and urine; bathroom or bath waste-water; wash-hand basin and sink waste-water; kitchen waste-water; laundry waste-water; rain run-off waste-water; and industrial waste-water. Sewage and waste-water are used synonymously as there is no significant difference. By way of definition, sewerage system is the network of underground waste pipes which are employed to collect the waste-water from the community. The sewers or pipes are laid in such a way that the flow is under gravity.

These waste-water or sewage have some characteristics that are not in consonance with humans, that is that they affect human beings, animals, plants as well as our environment negatively if not treated. Against this background, there is the need for sewage treatment. In treating same, one has to understand its content and behavourial characteristics like its flow rates, etc. At present, a lot of methods or procedures are at our disposal for the treatment of our waste-water. They range from primary to secondary to tertiary treatment methods. Some of the methods mentioned in this course include: waste-water treatment introduction, screening, use of communitor and grit removal processes (primary processes), sedimentation and flotation processes, tricking filters, rotating biological discs, activated sludge and oxidation pond, physic-chemical treatment processes (secondary processes), ultra filtration process, reverse osmosis process, activated carbon filter and UV sterilisation processes (advanced waste-water treatment or tertiary processes).

I wish you happy reading and pray you will make this course material your companion. Good luck.

MODULE 1 INTRODUCTION TO SEWAGE AND WASTE-WATER TREATMENT

UNIT 1 DEFINITIONS AND CONCEPTS OF SEWAGE AND SEWERAGE

CONTENTS

1.0 INTRODUCTION

You are welcome to this course entitled Sewage and Waste-water Treatment-(EHS 409). In your "Hydrology and Sanitation course– (EHS 304), you were introduced to some units that dealt with the introductory aspect of this present course. In the first unit of this course, we are to explain the meaning (definition) and concepts of sewage and sewerage systems with a view to helping you understand the entire course contents which you will study as you go on.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define the words sewage and sewerage
- explain the concepts of sewage and sewerage
- list and explain the types of sewerage.

3.0 MAIN CONTENT

3.1 Definitions and Concepts of Sewage

According to Waheb (1991), sewage is the collective name for the liquid waste of a community. It consists of the following:

- excreta that are faeces and urine
- bathroom or bath waste-water
- wash-hand basin and sink waste-water
- kitchen waste-water
- laundry waste-water
- rain run-off waste-water
- industrial waste-water.

3.1.1 Characterisation of Sewage

As seen above, sewage contains things like faeces, urine and gray water, etc. Gray water results from washing, bathing and meal preparations. Agricultural run-off water and waste from nearby industries may also enter the system. The important physical characteristic of waste-water is its total solid content. It includes floating, suspended colloidal and dissolved solids. Total solids are those that remain as residue upon evaporation at 105 degree centigrade. More details about these will be discussed later.

Sullage water is another name for gray water (Sridhar, 2007). It is domestic waste-water other than that which comes from the toilet with sources as seen above. The word 'gray' is used to distinguish it from backwater which describes wastes containing human excreta.

Sewage or waste-water originates mainly from domestic, industrial, groundwater, and meteorological sources and these forms of waste-water are commonly referred to as domestic sewage, industrial waste, infiltration, and storm-water drainage, respectively. Domestic sewage results from people's day-to-day activities. The quantity and character of industrial waste-water is highly varied, depending on the type of industry, the management of its water usage, and the degree of treatment the waste-water receives before it is discharged.

3.2 Definition and Concepts of Sewerage

By way of definition, sewerage system is the network of underground waste pipes which are employed to collect the waste-water from the community. The sewers or pipes are laid in such a way that the flow is under gravity.

A sewerage system collects waste-water and can be in the form of backwater separated from gray water, or mixed with it (sewage). Gravity is used wherever possible to convey the waste-water. It is not surprising therefore that natural storm water drainage is usually used, because this is how rainwater run-off is conveyed in nature by gravity. The principle of using gravity as the driving force for conveying waste-water in a sewerage system should be applied wherever possible, because this will minimize the cost of pumping. Natural storm water drainage occurs in what is usually termed a catchment basin. In a catchment basin, rainwater run-off flows to a common point of discharge, and in so doing, forms streams and rivers. Crossing a catchment boundary may mean that the water has to be unnecessarily pumped, requiring an energy source. A waste-water sewerage system should therefore be within a storm water catchment basin.

Sewerage systems can be classified into combined sewerage and separate sewerage. Combined sewerage carries both storm water and waste-water, while separate sewerage carries storm water or waste-water separately. Recent trends have been for the development of separate sewerage systems. The main reason for this is that storm water is generally less polluted than waste-water, and that treatment of combined waste-water and storm water is difficult during heavy rain falls, resulting in untreated overflows (commonly termed Combined Sewer Overflow, CSO). In practice there is usually ingress of storm water into waste-water sewerage pipes, because of unsealed pipe joints, and unintentional or illegal connections of rainwater run-off. Conversely there may be unintentional or illegal waste-water connections to storm water sewerage.

3.2.1 Types of Sewerage

Waste-water sewerage systems can be classified into three major types:

- conventional sewerage
- simplified sewerage
- settled sewerage

A Conventional Sewerage: conventional sewerage is also termed deep sewerage because the sewerage pipes are laid deep beneath the ground. Pumping is generally required at various stages of the sewer pipe network, especially if the landscape is fairly flat. The larger the population served by the sewerage system, and the longer the planning horizon is to cope with future population increases, the larger the diameter of the final pipes becomes. The costs of the pipes, inspection manholes, pumps and pumping stations and their construction/installation are therefore high. The costs of operation and maintenance are correspondingly high because of very conservative design assumptions.

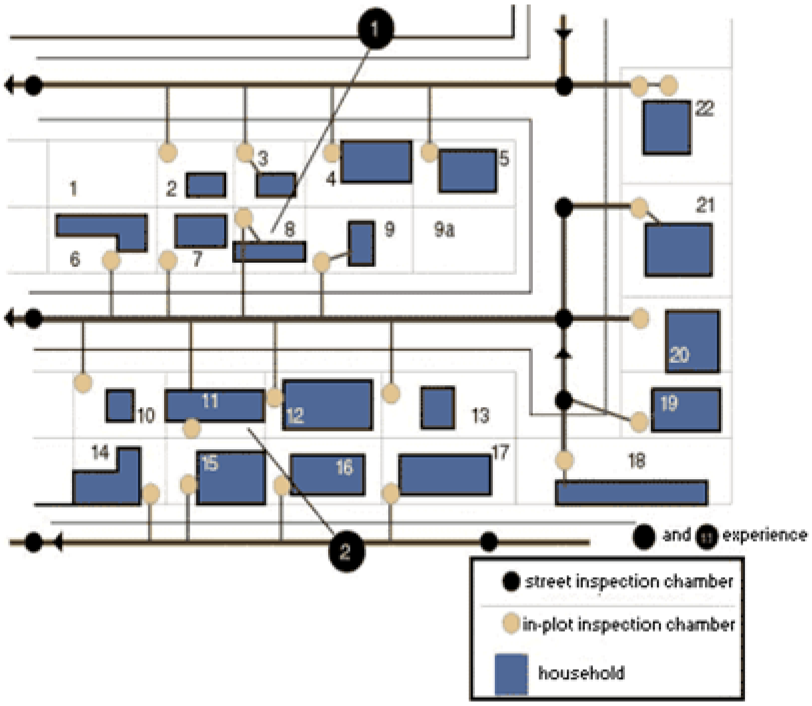


Fig. 1.1: Pipe Layout for Conventional Sewage
Source: UNEP.www.unep.or.jp/iet/publications/freshwater/sb summary/index.aspx

3.2.2 Simplified Sewerage

Simplified sewerage is also known as shallow sewerage, reflecting the shallower placement of the pipes in contrast to the conventional or deep sewerage. The purpose of simplified sewerage is to reduce the cost of construction and the corresponding cost of operation and maintenance. Simplified sewerage design is based on hydraulic theory in the same manner as for conventional sewerage but has less conservative design assumptions. Smaller diameter pipes are used when water use per person is known to be less and the minimum depth of cover of pipes can be as low as 0.2 m when there is only light traffic. Manholes can be replaced by inspection cleanouts because of the shallow pipes. The design planning horizon can be shorter because the population projection may be uncertain. In a variation of the simplified sewerage, the pipe layout passes through property lots (condominial) rather than on both sides of a street (conventional). Figures 1.1 and 1.2 show the sewerage layouts in conventional sewerage and in condominial sewerage systems. The cost of construction of simplified sewerage can be 30 to 50 % less than conventional sewerage depending on local conditions.

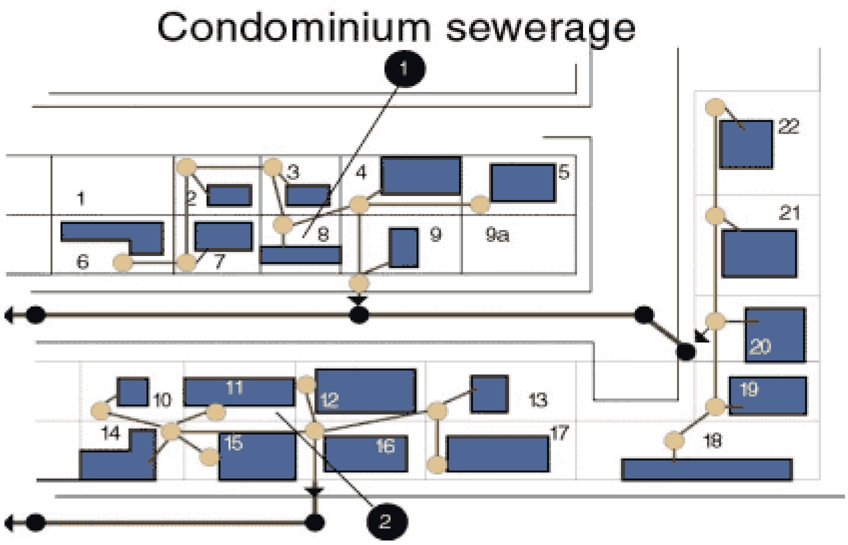


Fig.1.2: Pipe Layout for Condominium Sewerage
Source:UNEP.www.unep.or.jp/ietc/publications/freshwater/sb_ summary /index.aspx

Shallow sewerage is also conducive to local community participation because sewer pipes have to cross property boundaries. The community has to agree to this arrangement which extends after construction for maintenance (e.g. unblocking of sewer pipes). The shallow pipe, and hence the shallow trenches, also allow members of the community to participate by, for example, providing labour for digging the trenches. This is in contrast to conventional sewerage where specialised machinery is required for the deep trenches.

Simplified sewerage was originally developed in Brazil and is increasingly being used in other parts of the world. The 'International Source Book on Environmentally Sound Technologies for Waste-water and Storm water Management' (hereafter referred to as the Source Book), published by IWA and IETC, provides useful case studies.

3.2.2 Settled Sewerage

Settled sewerage refers to sewerage for conveying waste-water that has been settled, for example, in a septic tank. Settled sewerage originated to convey the overflow from septic tanks where the soil cannot cope or absorb the overflow. This usually occurs when the groundwater table is high, or where the soil permeability is low, or where there are rock outcrops. It can also be used when effluent from septic tanks pollutes groundwater and it is necessary to convey the effluent off-site and treat it. Because there are no solids that can potentially sediment in the sewerage pipes, there is no requirement for the self-cleansing velocity.

Smaller pipes and lower gradients can be used. The cost of settled sewerage is between a third and a half of conventional sewerage. Originally developed in South Australia to overcome problems with failing septic tanks, it has been used quite widely worldwide to upgrade septic tank systems.

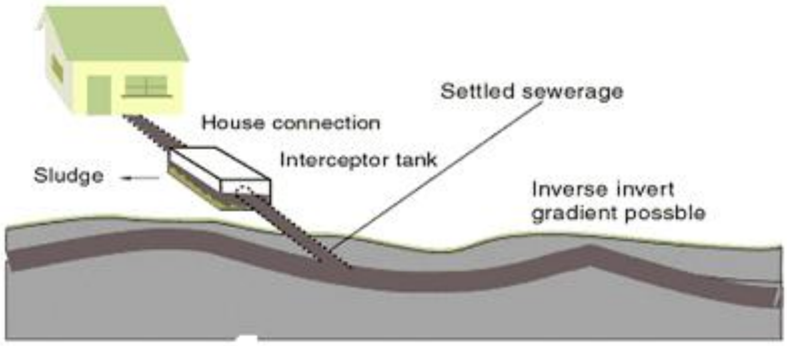


Fig. 1.3: Pipe Layout for Settled Sewerage

Source: UNEP.www.unep.or.jp/ietc/publications/freshwater/sb_ summary/index.aspx

Where there is no existing septic tank, an interceptor box or tank can be used. It functions like a septic tank and designed in the same way (Figure1.3). To reduce cost, the waste-water from a group of houses can be connected to one interceptor tank. Just like in a septic tank, the accumulation of sludge has to be removed regularly from an interceptor tank.

3.2.3 Storm Water Collection

Storm water flows through the landscape's natural drainage system. Piped storm water collection was a development in European cities to overcome odour and improve aesthetic appearance of waste-water disposed with storm water. The covering of ditches used for combined sewerage was an intermediate step in using natural drainage to construct sewerage for combined waste-water and storm water. Piped sewerage also allows more land area for road and footpaths. With the separate collection of waste-water there is an opportunity to return some storm water flow path to its more natural state to improve urban amenity value.

4.0 CONCLUSION

You have learnt that sewage is a collective name for waste-water of the community which is composed of human waste (faeces and urine), kitchen waste-water, laundry, storm water, etc. These components are not friendly to man or his environment, hence are always seen as such. It is because of this that he handles them with caution in a network of pipes (sewers) which is collectively called sewerage system. Sewerage systems are of various types as have seen.

5.0 SUMMARY

In this unit you have learnt the following:

- The definitions and concepts of sewage and sewerage systems. You were made to understand that while sewage is the content which is more or less in liquid form, sewerage is the network of pipes containing the sewage.
- The different types of sewerage systems which include; conventional, simplified and settled sewerage systems. Each of them has some conditions in which it works better.

6.0 TUTOR-MARKED ASSIGNMENT

1. (a) Explain the concepts of sewage and sewerage.
   (b) Explain the characterisation of sewage.
2. List the types of sewerage system you have learnt about and explain any one of them.

7.0 REFERENCES/FURTHER READING

Sridhar, M.K.C. (2007). 'Sewage Treatment.' Lecture Notes Delivered During the 2007 Mandatory Continuous Education Programme (MCEP) for Environmental Health Officers' Registration Council of Nigerians, at Filbon Guest House, New Haven Enugu.

Typical Domestic Drainage System Layout Plans– DRAINDOMAIN.COM. Draindomain.com/systemlayout.html. Accessed 24/0802012.

Waste-water and Storm-water Collection. in Environmentally Sound Technologies in Waste-water Treatment for the Implementation of UNEP Global Programme of Action,(GPA). "Guidance on Municipal Waste-water". Publisher-UNEP, in Collaboration with Murdoch University Environmental Technology Centre.

West Africa Health Examination Board. (WAHEB). (1991). *Waste Disposal and Environment Hazard Control* .Ibadan: Sterling Publishing Ltd.

West Africa Health Examination Board (WAHEB). (1991). *Water and Building Sanitation. Ibadan*: Sterling Publishing.

Wilkie, W. (1965). *Jordan's Tropical Hygiene and Sanitation*. United Kingdom: Bullsie Tundal and Co.

www.uneb.or.jp/ietc/publications/freshwater/sb_summary. index.aspx . Accessed 14/09/2012.

UNIT 2 TYPES AND SOURCES OF WASTE-WATER

CONTENTS

1.0 INTRODUCTION

In unit one, you were introduced to the meaning and concepts of sewage and sewerage system. You learnt that sewage is waste produced by toilets, bathing, laundry or culinary operations or the floor drains associated with these sources and includes household cleaners, medications and other constituents in sewage restricted to amount normally used for domestic purposes. In this unit, you will learn about the types and sources of waste-water. I urge you to remain focused and read with joy as you go down the lines.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- enumerate and discuss the types of waste-water
- explain in detail the sources of waste-water.

3.0 MAIN CONTENT

3.1 Types of Waste-water

There are several types or categories of sewage that have been nationally defined by the Consortium of Institutes for Decentralised Waste-water Treatment (CIDWT, 2009):

1. Black-water: Portion of the waste-water stream that originates from toilet fixtures, dishwashers and food preparation sinks.

2. Gray water: water captured from non-food preparation sinks, showers, baths, baths, clothes washing machines, and laundry tubs. Gray water is defined in MN Rules Chapter 7080.1100, Subp 37 as; ‘sewage that does not contain toilet wastes’. A Gray water system is one that receives, treats, and disperses only gray water or other similar system as designated by the commissioner (MN Rules Chapter 7080.1100, Subp. 38). Toilet wastes from the residence or other establishment have to be treated in some other system, or the residence has to have a privy.

   To prevent hooking up a flush toilet onto a gray water system, the plumbing of the system must have two-inch diameter pipe, rather than four-inch. Even the floor drains have to use two-inch pipe. The exception is for a gray water system being installed for an existing building. There is no need to re-plumb the entire structure. Gray water systems cannot accept garbage disposal waste.

3. Yellow water: an isolated waste stream consisting of urine collected from specific fixtures and not contaminated by faeces or diluted by gray water sources; see also urine separating device.

3.1.1 System Size and Factors influencing it

The amount and type of water discharged to an onsite sewage treatment system is one of the factors used in sizing that system. Other factors that influence sizing include soil properties such as texture, structure, and percolation rate.

Designing a waste-water treatment system based upon average daily flow would imply that the system is operating beyond its design capacity 50 percent of the time. For this reason, treatment systems are typically designed to produce the required effluent quality when treating the maximum daily flow. This accounts for the natural variability in the amount and strength of waste-water entering any system.

The amount of waste-water entering the treatment system is the hydraulic loading rate. In sizing for the hydraulic loading rate, the volume of water flowing through the treatment process is the design parameter under consideration. For the concept of mass loading rate, the idea of the mass or weight of a particular contaminant flowing through the system over some time is considered. The “organic loading rate,” the number of pounds or kilograms of BOD per day, and the “solids loading rate,” the number of pounds or kilograms of TSS per day, are common mass loading rates.

Water use varies widely among individuals, depending on such factors as background, age and economic status. For example, an individual who was raised in a household without running water will probably be very conservative in water use even when running water is available. Teenagers are typically high water users. The use of hot tubs or water-circulating devices for therapeutic services greatly increases water use.
A number of studies have been done throughout the country on water use habits and rates. In studies done during the 1970s, average water use per person, nationwide, was about 45 gallons per day. A 1999 study found a national water-use rate of about 60 gallons per person per day with a variation of plus or minus 40 gallons per day (Mayer, et. al., 1999). Domestic sewage is generated by a dwelling, a toilet facility at an establishment open to the public, rental units such as motels and resort cabins, shower and toilet facilities for schools or campgrounds, or anywhere typical domestic waste-water is created.

3.2 Sources of Waste-water

3.2.1 Sewage Sources

From unit 1, the introduction of this unit and the types of waste-water listed above, you are already through with the sewage sources of waste-water. In other words, sewage could be got from domestic sewage, industrial or trade sewage and storm water (Feacham, Mcgarry and Mara, 1978; Oluwande, 1983). For this course however, industrial waste will be considered under non-sewage sources.

(a) Domestic sewage: This is a mixture of:
    (i) Human excreta (faeces and urine, often termed night-soil, when collected separately.
    (ii) Sullage - which is the waste-water from bathrooms; wash-hand basins, kitchen sink, laundry.
(b) Industrial or Trade Sewage: industrial waste-water is the water or liquid-carried waste from an industrial process resulting from industry, manufacture, trade, automotive repair, vehicle wash, business or medical, activity that may contain toxic or hazardous constituents.

Garage floor drain liquid wastes from garages serving single and multi-family homes can consist of the following:

- precipitation draining from vehicles and liquids from vehicle washing
- spills from materials stored or used in the garage such as: Thinners, solvents, paints, pesticides, cleaners, etc.
- liquids from vehicle repair such as: gasoline, used oil, antifreeze, and others.

Therefore, there is a potential for hazardous waste and other damaging waste entering the floor drain system.

(c) Storm Wastes: This is the waste-water that arises as result of surface run-off from rain. This is of particular interest in the tropics because during the wet season, the quantity of surface run-off becomes a considerable part of sewage.

3.2.2 Non-Sewage Sources

Clear water additions

Clear water (including groundwater, rainwater, surface water, condensate, ice machine drainage, and/or discharge from pools, hot tubs, and water treatment devices) fits into this category. Sources of clear water should not be directed to the system; if connected, they can create problems in the system. A number of water-using devices (such as water softeners, iron filters and water treatment devices) do not produce sewage as defined in MN Rules Chapter 7080. These devices do produce effluent, but that effluent has not come in contact with humans or laundry to create contamination that needs to be treated or removed. Water treatment discharge is defined by CIDWT as the by-product from a water treatment device, such as regeneration water from an ion-exchange unit; reject water from a reverse-osmosis unit, or the backwash from an iron filter.

Water softeners reduce the number of or remove calcium and magnesium ions, which are the principal causes of hardness in water. Cation exchange resin method is most commonly used for residential and commercial water treatment. Water softener and iron filter recharge water adds a large volume of water to the system – typically 30 to 80 gallons per cycle. This is water that does not require treating.

A growing concern with water softener recharge water is that it may cause an increase in the amount of solid material that remains suspended in the liquid layer (effluent) in the septic tank and ends up in the drain field trenches or a mound. These solids may shorten the life of the soil treatment system, increasing the chance of drain-field or mound failure. Water softener discharge has conflicting results in research studies, but it does appear that scum layers are often absent in tanks where the water softener recharge water enters the septic tank.

Iron filters are similar to water softeners in that the effluent is not sewage, but the discharge does have different characteristics. The two choices for iron removal are ion exchange (water softener) and oxidation filtration. Water softener is applied to water where the iron concretions are in the 2-5 ppm range. If the iron concentrations are higher (> 5 ppm) or the natural pH is high (> 8) then applying an oxidation filtration system may be more effective. These systems physically filter the iron and then are back-flushed, removing the iron as a solid. These systems will need to be discharged into a settling component before being discharged to the soil to remove the solids that would plug the soil surface.

Reverse osmosis is a separation process that uses pressure to force water through a membrane that retains the solute on one side and allows the pure solvent to pass to the other side. More specifically, it is the process of forcing a liquid from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. This is the reverse of the normal osmosis process, which is the natural movement of solvent from an area of low solute concentration, through a membrane, to an area of high solute concentration when no external pressure is applied. The membrane here is semi-permeable, meaning it allows the passage of liquid but not of solute or particles.

The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases, the membrane is designed to allow only water to pass through this dense layer while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–70 bar (600–1000 psi) for seawater, which has around 24 bar (350 psi) natural osmotic pressure which must be overcome.

Reverse osmosis units sold for residential purposes offer water filtration at the cost of large quantities of waste water. For every five gallons of output, a typical residential reverse osmosis filter will send around ten to 20 gallons of water down the drain (although many people capture it and use it for watering plants and lawns). In some states this water is used for irrigation.

High-efficiency furnaces operate at a high efficiency and therefore save on energy use. One of the results of the heating process is that condensation occurs in the unit. When this condensation builds up, water slowly trickles out of the unit and into the plumbing that is often connected to an onsite system. The water can cause freezing problems in the onsite system because of the slow, steady flow. In addition, this water is clean and therefore does not need to be treated. When the furnace is in operation, this water typically trickles out of the unit at a volume of five to ten gallons on a cold day. In high-efficiency furnaces, the recharge water from water softeners and iron filters has the potential to cause problems with onsite sewage treatment systems.

3.2.3 Other Establishments

Domestic sewage is also generated by other establishments. An "other establishment" is any public or private structure, other than a dwelling, that generates sewage and discharges it into a public drain system or sewage. Other establishments may have large flows and/or high-strength waste.

Non-domestic waste is generated by many sources, such as restaurants, laundromats, barber shops, car washes and other light industrial establishments. Waste other than sewage is only allowed to be discharged into the sewage system if the waste is suitable to be discharged to groundwater. If waste strength parameters exceed the values identified in MN Rules Chapter 7081.0130, Subp. 2, the system should include pretreatment.

A range of systems can be designed for other establishments.

a. Type I: if domestic levels of waste-water can be achieved with septic tanks alone the system is classified as at Type I system.
b. Type II or III: if site or soil conditions are limiting.
c. Type IV: if the system uses a registered product (Treatment Level C) to reduce waste strength the system is considered to be a Type IV system.
d. Type V: if the system uses a non-registered product to reduce the waste strength the system is consider to be a Type V system.

Some "other establishments" include the following:

Apartment buildings
Rental situations have been known to have overuse of the system. The renter may not understand the impacts of their usage habits on the system and may have little concern about over using water. Multiple families can also impact the loading to the system. Low-flow fixtures and appliances along with education can assist in the management of the system.

Day cares
Day cares are always going to have higher flows associated with their use. The other concern here will the cleaners that are used and the type of food that is available. In-home day cares will have higher flows than are typical for the number of bedrooms in the house due to the amount of people that are in the home and the amount of time they are there. The kitchen or waste strength will be similar to a normal home. The use of cleaners must be watched in these systems. Excessive cleaning, which is common in day cares, can lead to the killing of the bacteria and lower efficiency in the treatment tanks.

Commercial kitchen

A commercial kitchen is a food preparation center that prepares multiple meals or food products and typically generates high-strength waste-water. The food service waste-water from these facilities is non-toxic, non-hazardous waste-water and is similar in composition to domestic waste-water, but which may occasionally have one or more of its constituents exceed typical domestic ranges. It includes all the sewage wastes from commercial food preparation, food processing or food production sources.

Restaurants and bars almost always have high-strength waste that makes sewage treatment difficult. For this reason, a number of best management practices can be taken to facilitate treatment:

- limit food particles and alcohol going down the drain
- limit the use of chemicals going down the drain: chemicals can kill the treatment system's good bacteria
- limit use of degreasers, even in cleaning supplies
- a grease interceptor, a watertight device designed to intercept, congeal and retain or remove fats, oils, and grease (FOGs) from food-service waste-waters; may be located inside (grease separator) or outside (grease tank or grease trap) of a facility that generates commercial food service waste-water
- isolate kitchen waste from other sewage production
- design tanks for a minimum of four to seven times the daily flow
- be aware that high water temperatures (140°F) do not allow grease to solidify, adding to treatment concerns
- more tanks in series can help cool effluent
- be aware that septic tanks alone usually will not get the job done.

4.0 CONCLUSION

From our discussions above, we can conclude that waste-water is a collection of sewage and non sewage liquid matter which originates from homes (from human and domestic activities), industries, and storm water etc. These are not friendly to human being because they are rejected and until when treated for reuse and or disposed off, man will not rest. Knowing their components or types and sources will help in handling them properly to avoid harming man or his environment.

5.0 SUMMARY

In this unit, we learnt the following:

The types of waste-water according to the Consortium of Institute for Decentralised Waste-water Treatment (CIDWT, 2009) include black-water, gray-water and yellow-water.

The system, sizes and factors influencing it were learnt and they included: amount and type of water discharged to an onsite treatment system, soil properties like texture and structure and percolation rate. Sewage waste source was discussed and they come from domestic activities like washing, kitchen sink, bathing, faeces and urine etc.

Non-sewage source was equally discussed and these include clear water addition, water softeners, reverse osmosis, and industrial waste etc.

6.0 TUTOR-MARKED ASSIGNMENT

1. a. List the types of waste-water known to you.
   b. Explain in detail any one of them.
2. Discuss the following in details:
   a. Sewage source of waste-water.
   b. Non-sewage source of waste-water.

7.0 REFERENCES/FURTHER READING

Consortium Institute for Decentralised Waste-water Treatment (CIDWT). (2009). 'Decentralised Waste-water Glossary'. Available online at http://www.onsiteconsortium.org/files/Glossary. pdf (verified 4/29/2009).

Feacham, R, Mcgarry, M. & Duncan, M. (1978). *Waste-water and Health in Hot Climates*.

Mayer, P.W. DeOreo, W.B. *et al.* (1999). *Residential End Uses of Water*. American Water Works Association.

Oluwande, P.A. (1983). *A Guide to Tropical Environmental Health and Engineering.* Ibadan: NISER.

Sridher, M.K. C. (2007). 'Sewage Treatment'. Lecture Notes Delivered During the 2007 Mandatory Continuous Education Programme (MCEP) for Environmental Health Officers' Registration Council of Nigerians, at Filbon Guest House, New Haven,Enugu.

Waheb (1991). *Water and Building Sanitation.* Ibadan: Sterling Publishers Ltd.

Wikipedia, the Free Encyclopedia – "Sewage Treatment".

UNIT 3 CHARACTERISTICS AND FLOW RATES OF WASTE-WATER

CONTENTS

1.0 INTRODUCTION

The effective management of any waste-water flow requires a reasonably accurate knowledge of its characteristics. This is particularly true for waste-water flows from rural residential dwellings, commercial establishments and other facilities where individual water-using activities create an intermittent flow of waste-water that can vary widely in volume and degree of pollution. Detailed characterisation data regarding these flows are necessary not only to facilitate the effective design of waste-water treatment and disposal systems, but also to enable the development and application of water conservation and waste load reduction strategies.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the different perspectives of viewing waste-water characteristics
- list the factors influencing the characteristics of waste-water flow
- interpret the tables, figures and graphs shown in the text.
- discuss the discrete characteristics of waste-water flows
- discuss waste-water flow rate, the need to measure waste water flow and estimating waste-water flow rates from water supply data.

3.0 MAIN CONTENT

3.1 Characteristics of Waste-water in Terms of Content

A number of chemical and physical characteristics are used to describe waste-water. The most common are:

Biochemical Oxygen Demand (BOD) is a measure of the amount of unstable organic matter in the water. It measures how much oxygen is required by the available micro organisms to break down the readily available organic matter into simpler forms, such as carbon dioxide, ammonia and water.

Total Nitrogen (TN) and **Total Phosphorus (TP)** are the sum of all forms of nitrogen and phosphorus in the water, respectively. Both nitrogen and phosphorus are nutrients essential for plant growth. A shortage of either one, or both, may limit the rate of plant growth in a water body. If the supply of the limiting nutrient is increased (and other circumstances such as appropriate amount of sunlight and appropriate temperature are favourable) blooms of algae or waterweeds may occur.
Faecal Microbes (which includes viruses, bacteria and protozoans) are found in waste-water and may cause disease. Faecal coliforms and faecal streptococci are bacteria that are found in the digestive tracts of humans and animals, including birds. Their presence in a water body indicates faecal contamination.

The average characteristics of raw waste-water are:

- Biochemical oxygen demand 250-300 mg/L
- Total nitrogen 50-60 mg/L

- Total phosphorus 10-15 mg/L
- Faecal coliforms 10,000,000 cfu/100 mL

mg/L = milligrams per litre
cfu/100 mL = colony forming units per 100 millilitre
(*Source - Bulletin No3 Waste-water Treatment - Water Corporation*).

3.1.1 Components of Waste-water

Effluent quality is the physical, biological, and chemical characteristics of a liquid flowing from a component or device. The components of waste-water may be divided into four categories:

- biochemical oxygen demand, total suspended solids and fats, oils and grease (BOD5 , TSS, FOG)
- pathogens (fecal coliform, viruses)
- nutrients (nitrogen, phosphorus), and
- other chemicals.

Table 3.1 shows typical concentrations of these components in raw waste, septic tank effluent, and soil.

Table 3. 1: Unsaturated Flow during Soil Treatment of Septic Tank Effluent

Parameter	Raw waste	Septic tank effluent.	One foot below trench bottom.	Three feet below trench bottom.
BOD5 (mg/L)	270-400	140-220	B	B
TSS (mg/L)	300-400	45-65	B	B
Fecal coliform (MPN/100ml)	1,000,000-100,000,000	100,000-1,000,000,000	B-100	B
Viruses (PFU/ml)	unknown	1,000-1,000,000,000	B-1,000	B
Nitrogen (mg/L)				
Total	100-150	50-60	-	-
NH4+	60-120	30-60	*B-60	*B
NO3-	<1	<1	*B-40	*B-40
Total phosphorus (mg/L)	10-40	7-15	*B-10	*B-1

* B = background,

(Magdorf et. al., 1974 and Metcalf and Eddy, 1991).

Biochemical Oxygen Demands (BOD5) - Biochemical oxygen demand (BOD5) is the most widely used parameter applied to waste-water.

BOD5 is a measure of the dissolved oxygen required by micro-organisms to oxidize or decompose the organic matter in waste-water. A typical BOD5 value for septic tank effluent is 150 milligrams per liter. For a Type I system, the BOD5 limit is 170 milligrams per liter.

When the dissolved oxygen (DO) contained in septic tank effluent is measured, it is usually very low, typically one milligram per liter. While DO in water can be as high as 12 milligrams per liter, the micro-organisms in the septic tank normally use up any available oxygen to break down organic matter.

Types of BOD

There are slight difference between ordinary BOD and BOD5 as can be seen below:

Biochemical Oxygen Demand

BOD or Biochemical Oxygen Demand is the quantity of dissolved oxygen consumed by micro-organisms during the microbial and chemical oxidation of the constituents contained in a waste-water sample during an incubation period at a given temperature. The biochemical oxygen demand represents the oxygen utilized during the oxidation of both carbon and nitrogenous compounds.

Biochemical Oxygen Demand (BOD5)

BOD5 or Biochemical Oxygen Demand 5-day is the quantity of dissolved oxygen consumed by micro-organisms during the breakdown of organic matter in a waste-water sample during a 5-day incubation period and measured in mg/L at 20oC. It is used as a means to describe the amount of organic matter present in the water.

Biodegradable organic matter is provided in terms of pounds of BOD5 per person (capita) per day by using the BOD5 concentration and daily flow. Biochemical oxygen demand is a measure of the oxygen required by bacteria, chemicals, and other organisms to break down organic matter over a five day period. It is an indicator of the overall strength of the waste-water. Most designs assume that all residential sources generate a concentration of 300 mg/L of BOD5, and after pretreatment in a properly sized septic tank the BOD5 is reduced to approximately 170 mg/L However, these concentrations can vary from site to site.

Carbonaceous Biochemical Oxygen Demand (CBOD)

CBOD or Carbonaceous Biochemical Oxygen Demand is the quantity of dissolved oxygen consumed by micro-organisms during the breakdown of organic carbon in a waste-water sample during an incubation period of 5 days at 20°C. An inhibitor is placed in the sample to prevent growth of nitrogenous oxidizing microbial populations. It is used as a means to describe the amount of organic carbon present in the water that can be broken down with microbial processes.

Nitrogenous Biochemical Oxygen Demand (NBOD)

NBOD or Nitrogenous Biochemical Oxygen Demand is the quantity of dissolved oxygen consumed by micro-organisms during the oxidation of nitrogenous compounds such as protein and ammonium in a waste-water sample during an incubation period of 5 days at 20°C. It is used as a means to describe the amount of organic nitrogen (such as urea, proteins, etc.) present in the water. It is not usually used in typical waste-water analysis.

Ultimate Biochemical Oxygen Demand (UBOD)

Ultimate Biochemical Oxygen Demand is the measure of the oxygen required to complete the breakdown of the organic matter. The UBOD consists of summing the oxygen demand required to oxidize the organic matter in the waste-water, synthesize the organic matter into new cell tissue, and the endogenous respiration where cell tissue is consumed by other microbes to obtain energy for cell maintenance. The UBOD is not typically a value measured in lab analysis.

Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is a measure of the amount of organic matter oxidized by a strong chemical oxidant. COD is used to measure organic matter in commercial, industrial, and municipal wastes that contain compounds toxic to biological life where the BOD5 test would not work. The COD levels in a waste-water sample are almost always greater than BOD5 levels because more compounds can be chemically oxidized in the COD test than can be biologically oxidized in the BOD test. In most cases, once the COD/BOD5 relationship is known for a particular facility, the COD concentration of a sample can be used to approximate the BOD5 concentration. The COD test can generally be done within 2.5 hours, whereas a BOD5 test takes five days. A COD test is performed when a quick determination of oxygen demand is needed.

Dissolved Oxygen

Dissolved Oxygen (DO) is the amount of oxygen dissolved in water. It is influenced mainly by temperature, barometric pressure (altitude), and water salinity. As temperature decreases, the amount of dissolved oxygen that can be accepted by water increases until it becomes saturated.

The three oxygen states are aerobic, anaerobic, and anoxic conditions. The term aerobic is defined as having molecular oxygen (free oxygen, O_2) as a part of the environment or a biological process that occurs only in the presence of molecular oxygen. An anaerobic condition is the absence of molecular oxygen as a part of the environment or a biological process that occurs in the absence of molecular oxygen but can utilize oxygen bound in other molecules, such as nitrate (NO_3^-). Anoxic is the condition in which all waste-water and/or effluent constituents are in their reduced form, meaning there are no oxidants present.

The micro-organisms (bugs) that are used for biological treatment can be categorized by the state of oxidation in which they operate. These categories of micro-organisms include:

- Aerobes – thrive in aerobic conditions
- Anaerobes – thrive in anaerobic conditions
- Facultative – thrive in both aerobic and anaerobic conditions

Free oxygen (O_2) is needed for aerobic treatment to take place, and aerobic bacteria need oxygen to grow and live. Aerobic organisms respire dissolved oxygen contained in the water. Anaerobic bacteria grow and live in the absence of free oxygen. Facultative organisms have the ability to respire free oxygen when it is available and shut down the respiration process when dissolved oxygen is lacking. The table below gives the desired ranges of DO in waste-water.

Anaerobic bacteria are significantly slower at oxidation and smaller in size than aerobic bacteria, but they are much more resilient to environmental changes. Aerobic micro-organisms are more sensitive to waste-water parameters (such as DO, pH and temperature), but in optimal conditions, they digest organic matter and pathogens more rapidly than do anaerobic organisms.

Table 3.2: Ideal Dissolved Oxygen Range in Waste-water

Microbe	Anaerobe	Facultative	Aerobe
Low DO (mg/L)	0	0	0.5
High DO (mg/L)	0.5	5	5
Typical (mg/L)	0-0.3	0-1	1-3

Source: (Magdorf et. al., 1974 and Metcalf and Eddy, 1991).

The septic tank is typically considered an anaerobic treatment component, although there can be aerobic zones. For the most part, septic tank microbes assimilate the waste constituents in the absence of a respiration process and are commonly referred to as anaerobic microbes. Facultative microbes utilise free oxygen or assimilate waste without respiration. During assimilation of waste, the bonds holding the oxygen are broken.

Total Suspended Solids (TSS)

Total Suspended Solids (TSS), is a measure of the solids that remain in the waste-water after settling has occurred in the tank. A typical TSS value is 60 milligrams per liter. BOD and total suspended solids together measure the strength of the waste-water. They can serve as an indicator of system performance.

Total suspended solids or TSS is the most common measure of the amount of solids in waste-water effluent. TSS is the measure of all suspended solids in a liquid, typically expressed in mg/L. It is measured by filtering a well-mixed sample through a standard glass fiber filter and drying the residue retained on the filter at 217 to 221 degrees F (103 to 105 degrees C). The increase in the weight of the filter represents the amount of total suspended solids.

Other terms and measurements of solids in waste-water treatment systems are:

- Solids, settleable: suspended solids that will settle out of suspension within a specified period of time, expressed in milliliters per liter (mL/L)
- Solids, total (TS): mineral, cells, etc. left in waste-water after evaporation of the water fraction at 103 degrees C, typically expressed in mg/L
- Solids, total dissolved (TDS): material that passes a standard glass fiber filter, and remains after evaporation at 103 degrees C, typically expressed in mg/L
- Solids, volatile: weight loss on ignition of total, solids, not distinguishing between inorganic and organic matter and including loss due to decomposition or volatilisation of some mineral salts at 550 degrees C

TSS and BOD_5 are typically the two parameters used to measure waste-water strength and treatment performance relating to organic/inorganic matter. TSS (as stated earlier) is measured by performing a solids analysis but can also be estimated by a turbidity test.

Turbidity is the physical clarity of the water and is an indicator of the presence of suspended matter in waste-water. A “quick and dirty” TSS test can be determined with an Imhoff Cone. A visual test will determine if TSS levels are high or low when a sample of waste-water is placed in a cone against a light background.

Fats, Oils and Grease (FOG)

FOG (fats, oils, and grease) is a constituent of sewage typically originating from food stuffs (animal fats or vegetable oils) or consisting of compounds of alcohol or glycerol with fatty acids (soaps and lotions), typically measured in mg/L.

Sources of FOG: Fat found in on-site waste-water treatment systems is animal fat, oil is from vegetable and cooking oils, and grease is from petroleum based soaps. FOGs are generally treated in on-site waste-water treatment systems by separating them from the waste-water stream. At high temperatures FOG are in a liquid state, but as the temperature cools, the fats component will solidify. FOG can be trapped in pretreatment components, such as septic tanks and grease traps, where they typically float to the top of tanks. They are less dense and lighter than water. It is important to try to contain FOG early in the system, because they can accumulate inside pipes and lead to clogging of downstream components. FOG also contributes to BOD and TSS concentrations. FOG in excessive amounts interfere with aerobic biological processes and lead to decreased treatment efficiency. The expected levels of FOG concentration must be considered during waste-water treatment design.

FOG in domestic waste-water will generally originate in the kitchen or bathroom. Kitchen FOG usually comes from disposing animal- or vegetable-based food scraps and liquids down the sink. Households using garbage disposals will have 30-40 percent more FOG than households not using garbage disposals. Bath oils, sun tan lotions, hair conditioners, and moisturizing creams are bathroom sources of FOG that enter the waste-water stream. An increased use in cooking oils, lotions, and hair conditioners will directly increase the FOG concentration in the waste-water. Low FOG, although it is not considered a problem, could be the result of not using the kitchen or of higher than normal flows entering the system. Low FOG can also be attributed to the use of bar soap instead of liquid soaps.

The waste strength of sewage and effluent as it passes through a treatment system can indicate the performance of a septic system. Understanding how these components enter the waste stream and are removed through the treatment process is critical for system designers and service providers.

3.2 Characteristics of Waste-water in Terms of Flow Rates (Residential Waste Water Characteristics)

3.2.1 Factors Influencing the Characteristics of Waste-water Flow

The characteristics of the waste-water can be influenced by several factors. Primary influences are the characteristics of the plumbing fixtures and appliances present as well as their frequency of use. Additionally, the characteristics of the resident family in terms of number of family members, age levels and mobility are important as is the overall socioeconomic status of the family. The characteristics of the dwelling itself, including seasonal or yearly occupancy, geographic location, and method of water supply and waste-water disposal, appear as additional, but lesser, influences.

3.2.2 The Discrete Characteristic of Residential Waste-water

3.2.2.1 Waste-water Flow

3.2.2.1.1 Average Daily Flow

The average daily waste-water flow from a typical residential dwelling is approximately 45 gallons/capita/day (gpcd; or 170 liters/capita/day, lpcd). While the average daily flow experienced at one residence compared to that of another can vary considerably, it is typically no greater than 60 gpcd (227 lpcd) and seldom exceeds 75gpcd (284 lpcd).

