All About

WASTEWATER TREATMENT

A Comprehensive Guide

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Professional Help/ Advice on Waste Water, Treatment, and related topics

This eBook, commissioned by Geostar Publishing LLC, is the compilation of material written by several authors who are specialists in their respective realms of Waste Water Treatment.

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Quaking in our boots has become a way of life. And we appear to be doing it for all the wrong reasons. Oil, Weapons of Mass Destruction, terrorism - to mention a few - all keep conjuring images of the Apocalypse. These are problems you can fight or run from. And if you have the temerity, even laugh at.

But consider water; is it a renewable resource? If you said "Yes", you are right. But how long will it be before you are wrong?

It's not a widely published fact. But that's no reason why it should not be a widely acknowledged problem. The world's supply of fresh water is slowly running dry. Forty percent of the world's population is already reeling under the problem of scarcity. Most of the diseases plaguing them are water-borne. And while there is a child being born every eight seconds in America, there is a life being taken every eight seconds by some water-borne disease in other parts of the world.

Is the cause and what is the effect, is not clear as yet. Is it the lopsided distribution of fresh water that is causing climate change, or is it the climatic change that is causing this lopsided distribution? The fact is that there is a significant climate change, and as a consequence of this change, some regions are becoming drier while others are getting wetter. Some parts of the world are experiencing greater desertification, while some others are suffering category 4 and 5 hurricanes.

According to the United Nations, water is one of the most serious crises facing the world. And things are only getting worse.

Uzbekistan and Kazakhstan of the erstwhile USSR, Chile, Mexico, Paraguay, Argentina, Peru and Brazil in Latin America, parts of China and the Middle East especially Iran, and more than 25 countries of Africa are all suffering from varying degrees of desertification.

Global weather is a system gone awry. It is making poor countries poorer. Countries that are already facing drought and famine are getting less and less water. For how long can these countries run on dry?

Nowhere is the situation worse than in Africa. Almost 40 million people in 19 countries are facing imminent food shortage. Much of the livestock there, will perish. The growing water shortage will make food more scarce, potable water less accessible and water-borne diseases even more rampant. And the number of people who will suffer all this is expected to touch more than 500 million by the 2025. And the global consequence: A greater dependance on international aid.

If you say that this is an African problem, you're the original sandman. Who would have thought that 91% of New South Wales would go dry? Who would have imagined that the southwestern United States would also face similar water problems? No one can tell which part of the globe will be next.

Blame this on nature. It's most convenient. But fact is, much of the blame belongs to increasing consumption and improper usage.

At every opportunity nature reminds us by what it does and what it doesn't, that it is one of the forces we have little control over. So there's no way we can stop the rain or start it. But what we can do is become more water-efficient - get more from every gallon of water. And the only way to do this is to recycle and reuse wastewater.

Water is the giver of life. It has no substitute. And every drop counts!

Many believe that the next world war is likely to be fought on the issue of water. Even though the world is two-thirds water, most of it is not potable, and much of it is not usable for any other purpose as well.

And we are busy consuming and contaminating whatever is left of it, as if it were a non-depletable resource. In this eBook, we make an attempt to identify ways to make the best use of water, an increasingly scarce resource, by recovering it from wastewater, whether we intend to reuse the water so recovered or let it just charge our ground water reserves.

This eBook is meant for a wide cross-section of people involved in taking corrective action across the world policy makers, administrators, municipal engineers & scientists, engineers & administrators in industries vested with the responsibility to manage their wasterwater, industrial & residential property builders, academics, students and just about everyone who cares about posterity.

Before writing this eBook, a massive Survey was undertaken, covering 405 persons from all the above sections of the society, across the world. We tried to find out what they all would like covered in this eBook, and we have made an attempt to address all the relevant questions they had raised, in as much detail as practically feasible.

This is an evolving eBook, and we propose to take feedback from all you, readers of this eBook, and incorporate your suggestions, and cover whatever more you like to covered, subject to feasibililty. So, please feel free to give us your valuable feedback, addressed to

support@allaboutwastewater.com.

Also, since the readership is varied, we have the daunting task of having to cover most topics in depth, and yet make the eBook readable to all. Not all chapters may interest all readers.

We need to use jargon for the benefit of those who use them day in and day out, and yet not use jargon in the interest of those who don't know them. A water chemist, for instance, may want us to use jargon related to water chemistry, while an Engineer may find it a little heavy. We hope we have struck a fair balance; if you think otherwise, in parts or in full, please give us your feedback and suggestions.

We have much bigger plans, and hope to be able to accomplish them with your help. Since we reach this eBook across to you through electronic means, we would keep you informed of our acitivites as they take shape.

2.1 Acidity

Can water be acidic in taste? Most natural water, domestic wastewater and many industrial wastewater are buffered by a carbon dioxide-bicarbonate system. Acid waters are of concern because of their corrosive characteristics and the expense involved in removing or controlling the corrosion-producing substances. Mineral acids are measured by titration to a pH of about 3.7.

2.2 Alkalinity

When will the water be alkaline in taste? The alkalinity of natural water is primarily due to the salts of weak acids. Although, weak or strong bases may also contribute. Natural water contains appreciable amounts of carbonate and hydroxide alkalinity. Higher alkaline waters are usually unpalatable. Alkalinity is measured volumetrically by titration with N/50 or 0.020 N H_2SO_4.

2.3 Hardness

Water is more often hard. Do you agree? Hardness is caused by metallic ions that are capable of reacting with soap to form a precipitate. Calcium bicarbonate, magnesium sulfate, strontium chloride, ferrous nitrate and manganese silicate are the major sources for hardness in wastewater. Hardness is determined using ethylene-di-amine tetra acetic acid (EDTA) or its sodium salts as the titrating agent.

2.4 Chloride

Chloride is a major contributor to the 'total dissolved solids' in water/wastewater. The chloride content of water/wastewater increases as its mineral content increases. Chlorides at a concentration above 1000 mg/l give a salty taste, which is objectionable to many people. Chloride concentration of wastewater is estimated by Mohr’s method using silver nitrate with potassium chromate as an indicator.

2.5 Biochemical oxygen demand (BOD)

The strength of wastewater is judged by BOD. This is defined as the amount of oxygen required by bacteria while stabilizing the organics in wastewater under aerobic conditions, at a particular time and temperature. This can be referred as BOD_5, which accounts for 70% of the total BOD. The measurement of BOD is based on the principle: determination of dissolved oxygen content of water/wastewater on the first day and dissolved oxygen content on the fifth day ('5' in BOD5 indicates this). The difference in dissolved oxygen concentrations between first day and fifth day is expressed as BOD of wastewater.

2.6 Chemical oxygen demand (COD)

What does COD of wastewater mean? This reflects the concentration of organic compounds present in wastewater. This measures the total quantity of oxygen required for oxidation of organics into carbon dioxide and water. The oxidation of organics in wastewater is carried out by the action of strong oxidizing agents. Generally, acidified potassium dichromate is used as an oxidizing agent for the determination of COD. Silver sulfate is used as the catalyst for the oxidation of organics in wastewater during the determination of COD. Mercuric sulfate is added to control the interference of chloride in the estimation of COD. The method consists of adding a known concentration of potassium dichromate (added with silver sulfate and mercuric sulfate) into wastewater containing organic compounds to be oxidized in the heating condition. After oxidation, the excess potassium dichromate is back titrated with ferrous ammonium sulfate.

2.6.1 Importance of COD:

Estimation of COD expresses the total concentration of organics present in the wastewater. This measures approximately the theoretical oxygen demand of wastewater. The determination accounts for about 95% of the organic concentration in wastewater. This forms about 1.43 times the BOD of wastewater. BOD to COD ratio reveals the treatability of wastewater. If the ratio of BOD/COD is above 0.5, the wastewater is considered to be highly biodegradable. If the ratio is less than 0.3, the wastewater is deemed to undergo a chemical treatment before the routine biological treatment.

2.7 Ammonia nitrogen:

This is derived from ammonium compounds and organic compounds in wastewater by aerobic or anaerobic digestion. Un-ionized ammonia is toxic to fish life. Free ammonia, in concentration above about 0.2 mg/l can cause fatalities to fish. Ammonia toxicity is not a problem in receiving waters with pH below 8.0. This can be estimated by distillation of wastewater at pH above 9. The ammonia liberated is neutralized in sulfuric acid. The excess sulfuric acid is back titrated with alkali. The estimation of ammonia can be done by any other methods like nesslerization or digestion.

2.8 Nitrate nitrogen:

Nitrate nitrogen in drinking water with high nitrate content often causes methemoglobinemia (blue-baby disease) in infants. The maximum concentration should not be allowed to exceed 45 mg/l. Nitrate is reduced to nitrite in digestive system which, in turn, attacks the hemoglobin in infants resulting in methemoglobinemia. Nitrate nitrogen can be estimated by measuring the optical density at 220 nm and 275 nm in spectrophotometer.

2.9 Nitrite

Nitrite can also interact with amine chemically or enzymatically to form nitrosoamines which are carcinogens. This is measured by colorimetric determination using sulfanilamide.

2.10 Sulfate

Sulfate is one of the major anions occurring in natural waters. Sulfates form hard scales in boilers and heat exchangers. Sulfate assumes significance in water and wastewater, as it is associated with odor and sewer-corrosion problems resulting from the reduction of sulfate into hydrogen sulfide under anaerobic conditions. Sulfate in water or wastewater can be estimated by precipitation with barium chloride, acidified with hydrochloric acid.

2.11 Phosphates

Most of the synthetic detergents designed for the household applications contain large amounts of polyphosphates as builders. Many of them contain 12-13% phosphorous or over 50% poly-phosphates. The organisms involved in the biological processes of wastewater treatment require phosphorous for reproduction and synthesis of new cellular material. Phosphorous in wastewater causes eutrophication, which affects transportation in sea/lakes. The presence of phosphorous in wastewater needs to be controlled before it is discharged into the receiving water bodies. Phosphorous present in wastewater can be estimated through colorimetric technique, by adding acidified ammonium molybdate solution to form a molybdophosphate complex.

2.12 Nutrients

Wastewater often contains large amounts of the nutrients like nitrogen and phosphorus in the form of nitrate and phosphate, which promote plant growth. In severe cases, excessive nutrients in receiving waters cause algae and other plants to grow quickly depleting oxygen in the water. Deprived of oxygen, fishes and other aquatic organisms die, emitting foul odors. Nutrients from wastewater have also been linked to ocean "red tides" that poison fishes and cause illness in humans.