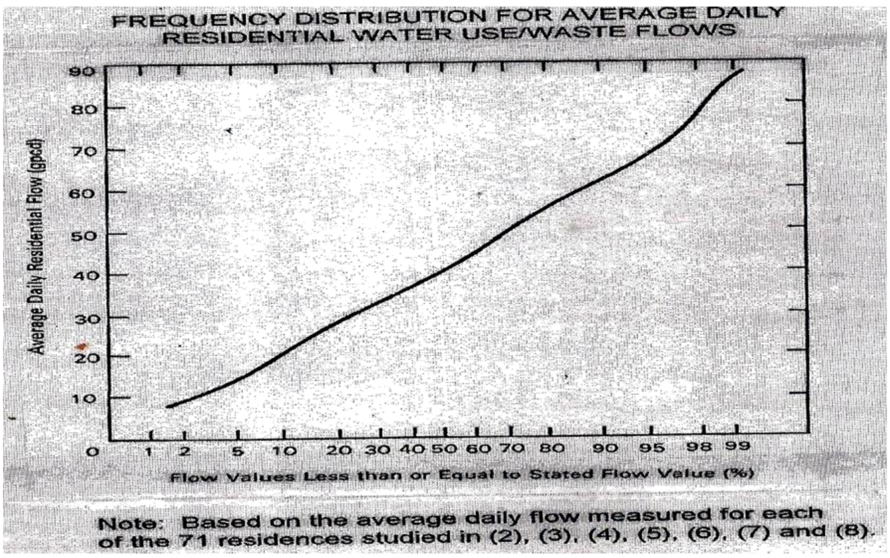


Fig. 3.1: Frequency Distribution for Average Daily Flows
Source: www.frbb.utn.edu.ar/.../Caracterisacion-aquas-residuales-Cap4-EPA

3.2.2.1.2 Individual Activity Flows

The individual waste-water generating activities within a residence are the building blocks that serve to produce the total residential waste-water discharge. The average characteristics of several major residential water-using activities are presented in Table 3.3. a water-using activity that falls under the category of "Miscellaneous " in this table, but deserves additional comment, is water softener backwash/regeneration flows. Water softener regeneration typically occurs once or twice a week, discharging about 30-88 gal (114-333 I) per regeneration cycle (11). On a daily per capital basis, water softener flows have been shown to average about 5 gpcd (19 ipcd), ranging from 2.3 to 15.7 gpcd (8.7-59.4 Ipcd) (7).

Table 3.3: Residential Water Use by Activity

Activity	Gallons/Use	Uses/Capita/Da	gpcdb
Flushing Toilet	4.3	3.5	16.2
	4.0-5.0	2.3-4.1	9.2-20.0
Bathing	24.5	0.43	9.2
	21.4-27.2	0.32-0.50	6.3-12.5
Washing Clothes	37.4	0.29	10.0
	33.5-40.0	0.25-0.31	7.4-11.6
Washing Dishes	8.8	0.35	3.2
	7.0-12.5	0.15-0.50	1.1-4.9
Grinding Garbage	2.0	0.58	1.2
	2.0-2.1	0.4-0.75	0.8-1.5
Miscellaneous	--	--	6.6
		Total	45.6
			41.4-52.0

(a) Mean and ranges of results reported in (4), (5), (6), (7) and (10).
(b) gpcd may not equal gal/use x uses/capita/day due to difference in the number of study averages used to compute the mean and ranges shown.

Source: www.frbb.utn.edu.ar/.../Characterization-aquas-residuales-Cap4-EPA

3.2.2.1.3 Waste-water Flow Variations

The intermittent occurrence of individual waste-water-generating activities creates large variations in the waste-water flow rate from a residence.

a. Minimum and Maximum Daily Flows

This is the daily waste-water flow from a specific residential dwelling in typically within 10 and 300% of the average daily flow at that dwelling, with the vast majority within 50 and 150% of the average day. At the extreme, however, minimum and maximum daily flows of 0% and 900% of the average daily flow may be encountered (2), (3), (12).

b. Minimum and Maximum Hourly Flows

Minimum hourly flows are typical. Maximum hourly flows are more difficult to quantify accurately. Based on typical fixture and appliance usage characteristics, as well as an analysis of residential water usage demands, maximum hourly flows of 100 gal/hr (380 i/hr) can occur (2), (13). Hourly flows in excess of this can occur due to plumbing fixture and appliance misuse or malfunction (e.g, faucet left on or worn toilet tank flapper).

c. Instantaneous Peak Flow

The peak flow rate from a residential dwelling is a function of the characteristics of the fixtures and appliances present and their position in the overall plumbing system layout. The peak discharge rate from a given fixture/appliances simultaneously can flow of up to 25 gpm (1.6 I/sec). The use of several fixtures/appliances simultaneously can increase the total flow rate from the isolated fixture/appliances. However, attenuation occurring in the residential drainage network tends to decrease the peak flow rates in the sewer exiting the residence.

Although field data are limited, peak discharge rates from a single-family dwelling of 5-10 gpm (0.3-0.6 I/sec) can be expected. For multi-family units, peak rates in excess of these values commonly occur. A crude estimate of the peak flow in these cases can be obtained using the fixture-unit method. This method was based on the premise that a given type of fixture had an average flow rate and duration of use under normal usage. One fixture unit was arbitrarily set equal to a flow rate of 7.5 gpm (0.5l/sec), and various fixtures were assigned a certain number of fixture units based upon their particular characteristics. Based on probability studies, relationships were developed between peak water use and the total number of fixture units present.

3.2.2.2 Waste-water Quality

Below are the discrete components of the waste-water quality. Try to reproduce them at the end of your reading them.

3.2.2.2.1 Average Daily Flow

The characteristics of typical residential waste-water are outlined in Table 3.4, including daily mass loadings and pollutant concentration. The waste-water characterized is typical of residential dwellings equipped with standard water-using fixtures and appliances (excluding garbage disposals) that collectively generate approximately 45 gpcd (170Ipcd).

Table 3.4: Characteristics of Typical Waste-water

Parameter	Mass Loading(gm/capita/day)	Concentration(mg/l)
Total Solids	115-170	680-1000
Volatile Solids	65-85	380-500
Suspended Solids	35-50	200-290
Volatile Suspended Solids	25-40	150-240
BOD_5	35-50	200-290
Chemical Oxygen Demand	115-125	680-730
Total Nitrogen	6-17	35-100
Ammonia	1-3	6-18
Nitrites and Nitrates	<1	<1
Total Phosphorous	3-5	18-29
Phosphate	1-4	6-24
Total Coliforms	- -	10^{10}-10^{12}
Fecal coliforms		10^{8-}-10^{10}

a. For typical residential dwellings equipped with standard water-using fixtures and appliances (excluding garbage disposals) generating approximately 45 gpcd (170lpcd). Based on the results presented in (5), (6), (7), (10), and (13).

b. Concentrations presented in organisms per liter.

Source: www.frbb.utn.edu.ar/.../Caracterizacion-aquas-residuales-Cap4-EPA

3.2.2.2.2 Individual Activity Contributions

Residential water-using activities contribute varying amounts of pollutants to the total waste-water flow. Individual activities may be grouped in to three major waste-water fractions: 1) garbage disposal waste, 2) toilet waste, and 3) sink, basin and appliance waste-waters. A summary of the average contribution of several key pollutants in each of these three fractions is presented in tables 5 and 6.

With regard to the microbiological characteristics of the individual waste fractions, studies have demonstrated that the waste-water from sinks, basins, and appliances can contain significant concentrations of indicator organisms as total and fecal coliforms 914), (15), (16), (17). Traditionally, high concentrations of these organisms have been used to assess the contamination of a water or waste-water by pathogenic organisms. One assumes, therefore, that these waste-waters possess some potential for harboring pathogens.

Table 3.5: Pollutant Contributions of Major Residential Waste-Water Fractions (Gm/Capita/Day)

Parameter	Garbage Disposal	Toilet	Basin/Sinks/Appliances	Approximate Total
BOD_5	18.0	16.7	28.5	63.2
	10.9-30.9	6.9-23.6	24.5-38.8	
Suspended	26.5	27.0	17.2	70.7
Solids	15.8-43.6	12.5-36.5	10.8-22.8	
Nitrogen	0.6	8.7	1.9	11.2
	0.2-0.9	4.1-16.8	1.1-2.0	
Phosphorous	0.1	1.2	2.8	4.0
	0.1-0.1	0.6-1.6	2.2-3.4	

Mean and ranges of results reported in (5), (6), (7), (10), and (14).

Source: www.frbb.utn.edu.ar/.../Caracterizacion-aquas-residuales-Cap4-EPA

Table 3.6: Pollutant Contributions of Major Residential Waste-Water Fractions (Mg/L)

Parameter	Garbage Disposal	Toilet	Basin/Sinks/Appliances	CombinedWaste-water
BOD_5	2380	280	260	360
Suspended solids	3500	450	160	400
Nitrogen	79	140	17	63
Phosphorous	13	20	26	23

Based on the average results presented in 5 and the following waste-water flows: garbage disposal, 2gpcd (8lpcd); toilet, 16 gpcd (61 lpc); basin/sinks/appliances, 29gpcd (110 lpcd); total, 47 gpcd (178 lpcd).

Source: www.frbb.utn.edu.ar/.../Caracterizacion-aquas-residuales-Cap4-EPA

3.2.2.2.3 Waste-water Quality Variation

Since individual water-using activities occur intermittently and contribute varying quantities of pollutants, the strength of the waste-water generated from a residence fluctuates with time. Accurate quantification of these fluctuations is impossible. An estimate of the type of fluctuations possible can be derived from the pollutant concentration information presented in table 3.5 considering that the activities included occur intermittently.

3.3 Waste-water Flow Rate

3.3.1 The Need to Measure Waste-water Flow

We need to measure waste-water flow as determining the rates of waste-water flow is a fundamental step in the design of waste-water collection, treatment and disposal facilities. In situation where waste-water flow rate data are limited or unavailable, waste-water flow rate estimates have to be developed from water consumption records and other information
Estimated residential flow rates need to account for not only averages, but peak flows. Peak flows of short duration may or may not have a deleterious effect, however peak flows that continue for days can include hydraulic failure.

3.3.2 Components of Waste-water Flow

The components that make up the waste-water flow from a community depend on the type of collection system used and may include the following:

- Domestic (also called sanitary) waste-water. These are waste-water discharged from residences and from commercial, institutional and similar facilities.
- Industrial waste-water. These are waste-water in which industrial wastes predominate.
- Infiltration/Inflow (I/I). This is water that enters the sewer system through indirect and direct means. Infiltration is extraneous (not directly connected) water that enters the sewer system through leaking joints, cracks and breaks or porous walls. Inflow is storm water that enters the sewer system from storm drains connection, roof leaders or through the manhole covers.
- Storm water- This includes runoff resulting from rainfall and snow melt. The percentage of waste-water components varies with local conditions and the time of the year.

3.3.3 Estimating Waste-water Flow Rates from Water Supply Data

It should be known that for areas served with sewers, waste-water flow rates are commonly determined from existing records or by direct field measurement. On the other hand, for new developments, waste-water flow rates are derived from an analysis of population data and corresponding projected unit rates of water consumption or from estimates of per capita waste-water flow rates from similar communities. If field measurements of waste-water flow rates are not possible and actual waste-water flow rate data are not available, water supply records can often be used as an aid to estimate waste-water flow rates.

Where water supply records are not available, useful data for various types of establishments and water - using devices are provided for making estimates of waste-water flow rates.

3.3.4 Analysis of Waste-water Flow Rate Data

Because the hydraulic design of both collection and treatment facilities is affected by variations in waste-water flow rates, the flow rate characteristics have to be analysed carefully from existing records. Where flow records are kept for treatment plants and pumping stations, at least two years of the most recent data should be analysed. Long term record may be analysed to determine changes or trends in waste-water generation rates. Important information that needs to be obtained through the analysis of waste-water flow rate data includes the following:

- Average Daily flow– Occurring over 24 hour period based on annual flow rate. The average daily flow rate is used in evaluation treatment plant capacity and in developing flow rate ratios used in design.
- Maximum daily flow – Calculated on over a 24 hour period based on annual operating data. The maximum daily flow rate is important particularly in the design of facilities involving retention time such as equalisation basins.
- Peak hourly flow – The peak sustained hourly flow rate occurring during a 24 hour period based on annual operating data. Data on peak hourly flows are needed for the design of collection and interceptor sewers, waste-water – pumping stations, waste-water flow meters, sedimentation tanks and channels in the treatment plants.
- Minimum daily flow – The flow rate occurs over a 24 hour period based on annual operating data. Minimum flow rates are

important in the sizing of the conduits where solids deposition might occur at low flow rates.

- Minimum hourly flow – The minimum sustained hourly flow rate occurring over 24-hour period based on annual operating data. Data on the minimum hourly flow rate are needed to determine possible process effects and for sizing of waste-water flow meters, particularly those that pace chemical-feed systems. At some treatment facilities, such as those using tricking filters, recirculation of effluent is required to sustain the process during low-flow period. For waste-water pumping, minimum flow rates are important to ensure that the pumping systems have adequate turn down to match the low flow rates.

3.3.5 Forecasting Average Flow Rates

The development and forecasting of average daily flow rates is necessary to determine the design capacity as well as the hydraulic requirements of the treatment system. Average flow rates need to be developed both for the initial period of operation and for the future (design) period. In determining the design flow rate, elements to be considered are:

i. the current base flows
ii. estimated future flows for residential, commercial, institutional and industrial sources and
iii. no excessive infiltration/inflow.

4.0 CONCLUSION

From what have been discussed, one can conclude that characteristics of waste-water are viewed from two perspectives, viz: the content and its flowing abilities and potentialities. In terms of the content, Biochemical Oxygen Demand (BOD), Total Nitrogen (TN) and Faecal Microbes (FM) are the most considerable. The flow ability of waste-water depends on their content, the plumbing fixtures and appliances present as well as on their frequency of being used. The graphs, tables and illustrations help to make it clearer or understandable.

5.0 SUMMARY

In this unit, you learnt that the characteristics of waste-water were based on their material content and the flow-ability of water. The material contents of waste-water were given before dealing with its flowing characteristics. For its flowing characteristics we discussed the average daily flow, individual activity flow, waste-water flow variations and we were made to understand that there is a difference between the residential and non residential waste-water characteristics especially in terms of constancy of use.

Uses of tables, illustrations and graphs were employed to bring home the ideas being discussed in this unit and all were given as adopted from the work of past researchers. Furthermore, the flow rates of waste-water were discussed later. Under this we discussed why the need to measure waste-water flow rates, and components of waste-water flow and how rates flow are estimated.

6.0 TUTOR-MARKED ASSIGNMENT

1. Using the experience you gathered in this unit, classify the characteristics of waste-water.
2. Discuss briefly any three of the following:
    a. Average daily flow
    b. Individual activity flows
    c. Waste-water flow variation
    d. Biochemical oxygen demand
    e. Faecal microbes.

7.0 REFERENCES/FURTHER READING

Afifi, S. ‘Waste-water Flow Rate’ (n.d). *Bulletin No3 Waste-water Treatment.* Water Corporation.

Haas, C.N. Boland. A., Stevens, D. & Kelly, J. (1999). *Quantitative Microbial Risk Assessment*. London: John Wiley and Sons.

Hamilton, A.J., Mebalds, M., Aldaoud, R. & Heath, M. (2005). ‘A Survey of Physical, Agrochemical and Microbial Characteristics of Waste-water from the Carrot Washing Process: Implications for Reuse and Environmental Discharge’. *J. Vegetable Sc ill, 52-72*

Metcalf & Eddy. (1991).*Waste-water Engineering: Treatment, Disposal, and Reuse*. (3rd. ed.) New York: McGraw-Hill.

www.frbb.utn.edu.ar/.../Caracterisacion-aquas-residuales-Cap4-EPA.

UNIT 4 IMPACTS OF WASTE-WATER ON THE ENVIRONMENT, TREATMENT OBJECTIVES AND DISPOSAL REGULATIONS

CONTENTS

1.0 INTRODUCTION

In the previous units, we have been introduced to waste-water types and their sources as well as their characterisation and flow rates. In this unit, we are to deal with the impact of waste-water on the environment, treatment objectives and disposal regulations.

There is no denying the fact that waste-water will have a lot of impacts on our environment, most of which may not be favourable to the plants, animals and man at all times. Sequel to this, there is a clarion call for the treatment of the said waste-water before disposal. In order to achieve this, a well thought out treatment objectives have to be postulated and pursued vigorously. In order not to deviate or cause more problems with the treated waste-water, there is the need to develop and have functional disposal regulations that will guide men as they do this all important function.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- enumerate the impacts of waste-water on the environment
- explain the treatment objectives
- list the disposal regulations.

3.0 MAIN CONTENT

3.1 Impact of Waste-water on the Environment

According to the *Oxford Advanced Learners Dictionary* of Current English, the word ‘impact’ means among other things, ‘the powerful effect that something has on somebody or some other thing(s)’. The question now is what are the powerful effects has waste-water on man’s total environment? This will be viewed in two perspectives; negative impacts of waste-water, impact of waste-water disposal on the site.

3.1.1 Negative Impacts of Waste-water

There is no gainsaying the fact that waste-water has a lot of negative impact on the environment in which it is found. In order words, there are some noticeable effects of waste-water on and in wherever it is found. In our previous units we saw the characterization of waste-water and found out that it contains sewage, which contains things like faeces, urine etc and gray water which results from washing, bathing and meal preparations and then the storm water which results from surface run-off. Agricultural run-off water and waste from nearby industries may also enter the system, etc. One or a combination of the above whenever present poses a threat to the nearby surrounding.

Apart from defacing the environment in which it is found, causing unsightliness to the people who may pass by, it is equally odorous as it emits obnoxious odour. The waste-water wherever it is found occupies space that could have been used for another purpose impacting negatively on same. Also of importance is the fact that it is a breeding focus for mosquitoes and other insects including some helminthes.

Waste-water especially storm water impacts negatively erosion wise eroding the topsoil most of the time and destroying our possessions as it does so. Of importance is the fact it also, with accumulated debris causes blockage of our drainage lines and enters into the compound of people destroying peoples’ property.

Waste-water in rivers, streams, lakes or even oceans results to pollution. Scientific evidence supports significant impact of sewage pollution on water quality and health of sea grasses and corals (Lapoint, 2004). Nutrient levels in sewage pollution are considerable relative to the low nutrient environment of the marine waters surrounding the islands. Dissolved inorganic nitrogen (DIN) composed of ammonium (NH_4+), nitrate ($N0_3$-), and nitrite ($N0_2$-) is causing an excessive biomass of macroalgae that overgrow sea grasses and adult corals, obstruct development of juvenile coral, and develop areas of anoxia and hypoxia, depleting fish populations and other biological diversity (Lapointe, 2004). Furthermore, sewage contamination in the marine ecosystem surrounding the Keys is a public health hazard due to known microbiological components such as Escherichia coli and Enterococcus.

Waste-water is richly blessed with disease pathogens and is ready to infect people and animals (both aquatic and terrestrial) around it. It is mostly because of this factor that there is the need to have it treated to some reasonable extent before reuse or disposal. A look at the table below will show the pathogens most likely to be found in waste-water / water. The list in the table is never exhaustive of microbes that are pathogenic in the waste-water. It has no helminthes in them in the first place.

SELF-ASSESSMENT EXERCISE

You are required to find other pathogens present in waste-water not found in the ones given below.

Table 4.1: Common Water -Borne Pathogens

S. No.	Bacteria	Diseases caused	Viruses	Diseases caused
1.	*Salmonella typhi*	Typhoid	Hepatitis A virus	Hepatitis
2.	Other *Salmonella* spp	Salmonellosis (gastroenteritis)	Polio virus	Poliomyelitis
3.	*Shigella* spp.	Shigellosis (bacillary dysentery)	Protozoa	Diseases caused
4.	*Vibrio cholerae*	cholera	*Giardia intestinalis*	Giardiasis
5.	*Vibrio parahaemolyticus*	Gastroenteritis	*Balantidium coli*	Balantidiasis
6.	*Escherichia coli*	Gastroenteritis	*Entamoeba histolytica*	Amoebic dysentery
7.	*Legionella pneumophila*	Legionnaire'sdisease	*Cryptosporidium parvum*	Cryptosporidiosis
8.	*Yersinia enterolitica*	Gastroenteritis	*Cyclospora cagetanensis*	Diarrhoea
9.	*Campylobacter* spp.	Gastroenteritis	*Naegleria fowleri*	Encephalitis
10	*Leptospira spp*		*jaundice*	

Source: Anuradha S.Nerurkar, 2007

3.1.2 Impact of Waste-water Disposal on the Site

The impact of waste-water disposal on the site depends on the scope or nature of treatment given to the waste-water in question before the disposal. Rural areas have the highest numbers of septic systems because municipal infrastructure is not in place to convey sewage from homes and business to central sewer treatment plants. The United States Environmental Protection Agency says "adequately managed decentralized waste-water systems are a cost-effective and long-term option for meeting public health and water quality goals, particularly in less densely populated areas" (USEPA, 1997). Although current onsite sewage treatment methods are somewhat effective at reducing pathogens in waste-water, nutrient levels are not significantly decreased. The implication is that whereas waste-water can be a source of pollution of the immediate environment, it can be of help to farmers who may need such nutrients.

Nutrient couplings between onsite waste-water systems and adjacent marine waters were studied by LaPointe et al. (1990) between December 1986 and September 1987.

Monitoring wells were installed on seven residential lots that were inhabited for at least 3 yr and up to 20 yr (LaPointe *et al.,* 1990). The wells were installed in pairs, one near the septic system and the other midway between the septic systems and adjacent canals at each residential lot. Water samples were collected monthly from every well and analyzed for salinity, temperature, and dissolved inorganic nutrients (Lapointe *et al.,* 1990). Two statistical comparisons were made in this study. First, monthly groundwater and surface water nutrient concentration data from the winter and summer were pooled separately to determine any significant difference between the wet and dry season (LaPointe *et al.,* 1990). Second, the pooled seasonal nutrient data from both monitor wells at the residential sites was compared to the control data (Table 4.2). Nutrient enrichment was significant (up to 5000 fold) with the highest concentrations of ammonium, nitrate plus nitrate, and soluble reactive phosphate occurring in monitoring wells adjacent to septic system drain fields as compared to the control ground waters (Lapointe *et al.*, 1990). Lower concentration of these nutrients, although still enriched, occurred in ground waters extracted from wells installed midway between septic system drain fields and surface waters. Lowest concentrations of nutrients occurred in control ground waters extracted from wells installed within the Key Deer National Wildlife Refuge (Lapointe *et al.*, 1990). Mean concentrations of nutrients in ground waters decreased from winter to summer, contrasting with increases in measured nutrients in surface water from winter to summer.

Table 4.2;

Mean Values for Nutrient Concentrations (micro molar, µM)			
Location	Mean nitrate plus nitrite	Mean ammonium	Mean soluble reactive phosphate
Winter			
Adjacent wells[1]	817	784	17
Midway wells[1]	118	256	2.54
Wells combined[2]	467	520	9.77
Control groundwater[3]	0.76	1.91	0.11
Canal[4]	1.61	0.88	0.15
Summer			
Adjacent wells[1]	220	502	6.37
Midway wells[1]	30.7	188	1.62
Wells combined[2]	125	346	4.0
Control groundwater[3]	0.20	1.40	0.14
Canal[4]	3.22	1.69	0.43

Notes	1	Adjacent wells – water extracted from wells installed adjacent to septic systems, pooled data. Midway wells – water extracted from wells installed midway between septic systems and canals, pooled data.
	2	Wells combined – water extracted from adjacent wells and midway wells, then pooled.
	3	Control groundwater – water extracted from monitoring well installed at Key Deer National Wildlife Refuge (KDNWR)
	4	Canal – Surface water collected from canal systems adjacent to septic system site *Source: Adapted from Lapointe et al., 1990.*

The elevated nutrient concentrations, summarised in Table 4.2, indicate that waste-water effluent from septic systems is a significant source of enrichment to groundwater and surface waters in the Keys (Lapointe *et al.*, 1990). The predominant nitrogenous species in the groundwater was ammonium, likely caused by suboxic and anoxic conditions due to limited vadose zone underlying septic systems, preventing maximum nitrification (Lapointe *et al*., 1990).

The effects of treated waste-water especially sewage on the environment depends on the level of treatment and the population of the surrounding environment. For instance, discharge of sewage into cesspits, shallow holes, and directly into the adjacent coastal water were common methods of sewage disposal during the years of early development of the Florida Keys. By then, ecological impact was minimal due to the sparse population common during the first half of the 20th century. However, the Keys gradually became a popular vacation destination and a desirable place to live because of climate and proximity to pristine ocean waters. Since land area is limited, early subdivisions were high density with 50 foot by 50 foot lot sizes not uncommon (Kruczynski and McManus, 2002). Direct release of untreated sewage resulted in nutrient enrichment and pollution of ground water and nearby surface waters with human fecal pathogens. The State Board of Health gradually adopted rules and enforced the use of septic systems during the mid 1960s to protect public health. Components of these septic systems included a septic tank with effluent disposal achieved using a drain field or injection well. The porous nature of the Keys substrate limestone results in high nutrient effluent seeping directly into groundwater and adjacent surface waters. Starting in 1992, the Florida Department of Health required that drain fields be underlined by a minimum 12 inches of clean fill sand (Kruczynski and McManus, 2002). Although underlying drain fields with clean fill sand provides filtration of pathogens through cat ion exchange entrapment, little or no removal of nutrients such as nitrogen or phosphorus is afforded (Kruczynski and McManus, 2002). Furthermore, early installed septic tanks were punctured, allowing infiltration of groundwater to prevent groundwater induced flotation of the tanks. This practice short-circuits the system and allows raw sewage to directly contact groundwater (Kruczynski and McManus, 2002).

Deposition of treated sewage or waste-water into the water body affects its quality. For instance, water quality in Florida Bay began showing signs of significant degradation in the late 1980s when such deposition occurred. Clear water began to turn green and turbid with sea grass die-offs and algae blooms occurring with greater frequency (Dillon *et al.,* 2000). Causes of these ecological changes were hypothesized to be elevated salinity and increased nutrient loading due to the urbanization of the south Florida mainland and the Keys. Still others suspected natural variability within the ecosystem (Dillon *et al.*, 2000). Coral die-offs, coupled with colonisation of benthic algae on dead and dying coral indicated increased nitrification of the coastal waters around the Keys.
When undertaking an assessment of the real cost of employing any given method of waste-water disinfection, it is necessary to consider both human and environmental risks which may be tangible and/or intangible.

Literature clearly reports the potential adverse toxicological impacts of chlorine chemicals and byproducts of chlorination on the aquatic environment (Queensland Department of Environment and Heritage, 1993). High total residual chlorine in discharges to water may lead to an acute response of aquatic organisms, ranging from avoidance to death. The threshold tolerance limit of some aquatic species to chlorine is 0.002 milligrams per litre in freshwater and 0.01 milligrams per litre in saline water (Department of Environment and Heritage Report QLD, 1991). Disinfection by-products also have the potential to bioaccumulate in the aquatic environment. Dechlorination eliminates the toxicity of the free or combined chlorine residual, but does not effectively reduce other disinfection byproducts. In summary, the beneficial use of aquatic ecosystem protection may be compromised when chlorinated waste-water is discharged to receiving surface waters.

Chlorination should not pose a significant risk to the environment if the treated waste-water is beneficially reused rather than discharged to receiving surface waters. This is an acceptable disinfection method for waste-water reuse. It should also be noted that chlorination is considered best practice for reuse applications where a residual is required to prevent microbial re-growth and hence re-contamination of distribution and storage systems. However, there is a limit of one milligram per litre of chlorine at the point of application of reclaimed water. This limit corresponds to the aesthetic threshold and will not usually cause adverse effects on plants. However, some sensitive crops may be damaged at chlorine levels below one milligram per litre and users should consider the sensitivity of any crops that may be irrigated with chlorine disinfected reclaimed water.

Although the direct use of chlorine for disinfection of reclaimed water should pose little environmental risk, the manufacture, storage and transportation of chlorine products still poses a risk to the environment. The risk that ozone poses to aquatic organism health requires further research. It has been suggested that the strong oxidation potential of ozone may cause the formation of toxic by-products, but this is yet to be proven. Ozone gas, however, may adversely impact on surrounding vegetation due to its corrosive and toxic nature. Microfiltration only poses a risk to the environment if there is a spill of cleaning agents or the contaminated backwash waste is disposed of incorrectly.

The potential environmental risks associated with UV are less compared to other methods, but may include photo-reactivation and mutation of the microbial population present in the discharge. There is presently no reuse option for spent UV lamps.

Control over biological disinfection methods, such as detention lagoons, is more difficult as they are natural systems. A significant environmental risk associated with lagoon-based disinfection, is the potential for the excessive growth of undesirable organisms, such as blue-green algae.

Blue-green algal blooms may pose a risk to stock and human health through the production of toxins and to the environment via an increase in SS and BOD levels. In terms of potential environmental cost, it would appear UV, lagoons and microfiltration has the least potential to impact adversely upon the environment, followed by ozonation then chlorination. This ranking is based on the potential production of disinfection by products and the potential toxicity of the discharge to the receiving environment.

3.2 Treatment Objectives

Satisfactory disposal of waste-water, whether by surface, subsurface methods or dilution, is dependent on its treatment prior to disposal. Adequate treatment is necessary to prevent mination of receiving waters to a degree which might interfere with their best or intended use, whether it be for water supply, recreation, or any other required purpose. The purpose or objective of waste-water treatment is generally to remove from the waste-water enough solids to permit the remainder to be discharged to receiving water without interfering with its best or proper use. The solids which are removed are primarily organic but may also include inorganic solids. Treatment must also be provided for the solids and liquids which are removed as sludge. Finally, treatment to control odours, to retard biological activity, or destroy pathogenic organisms may also be needed. . The above reasons inform the main aim of waste-water treatment. To achieve the said broad aim of its treatment, some specific treatment objectives must be met, thus given below.

Preliminary treatment-Preliminary devices are designed to remove or cut up the larger suspended and floating solids, to remove the heavy inorganic solids, and to remove excessive amounts of oils or greases.
To effect the objectives of preliminary treatment, the following devices are commonly used:

1. Screens – rack, bar or fine
2. Comminuting devices- grinders, cutters, shredders
3. Grit chambers
4. Pre-aeration tanks

In addition to the above, chlorination may be used in preliminary treatment. Since chlorination may be used at all stages in treatment, it is considered to be a method by itself. Preliminary treatment devices require careful design and operation.

Primary treatment – The purpose of primary treatment is to reduce the velocity of the waste-water sufficiently to permit solids to settle and floatable materials to surface. Therefore, primary devices may consist of settling tanks, clarifiers or sedimentation tanks. Because of variations in design, operation, and application, settling tanks can be divided into four groups:

1. Septic tanks
2. Two story tanks – Imhoff and several proprietary or patented units.
3. Plain sedimentation tank with mechanical sludge removal.
4. Upward flow clarifiers with mechanical sludge removal.

Secondary treatment – Secondary treatment depends primarily upon aerobic organisms which biochemically decompose the organic solids to inorganic solids. It is comparable to the zone of recovery in the self-purification of a stream. The devices used in secondary treatment may be divided into four groups:

1. Trickling filters with secondary settling tanks
2. Activated sludge and modifications with final settling tanks
3. Intermittent sand filters
4. Stabilisation ponds

Chlorination – chlorination is a method which can apply in all the stages of treatment. It has been employed for many purposes in all stages in waste-water treatment, and even prior to preliminary treatment. It involves the application of chlorine to the waste-water for the following purposes:

1. Disinfection or destruction of pathogenic organisms
2. Prevention of waste-water decomposition – (a) odour control, and (b) Protection of plant structures.

Sludge treatment – The solids from waste-water in both primary and secondary treatment units, together with the water removed with them, constitute waste-water sludge. Sludge treatment has two objectives – the removal of part or all of the water in the sludge to reduce its volume, and the decomposition of the putrescible organic solids to mineral solids or to relatively stable organic solids. This is accomplished by a combination of two or more of the following methods:

1. Thickening
2. Digestion with or without heat
3. Drying on sand bed – open or covered
4. Conditioning with chemicals
5. Elutriation
6. Vacuum filtration

7. Heat drying
8. Incineration
9. Wet oxidation
10. Centrifuging

(Source: http://water.me.vccs.edu/courses/ENV149/methods.htm).

Tertiary and advanced waste-water treatment – The term tertiary treatment has come to describe additional treatment following secondary treatment. Quite often this merely indicates the use of intermittent sand filters for increased removal of suspended solids from the waste-water. In other cases, tertiary treatment has been used to describe processes which remove plant nutrients, primarily nitrogen and phosphorous, from waste-water. Improvement and upgrading of waste-water treatment units as well as the need to minimise environmental effects has led to the increased use of tertiary treatment.

In advanced treatment, the degree of treatment is usually achieved by chemical (for example coagulation) methods as well as physical methods (flocculation, settling and activated carbon adsorption) to produce high quality effluent water.

3.3 Disposal Regulations

Disposal regulations are sets of standards, rules and regulations that govern the disposal of waste-water, which ever the constituent it contains or it is made of, in the water body or on the land with aim of making sure that the recipient (the water body or the land) does not suffer adversely directly by itself or its content (aquatic or terrestrial/arboreal life). The question now is: Are there such regulations and how effective are those regulations? A little more and you will be abreast with the true situation of things.

Worldwide, there are laws, acts, and even by-laws that govern the disposal of waste-water with the aim of achieving good healthy living. For instance, in Australia there are acts like:

Environmental Protection Act 1970 – Under the Environmental Protection Act, 1970 discharges to the environment must be managed so they do not adversely affect the receiving environment (that is, land, surface water or groundwater).

Health Act 1958 – The Health Act 1958 makes provision for the prevention and abatement of conditions and activities that are, or may be, offensive or dangerous to public health.

At local level, the Public Health Ordinance states that a local or Native Authority may maintain a public sewer within its district. It provides a penalty for any person who introduces refuse or any matter likely to interfere with the free flow of sewage or affect its treatment and disposal.

The Public Health Ordinance lays down the procedure to be adopted by those who wish to connect their drainage systems to the public sewer. Where a public sewer exists, plans of new buildings must show satisfactory provision for the drainage of the building and connection to the public sewer; also owners of existing building may be required to provide satisfactory drainage in connection with their buildings, provided a sewer is available.

4.0 CONCLUSION

From all that have been discussed above, we can conclude that waste-water impacts negatively on our environment by its being and when disposed on the environment after treatment. Its presence before treatment spells doom for man and animals as they try to survive from diseases they cause. When discharged into water or on land after treatment, it impacts negatively and positively too. It generally enriches the soil where it is found but may also contain some harmful chemicals that are inimical to plants if they come from industrial wastes. In order not to do harm much to the environment where waste-water is found and in order to effectively treat same, there is the need to have functional and coordinated treatment goals and objectives. Each stage of the treatment should follow its regular pattern and achieve the specific objective so as to have the overall aim achieved. Disposal regulations should be made and followed vigorously to make sure that all is well with our environment. At present not much about this is in place.

5.0 SUMMARY

In this unit, you have learnt this topic in the order listed below:

- The definition of the word impact was given before dealing with the impacts waste-water has on the environment where it is found. There is no denying the fact that it has negative effects on the environment which ranges from disease spread, unsightliness to erosion problems in case of storm water.
- There are still the impacts of treated waste-water on the disposal site which are dependent on the scope of treatment given before disposal and the nature of the site where the disposal is made. It may affect the aquatic life if it is disposed into water. It may

enrich the soil so much with nitrogen and phosphorous, etc if it is disposed on the land.

- To ensure that negative impacts are not much witnessed and felt, functional treatment objectives must be followed. The major aim of treatment is to ensure that waste-water is not felt adversely by people, animals and plants whether aquatic or terrestrial after treatment and deposition on the land or in the sea. Specific treatment objectives were followed to achieve this.
- In order to achieve effective disposal of our waste-water, there is the need to have disposal regulations and standards. These enabling laws will ensure that the aims and objectives of disposals are achieved. There are not many such laws in this part of the world and the few available are not followed to the letter.

6.0 TUTOR-MARKED ASSIGNMENT

1. a. Explain the impacts of waste-water in its free state on the environment.
   b. Explain the impacts of treated waste-water on the disposal site.
2. a. Relate specific treatment objectives with the overall goal of waste-water treatment.
   b. What is disposal regulation and how effective has it been in the management of waste-water?

7.0 REFERENCES/FURTHER READING

Anuradha, S. N. (2006). *Applied Microbiology – Present Status of Applied Microbiology in India*. Department of Microbiology and Biotechnology Centre, Faculty of Science: The Maharaja Sayajirao University of Baroda.

DEH (1991). 'Microbiological Aspects of the Disinfection of Sewage Effluents. Environment Technical Report – Policy'. *Review Paper*. Queensland Department of Environment and Heritage (DEH).

Dillon, K. S., & Corbett, D. (2000). 'Bimodal Transport of a Waste Water Plume Injected into Saline Ground Water of the Florida Keys'. *Ground Water*. 38(4), 624. Retrieved from: EBSCOhost.

EPA Victoria. (September 2002). *Guidelines for Environmental Management- Disinfection of Treated Waste-water.* Southbank Victoria, Australia.

Lapointe, B, Barile P, & Matzie, W. (2004). 'Anthropogenic Nutrient Enrichment of Sea Grass and Coral Reef Communities in the Lower Florida Keys: Discrimination of Local *versus* Regional Nitrogen Sources'. *Journal of Experimental Marine Biology & Ecology*. 308(1):23-58.

Lapointe, B., O'Connell, J.D, & Garrett, G.S. (1990). 'Nutrient Couplings Between on-site Sewage Disposal Systems, Groundwaters, and Nearshore Surface Waters of the Florida Keys'.Vol. 10, No. 3. 289-307.

Kruczynski, W.L., & McManus, F. (2002). *Water Quality Concerns in the Florida Keys: Sources, Effects, and Solutions.*

Porter, J. W., & Porter, K. G. (2002). 'The Everglades, Florida Bay, and Coral Reefs of the Florida Keys'. *An Ecosystem Sourcebook.* Boca Raton, Fla: CRC Press, Page 827.

Tom, Higginbotham, (n.d). 'Environmental Impact of Waste-water Disposal in the Florida Keys, Monroe County'. *University of Florida Soil and Water Science.*

United States Environmental Protection Agency (USEPA). (1997). *Response to Congress on Use of Decentralised Waste-water Treatment System*s. EPA 832-R-97-001b: http://www.epa.gov/owm/septic/pubs/septic_rtc_all.pdf.

Wilkie, W. (1965). 'Jordan's Tropical Hygiene and Sanitation'. United Kingdom Bullsie Tundal and Co. http://water.me.vccs.edu/courses/ENV149/methods.htm.

UNIT 5 PRINCIPLES OF APPLIED MICROBIOLOGY

CONTENTS

1.0 INTRODUCTION

Microbiology is the study of small (microscopic) organisms which are too small to be viewed with unaided eyes and could be plants, animals or inanimate objects. It is through such studies that microscopic bacteria, protozoa, viruses, fungi etc. were discovered and their behavioural characteristics known.

In the field of microbiology, many branches of it exist, thus we have things like: environmental microbiology, microbiological ecology, applied microbiology and microbial biotechnology. All these relate and differ slightly at different times and occasions. Whereas microbial ecology is the study of the interaction of micro-organisms within the environment, environmental microbiology is an applied field where the study of micro-organisms in the environment leading to the benefit of the society is emphasised. It is a subset of applied microbiology and interfaces with water, waste-water, air, soil, food, industrial microbiology and others. Microbial biotechnology encompasses the field which includes the manipulation of the microbes to increase their practical benefit wherein the principles of applied microbiology are applied.

This unit discusses the present status of applied microbiology in the context of world scenario including waste-water, air and food and dairy microbiology.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the application of microbiology study in waste-water treatment processes
- explain the benefits of microbiology in portable water quality control
- discuss air microbiology as it relates to airborne disease, their transportation, and analysis and control
- explain in details food and dairy microbiology, both their beneficial and detrimental effects, including in food preservation.

3.0 MAIN CONTENT

3.1 Waste-water Microbiology

The new focus of environment as a whole has led to the development of new activities related to the application of principles of water, waste-water and air microbiology which forms the scope of environmental biotechnology. This part addresses various aspects of waste-water treatment since generally it is now suitably treated before dumping into the rivers/streams so as to reduce the threat of waterborne diseases.

3.1.1 Self- Purification

The fate of the discharged waste is determined by the self-purification potential of the receiving water body. Self-purification is based on biogeochemical cycling activities and inter-population relationships of the indigenous (autochthonous) microbial populations. Organic nutrients are mineralised by the heterotrophic aquatic organisms. Ammonia is nitrified and inorganic nutrients are utilised by higher aquatic plants. Non-indigenous (alochthonous) population of enteric pathogens that enter through waste is eliminated by competition and predation of the autochthonous microorganisms. The waste-water may overwhelm the self purification capacity of the aquatic system causing pollution of receiving water. Depending on the climatic and environmental factors the water may attain an acceptable quality level in the stream, downstream from the sewage outfall. A well-defined profile of pollution and self- purification of the receiving water is obtained by a succession of changes in water quality that occurs on the downstream of the point source of pollution (Figure 5.1). Self-purification is a slow process and a heavily polluted stream may have to traverse quite a long distance for days to get purified. Whenever the waste-water is discharged, the suspended matter either settles at the bed near the point of discharge or gets carried away.

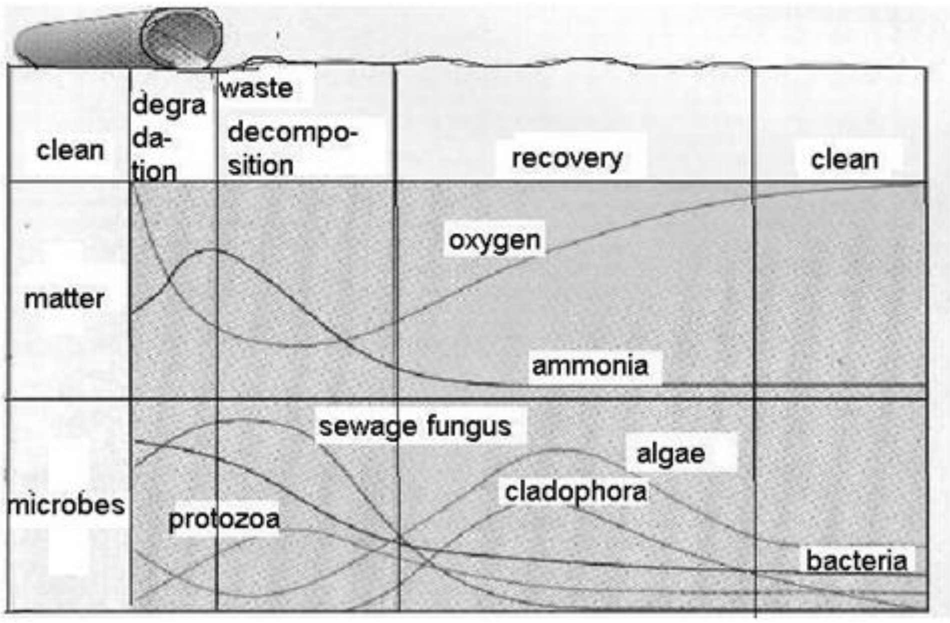


Fig. 5.1: Sewage Outfall and Self-purification
Source: Anuradha S. Nrurkar, 2006

The organic matter is utilised by the aerobic micro-organisms reducing the dissolved oxygen. As the organic matter is depleted, the number of micro-organisms is also reduced. The re-aeration rate of the atmosphere catches up. The water becomes clear and the stream returns to the original condition and the self-purification is accomplished. The Biochemical Oxygen Demand (BOD) and the Dissolved Oxygen (DO) of the receiving waters are parameters that give good measure of pollution that exists in the receiving stream.

3.1.2 Characterisation of Sewage

Domestic waste-water or sewage contains human waste like feaces, urine, and gray water. Gray water results from washing, bathing and meal preparations. Agricultural run-off water and waste from nearby industries may also enter the system. The important physical characteristic of the waste-water is its total solids content. It includes floating, suspended, colloidal and dissolved solids. Total solids are those that remain as residue upon evaporation at 105°C. The Total solids include suspended and filterable solids (about 1 μ size). Settlable suspended solids are the ones that settle in Imhoff cone in 60 min., while the remaining are non-settlable solids. Colloidal filterable solids impart turbidity to the water, measurement of which gives an idea about the waste-water quality. Dissolved filterable solids cannot be removed by conventional treatment and requires special treatment. Solids are called volatile solids if they are volatile at 600°C. Minerals are non-volatile solids that form ash when heated at 600°C. Depending on the amount of total suspended solids the sewage can be categorised as high strength (>500 ppm), medium strength (200-500 ppm) and weak (< 200 ppm). The odour in sewage usually is due to presence of amines, hydrogen sulfide, ammonia, organic sulfide etc. The color of fresh sewage is usually gray. After the organics are broken down the dissolved oxygen is depleted and the color changes to black. The chemical nature of a typical municipal sewage is primarily due to proteins, carbohydrates and fats. Surfactants, detergents, phenols, pesticides etc. form the minor components. Roughly the composition of the sewage can be represented in terms of its contents (Table 5.1).

Table 5.1: Composition of Average Sewage

S. No.	Component	mg/L	Component	mg/L	Component	mg/L
1.	Total solids	700	TOC	200	NO_3-N	0-1
2.	Dissolved solids	500	COD	400	Total P	10
3.	Settled solids	300	Total N	40	Organic P	3
4.	Suspended solids	200	Organic N	15	Inorganic P	7
5.	BOD	300	NH_3-N	25	Grease	100

Source: Anuradha S. Nrurkar, 2006

The need for characterisation of sewage arises in order to evaluate its capacity to cause pollution, decide correct type and size of the treatment plants, monitor the efficiency of the plant, and prevent the pollution of the receiving water. It helps to establish an effective and economical waste management system

3.1.3 Conventional Sewage Treatment

The conventional method of sewage treatment attempts to maintain acceptable BOD before it is discharged into the water body. A combination of physical unit operations and chemical and biological processes are used. In this, the forces that favor self-purification are purposefully intensified to get the desired treatment in short time and space. Major steps in the conventional sewage treatment are primary, secondary and tertiary or advanced treatment (Figure 5.2). Primary treatment is a physical operation that separates large debris followed by sedimentation to settle big suspended solids. 20-30% BOD that is present in the particulate form is removed. Raw sewage passes through a metal grating that removes large debris such as branches, tyres etc. A moving screen filters small items like bottles etc., after which a grit tank is provided where the sewage is kept for some time for sand and gravel to settle out. The waste then is pumped into primary settling or sedimentation tank. If dissolved solids are less, large chunk of BOD is removed with settled sludge in the sedimentation tank. Pathogens adsorbed to solids are removed. The effluent of primary treatment is called settled sewage.

Secondary treatment comprises the biological treatment in which remaining suspended and dissolved organic material along with about 90-95% BOD and pathogens are removed. The settled sewage is pumped into either trickling filter or activated sludge process for biological treatment.

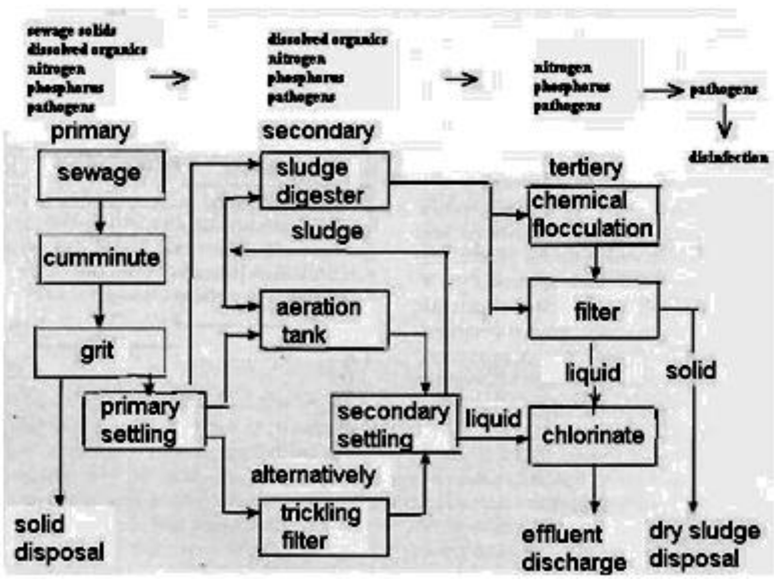


Fig.5.2: Conventional Sewage Treatment

Source: Anuradha S. Nrurkar, 2006

Tertiary treatment comprises of a series of additional steps after secondary treatment to further reduce organics, turbidity, nitrogen, phosphorus, metals and pathogen. Mostly some type of physicochemical or biological treatment such as coagulation, filtration, activated carbon, adsorption of organics, nutrient removal and disinfection is required. The tertiary treatment is done for additional protection of wildlife after discharge in rivers, lakes etc. or when the water is to be reused.

Table 5.2: Some Tertiary Treatment Processes

S. No.	Process	Purpose
1.	Disinfection	Final step in sewage treatment designed to kill entero-pathogens
2.	Suspended solid removal	Micro-screens, sand, anthracite or diatomaceous earth filters employed. Coagulation with alum, poly-electrolytes, lime and other chemicals aids the removal.
3.	Taste and odour removal	Activated carbons are widely used. Solutes are adsorbed onto the carbon by means of strong Van der Waals forces.
4.	Ion removal	Ion exchange used wherein ions that are held to functional groups on the surface of a solid by electrostatic forces are exchanged for ions of different species in solution and complete demineralization is achieved.
5.	Nutrient removal	Removal of nitrogen and phosphorus done biologically.

Source: Anuradha S. Nrurkar, 2006

The above processes involve so much when treated in full but for this unit an abridged form given as above will suffice as their details will form subsequent units. All the processes involved in them are classical show of the principles of applied microbiology. This is because apart from the preliminary stage of the primary treatment, which deals with the macroscopic elements like branches of trees, tyres, polythene materials, etc. and removes them from the content, other contents and their treatment are dealt with almost microscopically. The only thing needed of you now is patience for the units as they come.

3.2 Water Microbiology

This is another area where microbiological studies play important roles to man and his environment. Study of micro-organisms and their communities in water environment is called Aquatic microbiology, while Water Microbiology relates to the study of micro-organisms in potable water. The scope of Aquatic Microbiology is wide and includes the habitats like planktons, benthos, microbial mats and biofilm which may be found in lakes, rivers, streams, seas, groundwater, rain, snow and hail. *Planktons* are the collection of free living and drifting micro-organisms in ponds, lakes and oceans. Algae and cyanobacteria are phytoplanktons while protozoans and microbes are zooplanktons. These will suffice for now.

3.2.1 Drinking Water Microbiology

In EHS 309 (Hydrology and Sanitation), water treatment was done to an extent that you can boast of knowing this section without much problems. Drinking or *potable water* is water that is free from pathogens and chemicals that are dangerous to human health. Any taste, odor and color must be absent from the water to be palatable. Raw water may contain many contaminants derived from sewage and nearby industries. Many enteric pathogens are water borne. Therefore, water is treated and disinfected to remove chemicals and pathogens respectively. The raw waste is stored in reservoirs where the oxidisable organic materials are stabilised and discrete particles settle. The collected water or impounded water in the reservoir irrespective of its source contains sufficient nutrients for growth of algae which require only minerals and sunlight. Many phototrophic and chemolithotrophic bacteria grow in the dilute environment. Heteroptrophs flourish on the organic matter of dead autotrophs. Some organic matter is introduced by wind, rain or soil with runoff water. Bacterial activities cause transformation of iron, pH change, CO_2 release, mineralisation of organics which may lead to corrosion of pipelines and thereby fouling of water. Various algae, protozoans and iron bacteria impart bad taste and odours. Some produce slime causing clogging of pipes. Iron bacteria include sheathed and stalked bacteria that are typical water organisms. They are aerobic, widely distributed in nature esp. in stagnant water such as reservoir for potable water supply. *Siderocapsa*, *Sphaerotilus*, *Clonothrix*, *Leptothrix*,*Crenothrix*, *Caulobacter* and *Gallionella* are some common filamentous iron bacteria. Sulfur and sulfate reducing bacteria also contribute to fouling of impounded waters. A closer look at waterborne diseases is deemed necessary at this juncture.

3.2.2 Water-Borne Diseases

An important aspect of Water Microbiology is numerous disease causing micro-organisms spread through water. Many bacteria, viruses, fungi and protozoa are responsible for waterborne diseases. The recurrence of waterborne illness has led to the improvement in water purification. Some common water borne diseases are listed in the Table 5.3. You can also refer to EHS 309 for more details.

Table 5.3: Common Water-borne Pathogens

S. No.	Bacteria	Diseases caused	Viruses	Diseases Caused
1.	*Salmonella typhi*	Typhoid	Hepatitis A virus	Hepatitis
2.	Other *Salmonella* spp	Salmonellosis (gastroenteritis)	Polio virus	Poliomyelitis
3.	*Shigella* spp.	Shigellosis (bacillary dysentery)	Protozoa	Diseases caused
4.	*Vibrio cholerae*	cholera	*Giardia intestinalis*	Giardiasis
5.	*Vibrio parahaemolyticus*	Gastroenteritis	*Balantidium coli*	Balantidiasis
6.	*Escherichia coli*	Gastroenteritis	*Entamoeba histolytica*	Amoebic dysentery
7.	*Legionella pneumophila*	Legionnaire'sdisease	*Cryptosporidium parvum*	Cryptosporidiosis
8.	*Yersinia enterolitica*	Gastroenteritis	*Cyclospora cagetanensis*	Diarrhoea
9.	*Campylobacter* spp.	Gastroenteritis	*Naegleria fowleri*	Encephalitis
10.	*Leptospira spp.*	Jaundice		

Source: Anuradha S. Nrurkar, 2006

3.2.3 Microbiological Examination of Water

In order to maximise the use of water without falling into trouble caused by micro-organisms in the same, it is pertinent that microscopic examination be done before water is used for any purpose. Heterotrophic plate count (HPC) of more than 500 / ml in tap water indicates variation in water quality and potential for pathogen survival. They also mask the coliforms and fecal coliforms when present in high numbers. Bottled water and charcoal filters of household taps have high HPC. Gram negative bacteria belonging to bacterium *Pseudomonas, Aeromonas,* *Klebsiella, Flavo, Enterobacter, Citrobacter, Serratia, Proteus,* and *Moroxella,* etc., are detected in HPC. Monitoring and detection of indictor and disease causing micro-organisms is a major part of *Sanitary Microbiology*. Intestinal tract bacteria do not survive in the aquatic environment and are under physiological stress and loose their ability to grow on selective media. Although many pathogens can be detected directly in water, Environmental Microbiologists have generally used *indicator or index organisms* as an indirect evidence of possible water contamination by human pathogens which are considered to be of fecal origin. The criteria for an ideal indicator organism are:

1. It should be useful for all types of water.
2. It should be present whenever enteric pathogens are present.
3. The organism should have reasonably longer survival time than the hardiest of pathogens.
4. The organism should not grow in water.
5. The testing method should be easy to perform.
6. The density of indictor organisms should have direct relationship to the degree of fecal pollution.
7. The organism should always be found in intestinal microflora of warm blooded animals.

Conventionally, *coliforms* have been used as indicator organisms of fecal pollution. Various indicator organisms are now considered for their different attributes and usefulness as no organism satisfies all the above criteria. Among the various indicators are coliforms, fecal streptococci, *Clostridium perfringens*, *Bifidobacterium* and *Bacteroides*, phages of enteric bacteria, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Candida albicans* and *Aeromonas hydrophila*. Coliforms are defined as facultatively anaerobic Gram negative, non-spore forming, short rod-shaped bacteria that produce acid and gas on lactose fermentation in prescribed culture medium within 48h at 35º C. The group includes *Escherichia*, *Citrobacter*, *Enterobacter* and *Klebsiella*. *Escherichia coli* and *Klebsiella pneumoniae* are the important coliforms. *E. coli* is a natural inhabitant of the intestine and *K. pneumoniae* is that of soil. The test for coliforms involves presumptive, confirmed and completed tests. The *presumptive test* is clubbed with the multiple tube dilution technique which gives an estimate of most probable number (MPN) of coliforms in 100 ml of water sample and is also called MPN test. In MPN test different sample volumes are inoculated in lactose broth or McConkey broth at 35ºC for 48h incubation. The test is based on the principle that a single living cell can develop into a turbid culture. By determining the average dilution at which the tubes do not receive cells, the number of micro-organisms most probably present in the original sample can be computed using the MPN table. In the *confirmed test* typical greenish metallic sheen colonies on EMB indicate fecal coliforms whereas non-fecal coliforms give mucoid pink colonies with dark centers called atypical colonies. The *completed test* involves confirmation of coliforms. Gram negative non-spore forming, lactose fermenting (within 48h, rod shaped bacteria indicate fecal coliforms.

Membrane filter technique (MF) is another useful test that consists of passing the water through a membrane filter. The filter with bacteria is transferred to the surface of a solid medium or to an absorptive pad containing the desired liquid medium. Use of appropriate media helps in the detection of total, fecal and non-fecal coliforms. A resuscitation medium may be used to revive injured or stressed coliforms due to chlorination etc. The MF technique gives good reproducibility and the results are obtained in one step, filters can be transferred between different media, large volumes of sample can be processed, is time saving, can be performed on site and bears low cost. While the test is not suitable for high turbidity samples, other bacteria or metals and chemicals adsorb on the filter and may inhibit the growth of coliforms.

Table 5.4: Other Indicator Organisms

S/N	Indicator organism	Characteristics	Significance
1.	*Clostridium perfringens*	anaerobic spore former, gram positive rod shaped and exclusively of fecal origin. Spores are resistant and persist for long periods.	useful indicator of past pollution, a tracer for less hardy indicators, protozoans and viruses.
2.	*Bifidobacterium* and *Bacteroids*	primarily associated with humans they can distinguish human and animal contamination.	*B. bifidus*survives for a short time therefore its presence suggests relatively recent pollution
3.	F-specific RNA phage, f2, φx174, MS2, PRD-1	Coliphages, not always seen associated with fecal pollution however their presence in high numbers in waste-water and high resistance to chlorination can be an index of waste-water contamination and indicators of enteric viruses.	useful for evaluation of virus resistance to disinfectants, fate of enteric viruses in water treatment and surface or groundwater tracers and presence of host.
4.	Phages of *Bacteroides fragilis*	of human origin exclusively	An advantage over coliphage is they help to detect human fecal contamination. They do not multiply in the water and have decay rate similar to other viruses.

5.	*Pseudomonas aeruginosa*	associated with the diseases of eye, ear, nose and throat infections. common opportunistic pathogen, causes life threatening infection in burn patients and immunocompromised individuals. Folliculitis, dermatitis, ear and urinary infections are common in ill maintained swimming pools.	this organism is of no value as indicator of fecal pollution however coliforms do not suit as indictor of contamination of swimming pool water as the contamination is not of fecal origin.
6.	*Staphylococcus aureus* and *Candida albicans*	suggests the sanitary quality of water because it presence is associated with human activities	Useful for recreational waters.
7.	*Aeromonas hydrophila*	occurs in uncontaminated, as well as contaminated waters. also an opportunistic pathogen in humans, animals and fish.	Because of its association with nutrient rich conditions it has been suggested as an indicator of nutrient rich status of the waters.

Source: Anuradha S. Nrurkar, 2006

3.2.4 Water Purification

Water purification forms a critical link in promoting public health and safety. It involves variety of steps which depend upon the type of impurities in the raw water source. The major operations done are sedimentation, flocculation, filtration and disinfection. Raw water becomes potable after this treatment (Figure 5.3). Impurities in raw water include suspended, dissolved, colloidal solids, bacteria,toxic substances, color, odor and mineral or organic matter. These can be categorised as chemical, physical and microbiological.

Table 5.5 indicates the drinking water standards adopted from that obtained in India. Different unit processes and operations are performed to remove different impurities (Table 5.6).

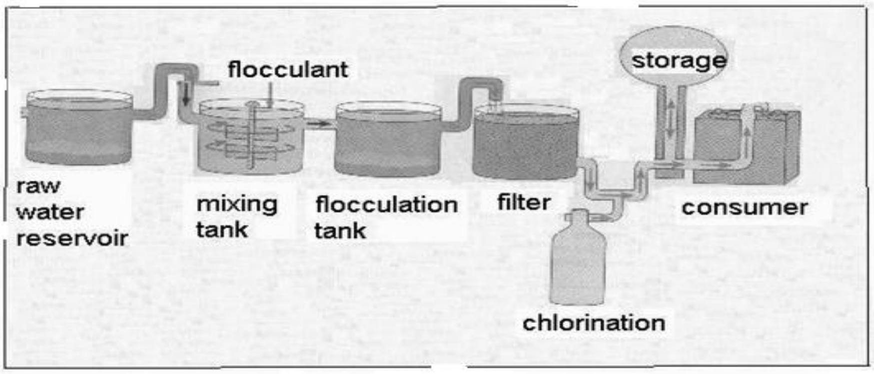


Fig. 5.3: Sequence of Processes in Water Purification
Source: Anuradha S. Nrurkar, 2006

Table 5.5: The Bureau of Indian Standards Defined Levels of Substances in Water and their Permissible Levels

S. No.	Substance / Test	Unit	Desirable limit	Maximum permissible limit*
1.	Physical turbidity	NTU	5	10
2.	Chemical pH	Number	6.5 – 8.5	No relaxation
3.	Hardness	as ($CaCO_3$) mg/l	300	600
4.	Chloride	as Cl mg/l	250	1000
5.	Iron	as Fe mg/l	0.3	1.0
6.	Nitrate	as N mg/;	45	No relaxation
7.	Fluoride	as F mg/l	1.0	1.5
8.	Residual chlorine	mg/l	0.2 – 0.5	No relaxation
9.	Arsenic	as As mg/l	0.05	No relaxation
10.	Coliforms	MPN/100 ml	10**	No relaxation
11.	E. coli	MPN/100 ml	0	No relaxation

Source: Anuradha S. Nrurkar, 2006

Table 5.6: Unit Processes and Operations and Specific Impurities Removed

S. No.	Unit Processes / operations	Effect
1.	Aeration, chemical oxidation, ion exchange, sedimentation	Colour and precipitate removal
2.	Chemical precipitation, (dosing, mixing, flocculation, settling) ion exchange	Softening (Ca, Mg removal)
3.	Chemical coagulation, (dosing, mixing, flocculation, settling) filtration	Turbidity removal
4.	Aeration, chemical oxidation, adsorption	Taste and odour removal
5.	Irradiation, ozonation, chlorination	Disinfection

Source: Anuradha S. Nrurkar, 2006

Most details of the above processes have been discussed in the course-Hydrology and Sanitation (EHS 304); hence you will gain much by referring to that for details. It should be known that without applied microbiology, the knowledge and practice of water purification would not have been easy. Most processes that take place in water treatment or purification still obtain in waste-water or sewage treatment. Against the above background, most of the above processes form different units in this course as you will see. The degree of treatment depends on the intended use or place or fate of final disposal site.

Potable water meant for drinking has to meet standards which will not allow the spread of water related and water borne diseases. To this end, any well-meaning country should meet with the standard approved by the World Health Organization (WHO). Applied water microbiology helps in achieving this. This is done through proper checking of water sources, storage, distribution, and supply systems to avoid its contamination/pollution. There is no denying the fact that EHO's are involved in doing this all important work.

The Nigerian Standard for Drinking Water Quality covers all drinking water except mineral water and packaged water. The standard applies to: drinking water supplied by state water agencies, drinking water supplied by community managed drinking water systems, drinking water supplied by water vendors and water tankers, drinking water used in public or privately owned establishments, drinking water used in food processing by manufacturers, drinking water from privately owned drinking water system and used solely for the family residence. Also, mineral water and packaged water shall comply with Nigerian Industrial Standards for Natural Mineral Water (NIS 345:2003) and Potable Water (NIS 306:2004) and used for regulation and certification by the National Agency for Food and Drug Administration and Control and SON respectively. (It is important to mention here that the standards for mineral water and packaged water have different allowable limits for various parameters presented here).

3.3 Air Microbiology

Aerobiology is defined as the study of life present in the air. *Aeromicrobiology* relates to the study of environmentally relevant micro-organisms. *Intramural Aerobiology* deals with indoor environment while *Extramural Aerobiology* deals with outdoor environment. No organism is indigenous to the atmosphere. Micro-organisms exist within 300-1000 feet of earth's surface that have become attached to fragments of dried leaves, straw or dust particles light enough to be blown by wind. In dry weather, the microbial load of air is high while in wet weather the rain washes the micro-organisms from the air. Air is not a medium in which micro-organisms grow, but it is a carrier of dust and droplets that may be laden with microorganisms. Large droplets settle out quickly while the droplet nuclei remain afloat. The spore formers and cyst formers are likely to survive better in the atmosphere for longer period. Depending upon the type and the climatic conditions the persistence of micro-organisms is observed. The micro-organisms come into the air via both land and water. Wind creates dust laden with microbes. From the ocean surface water droplets laden with microbes arise. Various agricultural, industrial and municipal processing facilities have the potential for generating microbe laden aerosols. The irrigation sprinkler, grain thrashing, sewage treatment facility, abattoirs etc, can serve as sources.

3.3.1 Air-borne Diseases

Air-borne diseases are caused by hardy micro-organisms and include diseases of plants, animals and human. The impact of plant pathogens esp. fungi on agricultural economy is enormous. Infection of pet and livestock by airborne pathogens is also significant as are the diseases in humans. The kinds of pathogenic micro-organisms present in the atmosphere associated with humans are viruses, protozoa, molds and bacteria (Table 5.7). Table 5.8 summarises the wide adverse effects on humans by contaminants present in the air which also includes the bacterial and fungal toxins. Air pollution by exhausts from industries is another matter. The consequences of industrial air pollution are irritation of skin, eyes and respiratory tract, thereby posing health hazards. Toxins of *Clostridium botulinum* is a potential biological warfare agent *Bacillus anthracis* has been used effectively in germ or biological warfare. A sophisticated training and machinery is required to tackle these agents.

Table 5.7: Air-borne Human Diseases of Importance and their Causative Agent

Bacteria	Disease	Virus	Disease
Streptococcus pyogenes	Sore throat	Influenza virus	Influenza
Corynebacterium diphtheriae	Diphtheria	Hantavirus	Pulmonary syndrome
Mycobacterium tuberculosis	Tuberculosis	Hepatitis virus	Hepatitis
Streptococcus pneumoniae	Pneumococcal pneumonia	Herpes virus	Chicken pox
Klebsiella pneumoniae	atypical pneumonia	Picorna virus	Common cold
Neisseria meningitidis	Meningococcal meningitis	Flavivirus	Dengue fever
Yersinia pestis	Bubonic plaque	Rubella virus	Rubella
Bordetella pertussis	Whooping cough	Measles virus	Measles

Haemophilus influenzae	Influenza	Influenza virus	Influenza
Nocardia asteroids	Nocardiosis	Hantavirus	pulmonary syndrome
Fungi		**Disease**	
Aspergillus fumigatus		Aspergillosis	
Blastomyces dermatiridi		Blastomycosis	
Coccidioides immitis		Coccidioidomyosis	
Cryptococcus neoformans		Cryptococcosis	
Histoplasma capsulatum		Histoplasmosis	
Pneumocystis carinii		Pneumocystitis	

(Source: Anuradha S. Nrurkar, 2006).

Table 5.8: Adverse Effects on Humans and Environment Associated with Exposure to Airborne Micro-organisms

S. No.	Agent	Humans	Environment
1.	Algae	Allergy	Odour
2.	Bacteria	Hypersensitivity, respiratory infections	Plant diseases, odour
3.	Fungi	Allergy, skin problems, respiratory infections	Deterioration of building materials, odour, plant diseases
4.	Endotoxin	Cough, headache, respiratory distress	None
5.	Mycotoxin	Cough, headache, respiratory distress	Disease in livestock
6.	Protozoa	Encephalitis, hypersensitivity infections	Protect other bacteria, disease to livestock
7.	Virus	Infections	Crop and livestock disease

Source: Anuradha S. Nrurkar, 2006

Without the knowledge of microbiology, the above ideas would have been strange before man and death of humans would have been recorded in their millions.

3.3.2 Fate and Transport of Micro-organisms in Air

The atmosphere is inhospitable place for microbes because of stress due to environmental factors like desiccation, temperature, relative humidity, radiation and oxygen. The majority of airborne micro-organisms are immediately inactivated as the result of this. Those hardy microbes that can survive these factors are able to cause the diseases. Oxygen stress relates to the reactive oxygen species. Another term, ‘Open Air Factor’ (OAF) in this connection describes the environmental effect that cannot be replicated in the laboratory settings. When ozone and hydrocarbons (usually ethylene) alone with the oxygen act together the inactivation rates of microbes is greatly affected. Micro-organisms like fungi cannot survive and complete their life cycles by staying afloat in air for an indefinite period of time. Bioaerosols in the air harbour the microbes. They vary in size. Large droplets in the air are of 100 μ and like dust, settles rapidly in quiet air. Small droplets on the other hand in warm, dry atmosphere dry quickly to form droplet nuclei. These are of 2-5 μm size, light and may float about for many minutes or even hours. The micro-organisms in them are protected by dried mucus which coats them. Being small, these escape the mechanical traps of the upper respiratory tract and enter the lungs. They may settle on the alveolar tissue. Transmission of airborne pathogens usually occurs via droplet nuclei. The *aeromicrobiological pathway* (AMB) describes the launching of the aerosols in the air, the subsequent transport via diffusion and dispersion, and finally their deposition e.g. droplet nuclei having influenza virus which is launched via coughing, sneezing or taking in the air.

3.3.3 Microbological Analysis of Air

Many sampling devises are available for air sampling. The impingement, bubbling, atomising, electrostatic membrane filter devices etc. are some of the devices used for collection of air. The choice rests on the availability, cost, air volume, mobility, sampling efficiency and overall efficacy of the device for sample microorganisms. On the basis of their sampling method, several types of samplers using impingement, centrifugation, filtration and deposition are available. *Deposition* is easiest and most cost effective method of sampling. It can be accomplished by merely opening an agar plate and exposing it to air which results in direct impaction, gravity settling and other depositional forces. This has quite low sampling efficiency.

Impingement is the trapping of airborne particles in liquid matrix. Impingement device operates by drawing air through an inlet that is similar in shape to the human nasal passage. *Anderson sampler* is multilevel, multi-orifice, cascade sampler which is commonly used (Figure 5.4). The air that is sucked through the sampling port strikes agar plates. Larger particles are collected on the first layer and each successive stage collects smaller and smaller sized particles.

Filtration is the trapping of airborne particles by size exclusion and deposition is the collection of airborne particles using only naturally occurring deposition forces. Filtration and deposition are widely used for cost and portability reasons. The filtration is used for lipopolysaccharide airborne levels. *Centrifugal sampler* uses circular flow patterns to increase the gravitational pull within the sampling device in order to deposit particles (Figure 5.5). The cyclone, a tangential inlet and return flow sampling device is the most common type. As a result of increased centrifugal forces imposed on particles in the airstream the particles are sedimented out. Liquid medium is used to trap the microbes. Its efficiency is low, but it is inexpensive, easily sterilised and portable. Traditionally, culturable and microscopic methods have been used. Now immunoassay method is used extensively in biomedical research for bioaerosol analysis. Fluorescence immunoassay and radioimmunoassay are used for allergens such as dust mite allergen and animal dander. Biochemical assays are used to measure endotoxins or mycotoxins.

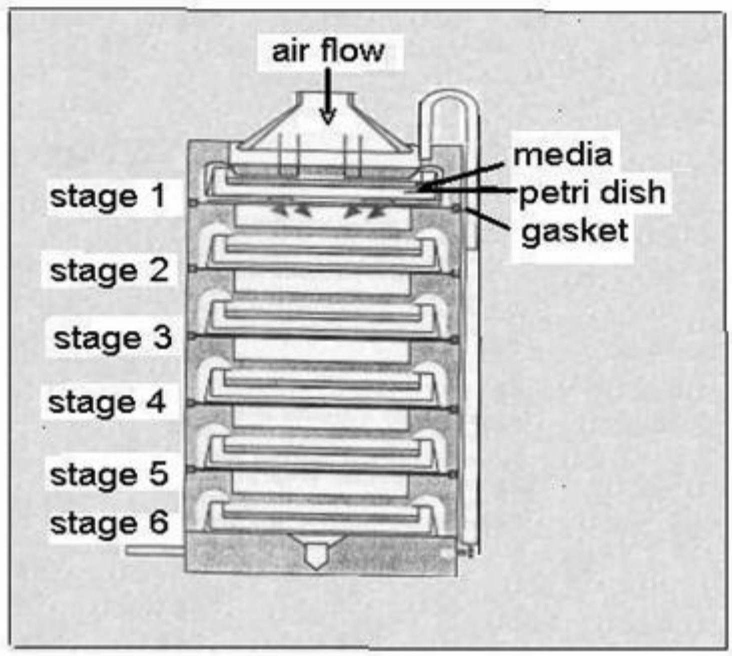


Fig. 5.4: Anderson Sampler

Source: Anuradha S. Nrurkar, 2006

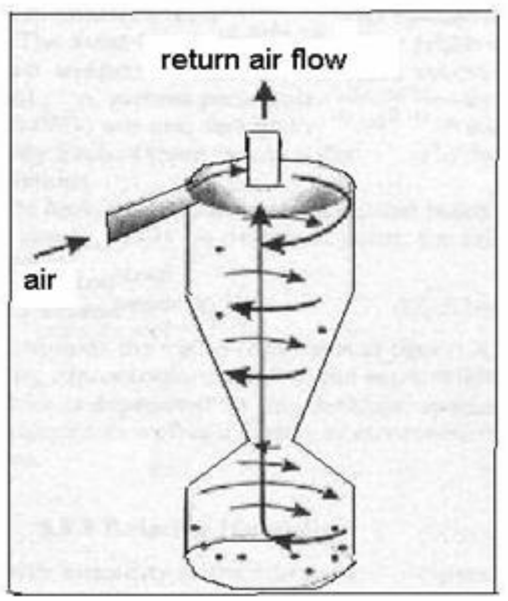


Figure 5.5: Centrifugal Sampler.
Source: Anuradha S. Nrurkar, 2006

3.3.4 Control of Airborne Microorganisms

Thorough dilution of contaminated air by ventilation is a very effective means of controlling airborne diseases indoors. However, it is expensive since special ducts or blowers need to be installed. Disinfection or more rarely sterilisation of air is desirable. Three general methods used for control of micro-organisms of indoor air are radiation, bactericidal vapors and dust control. Irradiation with ultraviolet light of the 254 nm wavelength is sufficiently microbicidal at the same time not irritating. UV lamps are attached at strategic points overhead. Deflectors are provided to prevent direct exposure of persons to UV rays which may be permanently injured. Many substances are lethal to micro-organisms in the vapor phase. These are formaldehyde, ethylene oxide, β propiolactone which are used as bactericidal vapor. Probably the most effective are propylene glycol and triethylene glycol. These are odorless, tasteless, nonirritating, nontoxic, noncorrosive and nonexplosive. They are highly effective in killing bacteria in the air although ineffective in the form of concentrated aqueous solutions. As little as 0.5 mg/L of propylene glycol vapor for 15 seconds can sterilise heavily contaminated air. Other agents like orthophenylphenol etc are used for surface applications. Dust control is also good means of keeping micro-organisms out of the air especially indoors or intramural air, as droplet nuclei remain afloat for long time in the air. In hospital wards dust from clothing or bedding can be a means of disease transmission. Floors and sweepings are oiled to control dust. Microbiological laboratories carrying out research with pathogens and recombinant microbes, generate aerosols via centrifuges, vortex etc. Special equipments e.g. the biosafety cabinets and other containment devices are designed to control spread of airborne microbes.

3.4 Food and Dairy Microbiology

The modern human diet includes a wide variety of foods including fruits, vegetables, meat, milk etc. Raw food, if properly handled and processed, should contain low levels of microorganisms. Different foods provide different conditions for microbial growth and thus differ in their microbial contents. *Food Microbiology* encompasses the study of micro-organisms causing detrimental as well as beneficial effects in food. *Microbial Biotechnology* is a modern adjunct of the traditional Food and Industrial Microbiology.

3.4.1 Micro-organisms in Food

Various kinds of micro-organisms are associated with food. Micro-organisms in fruits and vegetables depend on the post harvest handling. Fungi are predominant organisms associated with low acid food while the medium acid kinds have bacteria associated with them. Milk as soon as it is drawn from the cow has low microbial count. The milking equipment, the cow, personnel, air, and lack of sanitary practices contaminate the milk. Refrigerated meat has low counts. Chopping and grinding increases the numbers as new surfaces are introduced. Microflora in the poultry is introduced during killing, defeathering and evisceration. Eggs are free of micro-organisms due to the hard shell and the underlying thin membrane. Cracks in the shell however will result in contamination.

3.4.2 Beneficial Effects of Micro-organisms in Food

The effect of micro-organisms on food can be classified as beneficial effects e.g. fermented foods, microbes as food and genetically modified foods; neutral effects and detrimental effects e.g. food spoilages and food poisonings and infections. *Food* fermentations generate organic compounds and transform foods into those with more desirable characteristics like enhancement of flavor, texture, digestibility etc. Cheese is an ancient fermented food involving a significant role of micro-organisms in its preparation. Different starter cultures with variable conditions result in unique flavor and texture characteristic of cheese. Lactic acid bacteria are used as starter culture. Casein, the milk protein is destabilised by enzymes and heat in presence of calcium in the process of curdling. The excessive proteolysis of curd causes bitterness in cheese. Solids after curdling are separated and formed into cubes for unripened cottage cheese or paneer. In cream cheese preparation the starting material is cream. In the ripened cheeses selected bacterial and fungal species under specific conditions of time, temperature and humidity are encouraged to grow.

Ripening gives the characteristic flavor that is end result of release of many compounds due to the enzymes released by the ripening agents. Thus, every cheese uniquely has a typical taste, flavor, texture and appearance. Another classification of cheese is based on the specific amount of moisture removed from the curd with the help of salt. The soft cheese has 50-58%, semi-hard 45% and hard cheeses have < 40% moisture (Table 5.9).

Apart from cheese many *fermented dairy products* with enhanced nutritive and probiotic values are consumed world over (Table 5.10). The probiotic effects of these products include many beneficial effects. It modifies microbial flora in lower intestine, have antimicrobial activity, minimizes lactose tolerance, lowers serum cholesterol, have anticancer activity, promote calcium absorption and synthesise B complex vitamins. Locally, cassava is fermented to form 'Akpu' which is used in making the well-cherished cassava *foofoo*.

Bread is also an ancient food. Baker's yeast *Saccharomyces cerevisiae* is added to dough for leavening which causes the dough to rise. The maltase, invertase and amylase of yeast act on starch to produce sugars. Further fermentation of sugars is done to produce minimum alcohol and majorly CO_2. Alcohol imparts flavor while CO_2 causes the rise of dough giving it a texture. The dough is conditioned during fermentation by protease action on the flour producing gluten. Gluten makes the dough elastic and retains the CO_2. The leavening is done for 2h at 27°C. This follows baking at 100°C which kills the yeast, inactivates the enzymes, evaporates alcohol and expands the gas. Gelatinisation of starch due to action of enzymes earlier results in setting of the bread. The structural support to dough is given by the gluten while in the baked bread it is given by gelatinised starch. In rye bread, yeast like *Torulopsis holmii*, hetero-fermentative (those producing along with lactic acid other fermentation products) *Lactobacillus* spp. *L. plantarum, L. brevis,* L. *bulgaricus, Leuconostoc mesenteroides* and *Streptococcus thermophilus* are used.

Table 5.9: Major Types of Cheeses and Micro-organisms involved

Type of cheese	Micro-organisms in early stage	Micro-organisms in late stage
Soft, unripened Cottage cheese Mozzarella (Italy) Paneer (India)	*Lactococcus lactis ,* *Leuconostoc cremoris* *Streptococcus thermophilus,* *L.bulgaricus*	All are unripened

Soft, ripened Brie (France) Camembert (France)	*Lactococcus lactis,* *L . lactis, L .cremoris*	*Penicillium camemberti* *P. candidum,* *Brevibacterium linens* *P.camemberti, B.linens*
Semisoft Blue(France) Brick(US) Limburger (Belgium) Monterey (US) Muenster (US) Roquefort (France)	*L.lactis, L. cremoris* *L.lactis, L. cremoris* *L.lactis, L. cremoris* *L.lactis, L. cremoris* *L.lactis, L. cremoris* *L.lactis, L. cremoris*	*P.roquefortii* *B.linens* *B linens* *B linens* *B linens* *P.roquefortii*
Hard, ripened Cheddar (UK) Colby (US) Edam (Netherlands) Gouda (Netherlands) Swiss (Switzerland)	*L.lactis,L.cremoris* *Enterobacter durans* *L.lactis,L.cremoris* *Enterobacter durans* *L.cremoris, L.lactis* *L.cremoris, L. diacetylactis* *L. lactis, L.helveticus S.thermophilus*	*L.casei ,L. plantarum* *L.casei* *Propionibacterium shermanii* *P.freundenreichii*
Very hard, ripened Parmesan (Italy)	*L.lactis, L.cremoris* *S. thermophilus*	*Lactobacillus bulgaricus*

Source: Anuradha S. Nrurkar, 2006

Table 5.10: Fermented Milk Products

Product	Starter culture
Yogurt	*Streptococcus thermophilus, Lactobacillus bulgaricus*
Cultured buttermilk	*S.lactis, S.crenoris, Leuconostoc citrovorous* or *L.dextranicurn*
Bulgarian milk	*L.bulgaricus*
Acidophilus milk	*L.acidophilus*
Kefir and Kumiss	*S.lactis, L.bulgaricus,* lactose fermenting yeast

Source: Anuradha S. Nrurkar, 2006

Alcoholic beverages are produced by special strains of *Saccharomyces cerevisiae* carrying out alcoholic fermentation in anaerobic conditions. Wine, beer and distilled liquor are included in alcoholic beverages. *Wine* is fermented grape juice or juice from other fruits. The grapes are crushed to form juice called must. Special strains of *Saccharomyces cerevisiae* called wine yeast is used as inoculum. The conditions for fermentation include 24-27°C temperature for 3-5 days for red wine (from blue grapes) and 10-21°C for 7-14 days for white wines (from green grapes). Wines are called dry when no residual sugar is present. Sweet wines have residual sugar while sparkling wine has CO_2 imbibed in it. Anthocyanin in the skin of grapes gives it a red color. The wine is racked subsequent to fermentation. Racking filters the wine. Generally, wines are not distilled. Their spoilage is controlled by pasteurisation. Enzymes like pectinases are used to clarify the wine before pasteurisation. *Beer* and ale are called malt beverages because the substrate involves barley malt. Barley is malted by germination which releases mixture of amylases and proteinases. Malt adjuncts like corn, rice and wheat are added followed by mashing. The amylases act on carbohydrates and proteins of the adjunct. The mash is cooked at 70°C facilitating rapid starch hydrolysis. The insoluble material settles giving a clear liquid called wort. Hops that are dried flowers of *Humulus lupulus* or hop plant are added and the mixture is cooked. This concentrates the wort, inactivates the enzymes, kills micro-organisms and extracts soluble flavoring compounds from the hops. Resins and humulone have antibacterial property that protects the wort against Gram positive bacteria. The next step is the actual batch fermentation using special strains of *Saccharomyces cereivisae* called Brewer's yeast. The *S. cerevisiae* is top fermenting yeast since it flocculates while *S. carlsbergensis* is called bottom fermenting since it settles down at appropriate time, partially clarifying the beer. Inoculation of wort is called pitching. After initial aeration the fermentation is allowed to become anaerobic. Small amount of glycerol and acetic acid are formed. Higher alcohols, acids and esters also contribute to flavor. The resulting product is called green beer. This needs aging to achieve the flavor, taste and aroma of the finished beer. During aging precipitation of proteins, yeast and resins occur mellowing the beer. Mature beer is filtered and carbonated to achieve a CO_2 content of 0.42-0.52%. In commercial process, the CO_2 is collected during fermentation and reinjected. The alcohol contents of beer ranges from 3.6-8%. *Light beer* (low calorie), *ale* and *sake* (rice beer) are the variations of beer. Like wine, pasteurisation prevents spoilage of beer. *Distilled liquors* or spirits are high alcohol containing hard liquors. The general types of distilled liquors include brandy from fermented fruit juices, rum from fermented molasses and whisky from fermented mash of mixed grains. Distiller's strains of *S. cereivisiae* are used. Micro-organisms contribute significantly to improve fruits vegetables and beans after fermentation (Table 5.11).

Table 5.11: Fermented Fruits, Vegetables and Beans

Product	**Process / Micro-organisms**
Sufu (Chinese)	Tofu-coagulated soybean fermented by *Actinomucor elegans* and *Mucor* spp.
Tempeh (Indonesian)	Soybean mash is fermented by *Rhizopus*

	oligosporus and *R. oryzae*
Saurkraut	Shredded cabbage containing 2.2 –2.8% NaCl is fermented by *Leuconostoc mesenteroides*, *Lactobacillus plantarum* and *Lactobacillus brevis* successively
Cucumber pickles	Cucumber + dill seeds in brine at 50% NaCl is fermented by*Leuconostoc mesenteroides, Enterococcus faecalis, Pediococcus cerevisiae*, *Lactobacillus brevis, L. plantarum* (dominant)
Silo	Grass, chopped corn and animal feed is stored under moist anaerobic conditions, to undergo lactic acid mixed fermentation
Olives	Lactic acid fermentation by *Leuconostoc* spp. followed by *L. plantarum,* *L. brevis*, yeasts and various bacteria.

Source: Anuradha S. Nrurkar, 2006

Many fermented grain products are used world over. One such is soy sauce, a brown, salty, tangy sauce used as condiment by Japanese and Chinese. A mash of soy beans, wheat and wheat bran is fermented by *Aspergillus oryzae* in solid substrate fermentation. The mouldy substrate obtained at the end of the fermentation is called koji, which is extracted after drying. Proteases, amylases and lactic acid of the bacteria act on soybean and wheat. The extract, autoclaved soybean and crushed, steamed wheat are mixed. The resulting mixture is called maromi. This is incubated at 30°C for 10 weeks to a year. During this period a succession of micro-organism *Pediococcus soyae*, yeasts such as *Saccharomyces rouxii*, *Zygosaccharomyces soyae*, *Torulopsis* carry out alcoholic fermentation.

Aspergillus oryzae is the most important organism. *Lactobacillus* spp. produces lactic acid thereby preventing spoilage. *Miso* is also produced by koji fermentation of rice by *A. oryzae*. It is ground to paste and combined with other food. *Natto* is produced from boiled soybeans by *Bacillus subtilis*. Proteinase softens and increase flavour of soybeans. *Poi* is a Polynesian fermented product. Stems of Toro plant are steamed, ground and subjected to fermentation by succession of coliforms, *Pseudomonas*, *Lactobacillus*, *Streptococcus* and *Leuconostoc*. Finally yeasts and *Geotrichum candidum* flourish. The fermentation product are lactic acid, acetic acid, formic acid and CO_2.

Micro-organisms as products include Baker's yeast and Single cell protein. The *Baker's yeast* is produced by growing special *Saccharomyces cerevisiae* strains with high growth rate and white color, for their biomass in molasses and mineral medium. 0.5 – 1.5% sugar is used since too high a concentration represses respiratory enzymes. The yeast cream which is white in color is collected, centrifuged and dewatered. The processing steps decide whether high moisture containing compressed yeast is final product or granulated active dry yeast (8% moisture). The compressed yeast requires refrigeration while the active dry yeast does not. The wine, brewer's, distiller's and baker's yeast can also be used as food or feed supplement called *single cell protein* (SCP). In fact a variety of bacteria, yeasts and fungi have been cultivated as SCP, so named because they are derived from single celled organisms (Table 5.12). The protein is extracted from cultivated microbial biomass.

Table 5.12: Comparison of Various Parameters of SCP Production from Algae, Fungi and Bacteria

Parameters	Algae	Bacteria	Yeast	Moulds
Growth rate	Low	Highest	Quite high	Lower than bacteria
Substrate	Light, CO_2, inorganic solution	Wide range Agricultural waste, C_1, C_4 compounds, methanol, molasses etc.	Wide range, molasses, wheat, molasses, whey etc.	Mostly lignocellulosic
pH	Up to 11	5-7	5-7	3-8
cultivation	ponds Bioreactors	Bioreactors	Bioreactors	Bioreactors
Contamination risk	High	Precautions needed	Low	Least
S-containing amino acids	Low	Deficient	Deficient	Low
Nucleic acid removal	--	Required	Required	Low
Toxin	--	Endotoxin from Gm negative bacteria	--	Mycotoxins
Proteins	40-60 %	50-83 %	30-70 %	30-70 %
Lysine	Low	Low	High	High

Source: Anuradha S. Nrurkar, 2006

It can replace costly protein supplements like soya meal and fishmeal. Moreover, agricultural waste and inexpensive substrate can be used as raw material for SCP production giving value-added products. The proteins from microbial sources have all the essential amino acids.