3.1 Water and life

Without water, there is no life. The human body contains about 70% water. All body mechanisms in animals and plants depend on water as the media. Some of the salts naturally present in water serve as nutrients and are essential for the functions and growth of the body. About 97% of water available on the earth's crust is salty and non-potable and another 2% is available as polar ice.

Water, when contaminated, causes illness and disease. About 80% of the human diseases are related to water.

3.2 Physical properties of water

Density (25 °C), kg/m^3	997.075
Density (20 °C), kg/m^3	998.2
Maximum density, kg/m^3	1000.000
Temperature of maximum density, °C	3.940
Viscosity (25 °C), Pa/s	0.890×10^{3}
Kinematic viscosity (25 °C), m^2/s	0.89×10^{-6}
Melting point (101, 325 Pa), °C	0.0000
Boiling point (101,325 Pa), °C	100.00
Latent heat of ice, KJ/mol	6.0104
Latent heat of evaporation, KJ/mol	40.66
Specific heat capacity (15 °C), J/kg °C	4186
Thermal conductivity ((25 °C)m), J/cm.s. °C	0.00569
Heat of vaporization, J/kg	2.453×10^{6}
Surface tension (25 °C), N/m	71.97×10^{3}
Surface tension (20 °C), N/m	72.75×10^{3}
Surface tension (0 °C), N/m	75.64×10^{3}
Dielectric constant (25 °C)	78.54
Vapor pressure (20 °C), Torr	17.535

Source: Data from J.Schwoerbel, Handbook of Limnology, Ellis Horwood, Chichester, West Sussex, England, 1987; T.J.Marshall and J.W.Holmes, Soil Physics, 2nd Ed., Cambridge University

Press, Cambridge, 1988.

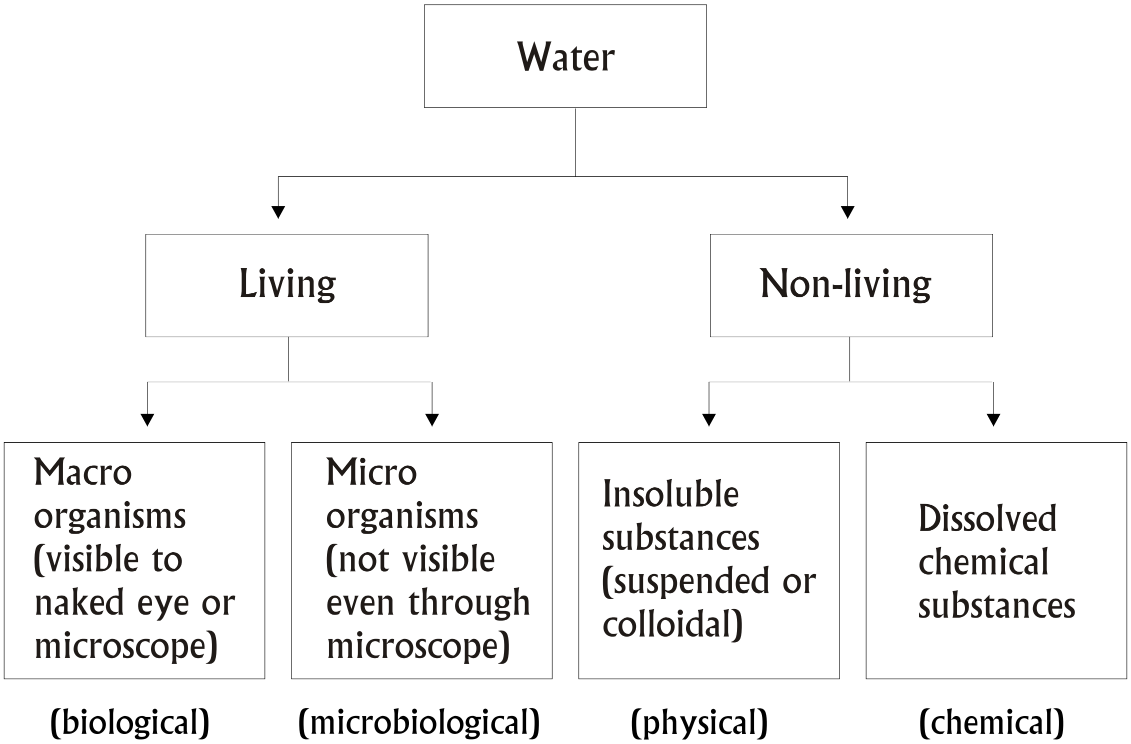
3.3 Water as a chemical

Pure water is a compound of hydrogen and oxygen.

It is colorless, odorless and tasteless.

It exists as liquid at ambient temperature.

3.4 Water - what it contains?



3.5 Water quality criteria

The quality of water is a function of:

a. Source

b. Place

c. Geological conditions

d. Depth of water level

e. Seasonal changes

f. Domestic activity

g. Agricultural activity

h. Industrial activity etc.

Excessive exploitation of natural resources and use of technological advances with no concern for ecology interfere with air, water and land.

The substances present in water can be classified as:

(a) Floating matter such as :

- Leaves
- Twigs
- Dead organisms
- Algae

(b) Suspended matter like :

- Silt

- Clay
- Decaying vegetable matter
- Bacteria
- Microorganisms
- Algae
- Insoluble iron
- Manganese

(C) Dissolved impurities includes:

- Gases like carbon dioxide, hydrogen sulfide etc.
- Chemical substances
- Minerals
- Salts

3.6 Water sources and water quality

Based on water quality, the water sources can be classified as follows:

Water	Surface water	Ground water	Sub-soil water in river beds
Turbidity	High	Colorless and clear	Colorless and clear
Total Dissolved Solids (TDS)	Low	High	High
Hardness, alkalinity, chloride, fluoride and nitrate	Low	High	Low
Level of bacteria	High	Low	Low
Level of organic matter	High	Low	Low

3.7 Water pollution

Water is essential for living, just like air. One may live without air for a few minutes. But, without water, one is sure to die within a few days. We all know about air pollution. Water pollution is also the gift of modern man to posterity.

How does water get polluted?

Pollution of water sources is caused by:

(i) Sewage and sullage from human settlements

(ii) Solid wastes dumping

(iii) Wastewater from industries

(iv) Chemicals in agriculture

When foreign materials harmful to us are added, the water is sure to get polluted. Which foreign materials? Two readily come to our mind:

a. Industrial wastes

b. Sewage from cities.

Why do we need good water? We know, we need it for many things including the following:

- Drinking by humans and animals
- Supporting aquatic life
- Generating electric power
- Irrigating crops in fields
- Recreating in water-based sports

3.8 Classification of infective diseases in relation to water supplies

I. Water borne diseases (fecal-oral)

(a) by bacterial organisms: cholera, typhoid, paratyphoid, dysentery, diarrhea, weil's disease (leptospirosis) and tuberculosis

(b) by phage virus or bacteriophages: infectious hepatitis, jaundice and poliomyelitis

(c) by protozoan: amoebic dysentery, ascarsis and amoebic meningo cephalitis (fatal encephalitis usually acquired while swimming in ponds)

Preventive measures: improve quality of drinking water. Prevent causal use of the unhygienic sources.

II. Water washed diseases

Scabies, skin diseases, typhus fever, leprosy, trachoma, conjunctivitis and bacillary dysentery

Preventive measures: increase water quantity for (washing/cleaning) use. Improve accessibility and reliability of domestic water supply.

III. Water based diseases

Schistosomiasis (liver fluke), dracunculosis (guinea worm disease)

Preventive measures: control snail populations; filter the water through a fine mesh cloth to remove larvae/cyclops/snail. Disinfect contaminated water.

IV. Water related diseases (by vector organisms)

Malaria, filaria, dengue fever, sleeping sickness (African sleeping sickness)

Preventive measures: destroy breeding sites of insects. Decrease the need to visit breeding sites. Use mosquito nets.

3.9 Water borne diseases of biological origin

Sl. No.	Disease	Causative agent / Type of organism / Life cycle (pathogenicity)	Clinical features
1	Dracunculiasis (guinea worm infestation)	Dracunculus Medinensis / Nematode worm / Adult stage in human host larval stage in fresh water crustaceans cyclops.	A stinging / burning sensation heralds the appearance of a blister, which ruptures to form an ulcer when the site of the skin is placed in water. The symptom appears when the female worm reaches the skin surface and is ready to discharge her larvae. Occasionally, there may be generalized symptoms of urticaria, nausea, vomitting and dyspnoea when the blister first appears.
2	Schistosomiasis [group of diseases Ischistosome dermatitis (swimmer's itch), katayama fever, urinary schistosomiasis, intestinal schistosomiasis, hepatic schistosomiasis]	schistosoma haematobium, s. mansoni, s. japonicum, s. intercalatum, s. mekongi / Trematode flatworms / For s. mekongi (usage of only lowercase characters suggested) host is dog - for other species host is man - eggs are passed in the urine or faeces - in fresh water, the first larval stage, a miracidium penetrates body	Schistosome dermatitis (swimmer's itch): it is caused due to the penetration of the free swimming cercariae through the skin. It is an itchy popular skin rash, which occurs within about 24 hours. The eruption is probably allergic in nature. Katayama fever: this occurs about 4 to 6 weeks after infection, usually due to s.japonicum or

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
		of freshwater snail - within the snail miracidia multiplies asexually to form numerous sporocysts - after 4 to 6 weeks released from snail as free swimming cercariae - cercaria penetrates the skin of man	s.mansoni and rarely to s.haematobium. There is an acute onset of fever, headache and cough. There is also enlargement of the liver, spleen and the lymph nodes. Examination of the blood film shows eosinophilia. Occasionally, katayama fever results in death. Urinary schistosomiasis, especially when the infestation is light, is frequently asymptomatic. Painless haematuria is usually the first sign. Terminal haematuria, passing small amounts of blood at the very end of micturition is characteristic. More serious disease is due to damage of the bladder and kidneys, as a result of obstruction to the flow of urine. Severe contraction of the bladder can occur, with fibrosis and calcification. Intestinal schistosomiasis can also be asymptomatic in light infestations. Patients may complain of fatigue, abdominal pain and diarrhoea, which can be bloody. Anaemia is common due to the blood loss. There is polyp and ulcer formation, which can occasionally cause bowel obstruction. Hepatic schistosomiasis can occur when there is a heavy infestation. This usually presents as a symptomless hepatomegaly, with or without enlargement of the spleen. In advanced cases portal hypertension may develop, with massive enlargement of the spleen and the appearance of oesophageal varices, which can bleed repeatedly.