Algae are rich in vitamins and low nucleic acids. Fungi are rich in B-complex vitamins. Yeasts also contain vitamins. Bacterial SCP has highest proteins (80%) but nucleic acids especially RNA is high. The limitations of SCP are presence of indigestible cellulosic cell wall in algae, mycotoxins of fungi, high cost of protein extraction and nucleic acid contents in bacteria. Yeast has acceptability due to familiarity while with others there is a psychological barrier to use the bacteria as major food source. The different micro-organisms as SCP are grown on different inexpensive substrates (Table 5.13).

Food additives enhance the quality of food nutrition and flavour. Many vitamins, amino acids, enzymes, nucleotides and organic acids used in food industry are obtained from microbial cultures. The metabolic control mechanisms that prevent it from overproducing these compounds must be circumvented before large quantities of the desired byproduct can be synthesized and harvested. Nucleotides are used to enhance taste of food. *Enzymes* are used in various roles in number of processes related to food processing (Table 5.13).

Table 5.13: Common Microbial Food Enzymes

Enzymes	**Source**	**Reaction & Applications**
Amylase	*Aspergillus*	Starch □□sugar, brewing, syrup production
Invertase	*Saccharomyces cerevisiae*	Sucrose □□glucose + fructose manufacture of candies
Pectinase	*Aspergillus*	Pectin □□oligosaccharides + galacturonic acid. fruit juice clarification and preparation of concentrates
Renin	*Endothocia, Mucor*	Coagulation of casein, curdling in cheese production
Proteases	*Bacillus, Aspergillus*	Protein hydrolysis, meat tenderization
Diacetyl reductase	*Enterobacter aerogenes*	Diacetyl removal, prevention of certain off flavors in beer and fruit juices
Lactose	*Kluveromyces fragilis*	Lactose □□galactose + glucose, digestion of lactose in milk,prevention of lactose crystallization in ice cream
Naringinase	*Aspergillus niger*	Elimination of naringin, removal of bitter taste from orange juice
Glucose oxidase	*Aspergillus niger*	Glucose □□gluconic acid, prevention of browning in dried eggs

Glucose isomerase	*Bacillus Arthrobacter*	Glucose □□fructose, preparation of very sweet syrups

Source: Anuradha S. Nrurkar, 2006

Vitamins are essential nutritional factors used as dietary supplements. Phenylalanine and aspartic acid are ingredients of aspartame, artificial sweetener. *Amino acids* from microbial fermentation are advantageous since products include only L-amino acids while chemical synthesis gives a racemic mixture. Economic production of amino acids is possible due to strains defective in regulation. Several *organic acids* including acetic, gluconic, citric, itaconic, gibberellic and lactic acid are produced by microbial fermentations (Table 5.14).

Table 5.14: Some Vitamins, Amino Acid and Organic Acid Produced by Fermentation

Product	Culture
Vitamin B12	*Propionibacterium shermanii*
Riboflavin	*Ashbya gosypii*
Vitamin C precursor (5 ketogluconic acid)	*Gluconobacter oxidans*
Lysine	Homoserine requiring auxotroph of *Corynebacterium glutamicum*
Glutamic acid (used in aginomoto or mono-sodium glutamate)	*Corynebacterium, Brevibacterium or Arthrobacter* spp.
Citric acid	*Aspergillus niger*
Lactic acid	*Lactobacillus delbruckii*
Fumaric acid	*Rhizopus*
Gluconic acid	*Aspergillus niger*

Source: Anuradha S. Nrurkar, 2006

Vinegar production is a two step process, first is the anaerobic alcoholic fermentation by *S. cerevisiae* followed by oxidative transformation of alcohol to give acetic acid by *Acetobacter*. The starting material may be fruits such as grapes, oranges, apples, pears, vegetables such as potatoes, malted cereals such as barley, rye, wheat and corn and sugary syrups such as molasses, honey etc. The resulting vinegar is called wine vinegar from wine, cider vinegar from apple and so on. The *Acetobacter* process has evolved progressively in fermenter design to accomplish optimum oxygen transfer to bacteria. In Orleans process the acetic acid bacteria grow as a film on the top of shallow static pans. Next evolved the Fringe’s vinegar generators with wood shavings on which the bacteria grow. Alcohol trickles down and is oxidised to acetic acid. When submerged culture reactors are employed, they are called acetator and cavitator. Forced aeration maximises the rate of acetic acid production. The product is filtered and allowed to age to achieve the desired flavour. Genetically modified food also called genetically engineered food, Franken food or genetically altered food. Genetically modified organisms are those whose genetic material is modified to create new life forms that would never occur in nature under natural conditions of crossbreed or natural recombination. To create genetically engineered crops genes from bacteria, viruses, plants, animals have been inserted into plants like soybean, corn, canola and cotton. Thus, genetic manipulation is directed to have food with long shelf life, enhanced disease resistance, enhanced taste, improve appearance and high nutritive value. A concern expressed is about the safety of the products since the regulations and laws are same as for the natural foods. However, the manufacturer must show that it does not contain allergic or toxic substances. Additionally changes in the levels of important nutrients have to be reported. Many products are on the shelves in the market. Some of the products on the way are listed in the Table 5.15. Rot-resistant tomatoes are among the first commercially available GM food. It is a product of antisense technology. Rotting is the effect of softening enzymes, fungal growth, or over ripening of the fruit. To prevent premature ripening (before arrival in the market) tomatoes that cannot express a ripening associated gene have been produced. This is accomplished by inserting another gene into the tomato plant, a gene with a nucleotide sequence complementary to that of the gene that produces an ethylene generating enzyme (ethylene is the plant hormone that triggers natural ripening). The single-stranded messenger RNAs transcribed from these genes are complementary and form a double-stranded RNA within the cell that cannot be translated. When ripening is desired it can be induced by exposing the tomatoes to ethylene. The antisense gene is introduced via *Agrobacterium tumifaciens* Ti plasmid.

BT cotton has an advantage of enhanced protection against lepidopteran insect the spp. that causes disease in cotton. The cotton is genetically engineered to produce *Bacillus thuringensis* var *kurstaki* insecticidal crystal protein and have inbuilt protection against these insect pests.

Table 5.15: Genetically Modified Products and Modification

Product	**Modification**
Rapeseed, tobacco, Soybean, Corn	Herbicide resistance
Cotton, Potato	Insect resistance
Baker’s yeast	Increased fermentation speed
Tomatoes (Flavr savr)	rot resistant
Rice (Golden rice)	Vitamin A gene introduced
Rice	Soybean glycinin gene has 20% more protein
Wheat	Withstand high glyphosphate

Maize	Herbicide resistance
Peas	has α-amylase inhibitor
Pharmaceutical crops	Vaccine producing
Fish	Growth faster

Source: Anuradha S. Nrurkar, 2006

3.4.3 Detrimental Effects of Micro-organisms on Food

Food, being perishable commodity is liable to microbial spoilage by intrinsic factors that include pH, moisture content, water activity or availability, oxidation-reduction potential and presence of antimicrobial substances. Substances like aldehydes, phenols, coumarines, lyzozyme in various foods prevent spoilage to certain extent. Moulds in moist conditions spoil corn and grains. *Claviceps purpura* produces hallucinogenic alkaloids that cause ergotism, a toxic condition. Aflatoxins and fumonisins of fungal origin are carcinogenic. Aflatoxins are produced by *Aspergillus flavus* in infected grains and nuts. Fumonisins are produced by *Fusarium moniliforme* and is implicated in oesophageal cancer in humans. Meats and dairy products are easily spoilt. Microbial spoilage causes putrefaction (degradation of proteins) since they are high protein containing foods. Food may be spoilt before canning or due to improper canning or leakage of cans during cooling. Spoiled canned food can alter its color, texture, odour and taste. Organic acids, sulfides and gases like CO_2 and H_2S spoilage in canned food can be classified according to the can's appearance.

Raw milk undergoes a predictable four steps succession of micro-organisms during spoilage. Acid production by *Lactobacillus lactis* is followed by additional acid production associated with the growth of more acid tolerant *Lactobacillus*. At this point, yeasts and moulds become dominant and degrade the lactic acid gradually decreasing the acidity. Eventually protein digesting bacteria become active resulting in putrid odor and bitter flavor making the milk clear.

Raw and pasturised milk are also spoilt by *Streptococcus lactis* (souring), coliforms (gas production), *Micrococcus*, *S. faecalis*, *Pseudomonas* spp., *Flavobacterium* spp., *Chromobacterium* spp. (proteolysis), *Alcaligenes viscolactis*, *Klebsiella pneumoniae*, *Enterobacter aerogenes* (ropines). Moulds like *Geotrichum*, *Cladosporium* and *Penicillium* spp. also attack fermented milk. Fruits and vegetables have much lower protein and fat contents. Therefore, they undergo spoilage by bacteria that degrade the carbohydrates. Soft rot is caused by *Erwinia carotovora* that produces hydrolytic enzymes like pectinases.

Initially, the fruits are attacked by moulds damage the outer layer leaving it open to bacterial attack. *Lactobacillus* and *Leuconostoc* spp. spoil the frozen citrus products by virtue of production of diacetyl-butter flavours. *Saccharomyces* and *Candida* are predominant spoilage organisms in juices. *Pseudomonas* spp. causes green rot, *Alcaligenes,* coliforms, *Acinetobacter,* and *Pseudomonas* cause colorless rot and *Proteus* causes black rot in eggs. Contaminated eggs with *Salmonella* are a common source of food poisoning.

Food borne diseases or food poisoning is a general term used, meaning food-borne illnesses. It may be caused by plant, animal or chemical contaminations in food apart from microbial ones. There are two general categories of microbial food poisonings. Firstly, food intoxication results from the ingestion of exotoxin secreted by bacterial cells growing in food. Vomiting, diarrhoea or severe muscle spasm are the symptoms. The second category is food infection, which is associated with the ingestion of the microorganism that causes gastrointestinal disorders. The major forms of bacterial food poisonings are summarised in Table 5.16.

Table 5.16: Major Forms of Bacterial Food Poisonings

I) Intoxications	**Food (s)**
Staphylococcus enteritis by *S. aureus*	custards, salad, dressings, pastries
Botulism by *Clostridium botulinum*	poorly canned low acid food
Enterotoxaemia by *C. perfringenes*	inadequately cooked meat
Enterotoxaemia by *Bacillus cereus*	reheated rice, potatoes, puddings
II) Infections	
typhoid by *Salmonella typhi*, Salmonellosis by others	Poultry, eggs, dairy products, mango pulp
Shigellosis by *Shigella* spp.	Unsanitary canned food
Enteritis by *Vibrio parahaemolyticus*	poorly cooked seafood
Listeriosis by *Listeria monocytogenes*	poorly pasteurized milk, cheese
Enteritis by *E. coli*	contaminated raw vegetables, cheese

Source: Anuradha S. Nrurkar, 2006

3.4.4 Food Preservation

Preservation methods are aimed at preventing the incorporation of microbes into food, removing or destroying microbes in food and keeping microbes from multiplying. Modern food preservation uses refrigeration, freezing, dehydration and canning. *Aseptic handling* and processing prevents the entry of microbes in the food. Fruits, vegetables, grains are vigorously washed to reduce contaminants level. Meat, milk and eggs are taken as aseptically as possible to reduce contamination during handling. Flies and insects are stopped by covering food or eliminating pests from canning area. Utensils are cleaned properly and care is taken to avoid cross contaminating cutting boards. *Refrigeration* retards microbial growth, however, on extended storage psychrophiles produce spoilage. *High temperature* is the safest and reliable method. Moist heat is generally used. *Canning* introduced by Appert is called Appertisation or commercial sterilisation intended to destroy the *C.botulinum* spores and not complete sterilisation. Enough heat is supplied for 12D treatment which means 12 decimal reduction or reduction in microbial population by 12 log cycles. Canned food is treated in special containers called retorts (which work on the principle of autoclave) at 115°C for 25-100 min. depending on the nature of the food.

Pasteurisation, another widely used process for milk, beer, wines etc. kills most of the disease causing bacteria esp. *Mycobacterium tuberculosis* in milk. The LTH, *low temperature holding process* or vat pasteurization is heating each and every particle of milk at 145°F (62.8°C) for 30 min. The HTST or *high temperature short time* process or flash pasteurisation uses 161°F (71.7°C) for 15 sec and the UHT, *ultra high temperature* is treated at 141°C for 2 sec. *Irradiation* both ionising and nonionising are used to target opportunistic pathogens like *E.coli* 0157H7. Herbs, spices and seasonings are irradiated to keep the microbial count low. It is also used to kill the insects from wheat products, prevent sprouting of potatoes during storage and delay fruit ripening. People need to be educated as regards the safety of irradiated food. A more familiar word like cold pasteurisation should be substituted to facilitate that. The irradiated foods carry the international irradiation logo. For deeper penetration gamma rays dose of 4.5 – 5.6 megarads produced by Cobalt 60 are used. Alternatively high energy electron accelerator generates electrons that are faster than γ rays but have low penetration.

Dehydration is an age-long process. Sun drying is used for grains, meat, fish and fruits. Microwaves are high frequency electromagnetic microwaves that create vibrations among the molecules of food creating heat that kills the microorganisms. High osmotic process is used to withdraw water from microbial metabolism. The effect is similar to dehydration. Chemicals that are 'generally regarded as safe' (GRAS), include organic acids, sulfite, ethylene oxide as sterilents. Sodium nitrite and ethyl formate are solid preservatives. The Food and Drug Administration of US gives the GRAS status to harmless chemicals. These chemicals damage the plasma membrane, denature various cell proteins, and interfere with the functioning of nucleic acids and kill microorganisms. The concentrations used are 0.1 –0.3% or 15–700 ppm. Antibiotics like nisin a polypeptide agent are used in food preservation. Nisin is produced by *Lactococcus lactis* and affects gram positive bacteria.

3.4.5 Microbiological Examination of Food

A problem in maintaining the food safety is the need to detect micro-organisms in order to curb outbreaks. Microbiological examination provides information on quality of raw food, cleanliness of food handling operations and efficacy of preservation method. Spoilage organisms can be detected making way to prevent it.

WHO has formulated Hazard Analysis and Critical Control Point (HACCP) programme. It is a management system in which food safety is addressed through the analysis and physical hazards from raw material production, procurement and handling to manufacturing distribution and consumption of the finished product

4.0 CONCLUSION

From all that have been discussed so far, we can conclude that without applied microbiology, man's existence in this world would have been summarized before now due to the effect of micro organism. This group of organism is ubiquitous and therefore thrives everywhere; in our water, waste-water, food, meat and meat products and air. Whereas some are harmless, some are harmful and a reasonable chunk of them are useful. The above scenario has made man study them in details with the full aim of eschewing their ill effects and harnessing their potentials for the betterment of man while he lives.

5.0 SUMMARY

In this unit, you have learnt some aspects of applied microbiology under so many headings and sub-headings.

- In waste-water microbiology, the study was made under self purification, characterisation of sewage and conventional sewage treatment. Here, processes of sewage treatment were discussed briefly and made to be discussed in details later.
- Water microbiology came next and in it the definition and qualities of portable water were given. Also learnt were issues about waterborne diseases, microbiological examination of water and its purification.
- In air microbiology study, its meaning was explained before discussing air-borne diseases. The fate and transport of micro-organisms in air were equally treated. Also explained were microbiological analysis of air and control of airborne microorganisms.
- Then came that of food and dairy microbiology where issues like micro-organisms in food, beneficial and detrimental effects in and on food were discussed. The study of food preservation and its microbiological examination came last.

6.0 TUTOR- MARKED ASSIGNMENT

1. Using a sketch, give the processes involved in conventional treatment of waste-water.
2. Why is the study of water microbiology important?
3. Discuss the beneficial aspect of microorganisms.
4. Discuss the detrimental effects of micro-organisms in food.

7.0 REFERENCES/FURTHER READING

Anuradha, S. N. (2006). *Applied Microbiology – Present Status of Applied Microbiology in India.* The Maharaja Sayajirao University of Baroda: Department of Microbiology and Biotechnology Centre, Faculty of Science.

Atlas, R.M. (1997). *Principles of Microbiology*.(2nd ed.). USA: WMCBrown Publishers.

Frobisher, M., Hinsdill, R.D., Crabtee, R.T. & Goodheart, C.R. (1974). *Fundamentals of Microbiology*. (9th ed.). London: W.B.Saunders Co.

Hammer, M.J. & M.J. Hammer, Jr. (1996). *Water and Waste-water Technology*. (3rd ed.). Prentice Hall, USA.

Hurst, C.J., Knudson, G.R., McInerney, M.J., Stetzenbach, L.D. & Walt, M.V. (1997). *Manual of Environmental Microbiology*. USA: ASM Press.

Nigerian Industrial Standard. (2007) & Nigerian Standard for Drinking Water Quality (2007).*Standard Organisation of Nigeria (SON).*

Maier, R.M., Pepper, I.L. & Gerba, C.P. (2000). *Environmental Microbiology*. New York: Academic Press.

Peleczar Jr, M.J., Chan, E.C.S. & Krieg, N.R. (1993). *Microbiology: Concepts and Applications.* (International Edition). New York: McGraw Hill Inc.,

Prescott, L.M.,J.P.Harley & D.A.Klein. (2002). *Microbiology*. (5th ed.). New York: McGraw Hill.

Tchobanoglous, G. &. Franklin, F.L. (1995). *Waste-water Engineering Treatment: Disposal and Reuse*. (3rd ed.). Metcalf and Eddy Inc. New Delhi: Tata McGraw-Hill Publishing Co. Ltd.

MODULE 2 PRIMARY AND SECONDARY WASTE-WATER TREATMENT

UNIT 1 WASTE-WATER TREATMENT: INTRODUCTION, SCREENING, COMMINUTOR AND GRIT REMOVAL PROCESSES

CONTENTS

1.0 INTRODUCTION

Waste-water contains large solids and grit that can interfere with treatment processes or cause undue mechanical wear and increased maintenance on waste-water treatment equipment. To minimise potential problems, these materials require separate handling. Preliminary treatment removes these constituents from the influent waste-water. Preliminary treatment consists of screening, grit removal, septage handling, odor control, and flow equalisation. This unit discusses screening and grit removal. Because various types of screening and grit removal devices are available, it is important that the proper design be selected for each situation. Though similarities exist between different types of equipment for a given process, an improperly applied design may result in an inefficient treatment process.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- describe the processes of screening, use of comminutor and grit removal
- discuss the design criteria for screening, comminutors and grit removal
- list the advantages and disadvantages of the above processes
- highlight the operation and maintenance procedures for screening, comminutors/grinders and grit removal processes.

3.0 MAIN CONTENT

3.1 Screening Process

Screening is the first unit operation used at waste-water treatment plants. Screening removes objects such as rags, paper, plastics, and metals to prevent damage and clogging of downstream equipment, piping, and appurtenances. Some modern waste-water treatment plants use both coarse screens and fine screens. Figure 1.1 below depicts a capable operated bar screen.

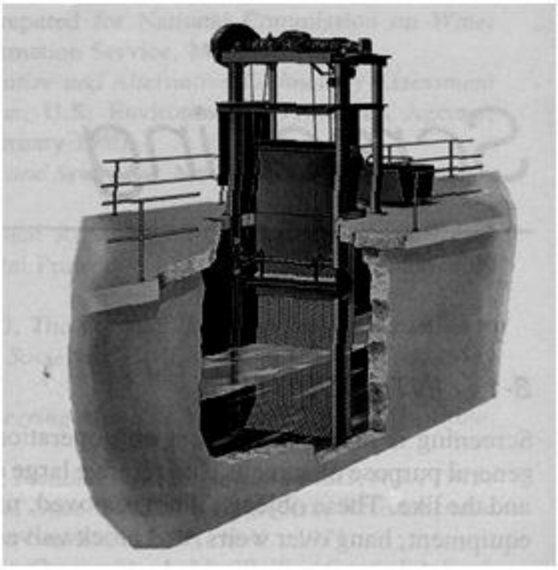


Fig. 1.1: Cable Operated Bar Screen (Qasim, 1994)

Coarse screens: Coarse screens remove large solids, rags, and debris from waste-water, and typically have openings of 6 mm (0.25 in) or larger. Types of coarse screens include mechanically and manually cleaned bar screens, including trash racks. Table 1.1 describes the various types of coarse screens.

Table 1.1: Description of Coarse Screens

Screen Type	Description
Trash Rack	Designed to prevent logs, timbers, stumps, and other large debris from entering treatment processes. Opening size: 38 to 150 mm (1.5-6 in).
Manually cleaned Bar screen debris.	Designed to remove large solids, rags, and Opening size: 30 to 50 mm (1 to2 in) Bars set at 30 to45 degrees from vertical to facilitate cleaning. Primarily used in older or smaller treatment facilities or in bypass channels.
Mechanically Cleaned Bar Screen	designed to remove large solids, rags, and debris. Opening size: 6 to 38mm (0.25 to1.5 in). Bars set at 0 to 30 degrees from vertical. Almost always used in new installations because of large number of advantages relative to other screens.

(Source: Design of Municipal Waste-water Treatment Plants, WEF MOP 8,4th edition, 1998).

Fine Screens: Fine screens are typically used to remove material that may create operation and maintenance problems in downstream processes, particularly in systems that lack primary treatment. Typical opening sizes for fine screens are 1.5 to 6 mm (0.06 to 0.25 in). Very fine screens with openings of 0.2 to 1.5 mm (0.01 to 0.06 in) placed after coarse or fine screens can reduce suspended solids to levels near those achieved by primary clarification

As discussed above, most large facilities use mechanically cleaned screening systems to remove larger materials because they reduce labor costs and they improve flow conditions and screening capture. Typically, only older or smaller treatment facilities use a manually cleaned screen as the primary or only screening device. A screening compactor is usually situated close to the mechanically cleaned screen and compacted screenings are conveyed to a dumpster or disposal area. However, plants utilizing mechanically cleaned screens should have a standby screen to put in operation when the primary screening device is out of service. This is standard design practice for most newly designed plants.

The use of fine screens in preliminary treatment has experienced resurgence in the last 20 years. Such screens were a common feature before 1930 but their use diminished because of difficulty in cleaning oils and grease from the screens. In the early 1980s, fine screens regained popularity because of improved materials.

3.1.1 Design Criteria for Screening

Screening devices are classified based on the size of the material they remove (the screenings). The "size" of screening material refers to its diameter. Table 1.2 lists the correlation between screening sizes and screening device classification. In addition to screening size, other design considerations include the depth, width, and approach velocity of the channel, the discharge height, the screen angle wind and aesthetic considerations as well as redundancy and head loss.

Table 1.2: Screening Device Classifications

Screening Device Classification	Size Classification/SizeRange of Screen Operation
Bar screen	
Manually Cleaned	Coarse/25-50mm (1-2 in)
Mechanically Cleaned	Coarse/15-75mm (0.6-3.0 in)
Fine bar or perforated coarse screen (mechanically cleaned)	
Fine Bar	Fine Coarse/3-12.5 mm (0.1-0.5 in)
Perforated Plate	Fine Coarse/3-9.5 mm (0.1-0.4 in)
Rotary Drum	Fine Coarse/3-12.5 mm (0.1-0.5 in)
Fine screen (mechanically cleaned)	
Fixed Parabolic	Fine/0.25-3.2 mm (0.01-0.13 in)
Rotary Drum	Fine/0.25-3.2 mm (0.01-0.13 in)
Rotary Disk	Very fine (micro)/0.15-0.38 mm(0.01-0.02 in)

Source: Crites and Tchobanoglous, 1998

Table 1.3: Design Criteria for Mechanically Cleaned Bar Screens

	Design Criteria	
Item	**Metric Units**	**English Units**
Bar width	5-15 mm	0.2-0.6 in
Bar depth	25-40 mm	1.0-1.5 in
Cleaning space between bars	15-75 mm	0.6-3.0 in
Slope from vertical	0-30 degrees	0-30 degrees
Approach velocity	0.6-1.0 m/s	2.0-3.25ft/s
Allowable Headloss	150 mm	6 in

Source: WEF, 1998

The use of fine screens produces removal characteristics similar to primary sludge removal in primary sedimentation. Fine screens are capable of removing 20 to 35 per cent suspended solids and BOD_5. Fine screens may be either fixed or movable, but are permanently set in a vertical, inclined, or horizontal position and must be cleaned by rakes, teeth, or brushes.

3.1.2 Advantages of Screening

Manually cleaned screens require little or no equipment maintenance and provide a good alternative for smaller plants with few screenings. Mechanically cleaned screens tend to have lower labor costs than manually cleaned screens and offer the advantages of improved flow conditions and screening capture over manually cleaned screens.

3.1.3 Disadvantages of Screening

- Manually cleaned screens require frequent raking to avoid clogging and high backwater levels that cause buildup of a solids mat on the screen.
- The increased raking frequency increases labor costs.
- Removal of this mat during cleaning may also cause flow surges that can reduce the solids-capture efficiency of downstream units.
- Mechanically cleaned screens are not subject to this problem, but they have high equipment maintenance costs.

3.1.4 Operation and Maintenance for Screening

Manually cleaned screens require frequent raking to prevent clogging. Cleaning frequency depends on the characteristics of the waste-water entering a plant. Some plants have incorporated screening devices, such as basket-type trash racks, that are manually hoisted and cleaned.

Mechanically cleaned screens usually require less labor for operation than manually cleaned screens because screenings are raked with a mechanical device rather than by facility personnel. However, the rake teeth on mechanically cleaned screens must be routinely inspected because of their susceptibility to breakage and bending. Drive mechanisms must also be frequently inspected to prevent fouling due to grit and rags. Grit removed from screens must be disposed of regularly.

3.2 Comminutor and Grinder Process

Processing coarse solids reduces their size so they can be removed during downstream treatment operations, such as primary clarification, where both floating and settleable solids are removed. Comminuting and grinding devices are installed in the waste-water flow channel to grind and shred material up to 6 to 19 mm (0.25 to 0.75 in) in size.

Comminutors consist of a rotating slotted cylinder through which waste-water flow passes. Solids that are too large to pass through the slots are cut by blades as the cylinder rotates, reducing their size until they pass through the slot openings.

Grinders consist of two sets of counter rotating, intermeshing cutters that trap and shear waste-water solids into a consistent particle size, typically 6 mm (0.25 in). The cutters are mounted on two drive shafts with intermediate spacers. The shafts counter rotates at different speeds to clean the cutters.

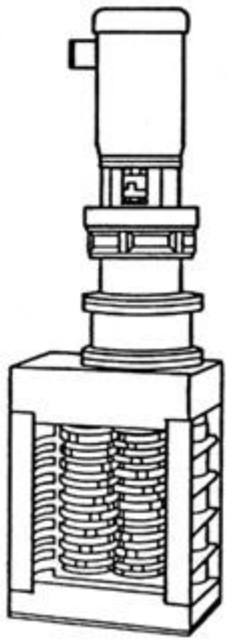


Fig. 1.2: Waste-water Grinder: Channel Unit (WEF, 1998)

The chopping action of the grinder reduces the formation of rag “balls” and rag “ropes” (an inherent problem with comminutors). Waste-waters that contain large quantities of rags and solids, such as prison waste-waters, utilize grinders downstream from coarse screens to help prevent frequent jamming and excessive wear.

3.2.1 Design criteria for comminutor and Grinder

Figure 6.3 depicts a typical comminutor. When designing a comminutor, head-loss should be considered. Head-loss through a comminutor is usually in the range of a few centimeters to 0.9 m (3 ft). Therefore, the manufacturer’s ratings should be decreased by 70 to 80 percent to account for clogging of the screen, since manufacturer’s head-loss characteristics are usually based on clean water flow (Crites and Tchobanoglous, 1998).

When a comminution device is installed upstream of a grit removal device, the teeth of the comminutor are subject to high wear and tear. Rock traps are recommended to prolong the life of the comminutor. In addition, a bypass manual bar rack should be installed in the event that flow rates exceed the comminutor capacity or there is a mechanical failure.

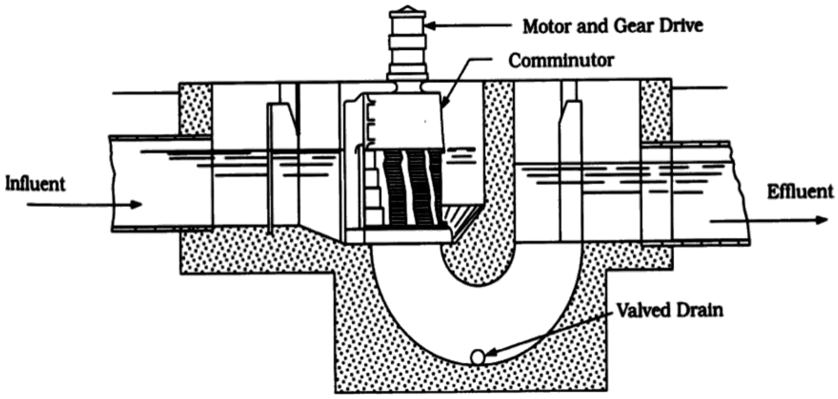


Fig. 1.3: Typical Communitor Installation
(Reynolds/Richards, 1996).

3.2.2 Advantages of Comminutor and Grinder

- A major advantage of using communitors and grinders is that removal of grit reduces damage and maintenance to downstream processes.
- Comminutors and grinders also eliminate screenings handling and disposal, which may improve the aesthetics of the plant, reducing odors, flies, and the unsightliness associated with screenings. Some recently developed grinders can chop, remove, wash, and compact the screenings.
- The use of comminutors in cold weather eliminates the need to prevent collected screenings from freezing.
- Comminutors and grinders typically have a lower profile than screens, so cost savings can be significant when the units must be enclosed.

3.2.3 Disadvantages of Communitor and Grinder

- Comminutors and grinders can create problems for downstream processes, such as increasing plastics buildup in digestion tanks or rag accumulation on air diffusers.
- In addition, solids from communitors and grinders will not decompose during the digestion process. If these synthetic solids are not removed, they may cause biosolids to be rejected for reuse as a soil amendment.

3.2.4 Operation and Maintenance for Communitor and Grinder

Comminutors can create operation and maintenance problems in downstream processes. While shredding solids eliminates the problem of handling screening materials at the head of the plant, problems inherent to the use of communitors, such as the decreased quality of digested biosolids and the accumulation of rags on air diffusers, have lessened the popularity of this technology. Comminutors are generally avoided in new designs and are being removed from many existing plants. Grinders are greatly affected by grit and other solids. As such, they require routine inspection every six months and replacement of bearings and cutter teeth every one to three years.

3.3 Grit Removal Process

Grit includes sand, gravel, cinder, or other heavy solid materials that are "heavier" (higher specific gravity) than the organic biodegradable solids in the waste-water. Grit also includes eggshells, bone chips, seeds, coffee grounds, and large organic particles, such as food waste. Removal of grit prevents unnecessary abrasion and wear of mechanical equipment, grit deposition in pipelines and channels, and accumulation of grit in anaerobic digesters and aeration basins. Grit removal facilities typically precede primary clarification, and follow screening and comminution. This prevents large solids from interfering with grit handling equipment. In secondary treatment plants without primary clarification, grit removal should precede aeration (Metcalf and Eddy, 1991).

Many types of grit removal systems exist, including aerated grit chambers, vortex-type (paddle or jet-induced vortex) grit removal systems, detritus tanks (short-term sedimentation basins), horizontal flow grit chambers (velocity-controlled channel), and hydrocyclones (cyclonic inertial separation).

Various factors must be taken into consideration when selecting a grit removal process, including the quantity and characteristics of grit, potential adverse effects on downstream processes, head loss requirements, space requirements, removal efficiency, organic content, and cost. The type of grit removal system chosen for a specific facility should be the one that best balances these different considerations. Specifics on the different types of grit removal systems are provided below

Aerated Grit Chamber
In aerated grit chambers, grit is removed by causing the waste-water to flow in a spiral pattern, as shown in Figure 6.4. Air is introduced in the

grit chamber along one side, causing a perpendicular spiral velocity pattern to flow through the tank. Heavier particles are accelerated and diverge from the streamlines, dropping to the bottom of the tank, while lighter organic particles are suspended and eventually carried out of the tank.

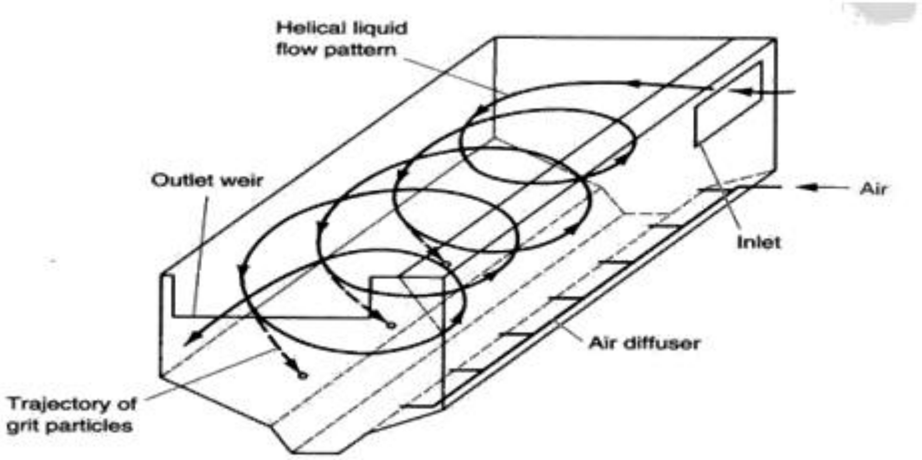


Fig. 1.4: Aerated Grit Chamber (Crites and Tchobanoglous, 1998)

Vortex-Type Grit Chamber

The vortex-type grit chamber consists of a cylindrical tank in which the flow enters tangentially, creating a vortex flow pattern. Grit settles by gravity into the bottom of the tank (in a grit hopper) while effluent exits at the top of the tank. The grit that settles into the grit hopper may be removed by a grit pump or an air lift pump.

Horizontal Flow Grit Chamber

The horizontal flow grit chamber is the oldest type of grit removal system. Grit is removed by maintaining a constant upstream velocity of 0.3 m/s (1 ft/s). Velocity is controlled by proportional weirs or rectangular control sections, such as Parshall flumes. In this system, heavier grit particles settle to the bottom of the channel, while lighter organic particles remain suspended or are re-suspended and transported out of the channel. Grit is removed by a conveyor with scrapers, buckets, or plows. Screw conveyors or bucket elevators are used to elevate the grit for washing or disposal. In smaller plants, grit chambers are often cleaned manually.

3.3.1 Design Criteria for Grit Removal

With respect to grit removal systems, grit is traditionally defined as particles larger than 0.21mm (0.008in) (65 mesh) and with a specific gravity of greater than 2.65 (U.S. EPA, 1987). Equipment design was traditionally based on removal of 95percent of these particles. However, with the recent recognition that smaller particles must be removed to avoid damaging downstream processes, many modern grit removal designs are capable of removing up to 75 percent of 0.15 mm (0.006 in) (100 mesh) material.

Aerated Grit Chamber

Aerated grit chambers are typically designed to remove particles of 70 mesh (0.21 mm/0.008 in) or larger, with a detention period of two to five minutes at peak hourly flow. When waste-water flows into the grit chamber, particles settle to the bottom according to their size, specific gravity and the velocity of roll in the tank. A velocity that is too high will result in lower grit removal efficiencies, while a velocity that is too low will result in increased removal of organic materials. Proper adjustment of air velocity will result in nearly 100 percent removal of the desired particle size and a well-washed grit.

Design considerations for aerated grit chambers include the following (WEF, 1998):

- Air rates typically range from 0.3 to 0.7 m^3/m•min (3 to 8 ft^3/ft•min) of tank length.
- A typical minimum hydraulic detention time at maximum instantaneous flow is two minutes.
- Typical length-to-width ratio is 2.5:1 to 5:1.
- Tank inlet and outlet are positioned so the flow is perpendicular to the spiral roll pattern.
- Baffles are used to dissipate energy and minimise short circuiting.

Vortex-Type Grit Chamber

Two designs of vortex grit units exist: chambers with flat bottoms and a small opening to collect grit and chambers with a sloping bottom and a large opening into the grit hopper. Flow into a vortex-type grit system should be straight, smooth, and streamlined. The straight inlet channel length is typically seven times the width of the inlet channel, or 4.6 m (15 ft), whichever is greater. The ideal velocity range in the influent is typically 0.6 to 0.9 m/s (2 to 3 ft/s) at 40 to 80 percent of peak flow. A minimum velocity of 0.15 m/s (0.5 ft/s) should be maintained at all time velocities will not carry grit into the grit chamber (WEF, 1998).

Horizontal Flow Grit Chamber

Horizontal flow grit chambers use proportional weirs or rectangular control sections to vary the depth of flow and keep the velocity of the flow stream at a constant 0.3 m/s (1 ft/s). The length of the grit chamber is governed by the settling velocity of the target grit particles and the flow control section-depth relationship. An allowance for inlet and outlet turbulence is added. The cross sectional area of the channel is determined by the rate of flow and the number of channels. Allowances are made for grit storage and grit removal equipment. Table 4 lists design criteria for horizontal flow grit chambers.

3.3.2 Advantages of Grit Removal

Some advantages of aerated grit chambers include:

Aerated Grit Chamber

- Consistent removal efficiency over a wide flow range.
- A relatively low putrescible organic content may be removed with a well-controlled rate of aeration.
- Performance of downstream units may be improved by using pre-aeration to reduce septic conditions in incoming waste-water.
- Aerated grit chambers are versatile, allowing for chemical addition, mixing, pre-aeration, and flocculation.

Vortex-Type Grit Chamber

- These systems remove a high percentage of fine grit, up to 73 percent of 140-mesh (0.11mm/0.004 in diameter) size.
- Vortex grit removal systems have consistent removal efficiency over a wide flow range.
- There are no submerged bearings or parts that require maintenance.
- The “footprint” (horizontal dimension) of a vortex grit removal system is small relative to other grit removal systems, making it advantageous when space is an issue.
- Head-loss through a vortex system is minimal, typically 6 mm (0.25 in). These systems are also energy efficient.

Horizontal Flow Grit Chamber

Horizontal flow grit chambers are flexible because they allow performance to be altered by adjusting the outlet flow control device. Construction is not complicated. Grit that does not require further classification may be removed with effective flow control.

Hydrocyclone
Hydrocyclones can remove both grit and suspended solids from waste-water. A hydrocyclone can potentially remove as many solids as a primary clarifier.

3.3.3 Disadvantages of Grit Removal Process

Grit removal systems increase the head loss through a waste-water treatment plant, which could be problematic if head loss is an issue. This could require additional pumping to compensate for the head loss. The following paragraphs describe the specific disadvantages of different types of grit removal systems.

Aerated Grit Chamber
Potentially harmful volatile organics and odours may be released from the aerated grit chamber. Aerated grit chambers also require more power than other grit removal processes, and maintenance and control of the aeration system requires additional labour.

Vortex-Type Grit Chamber

- Vortex grit removal systems are usually of a proprietary design, which makes modifications difficult.
- Paddles tend to collect rags.
- Vortex units usually require deep excavation due to their depth, increasing construction costs, especially if unrippable rock is present.
- The grit sump tends to clog and requires high-pressure agitation using water or air to loosen grit compacted in the sump.

Horizontal Flow Grit Chamber

- It is difficult to maintain a 0.3 m/s (1 ft/s) velocity over a wide range of flows.
- The submerged chain, flight equipment, and bearings undergo excessive wear.
- Channels without effective flow control will remove excessive amounts of organic material that require grit washing and classifying.
- Head loss is excessive (typically 30 to 40 percent of flow depth).
- High velocities may be generated at the channel bottom with the use of proportional weirs, leading to bottom scour.

3.3.3 Operation and Maintenance of Grit

Collected grit must be removed from the chamber, dewatered, washed, and conveyed to a disposal site. Some smaller plants use manual methods to remove grit, but grit removal is usually accomplished by an automatic method. The four methods of automatic grit removal include inclined screw or tubular conveyors, chain and bucket elevators, clamshell buckets, and pumping. A two-step grit removal method is sometimes used, where grit is conveyed horizontally in a trough or channel to a hopper, where it is then elevated from the hopper to another location.

Aerated grit chambers use a sloped tank bottom in which the air roll pattern sweeps grit along the bottom to the low side of the chamber. A horizontal screw conveyor is typically used to convey settled grit to a hopper at the head of the tank. Another method to remove grit from the chamber floor is a chain and flight mechanism. Once removed from the chamber, grit is usually washed with a hydrocyclone or grit classifier to ease handling and remove organic material. The grit is then conveyed directly to a truck, dumpster, or storage hopper. From there, the grit is taken to a landfill or other disposal facility.

4.0 CONCLUSION

For proper flow and functionality of the other processes of sewage and waste-water treatment, these discussed preliminary processes are sinequanon and must be thoroughly employed to achieve their roles. Whereas screening removes fairly big, combustible or non combustible, putriscible or non putriscible materials which can be scooped and removed finally, methods such as comminutors and grinders break down some smaller particles that were able to pass through screening material, grit removal removes the after effects of the comminutor and grinders.

5.0 SUMMARY

In this unit, you have learnt:

- The meaning and processes of screening, use of comminutors and grinders and grit removals. Whereas screening wards off bigger substances, comminutors break some breakable ones while the grit removals remove ground particles.
- Design consideration for screening which were based on size, screen angle and wind etc., were studied just as head-loss served for comminutor and air rates and detention served for grit removal.

- Comparative advantages and disadvantages of screening, comminutors/grinders and grit removal. In all the advantages outweigh the disadvantages of each item.
- The operation and maintenance of screening, comminutor/grinders and grit removal methods were equally discussed.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the processes of screening and grit removal.
2. Enumerate the advantages and disadvantages of any two of these: screening, comminutors and grit removal.

7.0 REFERENCES/FURTHER READING

Crites, R. & G. Tchobanoglous. (1998). *Small and Decentralised Waste-water Management Systems*. The McGraw-Hill Companies. Boston, Massachusetts.

http://www.epa.gov/owm/mtb/mtbfact.htm.

Martin, E.J. & Martin, E.T. (1991). *Technologies for Small Water and Waste-water Systems*. New York: Van Nostrand Reinhold.

Qasim, S. (1994).*Waste-water Treatment Plants: Planning, Design and Operation*. Pennsylvania: Technomic Publishing Co., Lancaster.

Reynolds, T.& Richards, P. (1996). *Unit Operations and Processes in Environmental Engineering*. Boston, Massachusetts: PWS Publishing Company.

United States Environmental Protection Agency. 'Waste-water – Technology Fact Sheet' (Screening and Grit Removal). http://water.epa.gov/aboutow/owm/upload2004 07 07 Septics finalsgrit removal.pdf.

Urquhart, L. (1962). *Civil Engineering Costs Include Construction, Operation, and Maintenance. Specific Cost Data from Contractor Bids*.

Water Environment Federation. (1998). *Design of Municipal Waste-water Treatment Plants.* Water Environment Federation. Alexandria, Virginia.

UNIT 2 FLOW EQUALISATION PROCESS

CONTENTS

1.0 INTRODUCTION

In the previous units, we have seen the sources of waste-water, its characteristics and flow rates. Before dealing with its actual treatment, it is necessary we determine how to ensure that the flows be maintained at a fairly constant rate so that there will be no time of its being in excess or being deficit. When this is done, there will be efficient management of time and the maximisation of machine output. It is a small unit simply made so because of the mathematical calculations involved. Your concentration is therefore highly needed. Do not be scared because it is easy to comprehend.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define flow equalisation
- explain the essence of flow equalisation
- describe the processes of flow equalisation
- express and explain the mathematical formulae of flow equalisation
- interpret the graphical representation of flow equalisation

3.0 MAIN CONTENT

3.1 Definition of Flow Equalisation

By way of definition, flow equalisation is the process of mitigating changes in flow rate through a portion of a system by providing storage to hold water when it is arriving too rapidly, and to supply additional water when it is arriving less rapidly than desired.

3.2 The Essence of Flow Equalisation

In many water treatment systems, it is useful to implement flow equalisation downstream of the plant, because the downstream demand is not steady, but in general, the treatment processes work more efficiently if the flow rate through them is steady. In treating waste-water, the rate at which the waste arrives at the treatment process might vary dramatically during the day, so it is convenient to equalise the flow before feeding it to the various treatment steps. In either case, the engineering issue is deciding how large an equalisation basin is required to allow a steady, the treatment processes to operate with a steady, average flow.