Sl. No.	Disease	Causative agent / Type of organism / Life cycle (pathogenicity)	Clinical features
3.	Giardiasis	giardia lambia (g.duodenalis) / Protozo / g. lambia exists in two forms. The trophozoites found adherent to the mucous membranes of the upper small intestines - passed along the intestines - passed in the faeces - in the new host passes into the duodenum - produces two daughter trophozoites which then colonize the small bowel.	In symptomatic patients, the predominant feature is the acute onset of diarrhoea, which is often explosive, abdominal cramps, bloating and flatulence. There is no blood or pus in the stool, which is often pale and at times almost white in color. Malaise is common and sulphuric belching is quite characteristic. Untreated, the acute illness usually lasts for at least 10 days and often for much longer (4-12 weeks). During this illness patients often lose considerable weight.
4.	Cryptosporidiosis	c. parvum (above 20 species are now known, of which c. Parvum pathogenic for humans) / protozoa / oocyst is ingested and passes through the stomach - excystation occurs with release of four motile sporozoites - sporozoites attach to the epithelial cell wall - sporozoite matures into a trophozoite -divides forming a meront and releases merozoites - microgametes and macrogametes formed and fertilize - zygotes formed and matured as oocyst - oocyst is the infective stage and is passed in the faeces.	Diarrhoea stools, watery and offensive and contain mucus or slime, but rarely pus or blood cells. Patients may also complain of mild abdominal pain and a few also have a mild fever. Symptoms usually last from 2 to 26 days. In individuals suffering from aids, the disease is much more severe and more persistent. Illness can last for several months or until death.

Sl. No.	Disease	Causative agent / Type of organism / Life cycle (pathogenicity)	Clinical features
5.	Cyclospora	Cyclospora cayetanensis / Protozoa / life cycle not known	Diarrhoea, abdominal pain, nausea, vomiting and anorexia. Flatulence and bloating are also features. The diarrhoea is characteristically prolonged, lasting from one to eight weeks.
6.	Naegleria (free-living amoebo flagellate)	naegleria fowleri / Amoeboflagellates / n. Fowleri has three stages in its life cycle - in trophozoite stage (found in mud and surface of vegetation) the organism feeds and multiplies - motile biflagellate stage is found in surface layers of water - finally, the organisms are found as cysts - both trophozoite and biflagellate forms are potentially infectious for humans - infection occurs during swimming - pathogens penetrate through the nose - enters cerebrospinal fluid - finally penetrates and feed on brain.	Primary amoebic menigoencephalitis (pam). Initial symptoms are headache and a slight fever. Vomiting, stiff neck, increasing fever and severe headache leads to coma.
7.	Illness caused due to cyanobacteria	Cyanobacteria / Algae (but truly prokaryote bacteria)/Illness related to cyanobacteria is mediated by toxins - toxins include hepatotoxins, neurotoxins and lipopolysaccharides.	Clinical presentation of disease that implicates cyanobacteria is wide. The commonest clinical presentation is a self limiting diarrhoea, which lasts for a few days. Erythematous skin rashes are also commonly described.

Sl. No.	Disease	Causative agent / Type of organism / Life cycle (pathogenicity)	Clinical features
8.	Cholera and other vibrios (gram.negative, neotile, comma shaped bacilli)	Vibrio cholerae / Bacilli / the infectious dose is high i.e. 106 to 108 organisms. If gastric acidity is neutralized, then the infectious dose falls to as low as 103 organisms. The organism proliferates in small intestine - penetrates mucus barrier to attach to the mucosal surface - colonizes the lining of gut - secretes a potent enterotoxin - intracellular level of cyclic adenosine monophosphate (camp) increases - increased secretion of chloride and inhibition of sodium uptake.	Painless watery diarrhoea. In mild cases, faeces are passed 2-3 times per day for 5-7 days. In a typical severe case, passage of copious water stool can be continuous. Within a matter of a few hours the stool becomes colorless, known as rice-water stool. The life threatening effects of cholera are due to the rapid depletion of body fluids. Shock can develop within 4 - 12 hours, with death soon after. Complications include renal or cardiac failure due to the dehydration of the body. Metabolic acidosis due to loss of bicarbonate in the stool.
9.	Typhoid and paratyphoid	Salmonella typhi and salmonella paratyphi / bacilli / Infectious dose is below 1000 and possibly 10 organisms. After passing through the stomach, the organism penetrates the lining of the small bowel - then passes to the mesenteric lymph nodes and multiplies - the organisms are then released into the blood stream - any organ can be infected, gall bladder is mainly infected - again intestine is affected, perforation of intestine occurs - increase in the excretion of infective agent in the stool.	Diarhoea, watery stool with blood, colicky abdominal pain and fever. Nausea and mild vomiting.

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
10.	Shigellosis (bacillany dysentery)	Shigella dysenteriae, shigella flexneri, shigella boydii, shigella sonnei/ bacilli/ can cause disease in healthy adults with the administration of fewer than 200 viable organisms. The disease is produced by invasion and subsequent destruction of the superficial mucosa.	Diarrhoea accompanied by vomiting and leading to dehydration. Then fever, meningism and severe abdominal pain may occur/ diarrhoea mostly mucous with varying amounts of blood/ cholera type illness with watery diarrhoea or with a gangrenous form. May be associated with severe abdominal pain and the passage of stools containing altered blood and necrotic mucosa (lining of the bowel wall).
11.	Campylobacterios	Campylobacter spp/ bacilli/ these are sensitive to stomach -acid and infection is enhanced by the buffering effect of foods.	Diarrhoea with watery and occasionally bloody. Pus in the faeces. Cramping abdominal pain and can mimic appendicitis, acute crohn's disease and ulcerative colitis. Fever and malaise are also features.
12.	Escherichia coli	Escherichia coli/ bacilli/ adhere to gut wall and produce toxins.	Urinary tract infections, meningitis and septicaemia. Cause dehydrating diarrhoea in children. It is a common cause of traveller's diarrhoea. In infants can cause fever and watery mucoid diarrhoea.

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
13.	Yersinia infections	Yersinia pestis/ bacilli/ infective dose is high, up to 109-infection of the terminal ileum leads to ulceration and inflammation of the mesenteric lymph nodes.	Affects children under five years. It causes fever, diarrhoea and abdominal pain which lasts for about one to three weeks.
14.	Plesiomonas infections	Plesiomonas shigelloides/ bacilli/ pathogenic mechanism not known.	Gastroenteritis. Mild to severe mucoid and bloody diarrhoea. In some cases bacteraemia, osteomyelitis, septic arthritis and meningitis.
15.	Aeromonas infections	Aeromonas hydrophila, aeromonas caviae, aeromonas sobria/ bacilli/ pathogenesis unclear.	To start with mild, self limiting diarrhoea then develop fever, abdominal pain and bloody diarrhoea.
16.	Pseudomonas infections (aerobic, non-spore forming, gram negative bacilli)	Pseudomonas aeruginosa/ bacilli/pathogenesis differs with the syndrome and source of infection.	Respiratory infection, bacteraemia, meningitis and brain abscess, and ear, eye, bone and joint, urinary tract, gastrointestinal, and skin and soft-tissue infections. The most water-related skin rash is folliculitis.
17.	Melioidosis	Burkholderia pseudomallei/ bacilli/causes purulent abscesses, which can affect several body systems.	Asymptomatic infections. Clinically melioidosis may present as an acute localized suppurative lesion, an acute pulmonary or septicaemic illness or as a chronic suppurative infection.

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
18.	Legionnaire's disease	Legionella pneumophila/ bacilli/ enters the lung by direct inhalation of aerosols.	Pneumonia, pontiac fever (self limiting, influenza like illness characterised by malaise, myalgia, fever, chills and headache.
19.	Leptospirosis	Leptospira interrogans, l.biflexa, l.parva/ obligate aerobes/ gains access to the bloodstream, either through intact mucous membrane, conjunctivae or damaged skin. Bacteraemia then carries the organisms to sites throughout the body including the liver, kidneys, csf and eye. Multiplication at these sites is then responsible for end-stage disease.	Non-specific flu-like illness, which lasts for three to seven days. Sudden onset of high fever, prostration, rigors and muscle pains headache, photophobia and abdominal pain.
20.	Mycobacterial disease	Mycobacteria ulcerans, m. Avium (usage of the same case suggested), m.gordonae, m.marinum/ bacilli/ the skin diseases follow inoculation of the bacterium into the skin. Other infections follow from inhalation.	Tuberculosis and leprosy.

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
21.	Tularaemia	Francisella tularensis/ bacilli/ infection through skin abrasion or by inhalation. Initially, organisms reproduce at the site of entry for three to five days. From here, they are spread to regional lymph nodes, followed by bacteraemia. Disseminated infection can affect several organs, causing focal necrotic lesions and granulomas.	Clinical disease can be either of the cutaneous-lymphatic type where a nodular, suppurative or ulcerative lesion develops at the site of entry. In the typhoidal presentation the main feature is high fever with occasional pneumonitis.
22.	Helicobacter infections	Helicobacter pylori/ bacilli/ pathogenesis not known.	Nausea and abdominal pain which lasts for 3 - 14 days. Gastritis develops hypochlorhydria may persist for up to a year. In most patients, infection persists for several years or more.
23.	Viral hepatitis	Hepatitis A, hepatitis B/ virus/ acquired orally - virus passes through the stomach, where it replicates in the lower intestine before being carried to the liver, where most replication occurs. Virus is shed from the liver in the bile, from which it contaminates the faeces. Liver damage occurs at the point when circulating antibody appears in the blood.	Jaundice. Initial symptoms are non-specific, and include malaise, lassitude, myalgia, arthralgia and fever. Inflammation of the liver, darkening of the urine and pale or clay colored stools.
24.	Viral gastroenteritis	Rotaviruses (a, b & c)/ virus/ rotaviruses replicate in the villus epithelial cells of the small intestine and causes a loss of the absorptive cells.	Fever, vomiting and diarrhoea.