It is clear that waste-water seldom flows into waste-water treatment plants at the same rate throughout each day. In many cities, the greatest flows reaching the waste-water treatment plants arrive mid-morning. Such uneven flow volumes reduce waste-water treatment plants' efficiency.

To even out these periods of high and low flow, large basins are constructed at some waste-water treatment plants to store the waste-water flow from peak periods and release it for treatment. These basins require aeration and mixing to prevent odors and deposition of solids.

3.3 Processes of Flow Equalisation and its Mathematical Equation

Consider, for example, an Equalisation basin (i.e., a reservoir) downstream of a drinking water treatment plant. The flow rate out of the basin varies in a predictable way, but we wish to treat the raw water at a steady, average rate. How big a basin is required so that we can store the "excess" treated water until it is needed later? We can answer this question by writing a mass balance on water, with the basin as the control volume. Water is neither generated nor destroyed by any chemical reactions taking place in the basin, so $r = 0$ in the mass balance. Also, the "concentration" of water in the tank is constant and equal to the density of water. The required values of Qout are known as a function of time, and we intend to operate with Qin equal to Qavg at all times. The mass balance can therefore be written as follows:

{Rate of change of the amount of water in the system}	=	{Net rate [in –out] at which water enters the system by flow}	+	{Rate at which water is generated by reaction}

$$\rho \frac{dV(t)}{dt} = \rho\,(Q_{avg} - Q_{out}(t))$$

$$\frac{dV(t)}{dt} \approx \frac{\Delta V(t)}{\Delta t} = Q_{avg} - Q_{out}(t)$$

The preceding equation simply says that the rate of change in the volume of water stored in the basin over any short time period Δt equals the difference between the influent (average) and effluent flow rates during that period. Re-arranging slightly:

$\Delta V\, t = Q\text{avg} - Q\text{out}\; t\; \Delta t$

To use the equation to determine the required storage volume, we compute the change in the amount of water in the reservoir over time, start at some time that we designate as $t = 0$. We do not know much water is in the basin at $t = 0$, so we just call that volume $V(0)$ and deal with it later. We can then use the known values of Qavg and $Q(t)$ to compute the change in the volume of water in the basin between $t = 0$ and any future time; i.e., we can compute $V(t) - V(0)$ for all future t. If $V(t) - V(0) < 0$, then the implication is that more water has been withdrawn from the tank since $t = 0$ than has been provided to it. For this to be possible, there must have been a volume of water in the tank at $t = 0$ equal to at least $V(0) - V(t)$. Correspondingly, by finding the *maximum* negative value $V(t) - V(0)$, we can identify the *minimum* amount of water that must be in the basin at $t = 0$ to assure that the system meets the future demand for water.

By the same token, if $V(t) - V(0) > 0$, then the cumulative input of water to the basin since $t = 0$ has been greater than the cumulative removal; i.e., this has been a period during which more water was treated than was needed. We need to store this water for future use, so the available, empty volume in the basin at $t = 0$ must be large enough to accept this water. In this case, the *maximum* positive value of $V(t) - V(0)$ indicates the *minimum* amount of storage that must be available at $t = 0$ to hold all the "excess" water that will be treated and then held until it is demanded. The required volume of the basin equals the sum of the amount of water that must be present at $t = 0$ (the *maximum* negative value $V(t) - V(0)$) and the amount of empty space that must be available at that time for future use (*maximum* positive value of $V(t) - V(0)$). This sum can easily be determined either with a spreadsheet or by plotting

$V(t) - V(0)$ and determining the vertical gap between its minimum and maximum values.

Example: the water demand from a community during a typical day is summarized below, in half-hour increments. If the treatment plant supplying the water is to be operated at a steady rate, how large an equalisation basin should be constructed?

Table 2.1: Water Demand from a Community during a Typical Day

t (h)	*Q*(*t*) (m3/min)	*T* (h)	*Q*(*t*) (m3/min)	*t* (h)	*Q*(*t*) (m3/min)
0	8	8	18	16	14.8
0.5	6	8.5	17	16.5	15.3
1	5	9	14.5	17	16.6
1.5	3	9.5	14	17.5	17.5
2	2	10	13.5	18	17.5
2.5	2.2	10.5	13.5	18.5	18.5
3	1.8	11	14.5	19	19.5
3.5	2	11.5	15	19.5	16
4	2.4	12	15.5	20	13
4.5	3	12.5	16	20.5	14
5	4.4	13	15	21	13
5.5	6	13.5	13.5	21.5	12
6	10	14	13	22	11
6.5	13	14.5	13.2	22.5	11
7	22	15	14	23	9.5
7.5	22.5	15.5	14.3	23.5	9
				24	8

(Source: C:\Adata\CLASNOTE\483\483 in 06\Equalisation.doc)

Solution: The average flow rate during the whole day (Qavg) can be computed based on the given flow rates, and turns out to be 12.0 m3/min. (Note that $t = 0$ is essentially the same time as $t = 24$, so those values should be used only once in the averaging.) The average flow during each half- hour interval (Qavg,$i(t)$) can also be computed, as the mean of the values at the ends of the interval; these flow rates are plotted in Figure 2.1.

The difference Qavg $-Q$avg,$i(t)$ is the “excess” production rate. That is, it is the rate at which clean water is being produced above that which is needed at that instant; these values are plotted in Figure 2. Correspondingly, the excess volume of water produced during any interval Δt is $\{Q$avg $-Q$avg,$i(t)\}\Delta t$. If this value is positive, it represents the volume of water that must be put into storage for later use; if it is negative, it is the volume of water that must be removed from storage during the interval to meet the demand. We can then compute the cumulative excess volume of water produced since the start of the cycle (which, for this example, is midnight). To do this, we define the cumulative excess volume at midnight as zero, and we compute the cumulative excess volume at each subsequent time as the value at the previous time plus the excess production during the preceding interval.

The results, shown in Figure 3, indicate that the cumulative storage requirement has a maximum of 2297.5 m3 at Hour 6.5 (6:30am) and a minimum of −218.5 m3 at Hour 21.5 (9:30pm). The interpretation is that, at the beginning of the cycle, there would have to be at least 2297.5 m3 of available (empty) space in the reservoir to hold all the excess water that will be produced over the upcoming period, and there would have to be at least 218.5 m3 of water stored in the reservoir to supply the volume to be needed later in the day. The total reservoir volume would have to be the sum of these values, or 3216 m3. Figure 4 shows the volume of water in the basin as a function of time. The trend follows that in Figure 3 perfectly, but the vertical axis is adjusted by 218.5 m3, so that it shows the minimum volume stored as zero at 9:30pm. In reality, one would want to provide a safety factor by having the reservoir be somewhat larger than the minimum volume computed above, in which case the minimum volume stored would always be somewhat larger than zero. The graphical representations of the above are given below.

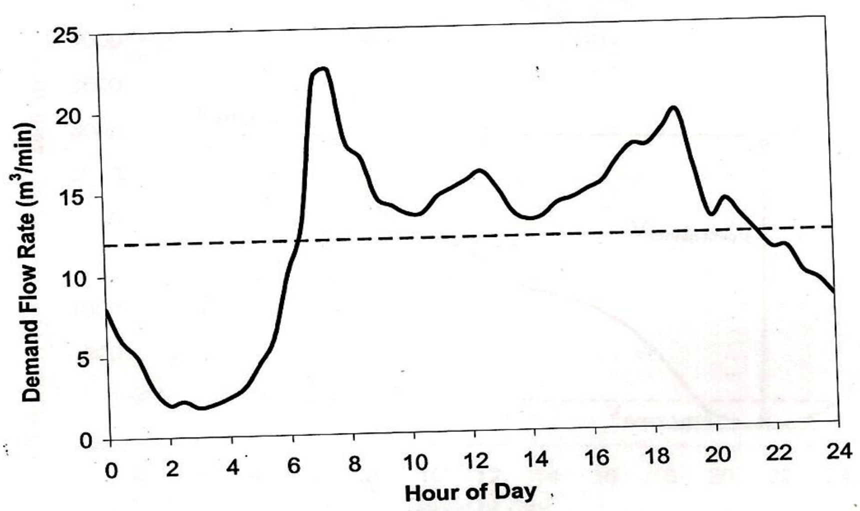


Fig. 2.1: Changes in the Demand Rate for Water during a Typical Day

(Source: C:\Adata\CLASNOTE\483\483 in 06\Equalisation.doc)

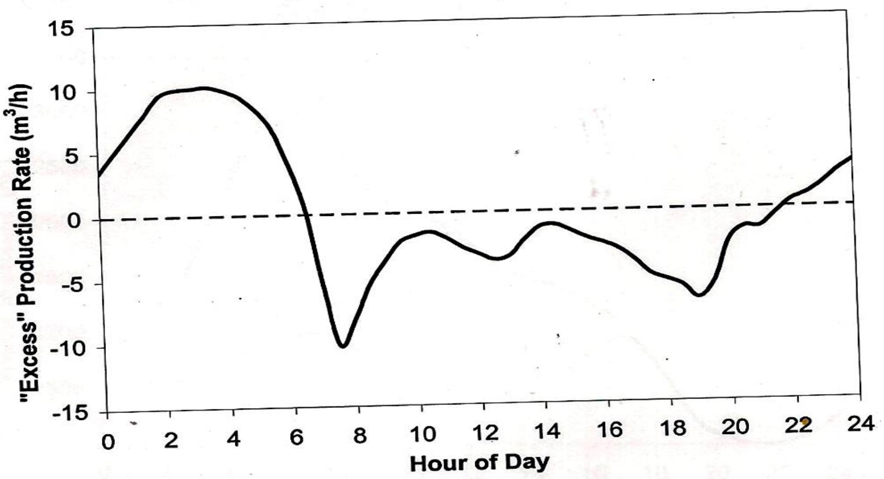


Fig. 2.2: Water Production Rate in Excess of the Demand

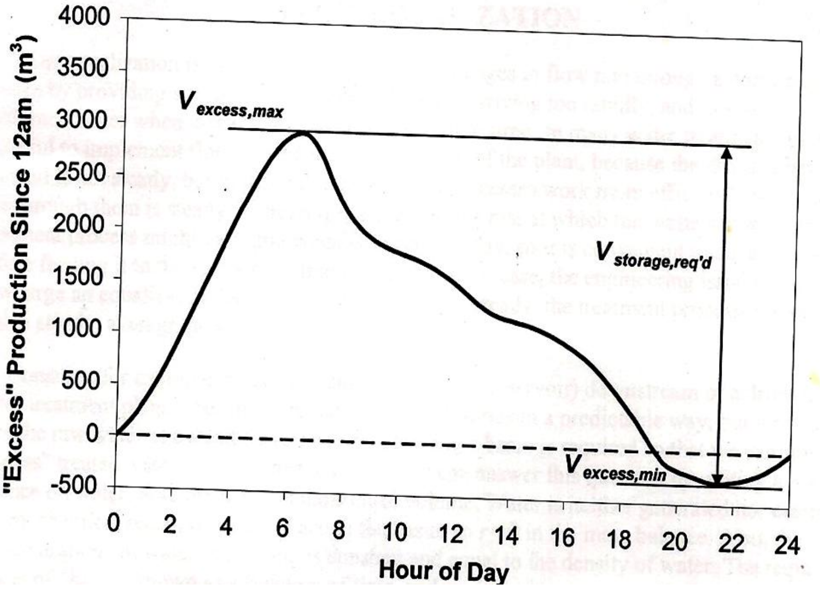


Fig. 2.3: The Cumulative Volume of Water Treated above that which has been needed, since Midnight

(Source: C:\Adata\CLASNOTE\483\483 in 06\Equalisation.doc)

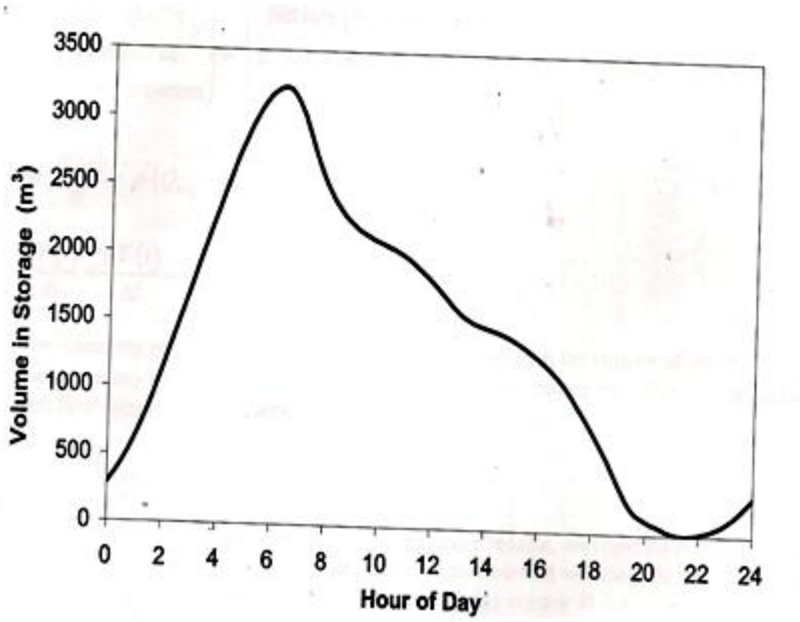


Fig.2.4: Volume of Water Stored in the Reservoir at Different Times During the Day

Source: C:\Adata\CLASNOTE\483\483 in 06\Equalisation.doc

4.0 CONCLUSION

From the foregoing, we can conclude that flow equalisation is a welcome development which is aimed at controlling or regulating the flow rates of waste-water so that there are regular and continuous flow of waste-water irrespective of un-continuous or irregular supply of same. This is aimed at maximising the potential efficiency of the waste-water treatment plant. This is achievable by the use of an equalisation basin which retains waste-water during peak flows and supplies same during period of scarcity thereby ensuring that the plant is busy at every time of the day

5.0 SUMMARY

In this unit, we have been able to define flow equalisation and give its essence. In the essence, we were made to understand that it is aimed at ensuring the constant supply of waste-water to the treatment plant in spite of the non-constant supply or arrival of the waste-water into the said plant. The process of doing this is by constructing an equalisation basin (i.e., a reservoir) to hold the waste-water during the time of peak flow and release same during the time of scarcity. This ensures even supply at all times and ensures also the maximum efficiency of the treatment plant. Illustrations, calculations and graphs were used for clarity.

6.0 TUTOR- MARKED ASSIGNMENT

1. a. Explain the rationale for flow equalisation.
   b. Describe the process of achieving the above feat.
2. Explain the graphs in the unit in relation to the achievement of the goal of flow equalisation.

7.0 REFERENCES/FURTHER READING

C:\Adata\CLASNOTE\483\483 in 06\Equalisation.doc. http://www.bcwater.org/waterfacts/waste-watertreatment.asp.

http://faculty.washington.edu/markbenj/CEE483/Equalisation.pdf.

UNIT 3 SEDIMENTATION AND FLOTATION PROCESSES

CONTENTS

1.0 INTRODUCTION

In our last unit, we saw how regulation of waste-water flow rates was achieved through flow equalisation with the full intent of making sure the treatment plant is made operational at all time in spite of differences in the said flow rates. In this unit, we are advancing further in the primary stages of waste-water treatment, having first dealt with**:** waste-water treatment introduction: screening, use of communitor and grit removal processes. We are to look into sedimentation and floatation processes.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define sedimentation and explain factors affecting flotation processes
- describe the processes of sedimentation in waste-water treatment
- give the meaning of flotation and list the various flotation processes
- explain the flotation processes in waste-water treatment.

3.0 MAIN CONTENT

3.1 Sedimentation Process

It is the main process of primary treatment which comes up immediately after screening, use of comminutor and grit removal processes. Just as we have primary sedimentation which is the main focus for now, we also have final sedimentation which comes up during secondary treatment, that will equally be discussed but in the later part of this section. A closer look at the meaning of sedimentation will, for now, suffice.

3.1.1 Meaning of Sedimentation

Sedimentation (primary) by way of definition is the process of letting suspended material settle by gravity. Suspended material may be particles, such as clay or silts, originally present in the water or waste-water sources. Sedimentation is accomplished by decreasing the velocity of the water or waste-water being treated to a point below which the particles will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow.

3.1.2 Factors affecting Sedimentation

Several factors affect the separation of settleable solids from water or waste-water. Some of the more common types of factors to consider are:

(1) Particle Size

The size and type of particles to be removed have a significant effect on the operation of the sedimentation tank. Because of their density, sand or silt can be removed very easily. The velocity of the water-flow channel can be slowed to less than one foot per second, and most of the gravel and grit will be removed by simple gravitational forces. In contrast, colloidal material, small particles that stay in suspension and make the water seem cloudy, will not settle until the material is coagulated and flocculated by the addition of a chemical, such as an iron salt or aluminum sulfate.

The shape of the particle also affects its settling characteristics. A round particle, for example, will settle much more readily than a particle that has ragged or irregular edges. All particles tend to have a slight electrical charge. Particles with the same charge tend to repel each other. This repelling action keeps the particles from congregating into flocs and settling.

(2) Water Temperature

Another factor to consider in the operation of a sedimentation basin is the temperature of the water being treated. When the temperature decreases, the rate of settling becomes slower. The result is that as the water cools, the detention time in the sedimentation tanks must increase. As the temperature decreases, the operator must make changes to the coagulant dosage to compensate for the decreased settling rate. In most cases temperature does not have a significant effect on treatment. A water treatment plant has the highest flow demand in the summer when the temperatures are the highest and the settling rates the best. When the water is colder, the flow in the plant is at its lowest and, in most cases, the detention time in the plant is increased so the floc has time to settle out in the sedimentation basins.

(3) Currents

Several types of water currents may occur in the sedimentation basin:

- Density currents caused by the weight of the solids in the tank, the concentration of solids and temperature of the water in the tank.
- Eddy currents produced by the flow of the water coming into the tank and leaving the tank.

The currents can be beneficial in that they promote flocculation of the particles. However, water currents also tend to distribute the floc unevenly throughout the tank; as a result, it does not settle out at an even rate.

Some of the water current problems can be reduced by the proper design of the tank. Installation of baffles helps prevent currents from short circuiting the tank

Sedimentation Basin Zones

Under ideal conditions, the sedimentation tank would be filled with the water that has been coagulated, and the floc would be allowed to settle before any additional water is added. That is not possible for most types of water treatment plants.

Most sedimentation tanks are divided into these separate zones:

Inlet Zone

The inlet or influent zone should provide a smooth transition from the flocculation zone and should distribute the flow uniformly across the inlet to the tank. The normal design includes baffles that gently spread the flow across the total inlet of the tank and prevent short circuiting in the tank. (Short circuiting is the term used for a situation in which part of the influent water exits the tank too quickly, sometimes by flowing across the top or along the bottom of the tank.) The baffle could include a wall across the inlet, perforated with holes across the width of the tank.

Settling Zone
The settling zone is the largest portion of the sedimentation basin. This zone provides the calm area necessary for the suspended particles to settle.

Sludge Zone
The sludge zone, located at the bottom of the tank, provides a storage area for the sludge before it is removed for additional treatment or disposal. Basin inlets should be designed to minimize high flow velocities near the bottom of the tank. If high flow velocities are allowed to enter the sludge zone, the sludge could be swept up and out of the tank. Sludge is removed for further treatment from the sludge zone by scraper or vacuum devices which move along the bottom.

Outlet Zone
The basin outlet zone or launder should provide a smooth transition from the sedimentation zone to the outlet from the tank. This area of the tank also controls the depth of water in the basin. Weirs set at the end of the tank control the overflow rate and prevent the solids from rising to the weirs and leaving the tank before they settle out. The tank needs enough weir length to control the overflow rate, which should not exceed 20,000 gallons per day per foot of weir.

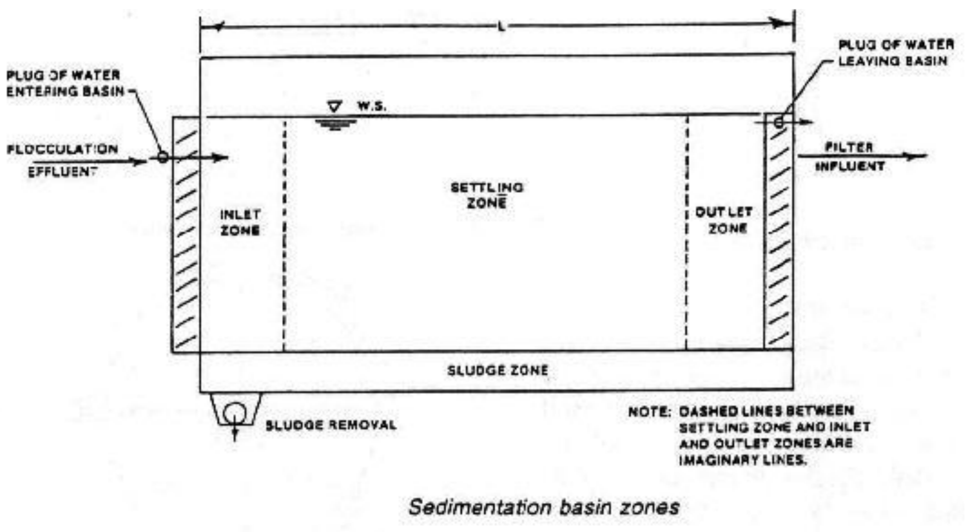


Fig. 3.1: Sedimentation Basin Zones
Source: Huber Company, Berching, Germany, 2012

Selection of Basin
There are many sedimentation basin shapes. They can be rectangular, circular, and square.

Rectangular Basins
Rectangular basins are commonly found in large-scale water treatment plants. Rectangular tanks are popular as they tend to have:

- High tolerance to shock overload
- Predictable performance
- Cost effectiveness due to lower construction cost
- Lower maintenance
- Minimal short circuiting.

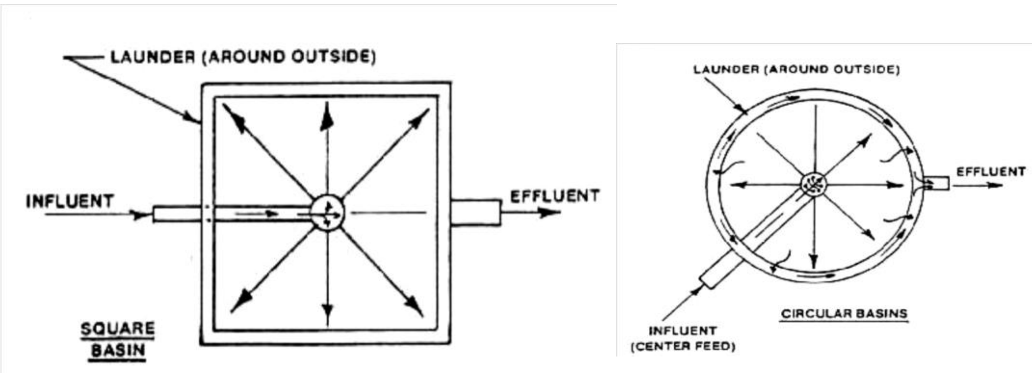


Fig. 3.2: Square and Circular Basins
Source: Huber Company, Berching, Germany, 2012

Circular and Square Basins
Circular basins are frequently referred to as clarifiers. These basins share some of the performance advantages of the rectangular basins, but are generally more prone to short circuiting and particle removal problems. For square tanks the design engineer must be certain that some types of sludge removal equipment for the corners are installed.

NB: Note that whereas most of the above facts concern water treatment, most of them still obtain in waste-water treatment, hence the need to have them discussed under this unit.

3.1.3 Sedimentation Processes in Waste-water Treatment

As stated earlier we have primary and secondary sedimentation in waste-water treatment. In the primary sedimentation stage, sewage flows through large tanks, commonly called "pre-settling basins", "primary sedimentation tanks" or "primary clarifiers"(Huber Company, Berching, Germany, 2012). . The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Grease and oil from the floating material can sometimes be recovered for saponification.

This removes as much as possible the organic matter of sewage. The sewage is allowed to flow in a rectangular tank. Some of them have paddles which help to rotate the sewage and collect the heavy particles (solid organic matter, inorganic matters) together and make them to sink as sediment. Within the tank, it stays 2-8 hours. At the end of 2-8 hrs, this process removes about 60% of suspended solids and about 40% of Bio-chemical Oxygen Demand **(BOD**). According to Sridhar (2007), the rate of sedimentation is increased in some industrial waste treatment stations by incorporating processes called chemical coagulation and flocculation in the sedimentation tank. Coagulation is the process of adding chemical such as aluminum sulfate, ferric chloride or polyelectrolyte to the waste-water; this causes the surface characteristics of the suspended solids to be altered so that they attach to one another and precipitate. Flocculation causes the suspended solids to coalesce. These two processes can remove more than 80 percent suspended solids. The solid particles are directed to the sludge digester for treatment and the effluent to the next apartment called the activated sludge (surplus) or filtration/Aeration chamber

Final Sedimentation- This occurs during the secondary treatment of the waste-water. Here the still remaining solids settle on top while the effluent goes into a lake or river, sea or any other place while the surplus activated sludge should be collected and re-cycled starting from the primary sedimentation (rear side of it). It should be directed to the sludge digester and have the action is anaerobic (no more aerobic). The sludge is pumped into digested anaerobic sludge, dewatered and tarry odour (innocuous). Gas could be produced (as fuels etc) while the effluent is discharged into the river. Dewatering means “air drying”.

3.2 Flotation Process

Having dealt with sedimentation process to this extent, this section will be used to treat flotation process with the view to understanding same equally. Finish up the deal before going to the next unit.

3.2.1 Meaning of Flotation Process

Flotation process (sometimes called flotation separation) is a method of separation widely used in the waste-water treatment and mineral processing industries. It is an alternative to sedimentation that is used in the treatment of some waste-water in which air is forced into the waste-water under pressures of 1.75 to 3.5 kg per sq cm (25 to 50 1b per sq in). The waste-water, supersaturated with air, is then discharged into an open tank; there the rising air bubbles cause the suspended solids to rise to the surface, where they are removed. Flotation can remove more than 75 percent of the suspended solids.

3.2.2 Various Flotation Processes

The above discusses the processes or conditions under which flotation works efficiently. According to http://en.wikipedia.org/wiki/ Flotation_process, the various flotation processes include the following:

- Dissolved air flotation.
- Induced gas flotation.
- Froth flotation; typical in the mineral processing industry.

Dissolved Air Flotation- A closer look at the above definition or its explanation shows that Dissolved Air Flotation (DAF) has been discussed. When particles to be removed do not settle out of solution easily, dissolved air flotation is often used. It is used in water and waste-water treatment processes. In the water treatment, after coagulation and flocculation processes, water flows to DAF tanks where air diffusers on the tank bottom create fine bubbles that attach to floc resulting in a floating mass of concentrated floc. The floating floc blanket is removed from the surface and clarified water is withdrawn from the bottom of the DAF tank (Edzwald, 2011).

Induced Gas Flotation- This is done when other gases outside air (oxygen) is/are used to cause or effect flotation. It is found useful in water and waste-water treatment processes.

Froth Flotation- This is typical in the mineral processing industry. In the sewage treatment, in some larger plants, fat and grease are removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as froth. Many plants, however, use primary clarifiers with mechanical surface skimmers for fat and grease removal. In the mineral processing industry, it is used mainly to recover or remove fats and oil from the other main constituent substances.

3.2.3 Flotation Process in Waste-water Treatment

Not much will again be said about this in this section as all vital information is already contained in the items above. Flotation process in waste-water treatment does help achieve the removal of oils, grease and some suspended solids through the methods explained above. Those parts removed therefore stand as the specific treatment objectives of flotation process.

4.0 CONCLUSION

From our discussion so far, one can conclude that sedimentation and flotation are processes found useful in the primary treatment of water or waste-water. Major focus in this unit has been that of the latter. While sedimentation deals with the removal of suspended solids, flotation deals with the removal of oils, grease and some solids that might stick with the oils. Just as there are factors affecting sedimentation, there are equally different sizes and shapes of sedimentation tanks.

5.0 SUMMARY

In this unit, we were able to have learnt the following:

- The meaning of sedimentation was discussed before dealing with the factors affecting its operation and efficiency. Also studied were the sizes and shapes of sedimentation tanks.
- The usefulness of the above are said to be more relevant in that of water treatment.
- Flotation which is an alternative to sedimentation, but for oils and greases was studied. After dealing with the definition, the types of flotation were studied and under this, we are made to understand that there are three, namely dissolved air flotation, induced gas flotation and froth flotation.

6.0 TUTOR- MARKED ASSIGNMENT

1. Discuss sedimentation under the following subheadings:
   a. Its meaning.
   b. Factors affecting it.
   c. Its sizes and shapes.
2. What is the usefulness of flotation in the waste-water treatment?

7.0 REFERENCES/FURTHER READING

Edzwald, James K. (Ed.). (2011). *Water Quality and Treatment.* (6th ed.). New York: McGraw-Hill.

Huber Company, Berching. Germany. (2012). "Sedimentation Tanks."

Sridhar, M.K.C. (2007). 'Sewage Treatment'. Lecture Notes Delivered During the 2007 Mandatory Continuous Education Programme (MCEP) for Environmental Health Officers Registration Council of Nigerians, at Filbon Guest House, New Haven Enugu.

Sridhar, M. K. C., (1995). *Sullage/Waste-water in Nigeria: Problems and Solutions for Utilisation for Gardening*. A Report Submitted to UNICEF, Lagos, Nigeria, July, pp 1-86.

EPA. Washington, DC, (2004). "Primer for Municipal Waste water Treatment Systems." Document no. EPA 832-R-04-001.

Wikipedia, the Free Encyclopedia.(n.d). "Sewage Treatment".

Wikipedia, the free encyclopedia - Flotation Process.

: http://en.wikipedia.org/wiki/Flotation_process.

UNIT 4 TRICKING FILTERS, ROTATING

BIOLOGICAL DISCS, ACTIVATED SLUDGE AND OXIDATION POND PROCESSES

CONTENTS

1.0 INTRODUCTION

We dealt in details with the issues that bother on primary treatment of waste-water. In this unit, we shall discuss the secondary treatment process which is an advanced process that aims at making sure that waste-water is not disposed off or reused in a manner that will adversely affect man and his environment. It is our belief that you will continue following the topics for the overall aim of understanding sewage and waste-water treatment in full.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the application and mechanism of trickling filters process in waste-water treatment
- discuss the rotating biological discs process in waste-water treatment
- describe the activated sludge system process in waste-water treatment
- discuss the issues of oxidation pond application.

3.0 MAIN CONTENT

3.1 Trickling Filter Process

A trickling filter is a bed of coarse stone or perforated plastic material over which waste-water is sprayed. The most common design is a bed of stones three to ten feet deep inside a large circular concrete tank. Some tanks are more than 200 feet in diameter. The waste-water is sprayed over the filter from rotating arms.

As the waste-water trickles through the bed, micro-organisms establish themselves on the stone or plastic surfaces as slime. The waste-water picks up oxygen as it is sprayed over the filter and passes over these microorganisms. These microorganisms, in the presence of high amounts of oxygen, feed on the organic materials in the waste-water.

The microbial slime on the filter bed will grow and eventually clog the filter if not washed out. Thus, the flow from the filter is sent to a sedimentation basin to allow these solids to settle out. This sedimentation basin is called a *secondary clarifier* or a *final clarifier* to distinguish it from the sedimentation basin used for primary treatment. I am sure you still remember where we stopped during the time we dealt with that under sedimentation. If not try and recollect please.

3.1.1 Detailed Study of a Trickling Filter

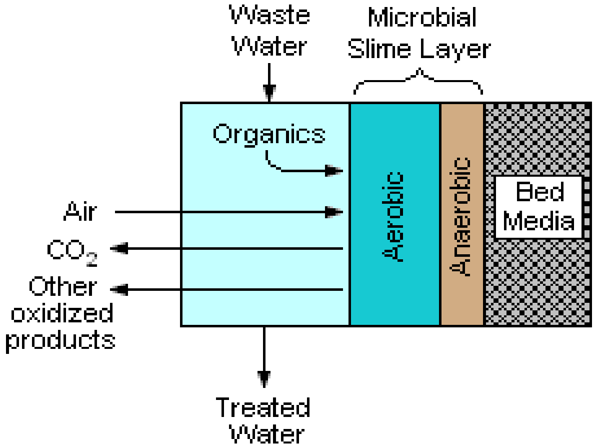


Fig. 4.1: A Schematic Cross-section of the Contact Face of the Bed of Media in a Trickling Filter

Source: *http://en.wikipedia.org/wiki/Trickling_filter*

Below is a detailed explanation.

A trickling filter consists of a fixed bed of rocks, lava, coke, gravel, slag, polyurethane foam. sphagnum peat moss, ceramic, or plastic media over which sewage or other waste-water flows downward and causes a layer of microbial slime (bio-film) to grow, covering the bed of media. Aerobic conditions are maintained by splashing, diffusion, and either by forced air flowing through the bed or natural convection of air if the filter medium is porous. The terms trickle filter, trickling biofilter, biological filter and biological trickling filter are often used to refer to a trickling filter. These systems have also been described as roughing filters, intermittent filters, packed media bed filters, alternative septic systems, percolating filters, attached growth processes, and fixed film processes.

Operation

The removal of pollutants from the waste-water stream involves both absorption and adsorption of organic compounds by the layer of microbial biofilm. The filter media is typically chosen to provide a very high surface area to volume. Typical materials are often porous and have considerable internal surface area in addition to the external surface of the medium. Passage of the waste-water over the media furnishes dissolved air, the oxygen which the slime layer requires for the biochemical oxidation of the organic compounds and releases carbon dioxide gas, water and other oxidised end products. As the biofilm layer thickens, it eventually sloughs off into the treated effluent and subsequently forms part of the secondary sludge. Typically, a trickling filter is followed by a clarifier or sedimentation tank for the separation and removal of the sloughing. Other filters utilising higher-density media such as sand, foam and peat moss do not produce a sludge that must be removed, but require forced air blowers and backwashing or an enclosed anaerobic environment.

The treatment of sewage or other waste-water with trickling filters is among the oldest and most well characterised treatment technologies.

Types

The three basic types of trickle filters are used for:

- the treatment of small individual residential or rural sewage
- large centralised systems for treatment of municipal sewage
- systems applied to the treatment of industrial waste-water.

Septic System Leach Field

This is the simplest form of waste liquid disposal system, typically using pipes buried in loose sand or gravel to dissipate the liquid outflow from a septic tank. Liquid purification is performed by a biofilm which naturally forms as a coating on the sand and gravel in the absorption field and feeds on the dissolved nutrients in the waste stream.

Due to the system being completely buried and generally isolated from the surface environment, the process of waste breakdown is slow and requires a relatively large surface area to absorb and process liquid wastes. If too much liquid wastes enter the field too quickly, the wastes may pass out of the biofilm before waste consumption can occur, leading to pollution of groundwater.

In order to prolong the life of a leaching field, one method of construction is to build two fields of piping side-by-side, and use a rotating flow valve to direct waste into one field at a time, switching between fields every year or two. This allows a period of rest to let the micro-organisms have time to break down the wastes built up in the gravel bed.

In areas where the ground is insufficiently absorptive (fails the percolation test) a homeowner may be required to construct a mound system which is a special engineered waste disposal bed of sand and gravel mounded on the surface of the ground with poor liquids absorption.

Leach Field Dosing

Generally, it is better if the biofilm is permitted a period of time to rest between liquid influxes and for the liquids to be evenly distributed through the leaching bed to promote biofilm growth throughout the pipe network. Typically flows from septic systems are either small surges (hand washing) or very large surges (clothes washer emptying), resulting in highly erratic liquid outflow into the field and uneven biofilm growth concentrating primarily around the field inlet and dropping off in the outer reaches of the piping system.

For this reason, it is common for engineered mound systems to include an electrically powered *dosing system* which consists of a large capacity underground storage tank and lift pump after the septic tank. When the tank fills to a predetermined level, it is emptied into the leaching field.

The storage tank collects small outflows such as from hand washing and saves them for dosing when the tank fills from other sources. During this fill period the field is able to rest continuously. When full, the discharge dose fills out the entire field completely to the same degree of flow, every time, promoting an even biofilm growth throughout the system.

Dosing systems have maintenance requirements over traditional non-powered surge systems. The pump and float system can break down and require replacement, and the dosing system also needs electricity.

However, the system can be designed so that in the event of power failure the storage tank overflows to the field operating in the traditional surge-flow manner until power is restored or repairs can be done.

Soil Compaction Issues

The biofilm is most productive if the absorption field is loosely packed, to permit easy air infiltration down into the biofilm bed. Consequently the land over the leaching field is often a restricted area where large vehicles cannot be allowed to drive, because the heavy weight will compact the bed, and potentially cause system failure due to hindering of biofilm growth.

One method to help prevent compaction of the field is to place a U-shaped cover over gravel trenches in the bed, with a dosing pipe suspended above the bed by the cover. Any weight from above is passed to the sides of the trench keeping the bed directly under the cover free from compaction.

Sewage Treatment Trickle Filters

Onsite Sewage Facilities (OSSF) are recognised as viable, low-cost, long-term, decentralised approaches to sewage treatment if they are planned, designed, installed, operated and maintained properly (USEPA, 1997). Sewage trickling filters are used in areas not serviced by municipal waste-water treatment plants (WWTP). They are typically installed in areas where the traditional septic tank system are failing, cannot be installed due to site limitations, or where improved levels of treatment are required for environmental benefits such as preventing contamination of ground water or surface water.

Sites with a high water table, high bedrock, heavy clay, small land area, or which require minimal site destruction (for example, tree removal) are ideally suited for trickling filters.

All varieties of sewage trickling filters have low and sometimes intermittent power consumption. They can be somewhat more expensive than traditional septic tank-leach field systems, however their use allows for better treatment, a reduction in size of disposal area, less excavation, and higher density land development.

Configurations and Components

All sewage trickling filter systems share the same fundamental components:

- a septic tank for fermentation and primary settling of solids
- a filter medium upon which beneficial microbes (biomass, biofilm) are promoted and developed
- a container which houses the filter medium
- a distribution system for applying waste-water to be treated to the filter medium
- a distribution system for disposal of the treated effluent or percolation ponds.

By treating septic tank effluent before it is distributed into the ground, higher treatment levels are obtained and smaller disposal means such as leach field, shallow pressure trench or area beds are required.

Systems can be configured for single-pass use where the treated water is applied to the trickling filter once before being disposed of, or for multi-pass use where a portion of the treated water is cycled back to the septic tank and re-treated via a closed loop. Multi-pass systems result in higher treatment quality and assist in removing Total Nitrogen (TN) levels by promoting nitrification in the aerobic media bed and denitrification in the anaerobic septic tank.

Trickling filters differ primarily in the type of filter media used to house the microbial colonies. Types of media most commonly used include plastic matrix material, open-cellpolyurethane foam, sphagnum peat moss, recycled tires, clinker, gravel, sand and geo-textiles. Ideal filter medium optimizes surface area for microbial attachment, waste-water retention time, allows air flow, resists plugging and does not degrade. Some residential systems require forced aeration units which will increase maintenance and operational costs.

Regulatory Approvals

Third-party verification of trickling filters has proven them to be a reliable alternative to septic systems with increased levels of treatment performance and nitrogen removal. Typical effluent quality parameters are Biochemical Oxygen Demand (BOD), Total suspended solids (TSS), Total Kjeldahl Nitrogen (TKN), and fecal coliforms.

The leading testing facility in the United States is the Massachusetts Alternative Septic System Test Center, a programme of the Buzzards Bay National Estuary Program. Testing conducted here includes the stringent Environmental Technology Initiative (ETI) where systems are tested in triplicate over two years, and the Environmental Technology Verification (ETV) program which is funded by the U.S. Environmental Protection Agency (EPA) and includes stress testing as well as evaluation of nitrogen removal over 14 months. Systems are approved for installation by local, state and federal regulations and controls.

TRICKLING FILTER

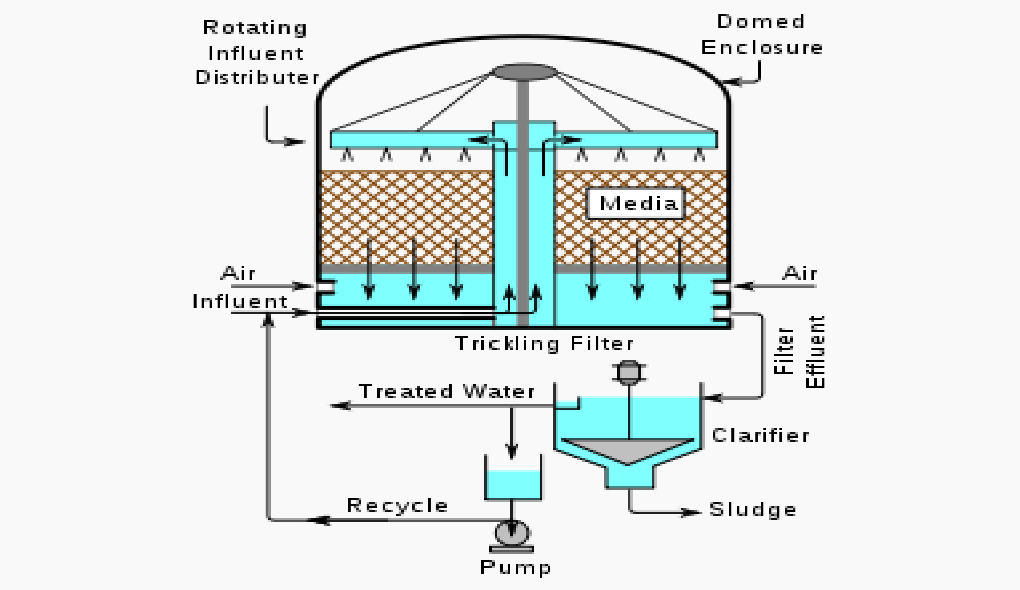


Fig. 4.2: A Typical Complete Trickling Filter

Source: http://en.wikipedia.org/wiki/Trickling_filter

Industrial Waste-water Treatment Trickle Filters

The trickling filter system is relatively simple and inexpensive. It is an aerobic sewage treatment method in which the sewage is distributed by a revolving sprinkler suspended over a bed of porous material as seen in the figure 4.3.

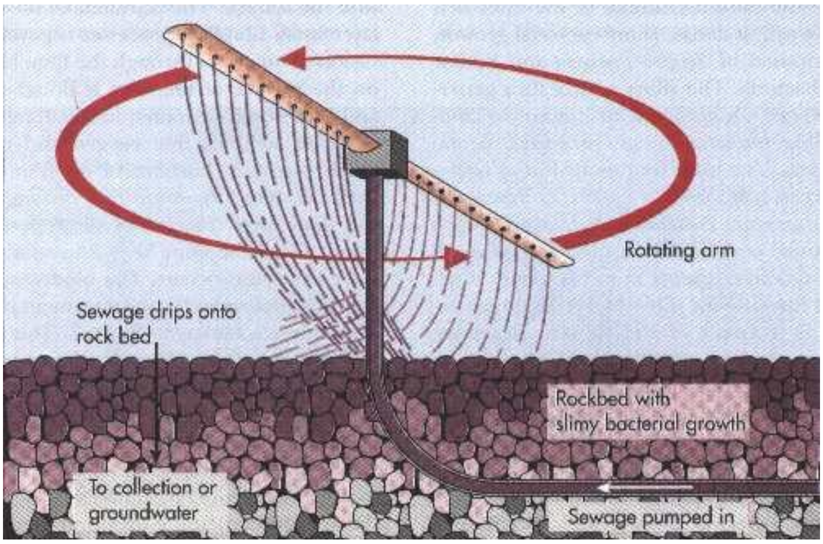


Fig.4.3: Trickling Filter

Source: http://www.rpi.edu/dept/chem-eng/Biotech-enviro/FUNDAMNT/stream/methods.html

The sewage slowly moves through the porous bed and the effluent is collected at the bottom. This porous material becomes coated with a dense slimy bacterial growth which provides a home for a heterogeneous microbial community which includes bacteria, fungi, and protozoa as well as other organisms. As the sewage drains through the porous bed, this microbial community absorbs and breaks down dissolved organic nutrients in the sewage; this reduces the BOD. Aeration of the sewage occurs by the movement of air through the porous bed. The sewage may need to be re-circulated several times through the filter in order to reduce the BOD sufficiently. One disadvantage to this system is that an excess amount of nutrients produces an excessive amount of slime on the bed which in turn reduces aeration, leading to the need to renew the porous bed. Cold winter temperatures also reduce the effectiveness of this method in outdoor treatment facilities.

Waste-waters from a variety of industrial processes have been treated in trickling filters. Such industrial waste-water trickling filters consist of two types:

- Large tanks or concrete enclosures filled with plastic packing or other media.
- Vertical towers filled with plastic packing or other media. The availability of inexpensive plastic tower packing has led to their use as trickling filter beds in tall towers, some as high as 20 meters(Millon,1967). As early as the 1960s, such towers were in use at: the Great Northern Oil's Pine Bend Refinery in Minnesota; the Cities Service Oil Company Trafalgar Refinery in Oakville, Ontario and at a Kraft paper mill (Bryan and Moeller, 1960).

The treated water effluent from industrial waste-water trickling filters is very often subsequently processed in a clarifier-settler to remove the sludge that sloughs off the microbial slime layer attached to the trickling filter media (see Image or fig 9.3 above).

Currently, some of the latest trickle filter technology involves aerated biofilters which are essentially trickle filters consisting of plastic media in vessels using blowers to inject air at the bottom of the vessels, with either downflow or upflow of the waste-water (Sperling, 2007).

3.2 Rotating Biological Discs Process

In order to understand this section well, a closer look at this sketch and others are quite necessary.

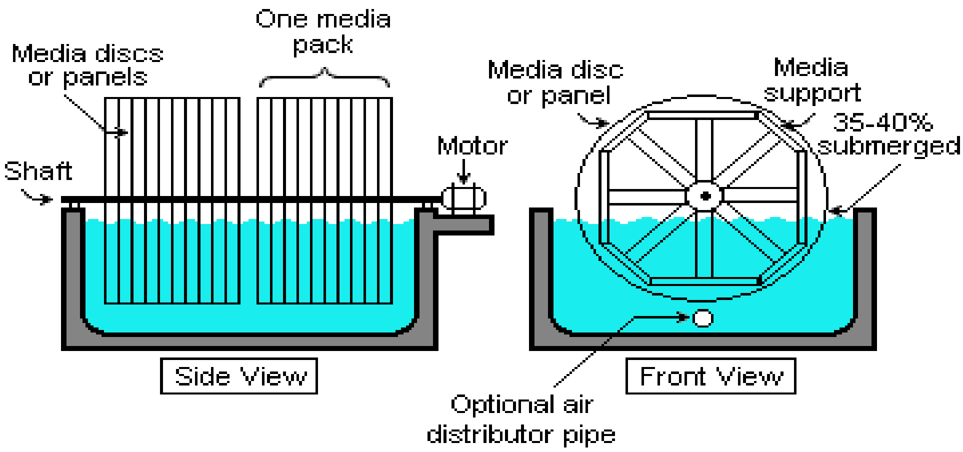


Fig. 4.4: Rotating Biological *Contactor*

Source: http://en.wikipedia.org/wiki/file:Rotating Biological Contactor.png). Schematic diagram of a typical Rotating Biological Contactor (RBC)

The treated effluent clarifier/settler is not included in the diagram. A rotating biological contactor or RBC is a biological treatment process used in the treatment of waste-water following primary treatment (Grady and Daigger et al, 1998). The primary treatment process removes the grit and other solids through a screening process followed by a period of settlement. The RBC process involves allowing the waste-water to come in contact with a biological medium in order to remove pollutants in the waste-water before discharge of the treated waste-water to the environment, usually a body of water (river, lake or ocean). A rotating biological contactor is a type of secondary treatment process. It consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the waste water. Micro-organisms grow on the surface of the discs where biological degradation of the waste-water pollutants takes place.
Rotating Biological Contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of micro-organisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia urinated into the aquarium water by the fish and other animals.

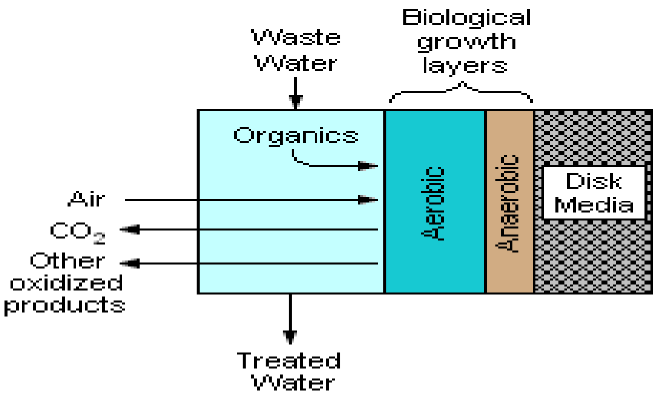


Fig.4.5: Operation of RBC (Beychok, 1967).

The rotating packs of disks (known as the media) are contained in a tank or trough and rotate at between 2 and 5 revolutions per minute. Commonly used plastics for the media are polythene, PVC and expanded polystyrene. The shaft is aligned with the flow of waste-water so that the discs rotate at right angles to the flow with several packs usually combined to make up a treatment train. About 40% of the disc area is immersed in the waste-water.

Biological growth is attached to the surface of the disc and forms a slime layer. The discs contact the waste-water with the atmospheric air for oxidation as it rotates. The rotation helps to slough off excess solids. The disc system can be staged in series to obtain nearly any detention time or degree of removal required. Since the systems are staged, the culture of the later stages can be acclimated to the slowly degraded materials.

The discs consist of plastic sheets ranging from 2 to 4 m in diameter and are up to 10 mm thick. Several modules may be arranged in parallel and/or in series to meet the flow and treatment requirements. The discs are submerged in waste water to about 40% of their diameter. Approximately 95% of the surface area is thus alternately submerged in waste water and then exposed to the atmosphere above the liquid.

Carbonaceous substrate is removed in the initial stage of RBC. Carbon conversion may be completed in the first stage of a series of modules, with nitrification being completed after the 5th stage. Most design of RBC systems will include a minimum of 4 or 5 modules in series to obtain nitrification of waste water.

Biofilms, which are biological growths that become attached to the discs, assimilate the organic materials in the waste-water. Aeration is provided by the rotating action, which exposes the media to the air after contacting them with the waste-water, facilitating the degradation of the pollutants being removed. The degree of waste-water treatment is related to the amount of media surface area and the quality and volume of the inflowing waste-water.

Secondary Clarification

Secondary clarifiers following RBCs are identical in design to conventional humus tanks, as used downstream of trickling filters. Sludge is generally removed daily, or pumped automatically to the primary settlement tank for co-settlement. Regular sludge removal reduces the risk of anaerobic conditions from developing within the sludge, with subsequent sludge flotation due to the release of gases.

3.3 Activated Sludge System Process

Activated sludge is a process for treating sewage and industrial waste-waters using air and a biological floc composed of bacteria and protozoans.

Purpose

In a sewage (or industrial waste-water) treatment plant, the activated sludge process is a biological process that can be used for one or several of the following purposes:

- oxidising carbonaceous matter: biological matter.
- oxidising nitrogenous matter: mainly ammonium and nitrogen in biological materials
- removing phosphate
- driving off entrained gases carbon dioxide, ammonia, nitrogen, etc.
- generating a biological floc that is easy to settle
- generating liquor that is low in dissolved or suspended material.

The Process

The process involves air or oxygen being introduced into a mixture of screened, and primary treated sewage or industrial waste-water (waste-water) combined with organisms to develop a biological floc which reduces the organic content of the sewage. This material, which in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria but also has an important protozoan flora mainly composed of amoebae, spirotrichs, peritrichs includingvorticellids and a range of other filter feeding species. Other important constituents include motile and sedentary Rotifers. In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including *Sphaerotilus natans* which produces a sludge that is difficult to settle and can result in the sludge blanket decanting over the weirs in the settlement tank to severely contaminate the final effluent quality. This material is often described as sewage fungus but true fungal communities are relatively uncommon.

The combination of waste-water and biological mass is commonly known as *mixed liquor*. In all activated sludge plants, once the waste-water has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new waste-water entering the tank. This fraction of the floc is called *return activated sludge* (R.A.S.). Excess sludge is called *surplus activated sludge* (S.A.S.) or *waste activated sludge* (W.A.S). W.A.S is removed from the treatment process to keep the ratio of biomass to food supplied in the waste-water in balance, and is further treated by digestion, either under anaerobic or aerobic conditions prior to disposal.

Many sewage treatment plants use axial flow pumps to transfer nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as **internal mixed liquor recycle pumps** (IMLR pumps). The raw sewage, the RAS, and the nitrified mixed liquor are mixed by submersible mixers in the anoxic zones in order to achieve denitrification.

Activated sludge is also the name given to the active biological material produced by activated sludge plants.

Activated Sludge Control

The general method of doing this is by monitoring sludge blanket level, SVI (Sludge Volume Index), MCRT (Mean Cell Residence Time), F/M (Food to Microorganism), as well as the biota of the activated sludge and the major nutrients DO (Dissolved oxygen), nitrogen, phosphate, BOD (Biological oxygen demand), and COD (Chemical oxygen demand). In the reactor/aerator + clarifier system:

- The sludge blanket is measured from the bottom of the clarifier to the level of settled solids in the clarifier's water column; this, in large plants, can be done up to three times a day.
- The SVI is the volume of settled sludge in milliliters occupied by 1 gram of dry sludge solids after 30 minutes of settling in a 1000 milliliter graduated cylinder (Burton and Stensel, 2003).
- The MCRT is the total mass (lbs) of mixed liquor suspended solids in the aerator and clarifier divided by the mass flow rate (lbs/day) of mixed liquor suspended solids leaving as WAS and final effluent (Burton and Stensel, 2003).
- The F/M is the ratio of food fed to the micro-organisms each day to the mass of micro-organisms held under aeration. Specifically, it is the amount of BOD fed to the aerator (lbs/day) divided by the amount (lbs) of MLVSS (Mixed Liquor Volatile Suspended Solids) under aeration. Note: Some references use MLSS (Mixed Liquor Suspended Solids) for expedience, but MLVSS is considered more accurate for the measure of microorganisms. Again, due to expedience, COD is generally used, in lieu of BOD, as BOD takes five days for results.

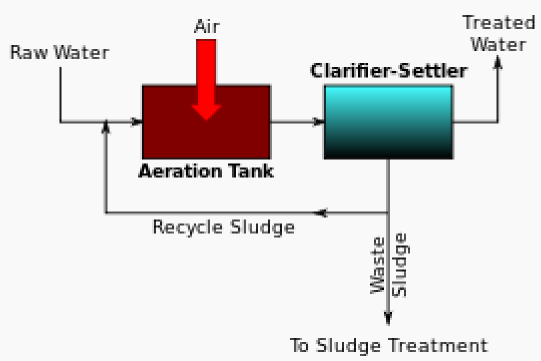


Fig.4.6: **A Generalised, Schematic Diagram of an Activated Sludge Process**

Source: http://en.wikipedia.org/w/index.php?title=File:Activated Sludge 1.svg&page=1

Arrangement

The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items:

- Aeration tank where air (or oxygen) is injected in the mixed liquor.

- Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs (the sludge blanket) to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen).

Types of Plants

Fig. 4.7: Activated Sludge System in China
(Source: http://en.wikipedia.org/wiki/File:STSTW Activated Sludge.jpg).

There are a variety of types of activated sludge plants according to Burton and Stensel (2003). These include:

Package Plants

There are a wide range of other types of plants, often serving small communities or industrial plants that may use hybrid treatment processes often involving the use of aerobic sludge to treat the incoming sewage. In such plants the primary settlement stage of treatment may be omitted. In these plants, a biotic floc is created which provides the required substrate.

Package plants are commonly variants of extended aeration, to promote the 'fit & forget' approach required for small communities without dedicated operational staff. There are various standards to assist with their design.

Activated sludge is another method of providing secondary treatment to waste-water, whereby a mixture of waste-water and biological sludge (microorganisms) is agitated and aerated. The biological solids are then allowed to settle out.

The name "activated sludge" comes from the biological mass formed when oxygen (in the form of air) is continuously injected into the waste-water. In this process, micro-organisms are thoroughly mixed with organics under conditions that stimulate their growth. As the micro-organisms grow and are mixed by the agitation of the air, the individual micro-organisms clump (or *flocculate*) together to form a mass of microbes called *activated sludge*. About eight cubic feet of air are required for every cubic foot of waste-water.

In the activated sludge process, waste-water flows continuously into an aeration tank where air is injected into the waste-water to mix the waste-water with the activated sludge, and also to provide the oxygen needed for the micro-organisms to break down the organic pollutants. The mixture of waste-water and activated sludge is called *mixed liquor*. The mixed liquor flows to a *secondary clarifier* (settling tank) where the activated sludge settles out. Some (usually twenty or thirty percent) of the settled sludge is returned to the aeration tank (and hence is called *return sludge*) to maintain a high population of microbes to break down the organics.

Since more activated sludge is produced than is needed for return sludge, the excess sludge is removed and disposed of.

Oxidation Ditch

In some areas, where more land is available, sewage is treated in large round or oval ditches with one or more horizontal aerators typically called brush or disc aerators which drive the mixed liquor around the ditch and provide aeration. These are oxidation ditches, often referred to by manufacturer's trade names such as Pasveer, Orbal, or Carrousel. They have the advantage that they are relatively easy to maintain and are resilient to shock loads that often occur in smaller communities (i.e. at breakfast time and in the evening).

Oxidation ditches are installed commonly as 'fit & forget' technology, with typical design parameters of a hydraulic retention time of 24 - 48 hours, and a sludge age of 12 - 20 days. This compares with nitrifying activated sludge plants having a retention time of 8 hours, and a sludge age of 8 - 12 days.

Deep Shaft

Where land is in short supply sewage may be treated by injection of oxygen into a pressured return sludge stream which is injected into the base of a deep columnar tank buried in the ground. Such shafts may be up to 100 metres deep and are filled with sewage liquor. As the sewage rises the oxygen forced into solution by the pressure at the base of the shaft breaks out as molecular oxygen providing a highly efficient source of oxygen for the activated sludge biota. The rising oxygen and injected return sludge provide the physical mechanism for mixing of the sewage and sludge. Mixed sludge and sewage is decanted at the surface and separated into supernatant and sludge components. The efficiency of deep shaft treatment can be high.

Surface aerators are commonly quoted as having an aeration efficiency of 0.5 - 1.5 kg O_2/kWh, diffused aeration as 1.5 - 2.5 kg O_2/KWh. Deep Shaft claims 5 - 8 kg O_2/kWh.

However, the costs of construction are high. Deep Shaft has seen greatest uptake in Japan, because of the land area issues. Deep Shaft was developed by ICI, as a spin-off from their Pruteen process. In the UK it is found at three sites: Tilbury, Anglian water, treating a waste-water with a high industrial contribution;[8] Southport, United Utilities, because of land space issues; and Billingham, ICI, again treating industrial effluent, and built (after the Tilbury shafts) by ICI to help the agent sell more.

Deep Shaft is a patented, licensed, process. The licensee has changed several times and, currently, it is Aker Kvaerner Engineering Services.

3.4 Oxidation Pond Application

Oxidation Ponds are also known as stabilisation ponds or lagoons. They are used for simple secondary treatment of sewage effluents. Within an oxidation pond heterotrophic bacteria degrade organic matter in the sewage which results in production of cellular material and minerals. The production of these supports the growth of algae in the oxidation pond. Growth of algal populations allows further decomposition of the organic matter by producing oxygen. The production of this oxygen replenishes the oxygen used by the heterotrophic bacteria. Typically oxidation ponds need to be less than 10 feet deep in order to support the algal growth. In addition, the use of oxidation ponds is largely restricted to warmer climate regions because they are strongly influenced by seasonal temperature changes. Oxidation ponds also tend to fill, due to the settling of the bacterial and algal cells formed during the decomposition of the sewage. Overall, oxidation ponds tend to be inefficient and require large holding capacities and long retention times. The degradation is relatively slow and the effluents containing the oxidized products need to be periodically removed from the ponds. An oxidation pond can be seen in the figure below.

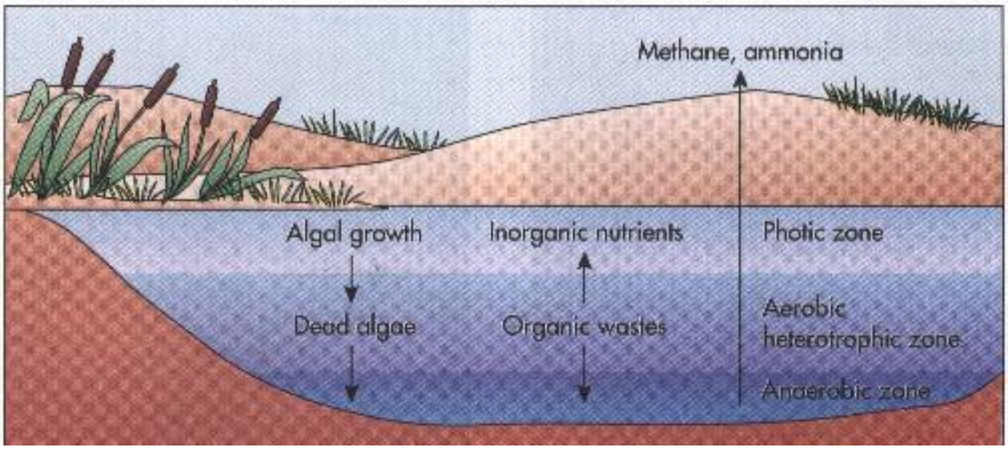


Fig.4.8: Oxidation Pond

Source: http://www.bcwater.org/waterfacts/waste-watertreatment.asp

4.0 CONCLUSION

From all that have been discussed, one can conclude that secondary treatment of waste-water involves the whole of tricking filters, rotating biological discs, activated sludge and oxidation pond processes. All are aimed at improving the quality of waste-water be discharging same into the sea or on the land. Whereas most of them employ biological principles in their mechanism of operation, some employ physical processes intermittently as the processes continue.

5.0 SUMMARY

In this unit, we were able to learn the following:

- The meaning and detailed facts about trickling filters. In this, we were made to understand that the removal of pollutants from the waste-water stream involves both absorption and adsorption of organic compounds by the layer of microbial biofilm. The filter media is typically chosen to provide a very high surface area to volume. Other issues discussed include: its operation, types, configurations and components, regulatory approvals, and industrial waste-water treatment trickle filters.
- Rotating biological contactor or discs were next to be discussed. In this we were made to know that the RBC process involves allowing the waste-water to come in contact with a biological medium in order to remove pollutants in the waste-water before discharge of the treated waste-water to the environment, usually a body of water (river, lake or ocean) and also that a rotating biological contactor is a type of secondary treatment process. Other thing learnt includes its operation mechanism.
- Activated sludge system was next. We learnt that it is a process for treating sewage and industrial waste-waters using air and a biological floc composed of bacteria and protozoans. Here we discussed its purpose, process and control measures. The types of activated sludge system were discussed last.
- The oxidation pond application came last in the group and its explanation was quite given. In all these, diagrams were used to add flesh to the study.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss trickling filter under the following headings:
   a. Description
   b. Types
   c. Configuration and components
   d. Regulatory approvals.
2. Describe the working mechanism of rotating biological contactor or disc.
3. What are the purpose and process of activated sludge?

7.0 REFERENCES/FURTHER READING

Beychok, M. R. (1967). *Aqueous Wastes from Petroleum and Petrochemical Plants* (1st ed.). John Wiley & Sons Ltd.

Biological Filter and Process U.S. Patent 4,351,729, September 28, 1982, Assigned to Celanese Corporation.

Bryan, E.H. & Moeller, D.H (1960). *Aerobic Biological Oxidation Using Dowpac*. Paper 42, Conference on Biological Waste Treatment. Manhattan College.

Leslie, Grady, C.P.; Glenn T. D. & Henry, C. L. (1998). *Biological Waste-water Treatment* (2nd ed.). CRC Press.

Lee, C.C. & Shun D. L. (2000). *Handbook of Environmental Engineering Calculations* (1st ed.). McGraw Hill.

Tchobanoglous, G., Burton, F.L.and Stensel, H.D. (2003). *Waste-water Engineering (Treatment Disposal Reuse) / Metcalf & Eddy, Inc*. (4th ed.). McGraw-Hill Book Company.

Frank, R. Spellman. (2000). *Spellman's Standard Handbook for Waste-water Operators*. CRC Press.

Mba, D (n.d). *Mechanical Evolution of the Rotating Biological Contactor into the 21st Century* . School of Engineering: Canfield University.

Beychok, M. R. (1967). *Aqueous Wastes from Petroleum and Petrochemical Plants* (1st ed.). John Wiley & Sons.

King Fahd University of Petroleum and Mineral., 'Course CHE 101.11'. Saudi Aramco Engineering Development Programme.

Marcus V. S. (2007). *Activated Sludge and Aerobic Biofilm Reactors*. IWA Publications. *Code of Practice, Flows and Loads-2, British Water.Review* of UK and International Standards.

Wikipedia, the Free Encyclopedia –'Trickling Filter'.

http://www.bcwater.org/waterfacts/waste-watertreatment.asp

http://www.water.siemens.com/en/applications/waste-water_treatment/secondary-treatment/Pages/default.aspx.

http://en.wikipedia.org/wiki/File:STSTW Activated Sludge.jpg.
http://en.wikipedia.org/wiki/file:Rotating Biological Contactor.png.

http://www.rpi.edu/dept/chem-eng/Biotech-enviro/FUNDAMNT/stream/methods.html.

UNIT 5 PHYSIC-CHEMICAL TREATMENT PROCESS

CONTENTS

1.0 INTRODUCTION

In our previous units and the other units to come, we have been and will be dealing with some waste-water treatment processes which their methods hover around the issues enlisted in the sub sections of 3.2 in the last unit. The essence of this specific unit is to have a review or summary of all of them, highlighting the major or essential points in each of them and bringing in some latent details not yet shown, all aimed at making sure that at the end of the day, no student will be left in the dark concerning sewage and waste-water treatment processes. You should know that more than one treatment is needed to achieve the desired change in quality of waste-water. Thus, it is a chain processes operating in sequence. In some cases, treatment processes do not destroy the impurity but simply concentrate them in the form of sludge or effluent stream. Selection of proper method based on the characteristics of waste-water is the key to solving treatment problems.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the nature of impurities in the waste-water
- describe the different processes of waste-water treatment
- classify appropriately each process.

3.0 MAIN CONTENT

3.1 Nature of Impurities

It should be known that rainwater, surface water, groundwater, seawater and waste-water can be considered as the different forms of some basic material, varying in form and amount of impurities. These impurities decide the level of treatment that should be provided for any of its use and or disposal.

While municipal water has many types of impurities like floating and large suspended solids (paper, rags, plastics, and grit), dissolved solids (organic and inorganic), dissolved gases (hydrogen sulfide, methane etc.) and micro-organisms (pathogen, bacteria and viruses); waste-water on the other hand can have much higher levels of impurities as earlier discussed because of the human organic waste added to water along with detergents, pesticides, and micro-organism.

But waste-water can be called as water of different form if the concentration of impurities is reduced, it can have applications similar to water. It is the task in this course to have a level of waste-water treatment that the end product should not be harmful to the user, be it the water left after treatment or the sludge used for fertilisation or disposed / deposited into the sea.

3.2 Different Treatment Processes

Waste-water treatment processes normally uses physical processes initially and later chemical processes like precipitation. But if it is not sufficiently treated by the two processes, then the three can be used. Therefore, it should be known that waste-water treatment is divided into three main processes, herein given below.

1. Physical processes comprising screening or straining, sedimentation, flocculation and filtration. This should be designated as P (Physical process)
2. Chemical treatment using adsorption, coagulation, ion exchange, precipitation. This should be known as C (Chemical process)
3. Biological treatment processes with dispersed growth system (activated sludge, stabilization ponds); fixed film reactors (biological filters such as tricking filter). This is known as B (Biological process).

Assignment: Pick your pen and write out some of the discrete processes known to you but is/are not contained in the list above, classifying same as you do that.

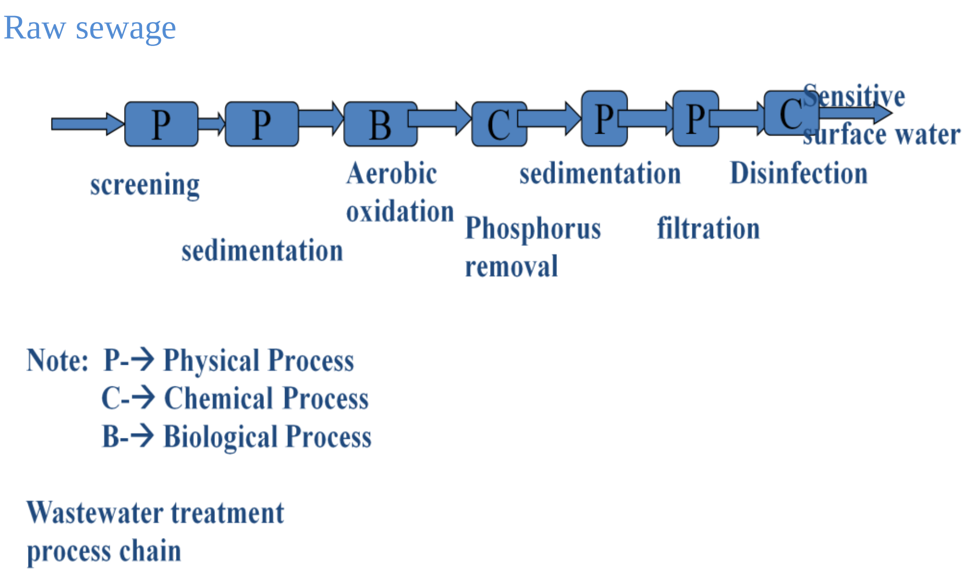


Fig. 5.1: Different Treatment Processes

Source: http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.ppt

3.2.1 Physical Treatment Processes

The main aim of physical treatment process in a water or waste-water treatment system is to protect the main treatment systems from possible damage or clogging. Various processes are used to remove large floating and suspended material.

Screening

This is the first operation in the physical treatment process. Micro strainer with specially woven stainless steel meshes size between 20 to 40 micrometer are usually used in water treatment plants.

The nature and quantity of screening collected depend upon the social, dietary, as well sewerage system of the city. It also depends on the screening bar spacing, which affect the loss of velocity head. This head-loss indicates the performance of a screen. On an average its quantity ranges from .01 to .03 cu.m./1000 population per day.

Screening is unpleasant in nature with a strong odor, particularly in high temperatures. Their density is usually 1800-1900 kg/cu.m. with a solid content of 15-30%.

Sample Problem

A bar screen is installed in a waste-water treatment plant receiving a daily peak flow of crude sewage of 50,000 cu.m. Estimate head-loss through the screen and also the gross area of the screen.

Solution

Maximum flow, Q= 50,000 cu.m. =.5788 cu.m/s

Desired velocity through the screen, V,at ultimate flow= 0 .8m/s

Net area of screen opening required, A= .5788/.8 = 0.72 m/s

Since Q= V/A.

Using rectangular bars in the screen having 1 cm width, 1 m height and placed 5 cm clear spacing.

Number of bars required = .7235 * 100/5 = 14.46

Say 15 bars of 1 cm each

Total area required for screen = 0.7235 + (15 * 10^-2) = 0.87 square meter

Assuming that the inclination of the screen to the horizontal is at 60 degrees

The gross area of screen would be

= 0.87 * (square root of 3/ 2) = 1 square meter

Velocity through the clear screen, v = 0.8m/s

Velocity above the screen, u = 0.8 * 5/6 m/s = 0.67 m/s

Using the equation of continuity

Head- loss through the screen is usually given as

– = 0.0729 (v^2- u^2)

– = 0.0729 (0.8^2 – 0.67^2)

– = 0.014 m

If the screen openings are half plugged with screenings, leaves and debris, the velocity through the screen is doubled.

– v = 0.8 * 2 m/s

– = 1.6 m/s

Maximum head- loss = .0729 (1.6^2 – 0.67 ^2)

= 0.15m

At this maximum head -loss, the screen is to be cleaned.

If you are not clear with the calculation try and read it over and over again before forging ahead. If at the end of the day you are still confused, consult your friends or superiors.

Comminution and Maceration

In situ maceration of floating and large suspended solids can be achieved by a comminutor or macerator in which the material is trapped between teeth mounted on a slotted rotating drum and a fixed comb.

Grit Removal

In most sewerage plant, considerable amount of sand and grit are transported to the waste-water treatment plant. These materials arise from roads and other paved areas. These two should be removed earlier in order to prevent damage on the pumps and other mechanical equipments.

Sedimentation

Is the separation of solids based on difference between densities of solids and waste-water due to gravity?

Stoke's law

Vs = (gd^2/18V) (Ss – 1)

Where Vs = discrete particle terminal velocity; g is acceleration due to gravity; d= diameter of the particle; V = kinematic viscosity of water
Ss = specific gravity of the particle

Practical consideration in settlement of the discrete suspension involves concept of ideal settling basin in which it is assumed that the following conditions exists.

- Quiescent settlement in the settling zone
- Uniform flow through the settling zone
- Uniform solids concentrations entering the settling zone
- Solids entering the sludge zone are not resuspended.

	Types of Sedimentation Tank	
Parameter	Rectangular	Circular
Max. length	90m	-
Max. width	30m	-
depth	2- 2..5	2- 3.5 m
Range of length/width ratio	1.5- 7.5	
Range of length/ depth ratio	5 – 25	
Bottom slope	1%	7.5 – 10% (from periphery to center)
Max. diameter		30m
Inlet	multiple pipes on the width side with baffle boards of depth 0.5 m and 0.8 m in front of the pipe inlets and surface for scum Passover	central inlet pipe with concentric inlet baffle of diameter 15% of tank diameter and extending 1m below surface
Outlet	Overflow weir with V-notches to Provide uniform flow at low heads Scum baffles provide ahead of weir for wastewater installations	peripheral weir provided with V- notch. Scum baffle extending 0.3 m below water surface provided ahead of effluent weir for waste-water installation
Peak velocity	Depends upon feed	
Scraper arms velocity	0.2 m.min Design features of waste-water sedimentation tank.	

Source:http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.ppt

Typical sedimentation tanks include (a) rectangular horizontal flow tank (b) circular, radial-flow tank (c) hopper-bottomed, upward flow.

Diagrammatic Presentation of the Types

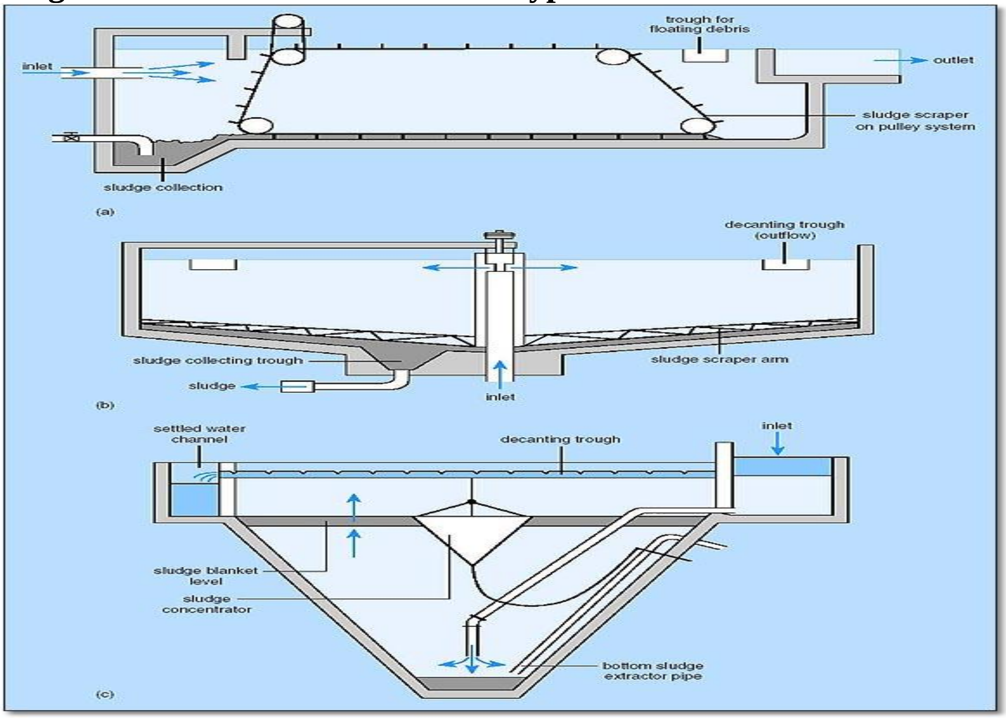


Fig.5.2: Important Parts of a Sedimentation Tanks

Source: http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.ppt

- (a) Inlet zone – at the central well, which has a round baffle plate, the flow is established in a uniform radial direction so that short-circuiting does not take place.
- (b) Settling zone – where settling is assumed to occur as the water flows towards the outlet.
- (c) Outlet zone – in which the flow converges up and over the decanting weirs.
- (d) Sludge zone – where settled material collects and is pumped out.

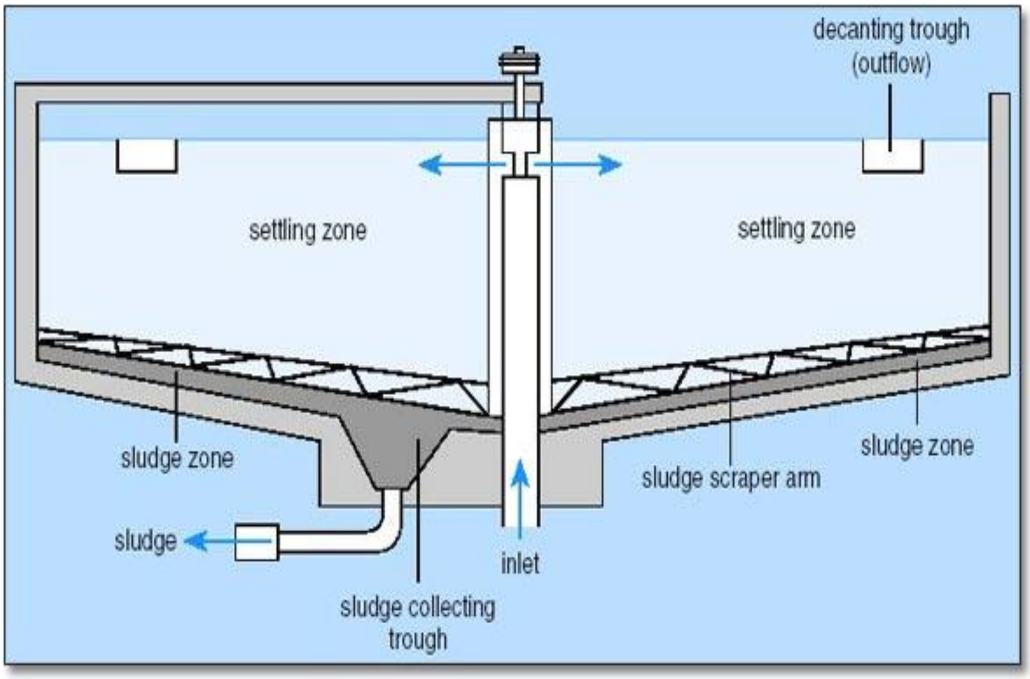


Fig.5.3: **Important Zones in Sedimentation**
Source: http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.ppt

Flocculation
This process is used when the small suspended solids having low specific gravity and low settling velocity cannot be separated by sedimentation easily. In waste-water treatment, this usually occurs particularly with particles of less than 50 micrometer in size.

3.2.2 Chemical Treatment Processes

Chemical precipitation- This is the method of addition of chemicals to the waste-water, converting undesired soluble substances into an insoluble precipitate which can be removed easily and rapidly.

The undesired constituents generally found in waste-water are:

- Suspended colloidal and supra colloidal solids and their associated organic matter. They should be removed in order to avoid damage to performance and reduction in efficiency.
- Phosphorus
- Toxic heavy metals and organics discharged from industrial plants and premises into the municipal waste-water treatment plant.

Coagulation
This is an important operation in removing colloidal solids. In waste-water treatment, chemical such as lime, ferric salts and commercial alum are used as coagulants. This process removes suspended solids (60-80%), BOD (50-70%) phosphorus (over 90%) and heavy metal (over 80%).

Chemical clarification of waste-water can be combined with the activated carbon adsorption process to provide complete physical – chemical waste-water treatment. The use of chemical clarification has restricted application in developing countries because of its constant requirement of consumable chemical and consequent higher running costs.

3.2.3 Biological Treatment Processes

In this method, use of micro organisms during the process is involved. Processes under this use mostly aerobic oxidation and include:

- Filtration process
- Trickling filter process
- Oxidation pond application

These have been discussed in various units in the past.
Assignment: Find other methods that involve biological process not included in the list above. Do you still remember the above processes?

3.2.4 Advanced Treatment Processes

Advanced physical processes
These are used in order to get better treatment efficiency. Some of the better known operations used in advanced treatment are ammonia stripping, distillation, foam, fractionation, and freezing.

Ammonia stripping
It is also known as air stripping of ammonia. It is a modification of the aeration process used for the removal of gases dissolved in water.

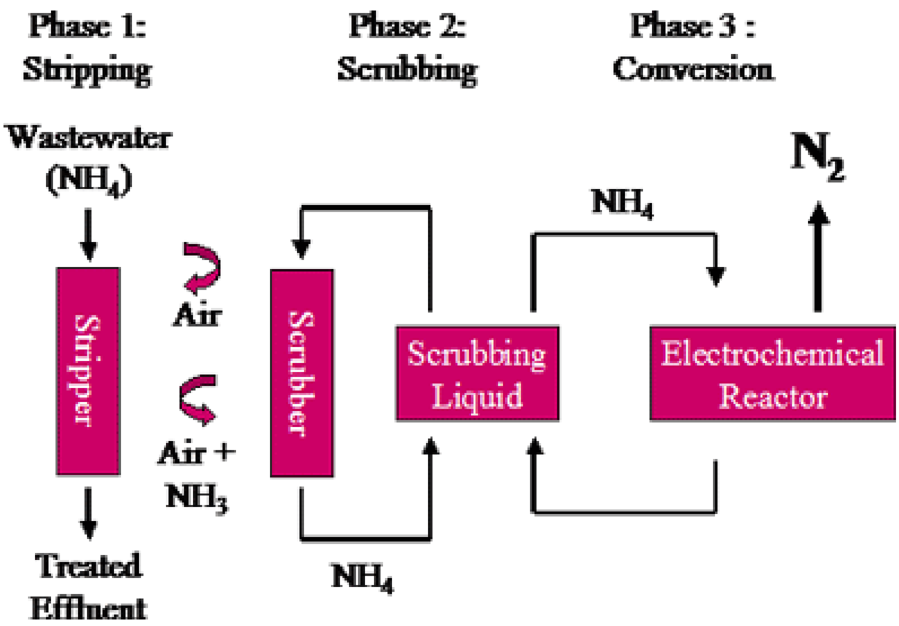


Fig. 5.4: Illustration of Ammonia Stripping

Source: http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.ppt

In the first phase, sodium hydroxide (NaOH) is added to the waste-water stream just before being pumped into the stripping column. This raises the water pH to the point where ammonium ions (NH 4 +) are converted to ammonia gas. Ammonia removal is enhanced by pumping the waste-water stream into the top of the column which is packed with high surface area packing material. Air is pumped into the bottom of the column. The ammonia carried by the air stream is then transferred to liquid in the scrub column.

At the core of AmmEL-HC is a patented electrochemical reactor that converts the ammonia dissolved in the scrubbing liquid to gaseous Nitrogen without producing nitrates or greenhouse gases. Chemically inert and occupying an 80 per cent proportion of our atmosphere, gaseous nitrogen is the ideal end product for safe dispersal into the environment.

Testing of the AmmEL-HC system has demonstrated its capabilities. As shown below, a percentage removal ranging from 93% to 99% was achieved throughout the test.

Other advantages of AmmEL-HC include:

- Improves performance of existing biological treatment plants by preventing ammonia toxicity in the activated sludge process
- Less expensive than conventional processes, including biological treatment

- Does not convert ammonia to nitrate and does not produce greenhouse gases
- Small footprint - can reduce overall cost of land for new biological treatment plants
- Can operate intermittently without start-up delays
- Fully automated - low maintenance
- Remotely monitored.

Distillation
This is a unit operation in which the components of a liquid solution are separated vaporisation and condensation.

Foam fractionation
This is the separation of colloidal and suspended material by floatation and dissolved organic matter by adsorption.

Freezing
Waste-water is sprayed into a chamber operating under a vacuum. A portion of waste-water gets evaporated and cooling effect produces contaminant free ice crystals in the remaining liquid.

Gas phase separation
It is a promising method for removal of ammonia as gas. This method is based on the development of selective permeable gas-phase membranes**.**

Reverse osmosis
It is the process in which water is separated from dissolved salts in the solution by filtering through semi permeable membrane at a pressure than the osmotic pressure caused by the dissolved salts in waste-water.

Sorption
Conventional alum treatment for removal of phosphate increases the concentration of sulphate ions in the solution. To avoid this, sorption is developed. Sorption is a process of removing various forms of phosphate without increasing the concentration of sulphates.

Advanced chemical processes
Ion exchange- although both natural and synthetic ion exchange resins are available, synthetic resins are used more widely because of their durability. Some natural zeolites (resins) are also used for the removal of ammonia from waste-water.

Electrochemical treatment
Waste-water is mixed with seawater and is passed into a single cell containing carbon electrodes.

Electro dialysis
Ionic components of solutions are separated through the use of semi permeable ion-selective membranes. If the electrical potential is applied between the two electrodes, it in turn causes a migration of cations toward the negative electrode and migration of anions towards the positive electrode. Due to the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed.

Principle of simple electrodialysis process – The diagram shows the membrane configuration with alternating cation-selective (1) anion-selective (2) membranes between two electrodes (3) and (4)), one at each end of the stack.

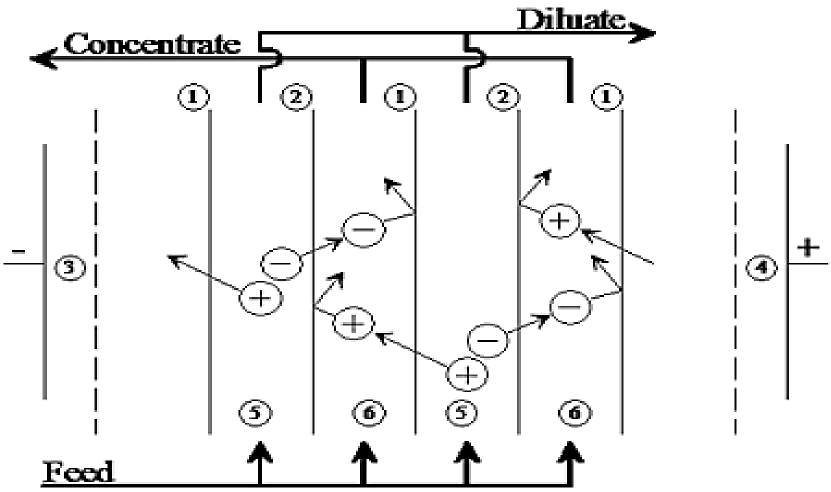


Fig.5.5: Simple Electrodialysis Process
Source: http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment

Oxidation and Reduction

Oxidation- Chemical oxidation is used to remove ammonia, to reduce the concentration of residual organics and to reduce bacterial and viral contents of waste-water. At present, one of the few processes for the removal of ammonical nitrogen, found operationally dependable, is chlorination. Ammonia can be removed chemically by adding chlorine or hypochlorite to form monochloramine and dichloramine as intermediate products and nitrogen gas and hydrochloric acid as end products. Problem associated with this method is the presence of various organic and inorganic compounds that will exert chlorine demand. Chemical oxidation of organic material in waste-water does this.

Reduction- Nitrates present in waste-water can be reduced electrolytically or by using strong reducing agents (e.g. ferrous oxide).