Sl. No.	Disease	Causative agent/Type of organism/Life cycle (pathogenicity)	Clinical features
25.	Enterovirus infections including poliomyelitis	(1) polio virus (2) coxsakie viruses A (3) coxsackie viruses B (4) echoviruses (5) enteroviruses/ virus/ infection follows the ingestion of faecally contaminated material. Initial site for replication is the submucosal tissue of the pharynx or distal small intestine. From the gut, virus may then spread directly to regional cervical or mesenteric lymph nodes or via the blood to various reticuloendothelial tissues such as liver, spleen, other lymph nodes and the bone marrow. Replication may then cease.	(1) aseptic meningitis, encephalitis, paralytic-poliomyelitis. (2) aseptic meningitis, encephalitis, paralytic disease, hand, foot & mouth disease; ulcerative stomatitis, lymphonodular pharyngitis, acute catarrh; pneumonitis, hepatitis; conjunctivitis, splenomegaly. (3) aseptic menigitis, paralytic disease, pericarditis, myocarditis, hepatitis, conjunctivitis, splenomegaly. (4) paralytic disease, respiratory -enteric disease, gastroenteritis, conjunctivitis. (5) paralytic poliomyetitis, epidemic conjunctivitis.
26.	Adenoviral infections	Adenovirus a,b,c,d,e&f/ virus/ virus infects the cell, replicates to produce up to a million new viruses and then kills the cell by lysis to release new infective particles.	Gastroenteritis, pharyngitis and conjunctivitis.

3.10 Viruses

3.10.1 General

The viruses of greatest significance in the water borne transmission of infectious diseases are essentially those that multiply in the intestine of humans and are excreted in large numbers in the feces of infected individuals. Although viruses cannot multiply outside the tissues of infected hosts, some enteric viruses appear to have a considerable ability to survive in the environment and remain infective. Discharges of sewage and human excreta constitute the main source of human enteric viruses in the aquatic environment. With the various analytical methods currently available, wide variations are found in the numbers of viruses present in sewage. The numbers of viruses and the species distribution will reflect the extent to which the population is carrying them. It may reduce the number of viruses by the population. Sewage treatment may reduce the number of viruses 10-1000-fold, depending on the nature and extent of the treatment given. However, it will not eliminate them entirely, and the sludge produced during sewage treatment will often contain large numbers. As sewage mixes with receiving water, viruses are carried downstream. They remain detectable for varying periods of time, depending on the temperature, the degree to which they are absorbed onto sediments, the depth to which sunlight penetrates into the water, and other factors. Consequently, enteric viruses can be found in sewage-polluted water at the intakes to water-treatment plants.

The relationship between the occurrence of viruses in water and risks to health is not a simple one.

3.10.2 The nature of viruses:

Viruses are replicating infectious agents that are among the smallest of all microorganisms. In essence, they are nucleic acid molecules that can enter cells and replicate in them, and code for proteins. They are capable of forming protective shells around them.

Viruses pathogenic to humans can occur in polluted water. Some of the diseases attributed to them are listed below:

Virus family	Members	No.of serotypes	Diseases caused
Picorna-viridae	Human polioviruses	3	Paralysis, meningitis, fever
	Human echoviruses	32	Meningitis, respiratory disease, rash, fever, gastroenteritis
	Human coxsackie Viruses al-22,24	23	Enteroviral vesicular pharyngitis, respiratory disease, meningitis, enteroviral vesicular stomatitis with exanthem (hand, foot and mouth disease)

Virus family	Members	No.of serotypes	Diseases caused
	Human coxsackile viruses b1-6	6	Myocarditis, congenital heart anomalies, rash, fever, meningitis, respiratory disease, epidemic myalgia (pleurodynia)
	Human enteroviruses 68-71	4	Meningitis, encephalitis, respiratory disease, rash, acute enteroviral haemorrhagic conjunctivitis, fever
	Hepatitis A virus	1	Hepatitis A
Reo-viridae	Human reoviruses	3	Unknown
	Human rotaviruses	5	Gastroenteritis, diarrhea
Adeno -viridae	Human adenoviruses	41	Respiratory disease, conjunctivitis, gastroenteritis
Parvo -viridae	Adeno-associated viruses	4	Latent infection following integration of DNA into the cellular genome
Calici-viridae	Human caliciviruses	5	Gastroenteritis in infants and young children.
	Small round structured viruses (including norwalk virus)	14	Gastroenteritis, acute viral gastroenteropathy (winter vomiting disease)
Calicivir -idae	Hepatitis E virus		Hepatitis E
Unknown	Astroviruses	1	Gastroenteritis, neonatal necrotizing enterocolitis

Virus family	Members	No.of serotypes	Diseases caused
Papova -viridae	Papillomaviruses	2	Planter warts

- The virus particle or virion consists of genome, either RNA or DNA, that is surrounded by a protective protein shell called the capsid. This shell by itself is often enclosed within an envelope that contains both

- Viruses replicate only inside specific host cells. They are totally dependent on the host cell's synthetic apparatus and energy sources, and are thus parasites at the genetic level.

3.11 Pathogens transmitted by water

Pathogen	Disease
Bacteria campylobacter jejuni	Gastroenteritis
Enteropathogenic escherichia coli	Gastroenteritis
Legionella pneumophila	Acute respiratory illness
Salmonella	Typhoid, paratyphoid, salmonellosis
Shigella	Becillary dysentery
Vibrio cholerae	Gastroenteritis
Protozoa cryptosporidium	Diarrhea
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia	Diarrhea
Naegleriafowleri	Meningoencephalitis
Enteroviruses	Respiratory illness
Enteroviruses	Eye infection
Adenovirus	Gastroenteritis

Pathogen	Disease
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Coxsackievirus A	Myocarditis, meningitis, respiratory illness
Echovirus	Meningitis, diarrhea, fever, respiratory illness
Hepatitis A virus	Infectious hepatitis
Norwalk virus	Diarrhea, vomiting, fever
Poliovirus	Meningitis, paralysis
Rotavirus	Diarrhea, vomiting

3.12 Recognition of seawater in ground water

Ground water samples taken from where there is seawater intrusion may have a chemical composition different from a simple proportional mixing of seawater and ground water. The popular belief is that, increase of total dissolved solids or chlorides alone is a valuable parameter to determine the extent of intrusion. However, the chloride-bicarbonate ratio (ratio of chlorides to the sum of carbonates and bicarbonates) is more important, which is definitely a pointer to the intrusion as given below:

Type of water	$\frac{Cl}{CO_3 + HCO_3}$
Normal good ground water in aquifer	1
Slightly contaminated ground water	1 to 2
Moderately contaminated ground water	2 to 5
Injuriously contaminated ground water	5 to 10
Highly contaminated ground water (near sea shore)	10 to 20
Sea water	200

4.1 When water becomes wastewater

The potable water becomes wastewater after it gets contaminated with natural or synthetic microbiological compounds that arises out of human activities, commercial and industrial sources. They may be accompanied with surface water, ground water and storm water.

Wastewater is sewage, storm-water and water that have been used for various purposes around the community. Unless properly treated, wastewater can harm public health and the environment. Most communities generate wastewater from both residential and nonresidential sources.

4.2 Residential wastewater

Although the word sewage usually brings toilets to mind, it is actually used to describe all types of wastewater generated from every room in a house. In the U.S, sewage varies regionally and from home to home. They are based on factors such as the number and type of water-using fixtures and appliances, the number of occupants, their ages, and even their habits, such as the types of food they eat. However, when compared to the variety of wastewater flows generated by different nonresidential sources, household wastewater shares many similar characteristics overall.

There are two types of domestic sewage: black-water or wastewater from toilets, and gray water, which is wastewater from all sources except toilets. Black-water and gray-water have different characteristics, but both contain pollutants and disease-causing agents that require treatment.

4.3 Nonresidential wastewater

Nonresidential wastewater in small communities is generated by diverse sources like offices, businesses, Super markets, restaurants, schools, hospitals, farms, manufacturers, and other commercial, industrial, and institutional entities. Storm-water is a nonresidential source and carries trash and other pollutants from streets, as well as pesticides and fertilizers from yards and fields.

Because of the different nonresidential wastewater characteristics, communities need to assess each source individually or compare similar types of nonresidential sources to ensure that adequate treatment is provided. For example, public restrooms may generate wastewater with some characteristics similar to sewage, but usually at higher volumes and at different peak hours. The volume and pattern of wastewater flows from rental properties, hotels, and recreation areas often vary seasonally as well.

Laundries differ from many other nonresidential sources because they produce high volumes of wastewater containing lint fibers. Restaurants typically generate a lot of oil and grease. It may be necessary to provide pretreatment of oil and grease from restaurants or to collect it prior to treatment. For example, by adding grease traps to septic tanks.

Wastewater from some nonresidential sources also may require additional treatment. For example, storm-water should be collected separately to prevent the flooding of treatment plants during wet weather. Screens often remove trash and other large solids from storm sewers. In addition, many industries produce wastewater high in chemical and biological pollutants that, can overburden onsite and community systems. Dairy farms and breweries are good examples. Communities may require these types of nonresidential sources to provide their own treatment or preliminary treatment to protect community systems and public health.

4.4 Volume of wastewater discharge

Wastewater is a combination of excreta, flushing water and other gray-water or sullage and is much diluted depending on the per capita water uses. The personal water consumption alone is between 200 and 300 liters per day. When the industrial and energy production usage is added to the equation, fresh water usage exceeds 5,000 liters per day on a per capita basis.

The volume of wastewater discharge can be reduced substantially through conservation of water. This is a good idea for a number of reasons:

- It lowers monthly water bills

- It can also reduce the money that homeowners and communities spend for wastewater treatment.

- Increased efficiency of wastewater treatment plant and savings on energy costs.

- Significant reduction in wastewater flows also can save on personnel costs, such as overtime, and can eliminate or postpone the need to upgrade or expand facilities.

- It lowers sewer charges and taxes for homeowners.

- Water conservation also directly benefits homeowners with onsite systems. Simply by reducing water use, homeowners can extend the life of their systems for many years, prevent system failures, and minimize maintenance costs, potentially saving hundreds of dollars.

- Water conservation also indirectly helps in maintaining the water quality. Excessive water drawing (exceeding the water holding capacity of the soil) from ground sources allows ground water contamination from neighboring areas or sea. So, avoid unnecessary water drawing from ground sources.

4.5 Important wastewater contaminants and quality factors

The presence of contaminants (or pollutants) in wastewater leads to the reduction of water quality and consequently interferes with its reuse. Presence of these contaminants also prevents the direct disposal of wastewater into environment since it degrades the quality of water and soil.

The table below lists:

- The contaminant sources
- The type of wastewater
- The effect

Significant wastewater contaminants

Contaminant	Type of wastewater	Effect
a) Biodegradable organics	Domestic and certain industrial wastewater	Depletion of oxygen and development of anaerobic conditions in receiving water bodies and land.
b) Pathogens	Domestic wastewater	Water borne diseases
c) Suspended solids	Domestic, industrial and storm wastewater	Unsightly sludge deposits and anaerobicity in receiving water bodies.

Contaminant	Type of wastewater	Effect
d) Nutrients	Domestic and agricultural wastewater.	Eutrophication of surface waters and likely contamination of ground waters.
e) Refractory organics (eg. Phenols, surfactants and agricultural pesticides)	Industrial and agricultural wastewater.	May cause taste and odor problems; may be toxic or carcinogenic and possibility of biomanification.
f) Heavy metals	Industrial wastewater	Toxicity to aquatic and terrestrial organisms.
g) Dissolved inorganics	Increased levels in water supply by domestic and/ or industrial operations.	Excessive salts may degrade quality of resource pool, and interface with effluent reuse.

The wastewater is categorized in terms of:

- Quality factors
- Quality parameters
- Tests

The physical parameters include:

- Temperature (which affects rates of chemical and biochemical reactions)

- Viscosity (and hence efficiency of sedimentation of settleable solids)
- Solubility of gases
- Odor
- Color
- Solids

The physical characteristics help assessing the condition of domestic wastewater, whether fresh or septic and its earlier incarnations, for example ground water and/or industrial wastewaters mixed with domestic wastewater.

The chemical quality of wastewater can be determined by studying the following:

- pH
- Alkalinity
- Chlorides
- Various forms of nitrogen

- Phosphorous
- Sulfur
- Heavy metals
- Toxic substances
- Gases
- Above all, tests like BOD, COD, and TOC (which are used to estimate the organic content either directly or indirectly as oxygen consumed by organic matter).

The BOD test, in spite of its limitation, which is large time requirement (5 days), is a universally used test as it measures the biodegradable fraction of organic matter, unlike any other test.

4.6 Strength

The strength of wastewater depends mainly on the degree of dilution. The wastewater characteristics can vary widely with local conditions, hour of the day, day of the week, season, and types of sewers

Parameter	Concentration		
	Strong	Medium	Weak
BOD	400	220	110
COD	1000	500	250
Organic Nitrogen	35	15	8
Ammonia Nitrogen	50	25	12
Total Nitrogen	85	40	20
Total Phosphates	15	8	4
Total Dissolved Solids	1200	720	350
Suspended Solids	350	220	100

All the values are expressed in mg/l

5.1 Organic matter

Vegetable Plants, animals and human beings are the sources for origination of natural or synthetic organic compounds. Human excreta, paper products, detergents, cosmetics, food, agricultural products, wastes from commercial activities and wastes from industrial sources are organic in origin and considerable in quantity.

Organic compounds generated from the above sources are a combination of carbon, hydrogen, oxygen, nitrogen, sulfur and other trace elements. Organic compounds such as proteins, carbohydrates, and fats are degradable by organisms, however they can cause pollution.

Large concentration of degradable organics in wastewater is dangerous to lakes, streams, and oceans, because organisms consume dissolved oxygen in water to break down the wastes. This can reduce or deplete the supply of oxygen in the water needed by aquatic life, resulting in fish kills, increasing the odors, and overall deterioration of water quality.

Some organic compounds are more stable than others and cannot be quickly broken down by organisms. This poses an additional challenge for treatment. This is true with many synthetic organic compounds developed for agriculture and industry.

Some of the synthetic organic compounds that belong to pesticides, herbicides, dyes, pigments, fried oils, and fried meats are toxic to humans, fish, and aquatic plants and often are disposed off improperly in drains or carried in storm-water. In receiving water bodies, they kill or contaminate fish, making them unfit to eat. They also can reduce the efficiency of the processes in treatment

5.2 Oil and grease

Animal fat, vegetable and petroleum oils are not quickly broken down by bacteria and can cause permanent pollution in receiving environments. When large amounts of oils and greases are discharged to receiving waters from community systems, they may float to the surface and harden, causing aesthetically unpleasing conditions. The floating oils and grease decreases the oxygen transfer efficiency of water causing septic condition. They also can bind with solid proteins, carbohydrate and other materials, causing foul odors, attracting flies, mosquitoes and other disease vectors.

5.3 Solids

Solid materials in wastewater can consist of organic and/or inorganic materials. The solids must be significantly reduced by treatment or they would increase BOD when discharged to receiving waters and provide places for microorganisms to escape disinfection. They can also clog soil absorption fields in onsite systems.

Settleable solids - certain substances, such as sand, grit, and heavier organic and inorganic materials settle out from the rest of the wastewater stream during the preliminary stages of treatment. On the bottom of settling tanks and ponds, organic material makes up a biologically active layer of sludge that aids in treatment.

Suspended solids - materials that resist settling may remain suspended in wastewater. Suspended solids in wastewater must be treated, or they will clog soil absorption systems and reduce the effectiveness of disinfection systems.

Dissolved solids - small particles of certain wastewater materials can dissolve like salt in water. Microorganisms in wastewater consume some dissolved materials, but others, such as heavy metals, are difficult to remove by conventional treatment. Excessive amounts of dissolved solids in wastewater can have adverse effects on the environment.

5.4 Heavy metals

Do you suspect heavy metals to be present in sewage? Municipal wastewater also contains a variety of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, etc. Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use. However, from the health point of view, the greatest concern in the agricultural use of wastewater are the pathogenic micro and macro organisms

5.5 Gases

What are the sources for gases in wastewater? Certain gases in wastewater can cause odors, affect treatment, so are potentially dangerous. Methane gas, for example, is a byproduct of anaerobic biological treatment and is highly combustible. Special precautions need to be taken near septic tanks, manholes, treatment plants, and other areas where wastewater gases can collect.

The gases hydrogen sulfide and ammonia can be toxic and pose asphyxiation hazards. Also, ammonia as a dissolved gas in wastewater is dangerous to fish. Both gases emit odors, which can be a serious nuisance. Unless effectively controlled or minimized by design and location, wastewater odors can affect the mental wellbeing and quality of life of residents. In some cases, odors can even lower property values and affect the local economy.

5.6 Oxygen depletion

Discharge of municipal wastewater treatment plant effluent with high BOD loads can cause reductions in Dissolved Oxygen (DO) in the receiving water. DO threats to fish and other organisms often occur during summer months. However, in colder climates where rivers and lakes are ice-covered for many months, DO depletion can occur due to ice cover preventing re-aeration. Acute effects of low DO are normally avoided in Canada as a result of municipal licensing conditions, though little information is available on the effects of chronic DO stress on aquatic organisms, particularly when other stressors are also present.

5.7 Toxicity of effluents

The toxicity of municipal effluents depends on a variety of factors, including the size and characteristics of the sewer-shed, the type and efficiency of treatment and disinfection processes and the physical, chemical and biological characteristics of the receiving waters.

In many cases, the acute toxicity of municipal wastewater treatment plant effluent is due to unionized ammonia, in the case of chlorinated effluents, it is because of total residual chlorine. Other contaminants including cyanide, sulfides, phenols, surfactants and heavy metals, such as copper, zinc and chromium, also contribute to acute or chronic toxicity.

Many factors including pH, hardness, dissolved organic

carbon and temperature can moderate the toxicity in the effluent or receiving environment. Despite considerable investment in treatment systems, acute and chronic toxicity remains a concern in many sites receiving municipal effluents.

Many chemicals detected in municipal effluents are hydrophobic and may tend to adsorb to particles in the effluent or sediments in the receiving environment, than remain in the water phase. The distribution of these chemicals may therefore differ considerably from more soluble compounds, which will tend to move with the effluent plume.

Hydrophobic chemicals may also tend to bio-accumulate in organisms and move through food webs. The distribution and fate of contaminants in the environment is extremely complex. It is dependent on the physical and chemical characteristics of the chemicals as well as the physical, chemical and biological characteristics of the receiving environment.

Ammonia, chloramines, nonyl phenol and its ethoxylates and textile mill effluents are associated with municipal effluents and have been declared toxic.

5.8 Aquatic organisms

Aquatic organisms exposed to pharma products do or die? Antibiotics, blood lipid regulators, analgesics, anti-inflammatory drugs, and beta-blockers, fragrances [musks], skin care products, disinfectants and antiseptics are the common ingredients of domestic wastewater. They cause physiological responses on organisms in the aquatic environment.

5.9 Sewage

Sewage wastewater is harmful to growth harmones. domestic wastewater contains chemicals that may disturb endocrine function; thereby reproduction or development in animals is severely affected. Natural and synthetic hormones and certain industrial chemicals that have effect on estrogens are identified in sewage effluents. Evidence suggests that these effects may occur even at low concentrations and/or from transient exposure.

5.9.1 Sewage contamination

Is sewage contaminated with pathogenic organisms? Many disease-causing viruses, parasites, and bacteria are also present in wastewater. These pathogens often originate from people and animals that are infected with, or are carriers of a disease. Gray water and black water from typical homes contain enough pathogens to pose a risk to public health. Other likely sources in communities include hospitals, schools, farms, and food processing plants.

5.9.2 Dry weather flow (DWF)

This is the flow in a sewer during a day in dry season. It is the average daily water consumption of the locality.

5.9.3 Low cost sewage treatment

Low cost treatment can be effected by treating the wastewater through Waste Stabilization Ponds. This is achieved by (a) aerobic, (b) anaerobic and (c) aerobic cum anaerobic oxidation ponds. (c) is also known as facultative ponds. In these ponds, photosynthesis (sunlight and oxygen are needed) mainly causes purification. If anaerobic, bacteria can do the job. So, sunlight and oxygen are not needed.

Biological treatment comes midway between waste stabilization ponds and conventional secondary treatment. Purification is wholly biological here and air is supplied by surface acting aerators. 90% organic removal is possible in a few days.