The reaction must usually be catalysed while using reducing agents. The two step processes using different reducing agents and catalysts are limited by the availability of chemicals at low cost, and the fact that the treated effluent and waste sludge may contain toxic compounds derived from the chemicals used for catalysing various reactions.

4.0 CONCLUSION

From all that have been discussed above we can conclude that this unit – "physic-chemical process" is just a collection of short forms of all the processes involved in the treatment of waste-water. It shows the categorisation of the processes involved which are mainly physical, biological and chemical processes. There are thus primary, secondary, tertiary or advanced forms of most of all the processes involved in the treatment as have been learnt in this unit and the preceding units.

5.0 SUMMARY

In this unit you learnt**:**

- The nature of impurities was done. Here we were made to understand that it is a collection of macro and micro materials that are contained in the waste-water which are of organic and inorganic origin, there are gases as well as micro organisms also.
- Different treatment processes were equally learnt. Here, we were made to understand that there are three major different methods, viz:

    i. Physical processes comprising screening or straining, sedimentation, flocculation and filtration. This is be designated as P (Physical process).
    ii. Chemical treatment using adsorption, coagulation, ion exchange, precipitation. This is known as C (Chemical process).
    iii. Biological treatment processes with dispersed growth system (activated sludge, stabilisation ponds); fixed film reactors (biological filters such as tricking filter). This is known as B (Biological process).
- Diagrams were used to add flesh to the topic.

6.0 TUTOR-MARKED ASSIGNMENT

1. a. Explain the nature of impurities of waste-water.
   b. Write short note on: (i) Screening (ii) Grit removal.
2. a. Use an annotated diagram to describe parts of sedimentation tank.
   b. Discuss the application of oxidation and reduction in waste-water treatment.

7.0 REFERENCES/FURTHER READING

Sridhar, M.K.C. (2007). 'Sewage Treatment'. Lecture Notes Delivered during the 2007 Mandatory Continuous Education Programme (MCEP) for Environmental Health Officers Registration Council of Nigeria, at Filbon Guest House, New Haven Enugu.

Sridhar, M. K. C. (1995). 'Sullage/Waste-water in Nigeria: Problems and Solutions for Utilisation for Gardening'. A Report Submitted to UNICEF, Lagos, Nigeria, July, pp.1-86.

West African Health Examination Board. (1991). *Waste Disposal and Environmental Hazard Control.* Ibadan: Sterling Publishers Ltd.

http://iansamonte.files.wordpress.com/2008/10/waste-water-treatment.

MODULE 3 ADVANCED WASTE-WATER TREATMENT

UNIT 1 ULTRA FILTRATION PROCESS

CONTENTS

1.0 INTRODUCTION

In module two, we dwelt much on the primary and secondary treatment of waste-water which I can say may not be too abstract to you, having been familiar with some of the topics in EHS 304 (Hydrology and Sanitation). In this module and its units, we will be dealing with advanced treatment of waste-water. The units are deliberately made to be in short forms for ease of understanding since they are very new to you.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define the word ultrafiltration
- explain the principles and processes of ultrafiltration
- discuss membrane geometries and module configuration involved in ultrafiltration
- list all the applications of ultrafiltration.

3.0 MAIN CONTENT

3.1 Meaning of Ultrafiltration

Ultrafiltration (UF) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane. Suspended solids and solutes of high molecular are retained, while water and low molecular weight solutes pass through the membrane. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration, nanofiltration or gas separation, except in terms of the size of the molecules it retains. Ultrafiltration is applied in cross-flow or dead-end mode and separation in ultrafiltration undergoes concentration polarisation. It is equally used in an advanced treatment of waste-water to get high quality end products like water that can be reused or recovered.

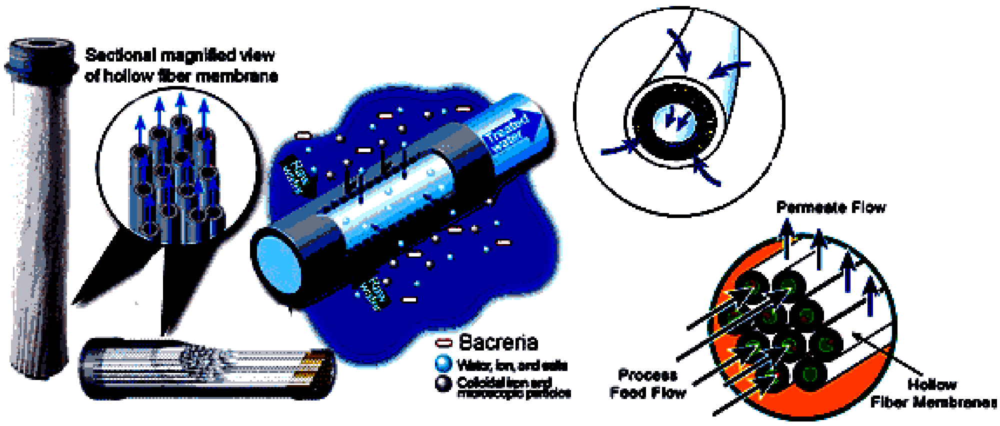


Fig. 1.1: Ultrafiltration Process
Sources: http://en.wikipedia.org/wiki/Ultrafiltration

Many of the Crystal Quest water coolers use the ultrafiltration water purification process. Ultrafiltration (UF) is an important purification technology used for the production of high-purity water in the biochemical, food and beverage, and biopharmaceutical industries. When strategically combined with other purification technologies in a complete water system, UF is ideal for the removal of colloids, proteins, bacteria, pyrogens, and other organic molecules.

3.2 Basic Principles and Process of Ultrafiltration Principles

Ultrafiltration is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency. Ultrafiltration pore ratings range from approximately 1,000 to 500,000 daltons, thereby making UF more permeable than nanofiltration (200 -- 1.000 daltons). UF membranes are composed of a polymer, such as polysulfone or polyamide that is usually extruded into flat sheets or hollow fibers or cut into disks as required by the specific application. A small disk of UF membrane may be subject to rapid fouling and produce a low flow rate for many processes.

As a result, UF membranes are typically arranged in a configuration which maximises surface area and reduces fouling by using a tangential flow design to reduce solute accumulation at the membrane surface. Tangential flow UF devices may be spiral-wound cartridges containing several square feet of membrane wrapped onto a central core tube or hollow-fiber cartridges containing dozens of thin UF membrane fibers.

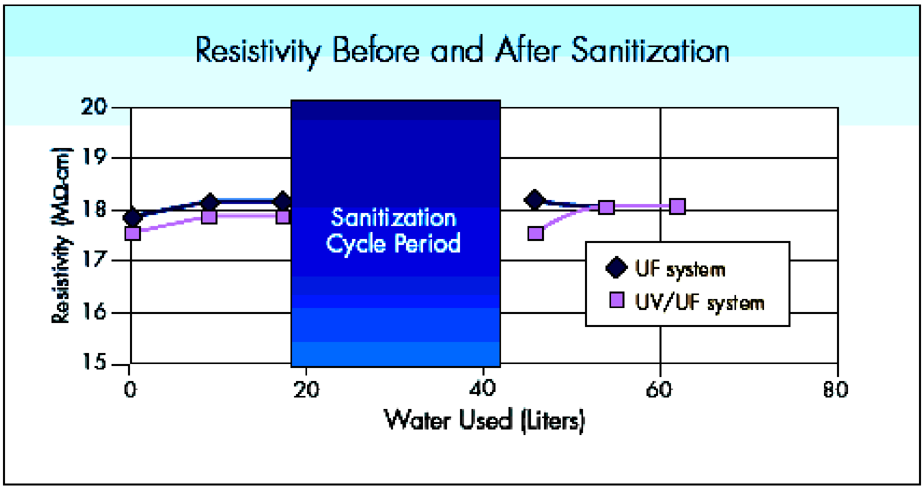


Figure 3

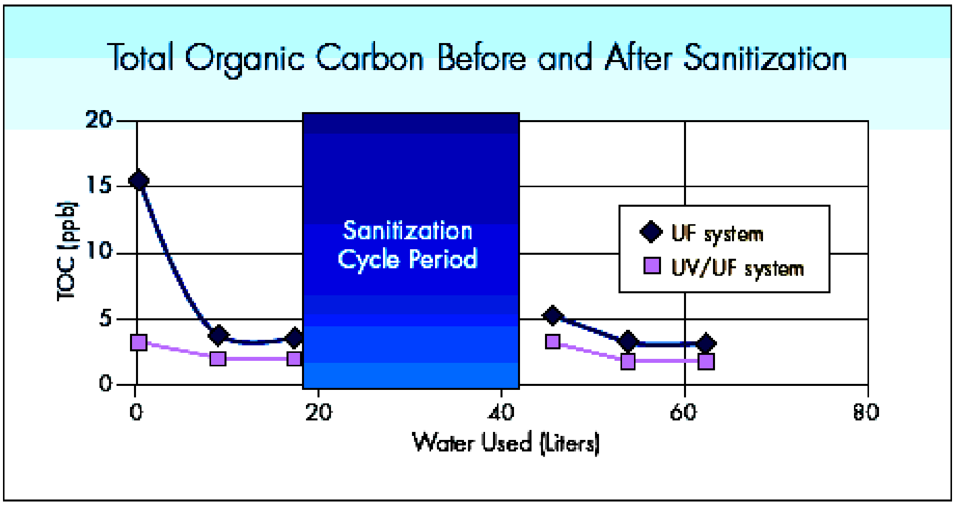


Figure 4

Fig. 1.2: Principles of Ultrafiltration

Source: http://www.purewateressentials.com/ulpr.html).

Process

Ultrafiltration systems eliminate the need for clarifiers and multimedia filters for waste streams to meet critical discharge criteria or to be further processed by waste-water recovery systems for water recovery. Efficient ultrafiltration systems utilise membranes which can be submerged, back-flushable, air scoured, spiral wound UF/MF membrane that offers superior performance for the clarification of waste-water and process water.

3.3 Membrane Geometries and Module Configuration

3.3.1 Membrane Geometries

i. Spiral wound modules

This consists of large consecutive layers of membrane and support material rolled up around a tube.

Advantages

(i) Maximises surface area
(ii) Less expensive.

Disadvantage

(i) More sensitive to pollution.

ii. Tubular membrane

The feed solution flows through the membrane core and the permeate is collected in the tubular housing.

Advantage

(i) Generally used for viscous or bad quality fluids.

Disadvantage

(i) System is not very compact and has a high cost per unit area installed.

iii. Hollow fiber membrane

The modules contain several small (0.6 to 2 mm diameter) tubes or fibers. The feed solution flows through the open cores of the fibers and the permeate is collected in the cartridge area surrounding the fibers. The filtration can be carried out either “inside-out” or “outside-in”.

3.3.2 Module Configuration

Pressurised system or pressure-vessel configuration: TMP (transmembrane pressure) is generated in the feed by a pump, while the permeate stays at atmospheric pressure. Pressure-vessels are generally standardised, allowing the design of membrane systems to proceed independently of the characteristics of specific membrane elements.

Immersed system: Membranes are suspended in basins containing the feed and open to the atmosphere. Pressure on the influent side is limited to the pressure provided by the feed column. TMP is generated by a pump that develops suction on the permeate side. Ultrafiltration, like other filtration methods can be run as a continuous or batch process

3.4 Applications of Ultrafiltration

- Dialysis and other blood treatments
- Concentration of milk before making cheese
- Downstream processing (e.g., concentration) of biotechnology-derived proteins (e.g., therapeutic antibodies)
- Desalting and solvent-exchange of proteins (via diafiltration)
- Fractionation of proteins
- Clarification of fruit juice
- Recovery of vaccines and antibiotics from fermentation broth
- Laboratory grade water purification

- Industrial waste-water treatment
- Drinking water disinfection (including removal of viruses)
- Removal of endocrines and pesticides combined with Suspended Activated Carbon pretreatment
- Ultrafiltration (industrial)
- Ultrafiltration (renal)
- Aquapheresis.

4.0 CONCLUSION

From the above we can conclude that Ultrafiltration is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency. It has got a wide variety of uses, one of which is in industrial waste-water treatment.

5.0 SUMMARY

In this unit, you have learnt the following:

- The meaning of Ultrafiltration (UF) was learnt where we are made to know that it is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane. Suspended solids and solutes of high molecular are retained, while water and low molecular weight solutes pass through the membrane. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 -10^6 Da) solutions, especially protein solutions.
- The basic principles and process of ultrafiltration were next studied. Ultrafiltration is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency.

    - Membrane geometries and module configuration came next in the line**.** Under the geometries, we have spiral wound module, tubular membrane and hollow fiber membrane. For the module configurations we have pressurised system or pressure-vessel configuration and the immersed system.

- The last was the applications of ultrafiltration and here we have a lot of them which include concentration of milk before making cheese, fractionation of proteins, clarification of fruit juice, industrial waste-water treatment and ultrafiltration (industrial) among others.

6.0 TUTOR-MARKED ASSIGNMENT

1. a. Define ultrafiltration.
   b. Explain its principles.
2. List all the applications of ultrafiltration and explain any three of them.

7.0 REFERENCES/FURTHER READING

Rizvi, S. (n.d). ‘Membrane Separations in Bio-processing’. Food Science Dept. Cornell University.

Sridhar, M.K.C. (2007). ‘Sewage Treatment’. Lecture Notes Delivered during the 2007 Mandatory Continuous Education Programme (MCEP) for Environmental Health Officers Registration Council of Nigeria at Filbon Guest House, New Haven Enugu.

Wikipedia, the Free Encyclopedia

http://www.purewateressentials.com/ulpr.html

http://en.wikipedia.org/wiki/Ultrafiltration

www.seccua.de/download/press/2010_04_WCP_Seccua_4922.pdf

UNIT 2 REVERSE OSMOSIS PROCESS

CONTENTS

1.0 INTRODUCTION

In the last unit, you were introduced to the advanced form of waste-water treatment. This unit equally takes you to another advanced form of the treatment. In the last unit, you were informed that Reverse Osmosis (RO) is the process in which water is separated from dissolved salts in the solution by filtering through semi permeable membrane at a pressure than the osmotic pressure caused by the dissolved salts in waste-water. It has got wide applications. In this unit, we will be looking deep into it with the view of making you have more facts about RO.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- give the meaning and historical background of reverse osmosis
- explain the process of reverse osmosis
- describe the applications and desalination of reverse osmosis
- enumerate the problems and prospects of reverse osmosis.

3.0 MAIN CONTENT

3.1 Meaning of Reverse Osmosis and Its Historical Background

3.1.1 Meaning of Reverse Osmosis

Reverse Osmosis (RO) is a membrane-technology filtration method that removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. The result is that the solute is retained on the pressurised side of the membrane and the pure solvent is allowed to pass to the other side. To be 'selective' this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as the solvent) to pass freely.

In the normal osmosis process, the solvent naturally moves from an area of low solute concentration (High Water Potential), through a membrane, to an area of high solute concentration (Low Water Potential). The movement of a pure solvent to equalise solute concentrations on each side of a membrane generates osmotic pressure. Applying an external pressure to reverse the natural flow of pure solvent, thus, is reverse osmosis. The process is similar to other membrane technology applications. However, there are key differences between reverse osmosis and filtration. The predominant removal mechanism in membrane filtration is straining, or size exclusion, so the process can theoretically achieve perfect exclusion of particles regardless of operational parameters such as influent pressure and concentration. Reverse osmosis, however, involves a diffusive mechanism so that separation efficiency is dependent on solute concentration, pressure, and water flux rate (Crittenden and Rhodes et al, 2005). Reverse osmosis is most commonly known for its use in drinking water purification from seawater, removing the salt and other substances from the water molecules.

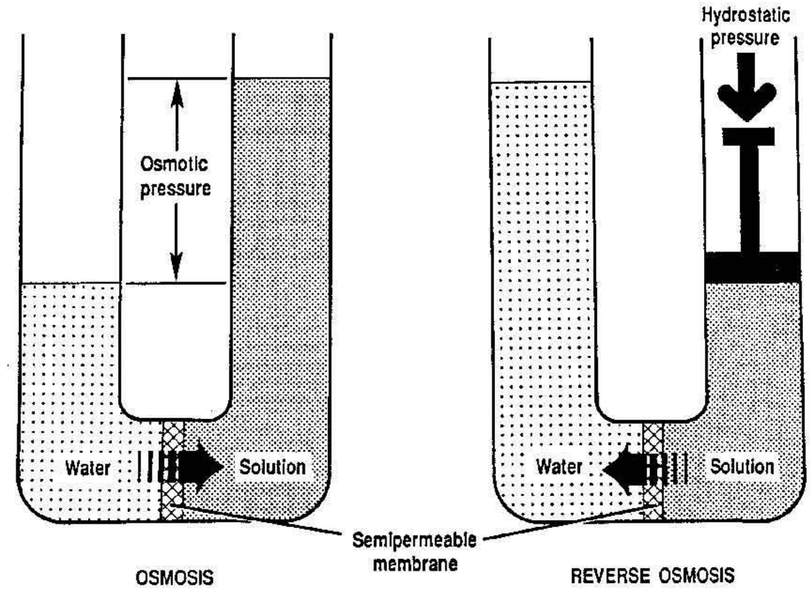


Fig. 2.1: Diagrammatic Illustration of Osmosis and Reverse Osmosis

Source: http://site.iugaza.edu.ps/safifi/files/2010/02/2-waste-water flowrate WWT.pdf

The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases, the membrane is designed to allow only water to pass through this dense layer while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–70 bar (600–1000 psi) for seawater, which has around 24 bar (350 psi) natural osmotic pressure which must be overcome.

3.1.2 The Historical Background of Reverse Osmosis

The process of osmosis through semi permeable membranes was first observed in 1748 by Jean-Antoine Nollet. For the following 200 years, osmosis was only a phenomenon observed in the laboratory. In 1949, the University of California at Los Angeles (UCLA) first investigated desalination of seawater using semi permeable membranes. Researchers from both UCLA and the University of Florida successfully produced fresh water from seawater in the mid-1950s, but the flux was too low to be commercially viable (Glater,1998), until the discovery by Loeb and Sourirajan of techniques for making asymmetric membranes characterised by an effectively thin "skin" layer supported atop a highly porous and much thicker substrate region of the membrane. By the end of 2001, about 15,200 desalination plants were in operation or in the planning stages worldwide (Crittenden and Rhodes, *et al.*, 2005).

3.3 The Process of Reverse Osmosis

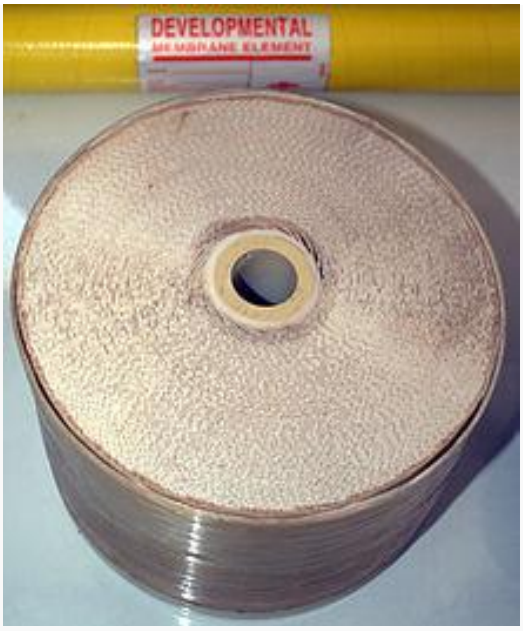


Fig. 2.2: A Semi Permeable Membrane Coil used in Desalination
Source: http://en.wikipedia.org/wiki/Reverse_osmosis

Osmosis is a natural process. When two liquids of different concentration are separated by a semi permeable membrane, the fluid has a tendency to move from low to high solute concentrations for chemical potential equilibrium.

Formally, reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a semi permeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. The largest and most important application of reverse osmosis is to the separation of pure water from seawater and brackish waters; seawater or brackish water is pressurised against one surface of the membrane, causing transport of salt-depleted water across the membrane and emergence of potable drinking water from the low-pressure side.

The membranes used for reverse osmosis have a dense layer in the polymer matrix-either the skin of an asymmetric membrane or an interfacially polymerised layer within a thin-film-composite membrane-where the separation occurs. In most cases, the membrane is designed to allow only water to pass through this dense layer, while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–82 bar (600–1200 psi) for seawater, which has around 27 bar (390 psi) natural osmotic pressure that must be overcome. This process is best known for its use in desalination (removing the salt and other minerals from sea water to get fresh water), but since the early 1970s it has also been used to purify fresh water for medical, industrial, and domestic applications.

Osmosis describes how solvent moves between two solutions separated by a permeable membrane to reduce concentration differences between the solutions. When two solutions with different concentrations of a solute are mixed, the total amount of solutes in the two solutions will be equally distributed in the total amount of solvent from the two solutions. Instead of mixing the two solutions together, they can be put in two compartments where they are separated from each other by a semi permeable membrane. The semi permeable membrane does not allow the solutes to move from one compartment to the other, but allows the solvent to move. Since equilibrium cannot be achieved by the movement of solutes from the compartment with high solute concentration to the one with low solute concentration, it is instead achieved by the movement of the solvent from areas of low solute concentration to areas of high solute concentration. When the solvent moves away from low concentration areas, it causes these areas to become more concentrated. On the other side, when the solvent moves into areas of high concentration, solute concentration will decrease. This process is termed osmosis. The tendency for solvent to flow through the membrane can be expressed as "osmotic pressure", since it is analogous to flow caused by a pressure differential. Osmosis is an example of diffusion.

In reverse osmosis, in a similar setup as that in osmosis, pressure is applied to the compartment with high concentration. In this case, there are two forces influencing the movement of water: the pressure caused by the difference in solute concentration between the two compartments (the osmotic pressure) and the externally applied pressure.

3.3 Applications and Desalination of Reverse Osmosis

3.3.1 Applications of Reverse Osmosis

Around the world, household drinking water purification systems, including a reverse osmosis step, are commonly used for improving water for drinking and cooking. Such systems typically include a number of steps:

- a sediment filter to trap particles, including rust and calcium carbonate
- optionally, a second sediment filter with smaller pores
- an activated carbon filter to trap organic chemicals and chlorine, which will attack and degrade TFC reverse osmosis membranes
- a reverse osmosis (RO) filter, which is a thin film composite membrane (TFM or TFC)
- optionally, a second carbon filter to capture those chemicals not removed by the RO membrane
- optionally an ultra-violet lamp for sterilising any microbes that may escape filtering by the reverse osmosis membrane.

In some systems, the carbon pre-filter is omitted, and cellulose triacetate membrane (CTA) is used. The CTA membrane is prone to rotting unless protected by chlorinated water, while the TFC membrane is prone to breaking down under the influence of chlorine. In CTA systems, a carbon post filter is needed to remove chlorine from the final product, water.

Portable reverse osmosis (RO) water processors are sold for personal water purification in various locations. To work effectively, the water feeding to these units should be under some pressure (40 psi or greater is the norm). Portable RO water processors can be used by people who live in rural areas without clean water, far away from the city's water pipes. Rural people filter river or ocean water themselves, as the device is easy to use (saline water may need special membranes). Some travelers on long boating, fishing, or island camping trips, or in countries where the local water supply is polluted or substandard, use RO water processors coupled with one or more UV sterilizers. RO systems are also now extensively used by marine aquarium enthusiasts. In the production of bottled mineral water, the water passes through an RO water processor to remove pollutants and microorganisms. In European countries, though, such processing of Natural Mineral Water (as defined by a European Directive) is not allowed under European law. In practice, a fraction of the living bacteria can and do pass through RO membranes through minor imperfections, or bypass the membrane entirely through tiny leaks in surrounding seals. Thus, complete RO systems may include additional water treatment stages that use ultraviolet light or ozone to prevent microbiological contamination.

Membrane pore sizes can vary from 0.1 nanometres (3.9×10^{-9} in) to 5,000 nanometres (0.00020 in) depending on filter type. "Particle filtration" removes particles of 1 micrometre (3.9×10^{-5} in) or larger. Microfiltration removes particles of 50 nm or larger. "Ultrafiltration" removes particles of roughly 3 nm or larger. "Nanofiltration" removes particles of 1 nm or larger. Reverse osmosis is in the final category of membrane filtration, "hyper filtration", and removes particles larger than 0.1 nm.

In the United States military, Reverse Osmosis Water Purification Units are used on the battlefield and in training. Capacities range from 1,500 to 150,000 imperial gallons (6,800 to 680,000 l) per day, depending on the need. The most common of these are the 600 and 3,000 gallons per hour units; both are able to purify salt water and water contaminated with chemical, biological, radiological, and nuclear agents from the water. During 24-hour period, at normal operating parameters, one unit can produce 12,000 to 60,000 imperial gallons (55,000 to 270,000 l) of water, with a required 4-hour maintenance window to check systems, pumps, RO elements and the engine generator.

Water and Waste-water Purification

Rain water collected from storm drains is purified with reverse osmosis water processors and used for landscape irrigation and industrial cooling in Los Angeles and other cities, as a solution to the problem of water shortages.

In industry, reverse osmosis removes minerals from boiler water at power plants. The water is boiled and condensed repeatedly. It must be as pure as possible so that it does not leave deposits on the machinery or cause corrosion. The deposits inside or outside the boiler tubes may result in under-performance of the boiler, bringing down its efficiency and resulting in poor steam production, hence poor power production at turbine.

It is also used to clean effluent and brackish groundwater. The effluent in larger volumes (more than 500 cu. meter per day) should be treated in an effluent treatment plant first, and then the clear effluent is subjected to reverse osmosis system. Treatment cost is reduced significantly and membrane life of the RO system is increased.

The process of reverse osmosis can be used for the production of deionised water.

RO process for water purification does not require thermal energy. Flow through RO system can be regulated by high pressure pump. The recovery of purified water depends upon various factors including membrane sizes, membrane pore size, temperature, operating pressure and membrane surface area.

In 2002, Singapore announced that a process named NEWater would be a significant part of its future water plans. It involves using reverse osmosis to treat domestic waste-water before discharging the NEWater back into the reservoirs.

Food Industry

In addition to desalination, reverse osmosis is a more economical operation for concentrating food liquids (such as fruit juices) than conventional heat-treatment processes. Research has been carried out on concentration of orange juice and tomato juice. Its advantages include a lower operating cost and the ability to avoid heat-treatment processes, which makes it suitable for heat-sensitive substances like the protein and enzymes found in most food products.

Reverse osmosis is extensively used in the dairy industry for the production of whey protein powders and for the concentration of milk to reduce shipping costs. In whey applications, the whey (liquid remaining after cheese manufacture) is concentrated with RO from 6% total solids to 10–20% total solids before UF (ultrafiltration) processing. The UF retentate can then be used to make various whey powders, including whey protein isolate used in bodybuilding formulations. Additionally, the UF permeate, which contains lactose, is concentrated by RO from 5% total solids to 18–22% total solids to reduce crystallisation and drying costs of the lactose powder.

Although use of the process was once avoided in the wine industry, it is now widely understood and used. An estimated 60 reverse osmosis machines were in use in Bordeaux, France in 2002. Known users include many of the elite classed growths (Kramer) such as Château Léoville-Las Cases in Bordeaux

Car Washing

Because of its lower mineral content, reverse osmosis water is often used in car washes during the final vehicle rinse to prevent water spotting on the vehicle. Reverse osmosis is often used to conserve and recycle water within the wash/pre-rinse cycles, especially in drought stricken areas where water conservation is important. Reverse osmosis water also enables the car wash operator to reduce the demands on the vehicle drying equipment, such as air blowers.

Maple Syrup Production

In 1946, some maple syrup producers started using reverse osmosis to remove water from sap before the sap is boiled down to syrup. The use of reverse osmosis allows approximately 75-90% of the water to be removed from the sap, reducing energy consumption and exposure of the syrup to high temperatures. Microbial contamination and degradation of the membranes has to be monitored.

Hydrogen Production

For small-scale production of hydrogen, reverse osmosis is sometimes used to prevent formation of minerals on the surface of electrodes.

Reef Aquariums

Many reef aquarium keepers use reverse osmosis systems for their artificial mixture of seawater. Ordinary tap water can often contain excessive chlorine, chloramines, copper, nitrogen, phosphates, silicates, or many other chemicals detrimental to the sensitive organisms in a reef environment. Contaminants such as nitrogen compounds and phosphates can lead to excessive, and unwanted, algae growth. An effective combination of both reverse osmosis and deionization (RO/DI) is the most popular among reef aquarium keepers, and is preferred above other water purification processes due to the low cost of ownership and minimal operating costs. Where chlorine and chloramines are found in the water, carbon filtration is needed before the membrane, as the common residential membrane used by reef keepers does not cope with these compounds.

3.3.2 Desalination of Reverse Osmosis

Areas that have either no or limited surface water or groundwater may choose to desalinate seawater or brackish water to obtain drinking water. Reverse osmosis is a common method of desalination, although 85 percent of desalinated water is produced in multistage flash plants. Large reverse osmosis and multistage flash desalination plants are used in the Middle East, especially Saudi Arabia. The energy requirements of the plants are large, but electricity can be produced relatively cheaply with the abundant oil reserves in the region. The desalination plants are often located adjacent to the power plants, which reduces energy losses in transmission and allows waste heat to be used in the desalination process of multistage flash plants, reducing the amount of energy needed to desalinate the water and providing cooling for the power plant.

Sea Water Reverse Osmosis (SWRO) is a reverse osmosis desalination membrane process that has been commercially used since the early 1970s. Its first practical use was demonstrated by Sidney Loeb and Srinivasa Sourirajan from UCLA in Coalinga, California. Because no heating or phase changes are needed, energy requirements are low in comparison to other processes of desalination, but are still much higher than those required for other forms of water supply (including reverse osmosis treatment of waste-water).

The Ashkelon Seawater Reverse Osmosis (SWRO) desalination plant in Israel is the largest in the world. The project was developed as a BOT (Build-Operate-Transfer) by a consortium of three international companies: Veolia water, IDE Technologies and Elran (Sauvetgoichon, 2007). The typical single-pass SWRO system consists of the following components:

- Intake
- Pretreatment
- High pressure pump
- Membrane assembly
- Remineralisation and pH adjustment
- Disinfection
- Alarm/control panel.

Pretreatment

Pretreatment is important when working with RO and nanofiltration (NF) membranes due to the nature of their spiral wound design. The material is engineered in such a fashion as to allow only one-way flow through the system. As such, the spiral wound design does not allow for backpulsing with water or air agitation to scour its surface and remove solids. Since accumulated material cannot be removed from the membrane surface systems, they are highly susceptible to fouling (loss of production capacity). Therefore, pretreatment is a necessity for any RO or NF system. Pretreatment in SWRO systems has four major components:

- Screening of solids: Solids within the water must be removed and the water treated to prevent fouling of the membranes by fine particle or biological growth, and reduce the risk of damage to high-pressure pump components.
- Cartridge filtration: Generally, string-wound polypropylene filters are used to remove particles of 1–5 µm diameter.
- Dosing: Oxidising biocides, such as chlorine, are added to kill bacteria, followed by bisulfite dosing to deactivate the chlorine, which can destroy a thin-film composite membrane. There are also bio-fouling inhibitors, which do not kill bacteria, but simply prevent them from growing slime on the membrane surface and plant walls.
- Pre-filtration pH adjustment: If the pH, hardness and the alkalinity in the feed-water result in a scaling tendency when they

are concentrated in the reject stream, acid is dosed to maintain carbonates in their soluble carbonic acid form.

$CO_3^{2-} + H_3O^+ = HCO_3^- + H_2O$
$HCO_3^- + H_3O^+ = H_2CO_3 + H_2O$
Note the following:

- Carbonic acid cannot combine with calcium to form calcium carbonate scale. Calcium carbonate scaling tendency is estimated using the Langelier saturation index. Adding too much sulfuric acid to control carbonate scales may result in calcium sulfate, barium sulfate or strontium sulfate scale formation on the RO membrane.
- Pre-filtration anti-scalants: Scale inhibitors (also known as anti-scalants) prevent formation of all scales compared to acid, which can only prevent formation of calcium carbonateand calcium phosphate scales. In addition to inhibiting carbonate and phosphate scales, anti-scalants inhibit sulfate and fluoride scales, disperse colloids and metal oxides. Despite claims that antis-calants can inhibit silica formation, there is no concrete evidence to prove that silica polymerisation can be inhibited by anti-scalants. Anti-scalants can control acid soluble scales at a fraction of the dosage required to control the same scale using sulfuric acid (Malki, 2008).
- Some small scale desalination units use **Beach wells**. They are usually drilled on the seashore in close vicinity to the ocean. These intake facilities are relatively simple to build and the seawater they collect is pretreated via slow filtration through the subsurface sand/seabed formations in the area of source water extraction. Raw seawater collected using beach wells is often of better quality in terms of solids, silt, oil and grease, natural organic contamination and aquatic microorganisms, compared to open seawater intakes. Sometimes, beach intakes may also yield source water of lower salinity.

High pressure pump

The pump supplies the pressure needed to push water through the membrane, even as the membrane rejects the passage of salt through it. Typical pressures for brackish water range from 225 to 375 psi (15.5 to 26 bars or 1.6 to 2.6 MPa). In the case of seawater, they range from 800 to 1,180 psi (55 to 81.5 bars or 6 to 8 MPa). This requires a large amount of energy.

Membrane Assembly

Fig. 2.3: The Layers of a Membrane

Source: http://en.wikipedia.org/wiki/file:Revers osmosis membrane element layers.jpg

The membrane assembly consists of a pressure vessel with a membrane that allows feedwater to be pressed against it. The membrane must be strong enough to withstand whatever pressure is applied against it. RO membranes are made in a variety of configurations, with the two most common configurations being spiral-wound and hollow-fiber.

Remineralisation and pH adjustment

The desalinated water is very corrosive and is "stabilised" to protect downstream pipelines and storages, usually by adding lime or caustic to prevent corrosion of concrete lined surfaces. Liming material is used to adjust pH between 6.8 and 8.1 to meet the potable water specifications, primarily for effective disinfection and for corrosion control.

Disinfection

Post-treatment consists of preparing the water for distribution after filtration. Reverse osmosis is an effective barrier to pathogens; however, post-treatment provides secondary protection against compromised membranes and downstream problems. Disinfection by means of UV lamps (sometimes called germicidal or bactericidal) may be employed to sterilise pathogens which bypassed the reverse osmosis process. Chlorination or chloramination (chlorine and ammonia) protects against pathogens which may have lodged in the distribution system downstream, such as from new construction, backwash, compromised pipes, etc.

3.4 Problems and Prospects of Reverse Osmosis

3.4.1 Problems (disadvantages) of Reverse Osmosis

Household reverse osmosis units use a lot of water because they have low back pressure. As a result, they recover only 5 to 15 percent of the water entering the system. The remainder is discharged as waste water. Because waste water carries with it the rejected contaminants, methods to recover this water are not practical for household systems. Waste-water is typically connected to the house drains and will add to the load on the household septic system. An RO unit delivering 5 gallons of treated water per day may discharge anywhere between 20 and 90 gallons of waste water per day.

Large-scale industrial/municipal systems have production efficiency typically 75% - 80%, or as high as 90%, because they can generate the high pressure needed for more efficient RO filtration. On the other hand, as efficiency of waste-water rates increases in commercial operations effective removal rates tend to become reduced, as evidenced by TDS counts.

Due to its fine membrane construction, reverse osmosis not only removes harmful contaminants that may be present in the water, it also strips many of the good, healthy minerals from the water as well. A number of Peer-reviewed studies have looked at the long term health effects of drinking demineralised water. However, demineralised water can be remineralised, and this process has been done in instances when processing demineralised water for consumption. An example of this process is Dasani.

3.4.2 Prospects (New developments) of Reverse Osmosis

Prefiltration of high fouling waters with another, larger-pore membrane with less hydraulic energy requirement, has been evaluated and sometimes used, since the 1970s. However, this means the water passes through two membranes and is often repressurised, requiring more energy input in the system, increasing the cost. Other recent development work has focused on integrating RO with electrodialysis to improve recovery of valuable deionised products or minimise concentrate volume requiring discharge or disposal.

4.0 CONCLUSION

From our discussion so far, one can conclude that reverse osmosis is one of the advanced forms of waste-water treatment which is the process of forcing a solvent from a region of high solute concentration through a semi permeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure . It has got a wide application among which are in: water and waste-water purification, car washing and food industry, etc.

5.0 SUMMARY

In this unit, we were able to have learnt the following:

- The meaning of reverse osmosis and its historical background were done where we learnt that reverse osmosis (RO) is the process in which water is separated from dissolved salts in the solution by filtering through semi permeable membrane at a pressure than the osmotic pressure caused by the dissolved salts in waste-water and that its discovery dates back to 1748 by Jean-Antoine Nollet.
- The next in line was the process of reverse osmosis. It uses the process of forcing a solvent from a region of high solute concentration through a semi permeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. See the first sketch in this unit.
- The applications of reverse osmosis came next. It has a lot of applications which include: water and waste-water purification, car washing and food industry, maple syrup production, hydrogen production and in reef aquariums.
- connected to the above was desalination of reverse osmosis where we learnt that areas that have either no or limited surface water or groundwater may choose to desalinate seawater or brackish water to obtain drinking water. Reverse osmosis is a common method of desalination. That simply means to remove the excess salt in the seawater or the brackish water and make it fit for use. It has methods of achieving this as seen above.
- The disadvantages and new developments involved in the reverse osmosis were also explained.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain what you understand by reverse osmosis (sketch is of necessity in your answer).
2. Reverse osmosis has got wide applications. Justify this statement.
3. Any hope for the use of seawater or brackish water and how?

7.0 REFERENCES/FURTHER READING

Crittenden, John; Trussell, Rhodes; Hand, David; Howe, Kerry & Tchobanoglous. *Council Directive of 15 July 1980 on the Approximation of the Laws of the Member States Relating to the Exploitation and Marketing of Natural Mineral Waters*. eur-lex.europa.eu.

Water-technology.net. "Desalination Plant Seawater Reverse Osmosis (SWRO) Plant".

George. (2005). *Water Treatment Principles and Design*. (2nd.ed). New Jersey: John Wiley and Sons.

Glater, J. (1998). "The Early History of Reverse Osmosis Membrane Development".*Desalination* 117: 297–309.

"Health Risks from Drinking Demineralised Water". http://www.thecoca-colacompany.com/flash/csr/dasani/index.html

Lachish, Uri. (n.d). "Optimising the Efficiency of Reverse Osmosis Seawater". *Desalination.*

"Water Technology – Shuaiba Desalination Plant". Water-technology.net. Retrieved on 19-06-2011.

"Israel is No. 5 on Top 10 Cleantech List in Israel 21c a Focus Beyond". Retrieved 21-12-2009.

Sauvetgoichon, B. (2007). "Ashkelon Desalination Plant-A Successful Challenge". *Desalination* **203**: 75–81.

Malki, M. (2008). "Optimising Scale Inhibition Costs in Reverse Osmosis Desalination Plants". *International Desalination and Water Reuse Quarterly*, **17** (4): 28–29.

"Treatment Systems for Household Water Supplies". Ag.ndsu.edu. Retrieved on 19-06-2011.
http://en.wikipedia.org/wiki/Reverse_osmosis.

Samir, Afifi. http://site.iugaza.edu.ps/safifi/files/2010/02/2-waste-water flowrate WWT.pdf.

UNIT 3 ACTIVATED CARBON FILTER AND UV STERILISATION PROCESSES

CONTENTS

1.0 INTRODUCTION

In our last two units, we discussed some advanced forms of waste-water treatment. In this unit, we are going to discuss yet two other types of advanced waste-water treatment. This time around, we are to deal with activated carbon filter and UV sterilisation processes. You are advised deserved concentration.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define carbon filtering and list the types of same
- explain the uses of carbon filters
- discuss UV sterilisation processes
- explain the mechanisms involved in sterilisation process
- enumerate the applications of sterilisation process.

3.0 MAIN CONTENT

3.1 Activated Carbon Filters Process

3.1.1 Meaning and Types of Carbon Filters

Carbon Filtering: This is a method of filtering that uses a piece of activated carbon to remove contaminants and impurities, utilising chemical adsorption. Each piece of carbon is designed to provide a large section of surface area, in order to allow contaminants the most possible exposure to the filter media. One pound (450 g) of activated carbon contains a surface area of approximately 100 acres (40 Hectares). This carbon is generally activated with a positive charge and is designed to attract negatively charged water contaminants. Carbon filtering is commonly used for water purification, but is also used in air purifiers.

Carbon filters are most effective at removing chlorine, sediment, and volatile organic compounds (VOCs) from water. They are not effective at removing minerals, salts, and dissolved inorganic compounds. It should be known that typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometres. The particle size will be used as part of the filter description. The efficacy of a carbon filter is also based upon the flow rate regulation. When the water is allowed to flow through the filter at a slower rate, the contaminants are exposed to the filter media for a longer amount of time.

Types of carbon filters

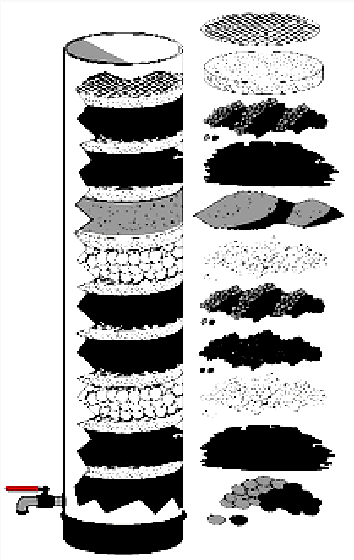


Fig.31: A Carbon Filter

Source: http://en.wikipedia.org/wiki/Carbon_filtering

Carbon filtering is usually used in water filtration systems. In this illustration, the activated carbon is in the fourth level (counted from bottom). There are two predominant types of carbon filters used in the filtration industry: powdered block filters and granular activated filters. In general, carbon block filters are more effective at removing a larger number of contaminants, based upon the increased surface area of carbon. Many carbon filters also use secondary media, such as silver or KDF-55, to prevent bacteria growth within the filter.

3.1.2 Uses of Carbon Filters

Carbon filters have been used for several hundred years and are considered one of the oldest means of water purification. Historians have shown evidence that carbon filtration may have been used in ancient Egyptian cultures for both air and water sanitization The first modern use of a carbon filter to purify potable water occurred in 1862.Carbon filtration was further advanced in the mid-1970s by H. Allen Rice and Alvin E. Rice when they first manufactured a porous carbon block for drinking water use. Currently, carbon filters are used in individual homes as point-of-use water filters, groundwater remediation and, occasionally, in municipal water treatment facilities. They are also used as pre-treatment devices for reverse osmosis systems and as specialised filters designed to remove chlorine-resistant cysts, such as giardia and cryptosporidium.

Hydrogen Production
For small-scale production of hydrogen water purifiers are installed to prevent formation of minerals on the surface of the electrodes and to remove organics and chlorine from utility water. First the water passes through a 20 micrometer interference (mesh or screen filter) filter to remove sand and dust particles, second, a charcoal filter (activated carbon) to remove organics and chlorine, third stage, a de-ionising filter to remove metallic ions. A test can be done before and after the filter for proper functioning on barium, calcium, potassium, magnesium, sodium and silicon.

Radiation or Nuclear Medicine
Carbon filters, along with HEPA filters, are widely used in the construction of hot cells. This allows the room to exhaust air that contains infinitesimal quantities of radioactivity and contaminants.

3.2 UV Sterilisation Process

3.2.1 What is Sterilisation Process?

Ultraviolet disinfection of water consists of a purely physical, chemical-free process. UV-C radiation attacks the vital DNA of the bacteria directly. The bacteria lose their reproductive capability and are destroyed. Even parasites such as *Cryptosporidia* or *Giardia*, which are extremely resistant to chemical disinfectants, are efficiently reduced (Harm, 1980). UV can also be used to remove chlorine and chloramine species from water; this process is called photolysis, and requires a higher dose than normal disinfection. The sterilised micro-organisms are not removed from the water. UV disinfection does not remove dissolved organics, inorganic compounds or particles in the water. However, UV-oxidation processes can be used to simultaneously destroy trace chemical contaminants and provide high-level disinfection, such as the world's largest indirect potable reuse plant in Orange County, California. That title will soon be taken by New York which is set to open the Catskill-Delaware Water Ultraviolet Disinfection Facility, by the end of 2012. A total of 56 energy-efficient UV reactors will be installed to treat 2.2 billion US gallons (8,300,000 m^3) a day to serve New York City (Wolfe, 1990).