This is a system similar to aerated lagoons, but the physical layout is different. Here, the channel is oval shaped to facilitate adequate velocity in the liquid. This in turn will keep the biological solids in suspension which results in a better reaction. A special system of aerators supply air, hence oxygen is available in plenty.

Biological treatment consists of a series of adjacent discs, partly submerged and slowly rotating in sewage to facilitate thegrowth of bacteria (on the discs) that stabilize the organic matter. The process is wholly biological in nature.

5.9.4 Chlorination

Chlorine is added to sewage to disinfect, remove odors and reduce Biochemical Oxygen Demand (BOD).

In sewage, organic matter will consume a large quantity of chlorine first. The remaining chlorine will kill bacteria. So, disinfecting doses will be much larger.

The normal chlorine dosage that may be sufficient for disinfecting sewage is as follows:

Raw sewage	20 to 25 mg/l
Settling tank effluent	20 mg/l
Trickling filter effluent	15 mg/l
Activated sludge effluent	8 mg/l
Sand filter effluent	8 mg/l

Full (100%) standby equipment must be provided.

5.10 Impact of wastewater on receiving water bodies

What is the impact of wastewater on receiving water bodies? Wastewater discharges nutrients, primarily nitrates and phosphates, to receiving water bodies and thus may cause eutrophication. Nutrients can accumulate in the bottom sediments and be released into the water at a later time, and thus have a long-lasting impact on water quality.

Nutrient addition to aquatic ecosystems can increase the growth of primary producers (algae and rooted aquatic plants) to levels that result in impairment of the ecosystem (e.g., Changes in food web structure, changes in habitat, loss of species, infestations of nuisance species). These ecological changes can affect human use of aquatic resources (including water-based recreational activities and fisheries) and impair water quality for municipal, industrial and agricultural users.

5.11 Byproducts of treatment, if untreated

If untreated-wastewater is allowed to accumulate, the decomposition of the organic materials it contains can therefore, lead to the production of large quantities of malodorous gases. In addition, untreated wastewater contains numerous pathogens, or disease producing microorganisms, that dwell in the human intestinal tract or that may be present in certain industrial wastewater. Wastewater may also contain nutrients, which can stimulate the growth of aquatic plants, which may contain toxic compounds.

5.12 Impact of wastewater on human health

What is the impact of wastewater on human health?

Some illnesses from wastewater-related sources are relatively common. Gastroenteritis can result from a variety of pathogens in wastewater; other important wastewater-related diseases include hepatitis A, typhoid, polio, cholera and dysentery. Outbreaks of these diseases can occur as a result of, drinking water from wells polluted by wastewater, eating contaminated fish, or indulging in recreational activities in polluted waters. Animals and insects that come in contact with wastewater can spread some illnesses as well.

Even municipal drinking water sources are not completely immune to health risks from wastewater pathogens. Drinking water treatment efforts can become overwhelmed when water resources are heavily polluted by wastewater.

Pathogenic viruses, bacteria, protozoa and helminthes may be present in raw municipal wastewater and will survive in the environment longer periods. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as No. of Total Coliforms / 100ml). Escherichia coli are the most widely adopted indicator of fecal pollution and they can also be isolated and identified fairly simply, with their numbers usually being given in the form of fecal coliforms (FC)/100 ml of wastewater.

There are various kinds of enteric microorganisms present in human excreta and animal manure; some of these are pathogens and some are non-pathogens. They can be classified into such major groups as bacteria, viruses, protozoa, and helminthes. Some of the important enteric pathogens commonly found in human excreta and wastewater, the diseases they cause, modes of transmission, and geographical distribution are shown below:

Pathogen	Disease	Transmission
Bacteria Vibrio cholerae	Cholera	Person -→ person
Salmonella typhi Other salmonellae	Typhoid fever, Various enteric fevers (often called paratyphoid), gastroenteritis, septicemia (generalized infection in which organisms multiply in the blood stream)	Person (or animals) → person
Shigella dysenteriae and other species Pathogens escheria coli	Bacterial dysentery, Diarrhea	Person-→ person Person-→ person
Viruses Poliovirus Coxsackievirus	Poliomycetes Various cases including respiratory disease, fevers, rashes, paralysis, aseptic meningitis, myocarditis	Person-→ person Person-→ person

5.13 Health protection measures in aquacultural use of wastewater

The measures, which can be taken to protect health in aquacultural use of wastewater, are the same as in agricultural use, namely wastewater treatment, crop restriction, control of wastewater application, human exposure control and promotion of hygiene. Workers in aquaculture ponds, may suffer due to bad quality of water, in a similar way to that of the contamination of fish or plants grown in excreta-fertilized or wastewater ponds.

Transmission of pathogens can occur through persons handling and preparing contaminated fish or aquatic plants, which make human exposure control and hygiene important features of aquaculture programs. Both the treatment applied to excreta, nightsoil or wastewater before introduction to an aquaculture pond will have an effect on the quality of water in the pond. The rate of waste application also effects the quality of water in the pond.

In the past, these factors have not been controlled for health reasons. But to ensure that a pond is not overloaded organically or chemically to the point, where it will not support fish life or be suitable for the growth of aquatic plants. Reliance has been placed primarily on minimizing the risk of pathogen transmission, through consumption by thorough cooking of the products. This has not always been satisfactory. And, where the pond products are eaten uncooked, no health protection is provided. In some aquacultural practices, for example in rural Indonesia, depuration techniques are used in attempting to decontaminate fish in the period immediately preceding harvesting.

5.13.1 Special concerns in aquacultural use of human wastes

A number of human excreted helminthic pathogens, when released to aquaculture ponds can involve fish or aquatic plants as intermediate hosts. Strauss (1985) has listed the following trematode infections as being capable of transmission in this way:

Clonorchis
Heterophys
Opistorchis
Metagonimus
Diphyllobothrium

However, he indicated that only clonorchiasis (liver fluke) and the closely related opistorchiasis have been transmitted through fish, grown in excreta-fertilized or wastewater ponds. The first phase of development of these pathogens occurs in specific snails or copepods (minute crustaceans), with fish acting as a second intermediate host.

These helminthic infections have significant public health importance in Asia, where fish are sometimes eaten raw. Strauss also pointed out that the helminthic pathogens fasciola (sheep and cattle liver flukes) and fasciolopsis (giant intestinal fluke) have the same pattern of life cycle, but depend on aquatic plants, such as water chestnut, water cress and water bamboo, as secondary intermediate hosts, onto which free-swimming cercariae become attached and where they encyst.

Aquatic snails also serve as intermediate hosts for the trematode-genus schistosoma that is the causative agent of schistosomiasis (bilharzia). Transmission can occur when workers wade into aquaculture ponds in which infected snails are present and the larval schistosome penetrates the skin. This occupational hazard exists only where this disease is endemic and where snail hosts are present in aquaculture ponds. Schistosome infection, particularly schistosoma japonicum, has been identified in excreta-fertilized fish ponds.

Fish grown in excreta-fertilized or wastewater ponds may also become contaminated with bacteria and viruses and serve as a potential source of transmission of infection if they are eaten raw or undercooked. Pathogenic bacteria and viruses may be passively carried on the scales of fish or in their gills, intraperitoneal fluid and digestive tract or muscle. Strauss (1985) reviewed the limited literature on excreta bacteria and virus survival in fish and concluded that:

- invasion of fish muscle by bacteria is likely to occur if the concentrations of fecal coliforms and salmonellae in the pond are greater than 10^4 and 10^5 per 100 ml, respectively;

- the potential for muscle invasion increases with the duration of exposure of the fish to contaminated pond water;

- little accumulation of enteric microorganisms and pathogens or their penetration into, edible fish tissue occurs when the fecal coliform concentration in the pond water is below 10^3 per 100 ml;

- even at lower-pond-water-contamination levels, high pathogen concentrations might be present in the digestive tract and the intraperitoneal fluid of the fish;

- pathogen invasion of the spleen, kidney and liver has been observed.

5.13.2 Quality guidelines for health protection in using human wastes for aquaculture

Only limited experimental and field data on the health effects of sewage-fertilized aquaculture are available. So, the WHO scientific group on health aspects on the use of treated wastewater for agriculture and aquaculture could suggest only a tentative bacterial guideline for the quality of aquaculture pond water. The tentative bacterial guideline suggested is a geometric mean number of fecal coliforms of 10^3 per 100 ml (WHO, 1989).

Furthermore, in view of the dilution of wastewater which normally occurs in aquaculture ponds, the scientific group suggested that, this ambient bacterial indicator concentration could be achieved by treating wastewater fed to ponds to a level of 10^3-10^4 fecal coliforms / 100 ml. Such a guideline should ensure that invasion of fish muscle is prevented. But pathogens might accumulate in the digestive tract and intraperitoneal fluid of the fish. This might then create a health risk, through cross-contamination of fish flesh or other edible parts and transmission to consumers, if standards of hygiene in fish preparation are inadequate. High standards of hygiene during fish handling and, especially, gutting are necessary. And, cooking of fish is also an important health safeguard. Similar considerations apply to the preparation and cooking of aquatic plants as well.

5.13.3 Bacteriological quality of fish from excreta-reuse systems

Total aerobic bacterial concentration in fish muscle tissue, bacteria/g	Fish quality
0- 10	Very good
10- 30	Medium
> 50	Un acceptable

Source: Buras et al. (1987)

Buras et al. (1985, 1987) have questioned the value of fecal coliforms as bacterial indicators for fish muscle because, in their studies, they were not always detected, whereas total aerobic bacteria (standard plate count) were. They proposed that total aerobic bacteria should be the indicators on the grounds that, if they were detectable in the fish, there was a chance that pathogenic bacteria would also be present. Consequently, the bacteriological standards for fish raised in excreta-fertilized and wastewater ponds, indicated in the above table were recommended by Buras et al. (1987).

A more recent state-of-the-art review of reuse of human excreta in aquaculture (Edwards, 1990), discussed this issue and gave its suggestion. It said, it was unlikely that fish will be of an unacceptable bacteriological quality when raised in excreta-fed ponds that are well-managed from an aquacultural point of view to produce good fish growth. Some fish ponds are loaded with excreta at a level that leads to the development of a relatively large biomass of phytoplanktons. These phytoplanktons serve as a natural food for the fish. If adequate levels of dissolved oxygen is maintained in the water, fish with acceptable bacteriological quality can be produced.

Transmission of the helminthic infections, clonorchiasis and fasciolopsiasis occurs only in certain areas of Asia. It can be prevented only by ensuring that no trematode eggs enter the pond or alternatively, by snail control. Similar considerations apply to the control of schistosomiasis in areas where this disease is endemic. The scientific group (WHO, 1989) recommended an appropriate helminth quality guideline for all aquacultural use of wastewater in the absence of viable trematode eggs.

5.14 Excreta disposal without water carriage

This is more frequently a problem of the rural areas or small towns having no amenities of a water carriage system. It is important that the human excreta should be removed or disposed of hygienically and in an efficient manner. Methods employed should generally aim at achieving the following objectives:

(i) All excreta should be removed to an isolated area.

(ii) The excreta should not be accessible to flies, insects or other animals.

(iii) It should not contaminate any surface or ground water supply.

(iv) There should be freedom from odors and unsightly conditions.

(v) The methods should be simple and economical both in construction and operation and further should ensure privacy and convenience.

5.15 Household hazards

How to dispose of household hazardous wastes safely? Many household products are potentially hazardous to people and the environment, and never should be flushed down drains, toilets, or storm sewers. Treatment plant workers can be injured and wastewater systems can be damaged as a result of improper disposal of hazardous materials.

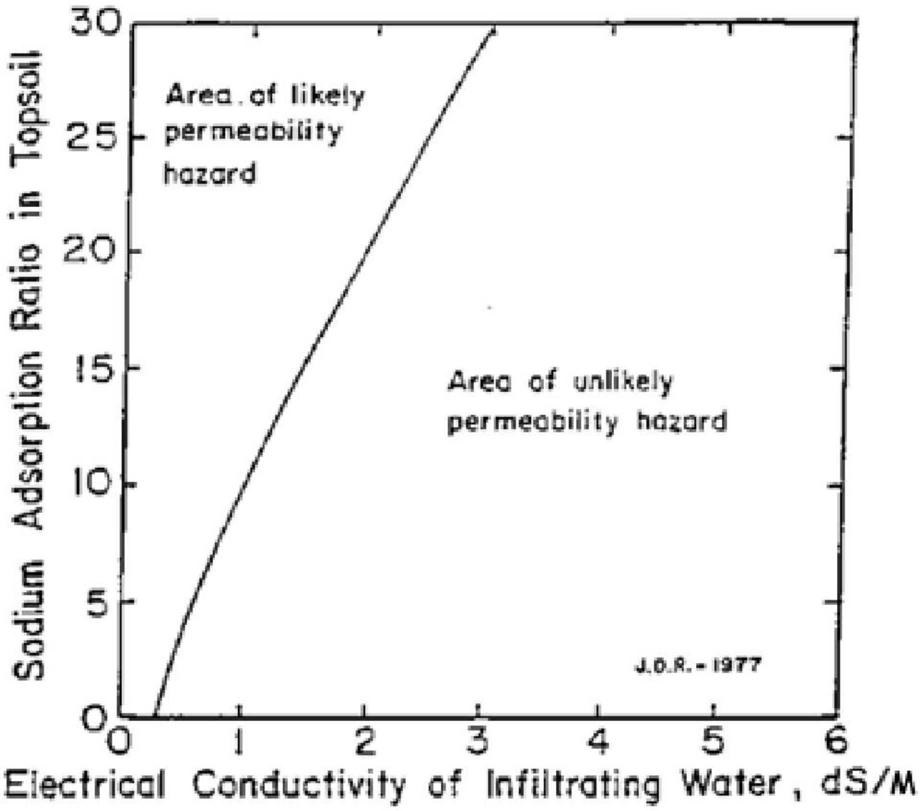
Other hazardous chemicals cannot be treated effectively by municipal wastewater systems and may reach local drinking water sources. When flushed into septic systems and other onsite systems, they can temporarily disrupt the biological processes in the tank and soil absorption field, allowing hazardous chemicals and untreated wastewater to reach groundwater.

Some examples of hazardous household materials include:

- Motor oil
- Transmission fluid
- Antifreeze
- Paint
- Paint thinner
- Varnish
- Polish
- Wax
- Solvents
- Pesticides
- Rat poison

- Oven cleaner
- Battery fluid
- Many of these materials can be recycled or safely disposed at community recycling centers.

5.16 Threshold values of sodium adsorption ratio and total salt concentration on soil permeability hazard (Rhoades 1982)



5.17 Classification of pesticides by function

Pesticide	Used to control
Acaricide	Mites and ticks
Algicide	Algae
Arachnicide	Spiders
Attractant	Insects by attraction
Avicide	Birds
Bactericide	Bacteria
Chemostreilant	Insects by sterilization
Defoliant	Leaf drop
Desiccant	drying leaves in plants
Disinfectant	General bacteria, fungi
Growth regulator	Growth of plants
Herbicide	Fungi
Insecticide	Insects
Molluscicide	Molluscs
Nematicide	Nematodes
Piscicide	Fish
Repellent	Flies, fleas, moths, etc.
Rodenticide	Rodents (mice, rats, etc.)
Slimicide	Slimes

6.1 Some tips for conservation of water:

Most water use can be reduced simply and inexpensively. For example, in homes, toilets, showers, and faucets together account for about two-thirds of total water use. In some cases, fixing leaks, installing low-flow fixtures and appliances, and using simple common sense can conserve household water use by as much as 50 percent.

6.2 The following are some ways to reduce water use around the home:

- Reduce water pressure.
- Limit shower time.
- Install low-flow showerheads or shower-flow control devices.
- Turn off faucets while shaving and brushing teeth.
- Install reduced-flow faucets or water-saving faucet inserts or aerators.
- Run washing machines and dishwashers only when full, or

adjust cycle settings to match loads.

- Use front-loading washing machines.
- Fix leaking or dripping faucets and running toilets.
- Replace old high-flow toilets (4 to 7 gallons per flush) with water saving (3.5 gallons) or ultra low-flush toilets (1 to 2 gallons).*
- Install dams in toilet tanks, or fill a milk jug or plastic container with rocks and place it in the toilet tank.
- Use gray water recycling/reuse systems for toilet flushing, irrigation, and other uses where permitted and appropriate.

*Plumbing in some buildings may not be adequately designed to accommodate certain low-flush toilets.

6.3 Manure value

Do biosolids/sludges have manure value as it is claimed? Wastewater treatment plants generate sludge, as a result of decomposition of organic matter in wastewater. Biosolids are the organic portion of the sewage sludge that has been stabilized through digestion to meet suitable criteria for application to land. Biosolids are rich in inorganic and organic materials and plant nutrients and are therefore, a desirable additive to agricultural land. However, the accumulation of heavy metals and potentially toxic constituents in bio solids has to be monitored. Sewage sludge is disposed off through thermal incineration, landfill, or anaerobic digestion. Land application of biosolids is expected to decrease owing to contamination of heavy metals and refractory organics. Alternatively, thermal incineration and solidification /stabilization would be a viable solution.

6.4 By-products of treatment

The physical and chemical processes of wastewater treatment may transform wastewater constituents. For example:

(i) Secondary treatment with activated sludge processes may increase ammonia concentrations, initially by converting organic material into ammonia nitrogen and then reducing it to nitrogen in the final effluent;

(ii) Nitrification to reduce ammonia levels will result in increased nitrate and nitrite levels in the effluent;

(iii) Degradation of certain components may result in different forms which are not necessarily less toxic (nonylphenol poly ethoxylates degrade to 4-nonphenol, a more toxic material); and

(iv) Disinfection of effluents with chlorine which results in residual chlorine which is toxic to fish.

How to treat your wastewater?

There are two sequential processes to be followed for the treatment of domestic wastewater.

A. Primary treatment process.

B. Treatment process.

7.1 How is treatment achieved?

Municipal wastewater effluents may contain a number of toxic elements, including heavy metals, because under practical conditions wastes from many small and informal industrial sites are directly discharged into the common sewer system. These toxic elements are normally present in small amounts and, hence, they are called trace elements. Some of them may be removed during the treatment process but others will persist and could present phytotoxic problems. Thus, municipal wastewater effluents should be checked for trace element toxicity hazards, particularly when trace element contamination is suspected. Table given below presents phytotoxic threshold levels of some selected trace elements.

Element	Recomm. Max. Conc. (mg/l)	Remarks
(Aluminum)	5.0	Can cause non-productivity in acid soils ($pH < 5.5$), but more alkaline soils at $pH > 7.0$ will precipitate the ion and eliminate any toxicity.
(Arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
(Beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
(Cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
(Cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
(Chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
(Copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.

Element	Recomm. Max. Conc. (mg/l)	Remarks
(Fluoride)	1.0	Inactivated by neutral and alkaline soils.
(Iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
(Lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to Boron.
(Manganese)	0.20	Toxic to a number of crops at few-tenths to a few mg/l, but usually only in acid soils.
(Molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock, if forage is grown in soils with high concentrations of available molybdenum.
(Nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline ph.

Element	Recomm. Max. Conc. (mg/l)	Remarks
(Lead)	5.0	Can inhibit plant cell growth at very high concentrations.
(Selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock, if forage is grown in soils with relatively high levels of added selenium. As essential element to animals but in very low concentrations.
(Tin)		
(Titanium)		Effectively excluded by plants; specific tolerance unknown.
(Tungsten)		
(Vanadium)	0.10	Toxic to many plants at relatively low concentrations.
(Zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

' the maximum concentration is based on water application rate which is consistent with good irrigation practices (10, 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10, 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

7.2 Primary treatment (pre-treatment)

What are the components of pre-treatment process?

This is carried out by means of:

(a) Screens

(b) Grit chambers

(c) Skimming tanks

(d) Grease traps

7.2.1 Screens

Why screens are provided?

The first step in the treatment of sewage is to remove floating and suspended matter such as cloth, paper, kitchen refuse, pieces of wood, cork, hair, fiber, fecal solids etc. The objective of the screening process is:

(i) To prevent clogging of sprinkler nozzles or the surface of trickling filters.

(ii) To protect pumping parts, siphons etc., from damage.