UV disinfection leaves no taint, chemicals or residues in the treated water. Disinfection using UV light is quick and clean. The *UV Tube* is a design concept for providing inexpensive water disinfection to people in poor countries. The concept is based the ability of ultraviolet light to kill infectious agents by disrupting their DNA. It was initially developed under an "open source" model at the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley. The form and composition of the UV Tube can vary depending on the resources available and the preferences of those building and using the device. However, certain geometric parameters must be maintained to ensure consistent performance. Several different versions of the UV Tube are currently being used in multiple locations in Mexico and Sri Lanka.

Water sterilisation kits

Fig. 3.2: A Portable Powered Low Pressure Mercury Vapour Discharge Lamp for Water Sterilisation

(Source: http://en.wikipedia.org/wiki/Ultraviolet_germicidal_irradiation#Water_sterilisation).

Fig. 3.3: A 9 W Germicidal Lamp in a Compact Fluorescent Lamp Form Factor

Source: http://en.wikipedia.org/wiki/Ultraviolet_germicidal_irradiation#Water_sterilisation

3.2.2 Mechanisms Involved in Sterilisation Process Germicidal Lamp

Germicidal UV is delivered by a mercury-vapor lamp that emits UV at the germicidal wavelength. Mercury vapour emits at 254 nm. Many germicidal UV bulbs use special ballasts to regulate electrical current flow to the bulbs, similar to those needed for fluorescent lights. In some cases, UVGI electrodeless lamps can be energised with microwaves, giving very long stable life and other advantages. This is known as 'Microwave UV.' Lamps are either amalgam or medium pressure lamps. Each type has specific strengths and weaknesses.

Low-pressure UV Lamps

These offer high efficiencies (approx 35% UVC) but lower power, typically 1 W/cm^3 power density.

Amalgam UV Lamps
A high-power version of low-pressure lamps is. They operate at higher temperatures and have a lifetime of up to 16,000 hours. Their efficiency is slightly lower than that of traditional low-pressure lamps (approx 33% UVC output) and power density is approx 2–3 W/cm³.

Medium-pressure UV
These lamps have a broad and pronounced peak-line spectrum and a high radiation output but lower UVC efficiency of 10% or less. Typical power density is 30 W/cm³ or greater. Depending on the quartz glass used for the lamp body, low-pressure and amalgam UV lamps emit light at 254 nm and 185 nm (for oxidation).185 nm light is used to generate ozone. The UV units for water treatment consist of a specialized low pressure mercury vapor lamp that produces ultraviolet radiation at 254 nm, or medium pressure UV lamps that produce a polychromatic output from 200 nm to visible and infrared energy. The optimal wavelengths for disinfection are close to 260 nm (Gadgil, 1997). Medium pressure lamps are approximately 12% efficient, whilst amalgam low pressure lamps can be up to 40% efficient. The UV lamp never contacts the water, it is either housed in a quartz glass sleeve inside the water chamber or mounted external to the water which flows through the transparent UV tube. It is mounted so that water can pass through a flow chamber, and UV rays are admitted and absorbed into the stream.

Sizing of a UV system is affected by three variables: flow rate, lamp power and UV transmittance in the water. UV manufacturers typically developed sophisticated Computational Fluid Dynamics (CFD) models validated with bioassay testing. This typically involves testing the UV reactor's disinfection performance with either MS2 or T1 bacteriophages at various flow rates, UV transmittance and power levels in order to develop a regression model for system sizing. For example, this is a requirement for all drinking water systems in the United States per the US EPA UV Guidance Manual. The flow profile is produced from the chamber geometry, flow rate and particular turbulence model selected. The radiation profile is developed from inputs such as water quality, lamp type (power, germicidal efficiency, spectral output, and arc length) and the transmittance and dimension of the quartz sleeve. Proprietary CFD software simulates both the flow and radiation profiles. Once the 3-D model of the chamber is built, it's populated with a grid or mesh that comprises thousands of small cubes.
Points of interest—such as at a bend, on the quartz sleeve surface, or around the wiper mechanism—use a higher resolution mesh, whilst other areas within the reactor use a coarse mesh. Once the mesh is produced, hundreds of thousands of virtual particles are "fired" through the chamber. Each particle has several variables of interest associated

with it, and the particles are "harvested" after the reactor. Discrete phase modeling produces delivered dose, headless and other chamber specific parameters.

When the modeling phase is complete, selected systems are validated using a professional third party to provide oversight and to determine how closely the model is able to predict the reality of system performance. System validation uses non-pathogenic surrogates to determine the Reduction Equivalent Dose (RED) ability of the reactors. Most systems are validated to deliver 40 mJ/[cm.sup.2] within an envelope of flow and transmittance.

To validate effectiveness in drinking water systems, the methods described in the US EPA UV Guidance Manual is typically used by the U.S. Environmental Protection Agency, whilst Europe has adopted Germany's DVGW 294 standard. For waste-water systems, the NWRI/AwwaRF Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse protocols are typically used, especially in waste-water reuse applications.

3.2.3 Applications of Sterilisation Process

As seen above, it is widely used in the treatment of water. When applied, wholesome water is got at the end.

UV systems destined for drinking water applications are validated using a third party test house to demonstrate system capability, and usually a non pathogenic surrogate such as MS 2 phage or Bacillus Subtilis is used to verify actual system performance. UV manufacturers have verified the performance of a number of reactors, in each case iteratively improving the predictive models.

Waste-water Treatment

Ultraviolet in waste-water treatment is replacing chlorination due to the chemical's toxic by-products. Individual waste streams to be treated by UVGI must be tested to ensure that the method will be effective due to potential interferences such as suspended solids, dyes or other substances that may block or absorb the UV radiation. "UV units to treat small batches (1 to several liters) or low flows (1 to several liters per minute) of water at the community level are estimated to have costs of 0.02 US$ per 1000 liters of water, including the cost of electricity and consumables and the annualized capital cost of the unit." (WHO, undated).

Large scale urban UV waste-water treatment is performed in cities such as Edmonton, Alberta. The use of ultraviolet light has now become standard practice in most municipal waste-water treatment processes. Effluent is now starting to be recognised as a valuable resource, not a problem that needs to be dumped. Many waste-water facilities are being renamed as water reclamation facilities, and whether the waste water is being discharged into a river, being used to irrigate crops, or injected into an aquifer for later recovery. Ultraviolet light is now being used to ensure water is free from harmful organisms.

Aquarium and Pond

Ultraviolet sterilizers are often used in aquaria and ponds to help control unwanted micro-organisms in the water. Continuous sterilisation of the water neutralises single-cell algae and thereby increases water clarity. UV radiation also ensures that exposed pathogens cannot reproduce, thus decreasing the likelihood of a disease outbreak in an aquarium.

Aquarium and pond sterilisers are typically small, with fittings for tubing that allows the water to flow through the steriliser on its way to or from a separate external filter. Within the steriliser, water flows near to the ultraviolet light source, usually through a baffle system that lengthens the time during which the water is exposed to the radiation.

Laboratory Hygiene

UVGI is often used to disinfect equipment such as safety goggles, instruments, pipettes, and other devices. Lab personnel also disinfect glassware and plastic ware this way. Microbiology laboratories use UVGI to disinfect surfaces inside biological safety cabinets ("hoods") between uses.

Food and Beverage Protection

Since the FDA issued a rule in 2001 requiring that virtually all fruit and vegetable juice producers follow HACCP controls, and mandating a 5-log reduction in pathogens, UVGI has seen some use in sterilisation of fresh juices such as fresh-pressed apple cider.

UV Dosing

One method for gauging UV effectiveness is to compute UV dose. The U.S. EPA publishes UV dosage guidelines Dosage involves the following parameters:

- flow rate (reflecting contact time)
- transmittance (reflects light reaching the target)
- turbidity ("cloudiness")
- lamp age (reflects reduction in UV intensity)
- lamp fouling
- % active lamps (reflects lamp outages in each lamp bank)
  (National Institute for Occupational Safety and Health. (2008, April). NIOSH eNews, 5(12). Retrieved September 10, 2008, from http://www.cdc.gov/niosh/enews/enewsV5N12.html).

4.0 CONCLUSION

We can conclude that carbon filtering is a method of filtering that uses a piece of activated carbon to remove contaminants and impurities, utilising chemical adsorption and that Carbon filters have been used for several hundred years and are considered one of the oldest means of water purification and is useful in waste-water treatment. In the same vein, UV sterilisation is a powerful method of waste-water treatment in this modern era. Its use is also found in water purification, aquarium and pond, laboratory hygiene, and food and beverage protection. The two above are advanced methods with high degree of efficiency.

5.0 SUMMARY

In this unit , you were taught the following:

- The activated carbon filters process was discussed under the following sub headings: meaning and types of carbon filters and the uses of carbon filters. For the meaning, it is a method of filtering that uses a piece of activated carbon to remove contaminants and impurities, utilising chemical adsorption. For the uses, apart from the uses in water and waste-water treatment, it is also used in hydrogen production and in radiation or nuclear medicine.
- The next to be discussed was UV sterilisation process. Here, we discussed what sterilisation process is before dealing with the mechanisms involved in sterilisation process.
- The last to be discussed was the applications of sterilisation process. Under this, we learnt that it has wide applications in water purifications, waste-water treatment, aquarium and pond, laboratory hygiene, food and beverage protection. They give good result when correctly applied.

6.0 TUTOR-MARKED ASSIGNMENT

1. a. What is carbon filtering process?
   b. What are its uses?
2. Discuss UV sterilisation under the following sub heading:
   a. Applications of sterilisation process
   b. UV Dosing.

7.0 REFERENCES/FURTHER READING

"Environmental Analysis of Indoor Air Pollution". CaluTech UV Air. Retrieved 12-05-2006.

Gadgil, A. (1997). "Field-testing: UV Disinfection of Drinking Water". *Water Engineering Development Center*. UK: University of Loughborough,

Harm, W. (1980). "Biological Effects of Ultra-violet Radiation. International Union of Pure and Applied Bio-physics*". Bio-physics Series*. Cambridge: University Press.

"How Does UV Disinfection Work"? *R. Franklin*. UVO3.co.uk. Retrieved 22/06/2011.

"Introduction to UV Disinfection". *Trojan UV*. 2012. Retrieved 24-05-2012.

Kowalski, W.J. et al, (2000). "Mathematical Modeling of Ultraviolet Germicidal Irradiation for Air Disinfection". *Quantitative Microbiology* (Springer).

Lupu, A. (2006). "UV Radiation – What UVA, UVB and UVC Rays Are and How They Affect Us". *Seasonal Discomforts*. Softpedia. Retrieved 2006-09-09.

"Municipal Drinking Water – Multi-barrier Disinfection Strategy, New York City". *Trojan Technologies*. Retrieved 15-11- 2011.

National Institute for Occupational Safety and Health. (2008, April). NIOSH eNews, 5(12). Retrieved September 10, 2008, from http://www.cdc.gov/niosh/enews/enewsV5N12.html.

"The Groundwater Replenishment System, Orange County, California". *Trojan UV*. (2010). Retrieved 30-08-2011.

"The Nobel Prize in Physiology or Medicine 1903". *Nobelprize.org*. *The Nobel Foundation*. Retrieved 09-09-2006.

"Trojan Technologies Wins New York City Drinking Water UV Project" (PDF). (Press Release). *Trojan UV*. 02-11-2005. Retrieved 01-30-2011.

Treatment Technology Report for Recycled Water. State of California Division of Drinking Water and Environmental Management. January, 2007. Retrieved 30-01-2011[c] (PDF).

Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule. Washington, DC: United States Environmental Protection Agency, November 2006. Retrieved 30 January, 2011.

Wolfe, R.L. (1990). "Ultraviolet Disinfection of Potable Water". *Environmental Science and Technology*, 24(6):768-773.

http://en.wikipedia.org/wiki/Carbon_filtering.

http://en.wikipedia.org/wiki/Ultraviolet_germicidal_irradiation#Water_sterilisation.

UNIT 4 TREATMENT OF SLUDGE–DISINFECTION AND DISPOSAL ON LAND/WATER

CONTENTS

1.0 INTRODUCTION

Sludge, which originates from the process of treatment of waste water, which due to the physical-chemical processes involved in the treatment has concentration of heavy metals, poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (virus, bacteria etc) and which also has high concentration of nutrients etc need to be properly treated before being discharged or disposed into the water or on land, hence the need for this unit.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the meaning of sludge and its generation processes
- explain the processes involved in sludge treatment.

3.0 MAIN CONTENT

3.1 Meaning and Generation of Sludge and its Importance

Sludge is produced from the treatment of waste-water in on-site (e.g. septic tank) and off-site (e.g. activated sludge) systems. This is inherently so because a primary aim of waste-water treatment is removing solids from the waste-water. In addition, soluble organic substances are converted to bacterial cells, and the latter is removed from the waste-water. Sludge is also produced from the treatment of storm water, although it is likely to be less organic in nature compared to waste-water sludge.

Bucket latrine and vault latrines store faecal sludge, which needs to be collected and treated. These two types of latrine are not discussed, because no treatment is involved at the latrines and is no more in use in general. In the former case human excreta is deposited in a bucket and the content of the bucket is emptied daily, usually at night giving the term 'night soil to the faecal sludge. In the latter, the excreta is stored in a vault for a longer period of up to two weeks before removal. The content of the vault should preferably be removed mechanically.

The characteristics of sludge vary widely from relatively fresh faecal materials generated in bucket latrines to sludge which has undergone bacterial decomposition for over a year in a double pit latrine. The treatment required is therefore dependent on the characteristics of the sludge. The former may contain large numbers of pathogens; whereas the latter will contain much less due to pathogen die off. Sludge should, however, always be handled with care to avoid contact with pathogens. Sludge may be contaminated with heavy metals and other pollutants, especially when industrial wastes are disposed into the sewer. Pre-treatment of industrial wastes is therefore essential before discharge to the sewer. Treatment of sludge contaminated with high concentrations of heavy metals or toxic chemicals will be more difficult and the potential for re-use of the sludge will be limited.

Faecal sludge contains essential nutrients (nitrogen and phosphorus) and is potentially beneficial as fertilisers for plants. The organic carbon in the sludge, once stabilised, is also desirable as a soil conditioner, because it provides improved soil structure for plant roots.

3.2 Sludge Treatment

In sludge treatment, a lot of options are available and they include:

- Stabilisation
- thickening
- Dewatering
- drying and
- incineration.

The latter is most costly, because fuel is needed and air pollution control requires extensive treatment of the combustion gases. It can be used when the sludge is heavily contaminated with heavy metals or other undesirable pollutants. Prevention of contamination of the sludge by industrial wastes is preferable to incineration. A conversion process to produce oil from sludge has been developed, which can be suitable for heavily contaminated sludge (Skrypsi-Mantele, *et al*, 2000). The costs of treatment of sludge are generally of the same order as the costs of removing the sludge from the waste-water.

3.2.1 Importance or Uses of Sludge Treatment

The following are the importance and or uses of sludge treatment:

- Reduces organic ingredients
- Removes odour
- Reduces volume and weight
- Improves hygiene by removing of pathogen organisms
- Prepares sludge for further utilisation or disposal.

The Technical Research Centre of Finland points out that sludge could be considered as a valuable source for nutrient use, reuse of inorganic material, carbon upgrading processes, and energy production. A new sludge treatment plant in Mid-Norway-a co-operation project between 51 municipalities produces biogas, electricity and fertiliser from 30 000 tons of annually waste. The plant was opened in March 2008 and started test production on energy, delivering the first electricity to the public net in June. The plant was designed and built by Cambi-using their patented Thermal Hydrolysis Process (THP). All together it annually produces 189 GWh biogas and around 10 GWh of electricity. The Cambi THP process is suitable for all types of waste-water treatment sludge and is particularly effective in treating biological sludge, which normally is very difficult to digest and dewater. The THP treats both municipal and industrial waste-water and bio-waste prior to anaerobic digestion. In order words, production of biogas, electricity and fertiliser are possible because of sludge and its treatment in some countries.

Econova Energy is one of the leading companies on the Swedish market for trading bio mass and recycling waste products from the forest industry, energy companies and municipals. Econova Energy utilises by and waste products such as barque and fibre sludge into bio mass, soil products or material for landfill restoration. The end-products are produced in an environmentally friendly manner by the use of sun and wind. The method also includes stone and metal separation, composting, mixing and preparation for sun and wind drying, harrowing and harvesting. The broad and integrated operations of Econova make it possible for us to offer an overall commitment without any new waste products. Can you now sieve out what this last paragraph is all about?

3.2.2 Processes of Sludge Treatment

A lot of processes are at our disposal for the treatment of sludge as can be seen below.

3.2.2.1 Stabilisation

Stabilisation is the term used to denote the process of BOD reduction. Faecal sludge collected from bucket or vault latrines has a very high biochemical oxygen demand (BOD) and is generally putrid and odorous. Primary and secondary sludges from an activated sludge treatment plant also have a high BOD and may be difficult to dewater. Even sludge from a septic tank, which has undergone bacterial decomposition over at least a year, still has a high BOD. The stabilisation process can be carried out under aerobic or anaerobic conditions.

Aerobic stabilisation of primary and secondary sludges can be carried out in an aeration tank in the same manner as in an activated sludge process. Because of the high oxygen requirement, this process is energy intensive and costs are high. Aerobic stabilisation requires less energy when carried out as part of a composting process. For composting of sludge, its solids content should be increased to at least 15 % so that it can be handled as a solid. Thickening and dewatering of primary and secondary sludges are required to achieve the required solids content. Faecal sludge may contain high enough solids. Mixing with dry materials such as dry sawdust may assist with achieving the required solids content as well attaining the required carbon to nitrogen ratio for composting.

3.2.2.2 Composting

Composting is an aerobic bacterial decomposition process to stabilise organic wastes and produce humus (compost). Compost contains nutrients and organic carbon which are excellent soil conditioners. Composting takes place naturally on a forest floor where organic materials (leaf litter, animal wastes) are converted to more stable organic materials (humus) and the nutrients are released and made available for plant uptake. The process is slow on a forest floor, but can be accelerated under optimum conditions. The optimum conditions for composting are moisture content of about 50 %, a carbon to nitrogen ratio of about 25 to 30, and temperature of 55 oC. Because waste-water sludge is rich in nutrients, its carbon to nitrogen ratio is low (5 to 10). It is also high in moisture. Addition of dry sawdust, which is very high in carbon to nitrogen ratio (500), can adjust both the moisture and carbon to nitrogen ratio. Other waste materials that can be used for this purpose are mulched garden wastes, forest wastes and shredded newspaper.

Composting can be carried out in a specially built composter, such as an inclined rotating cylinder, fed on one end with the raw materials, and the aerated product collected at the other end. As the materials are slowly tumbled over a period of about one week, they are mixed and aerated. Because bacterial decomposition produces heat, temperatures in the insulated composter can easily reach 55oC. The immature compost is then windrowed for at least 12 weeks to allow the composting process to complete, with occasional turning of the windrow.

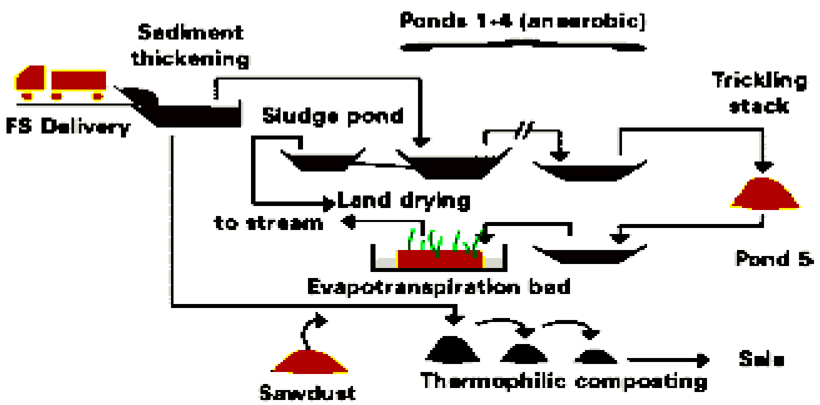


Fig.4.1: Windrow Composting of Faecal Sludge (FS)
Source: Heinss *et al., 1999*

Composting can be more simply carried out in windrows (Figure 4.1). Regular turning of the windrows assists with mixing of the materials and more importantly supply the oxygen to the bacteria. Temperatures can reach 55^0C, because compost has a good heat insulating property. Turning of the compost also ensures that all parts of the windrow reach the required 55oC essential for pathogen destruction. Turning is required every two to three days in the first two weeks when temperature is 55oC or above. After this period frequent turning of the compost windrow is not required as less heat is generated and less oxygen is required while the compost undergoes maturation.

3.2.2.3 Anaerobic Digestion

Anaerobic digestion is a bacterial decomposition process that stabilizes organic wastes and produces a mixture of methane and carbon dioxide gas (biogas). The heat value of methane is the same as natural petroleum gas, and biogas is valuable as an energy source.

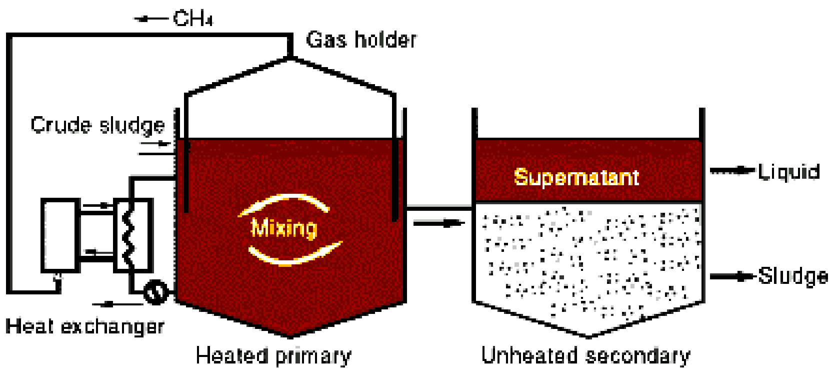


Fig. 4.2: Simple Anaerobic Digestion Process

Source: http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/10.asp).

Anaerobic digestion is usually carried out in a specially built digester, where the content is mixed and the digester maintained at 35 ^{oC} by combusting the biogas produced. After digestion the sludge is passed to a sedimentation tank where the sludge is thickened. Biogas is collected from the digester (Figure 4.2). The thickened sludge requires further treatment prior to reuse or disposal.

Anaerobic digestion can also be carried out at a slower rate in an unmixed tank or pond. Covering is usually by a UV resistant plastic sheet, because of the large area needed to be covered, and biogas is collected from the top of the sheet. Storage of biogas can be in a cylindrical tank with a floating roof. The cylindrical roof floats on water and its position is determined by the volume of the gas stored under the pressure of the roof. Biogas can also be stored in a balloon, but only under low pressure.

4.0 CONCLUSION

From all that have been discussed so far, we can conclude by saying that sludge treatment is of high essence so that the recipient which is either land or sea do not suffer much harm by its introduction or presence, rather it will turn into a blessing, by providing nutrient to the new environments or by being reused for other purposes.

5.0 SUMMARY

In this unit, we were able to go through the length and breadth of sludge treatment starting with its definition, its generation and the importance. We also explained sludge treatment processes which included stabilisation, composting and anaerobic digestion. The end product of sludge treatment is either for reuse or final disposal into the sea or on land.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by sludge treatment and what is its importance?
2. List the processes of sludge treatment and describe any two of them.

7.0 REFERENCES/FURTHER READING

http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/10.asp.

http://ec.europa.eu/environment.

www.cambi.no.

www.econova.com.

UNIT 5 SEWER CORROSION AND DESIGN OF WASTE-WATER TREATMENT UNITS

CONTENTS

1.0 INTRODUCTION

In the previous units, we have dealt with the entire processes- primary, secondary and tertiary- involved in the treatment of waste-water. In this last unit of the course, we will be looking at the chemical activities happening in and on the sewer lines (pipes) in the name of corrosion. We will equally look at the design of waste-water treatment units with a view to having it well understood by every student. With the same spirit with which you have been following in this course, it is expected that you finish up this last unit.

2.0 OBJECTIVES

At the end of this last unit, you should be able to:

- define corrosion and explain its causes
- discuss the types of corrosion and explain its effects
- enumerate the control measures of corrosion
- define the design of waste-water treatment units
- list the factors influencing the design of treatment units
- discuss the indicators of system performance and design of units.

3.0 MAIN CONTENT

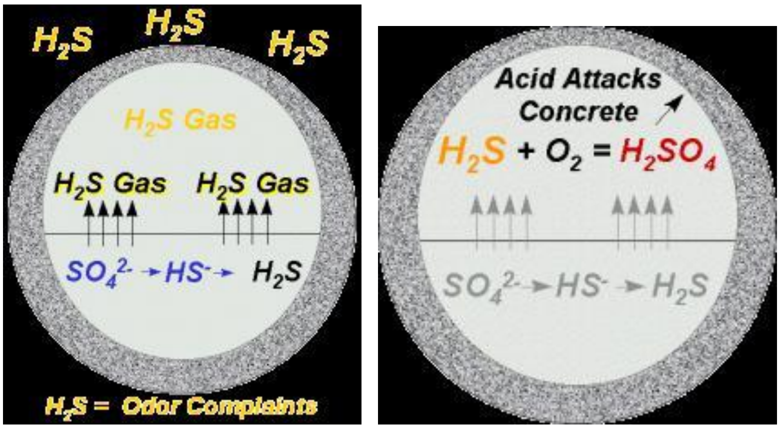
3.1 Sewer Corrosion

3.1.1 Definition of Corrosion

Corrosion is the rusting of metal in pipes or tanks due to the corrosive action of water, waste-water or soil. Scales are deposits caused by the deposition of calcium carbonate on the inner surface of the water or waste-water treatment equipment pipes or tanks. Stable water is the water, which tends to be neither corrosive nor scale-forming. Corrosive, also known as aggressive or unstable, water will tend to corrode (rust) metal in the pipes or tanks it passes through. Scale-forming water will tend to deposit calcium carbonate scale on the inner surfaces of these pipes or tanks. The above is more characteristic in water treatment plant, but for the waste-water, it involves other things as shall be discussed soon.

3.1.2 Causes of Corrosion in waste-water Treatment Plant

Bacteria in the slime under flowing sewage convert sulphates in the sewage into sulphides. Sulphides in the liquid make their way to the surface of the sewage and released into the sewer atmosphere as hydrogen sulphide (H2S) gas. H2S gas in atmosphere makes contact with slime in the crown of the sewer, which contains more bacteria. Bacterial action converts H2S gas to sulphuric acid which causes corrosion in the crown of the pipe and this corrosion is also called crown corrosion. If pipe material is of corrodible nature, sulphuric acid attacks the pipe material and causing ultimate failure.



(a) (b)

Fig. 5.1: The Chemical Actions during Corrosion

Source: http://www.the water treatment.com/wp-content/uploads/ 2010/08/ sewer-h2s- corrosion.jpg

3.1.3 Types of Corrosion

Corrosion can occur on the outside of a pipe (due to corrosive soil) or on the inside of a pipe (due to corrosive water.) Either outside or inside a pipe, the creation of the corrosion cell can be through electrolysis, oxygen concentration cells, or through galvanic action.

(a) Electrolysis

In electrolysis, a D.C. electric current enters a metal pipe and causes flow of electrons through the pipe and to the ground. The pipe, fueled by the electric current, becomes the anode while the soil becomes the cathode. The outside of the pipe corrodes, with the metal from the pipe plating out in the surrounding soil.

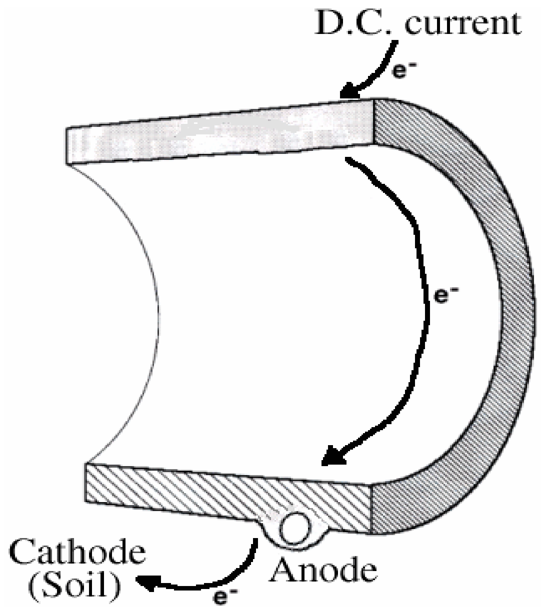


Fig. 5.2: Electrolytic Action on Pipes

Source: *http://www.the water treatment.com/wp-content/uploads/ 2010/08/sewer-h2s- corrosion.jp*

Electrolysis can occur when D.C. electric currents from nearby electric transit systems are grounded onto pipes. More commonly, the water and its constituents may set up a corrosion cell within the pipe. These corrosion cells, known as oxygen concentration cells, result from varying oxygen concentration in the water. The portion of the pipe touching water with a low oxygen concentration becomes the anode while the part of the pipe in contact with a high oxygen concentration becomes the cathode. Oxygen concentration cells are probably the primary cause of corrosion in the distribution system. They may occur at dead ends in the distribution system where water is stagnant and loses its dissolved oxygen. Alternatively, oxygen concentration cells may begin in annular spaces, which are ring-shaped spaces between two pipes or between a pipe and a pipe lining.

Oxygen concentration cells can also be caused by bits of dirt or bacteria. Both of these can become attached to the pipe walls, shielding the metal from dissolved oxygen in the water and setting up an anode.

(b) Galvanic Corrosion

Metals themselves can also set up corrosion cells. When a pipe consists of only one type of metal, impurities in the pipe wall can develop into anodes and cathodes. Alternatively, when two dissimilar metals come into contact, galvanic corrosion will occur. Galvanic corrosion is often set up in the distribution system in meter installations and at service connections and couplings.

Although inactive metals would make non-corrosive pipes, they are usually too expensive to use for the distribution system.

Galvanic series arrange the metal according to their tendency to corrode. At one end of the series are the metals which are less active and resist corrosion. At the other end of the galvanic series are metals which are very active and have a high tendency to corrode. These metals can be used as sacrificial anodes in cathodic protection. They should not be used for distribution system pipes. Most of the metals used in piping – iron and steel, are found in the middle of the galvanic series, and have some tendency to corrode. The distance on the galvanic series between two metals will also influence the likelihood of galvanic corrosion when the two metals are placed in conjunction with each other. For example, if aluminum is brought in contact with a steel pipe, the likelihood of corrosion is low since aluminum and steel are close together on the galvanic series. However, if a stainless steel or a bronze fitting is used on an iron pipe, the likelihood of corrosion is much higher.

When galvanic corrosion occurs, the more active metals always become the anodes. This means that they are corroded, and in extreme cases can begin to leak. The less active metal becomes the cathode and is not damaged

3.1.4 Effects of Corrosion and Scaling

Corrosion, like that shown below, can cause economic, health, and aesthetic problems. Economic problems result from damage to pipes, storage tanks, valves, and meters. Damage to pipes is the most prevalent, consisting of leaks and reduced carrying capacity of pipeline. Water treatment pipe corrosion problems often result from tuberculation which is the production of mounds of rust on the inside of the pipe as shown below.

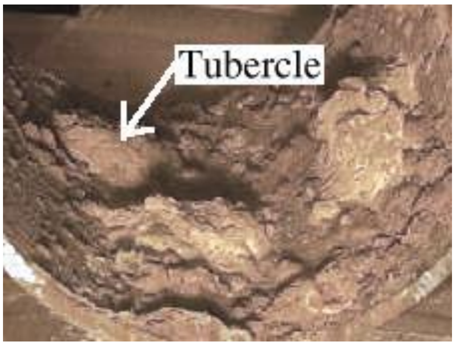


Fig. 5.3: Tubercles in the Pipeline

Source: *http://www.the water treatment.com/wp-content/uploads/ 2010/08/sewer-h2s-corrosion.jpg*

These mounds reduce the cross sectional area of the pipe available to carry water, just as scaling does. In addition, tubercles are usually associated with pits in the pipe wall, which may go all the way through the pipe and cause leaks.

When pipes in the water treatment distribution system are corroded, some of the metal from the pipes enters the drinking water and resulting health hazards to consumers.

When metal pipes corrode, the rust can break free and be carried in the water supply distribution system as red water, can stain laundry and plumbing fixtures and also results in taste problems.

Effects of Scaling

Unstable water causes problems mainly in the distribution system. Scaling is problematic because it forms in the insides of pipes and reduces the cross sectional area available to carry water. In addition, scaling can form on equipment and on hot water heaters and cause other problems.

Fig.5.4: Scales Formed Due to Corrosion

Source: http://www.the water treatment.com/wp-content/uploads/ 2010/08/sewer-h2s-corrosion.jpg

Despite these problems caused by scaling, a small amount of scale is beneficial because it coats the insides of pipes and retards corrosion.

3.1.5 Corrosion Control Measures

The following measures should be considered during design for corrosion control in Sewers.

Design shall provide for self-cleansing velocity, good ventilation, low turbulence, flushing facilities, minimal periods of flow and minimum stagnation. Pipes made of inert materials are preferable. In case of large diameter pipes, RCC with sacrificial lining of 25 to 50mm thick is the suitable pipe material.

Lining the inside of the RCC pipe with sulphate resistant or high alumina cement as sacrificial layer may increase the life expectancy of the pipe by 3 to 5 times. RCC pipes are manufactured with sulphate resistant cement when the soil contains sulphur and other corrosive substances. For metallic pipes (DI or MS) the acceptable linings are cement mortar lining either with sulphate resistant or high alumina cement. The design of sewer section with a depth of flow of about 0.8D will minimize the chance of corrosion. Good ventilation usually removes condensation in the immediate vicinity of the air inlet. Periodic flushing of sewers is necessary to remove solids accumulation and control their subsequent anaerobic decomposition and H2S formation

3.2 Design of Waste-water Treatment Units

3.2.1 Meaning and Concepts of Design of Waste-water Treatment Units

From all that have been discussed in this course, one can without equivocation say that waste-water treatment plant is broken into units for effective performance. The design of waste-water treatment units is in the opinion of the developer or the writer, the arrangement in sequence, the sizing and the use well fitted and quality materials in units to achieve the objectives of waste-water treatment and the end of the overall operation. It is against the above background that there are stages or processes of waste-water treatment as we saw.

Traditional design procedures for waste-water treatment systems attempt to minimize total capital cost by considering steady state concepts for unit processes and design guidelines. Recent work has minimised capital as well as operation and maintenance costs using a single objective function and steady state models which are flawed because plant inputs vary as much as seven fold during a 24-hour period. Previous work using dynamic models for optimal design does not simultaneously consider both fixed and variable costs in a single objective function.

The primary objective of waste-water treatment plant design is to provide treatment at a minimal cost while satisfying specific requirements. In least cost design studies, a total discounted cost is attained at the lowest possible level while satisfying a set of constraints. These constraints include (a) a specified effluent quality, and (b) various physical and biological constraints.

3.2.2 Factors Influencing the Design of Treatment Units

The amount and type of water discharged to an onsite sewage treatment system is one of the factors used in sizing that system. If the volume is high each unit is to be of big size so as to contain it and if the type of water is such that contains enough of solids both metals and non-metals etc, then the units have to be provided to handle them well before they enter other units of the treatment plant. Other factors that influence sizing include soil properties such as texture, structure, and percolation rate. These are of necessity because they determine the rate of flow of the said waste-water.

Designing a waste-water treatment system based upon average daily flow would imply that the system is operating beyond its design capacity 50 percent of the time. For this reason, treatment systems are typically designed to produce the required effluent quality when treating the maximum daily flow.

The rate of use of the system is another factor. This is influenced by the population of the users. If there are more people to be provided for or it is expected to be high later, then each unit is to be of big size to accommodate the waste-water. It is because of this that we have flow Equalisation and its processes as one of the methods of handling the above situation. Availability of fund and land space also affects the design of waste-water treatment units. If fund is highly available, then quality materials of big sizes and efficient performance will be provided. Equally if there is enough land space provided, then there could be adequate spacing between one unit and another for effective performance of the system.

3.2.3 Indicators of System Performance and Design of Units

It should be known that good quality materials or equipment are always recommended for each unit of the system to increase its performance. Indicators of system performance are things or evidence that show or help in showing that a given system are functional as expected.

Total Suspended Solids (TSS), is a measure of the solids that remain in the waste-water after settling has occurred in the tank. BOD and total suspended solids together measure the strength of the waste-water. They can serve as an indicator of system performance.

High TSS can place a great demand on the downstream devices and could lead to clogged components and orifices in distribution manifolds. High TSS can result from:

- The system being under-designed for the source supply
- Use of low flow fixtures—although they conserve water, they do not reduce the constituent mass loading and result in higher concentrations
- Use of a garbage disposal
- Kitchen practices—e.g., kitchen clean-up, food preparation, or cuisine
- Above average use of toilet paper, which can be broken down biologically but only by fungus, which needs air to function. Microbes present in septic tanks typically do not break down paper products which are wood-based
- Laundry machines—due to clothing fibers, clay, or soils present on the clothes. The volume of dirt or grime present in the laundry will directly relate to the habits, hobbies, and occupation of the residents.

Although low TSS is not a problem for the system, it could indicate that something else is wrong with the system. Low TSS could be due to:

- Fewer users on the system than considered in the original design
- Higher flows from low TSS sources
- Clear water inflows.

The implication of all the above is that in designing the units, they should be made to take care of the TSS and BOD. The expected levels of FOG concentration must be considered during waste-water treatment design. FOG means 'Fat Oil and Grease'. The sides of the baffle should be avoided so that the FOG buildup on the baffle wall is not added into the sample. If a sample is taken from a pump tank be sure to move aside a scum layer if it exists.

Fat

Animal fat is relatively easy to hold in a tank because it is quite sensitive to temperature. It becomes a solid at 80°F, and waste-water temperature is usually less than 80°F. Animal fat will break down in the soil, but it takes four times more energy to break down than the organic matter typically measured by BOD5. Fat is added to the system from cooking, clean up, and dish washing, so commercial systems will typically have higher levels of fat than residential systems. If a system is supplied with a lot of animal fat, it will typically stay in the septic tank. If it is contained in the septic tank, it may not be observed in FOG measurements in downstream components.

Oils

Vegetable oil is not as sensitive to temperature as fat and can pass through the system. Oil can also be broken down through a biological process, but it takes 12 times more energy to break down oil than the organic matter typically measured by BOD5. There are many different types of oils used, but vegetable is the most common. Vegetable oil is often used in the liquid form, but it can also be solid shortening. The liquid form is harder to hold in a tank. The ability of the oil to separate is influenced not only by temperature, but also by how the oil was generated and used. Free oil will rise to the waste-water surface and be easily separated when the mixture is allowed to become quiescent. Emulsified oil has been broken up into very small droplets and occurs either by mechanical or chemical action. An example of mechanical emulsification is when extremely hot water from a dishwasher is mixed with the oil. Given time and a decrease in temperature, this oil can be separated. Chemical emulsification occurs when detergents or cleaners produce a mix of oil and water. Degreasing compounds can generate dissolved oils, in which discrete oil particles are no longer present. Chemically emulsified oil will take a longer time to separate, increasing the risk of carrying it to downstream components unless long quiescent periods are available to allow separation.

Grease

Grease is petroleum-based and can be toxic to a system. Because grease is petroleum- based, it cannot be broken down, but it can be separated. Grease comes from lotions, hair products, and soaps. Typically, there will be a higher percentage of grease in the FOG from residential systems when compared to most commercial systems. Grease can build up over time, coating components and inhibiting treatment of other constituents in the waste-water.

Temperature

Septic tank effluent on average is approximately 20 degrees (°F) warmer than the ambient ground temperature. Microbial activity doubles in population every time the temperature increases by 18°F (10°C) until the optimum temperature is reached. As the microbial activity doubles, the biodegradation of constituents increases. This means that oxygen uptake is more rapid at warmer temperatures, requiring air to be supplied at a higher rate. The waste degrades more quickly at warmer temperatures, so it need not be held in the treatment system as long when it is warm. The converse is also true: in the winter, oxygen uptake is low and air need not be supplied as fast. However, the waste takes longer to degrade, and would thus need to stay in the treatment system longer during cold months. The practical implication of this is that aerators are designed using summer temperatures and detention tanks are designed using winter temperatures.

Forecasting Average Flow Rates

The development and forecasting of average daily flow rates is necessary to determine the design capacity as well as the hydraulic requirements of the treatment system. The maximum daily flow rate is important particularly in the design of facilities involving retention time such as equalisation basins. Data on peak hourly flows are needed for the design of collection and interceptor sewers, waste-water – pumping stations, waste-water flow meters, sedimentation tanks and channels in the treatment plants

3.2.4 Efficiency and Maintenance of Treatment Units

The efficiency of waste-water treatment units depends on the quality of materials used in the design of the units, the way of handling of the machines and the maintenance culture adopted while the machines are in operation and when they are at rest.

The material used in making or designing each unit has to be made to tackle the functions meant for them without any interference. They should be rust free and should also be free from the influence termites and other ants or insects. They should be readily available and have spare parts. Depending on the unit in question, the machines should be able to resist the influence of pressure on them without their being damaged. In terms of the handling of the machines in the units, they should be properly handled and maintained. Areas that need to be scooped should not be allowed to accumulate in excess so as not to interfere with their proper functioning and that of others. The same should be done to areas needing oiling or greasing. The unit needing nature to act on it should have its site cleared and not being overburdened by solid waste that are not part of sewage and waste-water. Equally, heavy vehicles, equipments or machines should not be placed on top of the units' machines as doing so would destroy them.

4.0 CONCLUSION

From all the foregoing, one can conclude that corrosion which is the rusting of metal in pipes or tanks due to the corrosive action of water, waste-water or soil is a major factor in the design of waste-water treatment units. This is because it has negative effects on the objectives and goals of treatment of sewage and waste-water. In order to defeat the ill effects of corrosion, the design of treatment units has to be made with materials that can resist rust still retaining its functionality and the desired longevity or where such is not possible, the application of safety measures to allow the proper functioning of the metallic materials used in making such units become mandatory, hence the need for this last unit.

5.0 SUMMARY

In this last unit, you have learnt the following:

- Corrosion was defined as the rusting of metal in pipes or tanks due to the corrosive action of water, waste-water or soil. Scales which are deposits caused by the deposition of calcium carbonate on the inner surface of the water or waste-water treatment equipment pipes or tanks emanate as a result of corrosion.
- The causes of corrosion in waste-water treatment plant was also discussed where you were made to know that bacteria in the slime under flowing sewage convert sulphates in the sewage into sulphides and the bacterial action then converts the H2S gas converted to sulphuric acid which causes corrosion in the crown of the pipe and this corrosion.
- The types of corrosion were explained next and in this you learnt that they can occur on the outside of a pipe (due to corrosive soil) or on the inside of a pipe (due to corrosive water.) Either outside or inside a pipe, the creation of the corrosion cell can be through electrolysis, oxygen concentration cells, or through galvanic action.
- The effects are that it can cause economic, health, and aesthetic problems. Economic problems result from damage to pipes, storage tanks, valves, and meters.

- To prevent corrosion, the design shall provide for self-cleansing velocity, good ventilation, low turbulence, flushing facilities, minimal periods of flow and minimum stagnation, etc.
- Finally, under the design of waste-water treatment units you learnt: the meaning and concepts of design of waste-water treatment units, factors influencing the design of treatment units, indicators of system performance and design of unit and the efficiency and maintenance of treatment units.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define corrosion and enumerate the causes of corrosion in waste-water treatment units.
2. List the types of corrosion and their effects.
3. What are the factors influencing the design of waste-water treatment units**.**
4. Enumerate how you can ensure the efficiency and maintenance of treatment units.

7.0 REFERENCES/FURTHER READING

Prasanta, K. B. & Michael K. S. (1986). *Optimal Design and Operation of Waste-water Treatment Plants*.

http://www.the water treatment.com/wp-content/uploads/2010/08/sewer-h2s- corrosion.jpg