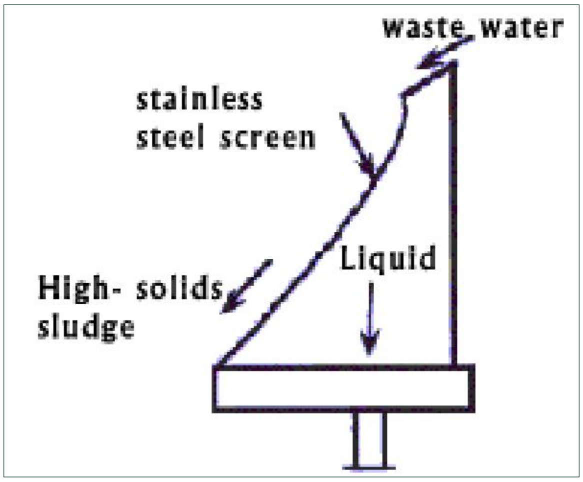
(iii) To improve the efficiency of the biological processes, as the floating solids occupy excessive space which ultimately reduce the retention time for wastewater.

(iv) To prevent floating matter in the receiving bodies of water.

7.2.1.1 Geometry and dimension

What is the geometry and dimension of the screen?

Screening is accomplished by means of screens, having openings of uniform size, circular or rectangular in shape. The screening element is comprised of parallel bars, rods or wires, grating, wire mesh or perforated plate. When composed of parallel bars or rods, it is called a rack or bar screen and when made from wire mesh, perforated plate etc, it is called screen. Screens may be further classified depending upon their sizes of openings as coarse, medium and fine. It is usual in sewage treatment to employ medium bar screens of opening 25 mm or more.



Screens and sizes of openings

Type	Class	Sizes of opening in mm.
Racks	Coarse	More than 50
	Medium	25 to 50
	Fine	Less than 25
	Medium	6 to 9
	Fine	Less than 6

In the bar screens, the racks or screens are constructed of flat iron bars set on edge across the channel through which sewage flows with a velocity of at least 0.45 m/sec. The bars stop in the direction of flow, the angle with the horizontal being 30 to 60. This facilitates manual cleaning of screens by the upward stroke of the rake. Screenings are allowed to drain off for some time on a perforated platform over the channel. Disposal may be through burial in trenches, incineration and disintegrating in shredders and returning to the sewage or passing to the sludge disposal plants.

7.2.2 Grit chambers

How to remove solids having specific gravity greater than water?

A grit chamber is an enlarged channel or long basin in which the cross-section is increased to reduce the velocity of the flowing sewage sufficiently to cause heavy inorganic matter such as grit, sand and gravel of size 0.2 mm, and larger to settle, while the lighter organic matter remains in suspension.

7.2.2.1 Design factors

What are the design factors to be considered?

The factors to be considered in grit chamber design are:

(i) Velocity of flow

Velocity of wastewater flow must be 0.3 m/sec. This will permit the deposition of the bulk of heavier mineral solids while most organic matter remains in suspension. A velocity of flow in the range 0.15 - 0.3m/sec. is generally recommended. In order to keep the velocity within the desirable limits, it is usually necessary to provide two or more channels to manage fluctuations in sewage flow.

(ii) Period of detention

One minute (volume of the grit chamber/flow rate) is the detention time normally employed. Since sedimentation of granular solids is dependent to a large extent upon the surface area of the chambers, their width could be kept large. A length to width ratio of 8 to 1 may be used limiting the effective depth to about 2 m.

(iii) Method of cleaning

Grit chambers are cleaned by hand, mechanically or hydraulically. Hand cleaning is done only in the case of smaller plants, is less hygienic and odor-free though somewhat easier for disposing off the removal material than in the case of mechanical cleaning.

(iv) Grit storage

Storage space for grit may be provided throughout the length of the chambers or by means of one or more pits deeper than the remainder of the basins. Concentration of grit is also useful for cleaning purposes. Channel may be provided with a frequency of cleaning of 15 days.

7.2.3 Skimming tanks

How to remove the floating solids from wastewater?

A skimming tank is a chamber so arranged that the floating matter, oil, fat, grease etc., rise and remain on the surface of the sewage until removed, while the liquid flows out continuously under partitions or baffles. It is necessary to remove the floating matter from sewage otherwise it may appear in the form of unsightly scum on the surface of settling tanks or interface with the activated sludge process of sewage treatment.

The chamber is a long trough-shaped structure divided into two or three lateral compartments by vertical baffle-walls having slots for a short distance below the sewage surface and permitting oil and grease to escape into stilling compartments. Blowing air into the sewage from diffusers placed in the bottom brings about the rise of floating matter. Sewage enters the tank from one end, flows through longitudinally and leaves out through a narrow inclined duct. A theoretical detention period of 3 minutes is enough. The floating matter can be removed by hand or mechanically.

7.2.4 Grease traps

Grease traps are designed with submerged inlet and bottom outlet. The traps must have sufficient capacity to permit the sewage to cool and grease to separate. Frequent cleaning through removable covers is essential for satisfactory operation.

8.1 Settling tanks

How to remove the settling solids from the wastewater?

This comprises of the following units:

(a) Sedimentation tanks: either plain or chemical precipitation

(b) Septic (Imhoff) tanks

(c) Sludge digestion tanks

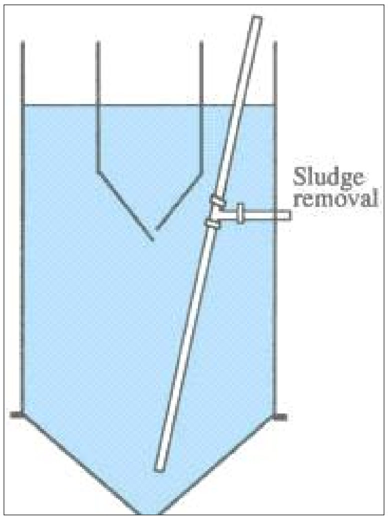
8.2 Sedimentation

This is carried out with the objective to remove suspended mineral and organic matter from sewage after the wastewater has been subjected to pass through screens and grit chamber.

8.2.1 Sedimentation tanks

These are the units in which sedimentation is brought about. The lighter organic sewage solids, which settle in the sedimentation tanks, are termed as sludge, while the sewage that has been partially clarified by the settling out of the solids is known as the effluent. Both sludge and effluent should be further treated in order to make them stable and unobjectionable.

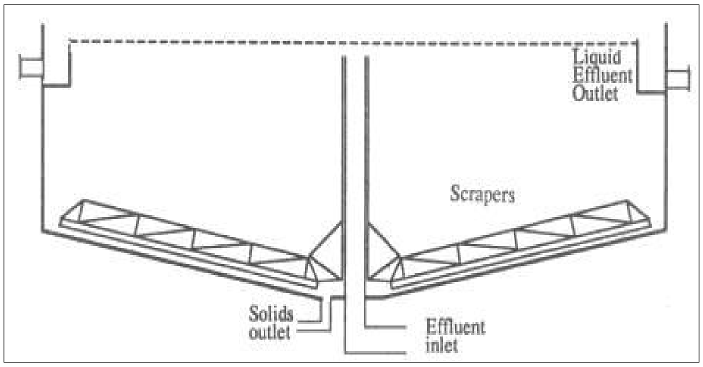
The settlement of the solids may either be caused by gravity or by aggregation or flocculation of sewage-particles. If the coagulating chemicals are not added in the sewage, the tanks are referred as plain sedimentation tanks. whereas, if chemicals are used for the purpose of bringing the finer suspended and colloidal solids into masses of large bulk, thus hastening the settlement process, these are then known as chemical precipitation tanks. The chemicals used are alum, lime, ferric chloride, ferric sulfate, chlorinated copper etc.



8.2.2 Types of sedimentation tanks:

Sedimentation is accomplished either in horizontal-flow or vertical-flow tanks. The former are usually rectangular and the latter circular. In a rectangular tank, sewage enters continuously at one end and passes at the other end, generally over a weir. Sludge is removed manually into sludge-digestion tanks. The scum formed at the surface is removed by the mechanical scraper with the aid of a second blade called skimmer, through a scum trough.

In the case of a circular or upward-flow tank, sewage enters at the center, rises vertically to be drawn off by flowing over a peripheral weir arranged at the surface. Such tanks are particularly designed to make use of the principle of flocculation whereby, small colloidal particles are agglomerated into bulky wooly masses, which are more easily settled as sludge on the bottom of the tank. Mechanical scrapers collect the sludge, concentrating it towards the center, from where it is removed for further treatment. The effluent flowing over the outlet weir is collected in an outlet pipe for further treatment.



When only raw sewage is to be treated in these tanks, they may be generally termed as primary settling tanks or primary clarifiers. While when a sewage that has received secondary treatment, as in trickling filters or aeration tanks, is to be treated in them, then they may be called as secondary settling tanks or secondary clarifiers.

8.2.3 Design criteria

What are the design criteria for primary sedimentation tank?

As with the sedimentation tanks in water supply, the capacity is determined by the volume of sewage-flow and the required detention period.

(i) detention period: 1 to 3 hours. Longer periods result in higher efficiency than shorter periods but too long a period induces septic conditions and should be avoided.

(Ii) velocity of flow: about 30 cm/min.

(iii) surface loading: it may be noted that the overall range of surface loading between 30,000 to 50,000 l / m^2 / day is in conformity with that used in case of horizontal flow and vertical flow sedimentation tanks.

(iv) liquid depth of mechanically cleaned settling tanks should not be less that 2.1 m. And for the final clarifier for activated sludge, not less than 2.4 m.

8.3 Septic tanks (Imhoff tanks)

Designed by Karl Imhoff of Germany, an Imhoff tank is an improved septic tank in which the incoming sewage or influent is not allowed to get mixed up with the sludge produced. And, the outgoing sewage or effluent is not allowed to carry with it large amount of the suspended matter as in the case of a septic tank.

8.3.1 Constructions and operational features

It is a double chamber tank, the upper chamber is called the sedimentation tank or flowing through chamber, through which sewage flows at a very low velocity and the lower chamber is the digestion chamber in which anaerobic or septic decomposition occurs.

solids of the sewage settle to the bottom of the sedimentation chamber through the sloping bottom walls (slope 5 vertical to 4 horizontal). They are made to fall in the digestion chamber through an entrance slot at the lowest point of the sedimentation chamber. The slot is trapped or overlapped in such a way that the gases generated in the digestion chamber cannot enter the sedimentation chamber.

A gas vent, also called scum chamber is provided with the digestion chamber to take care of the gases escaping to the surface. The chief gas is methane (CH^4) having a considerable fuel value and may, therefore, be separately collected for use.

In order to prevent particles of sludge or scum from penetrating into the sedimentation chamber, the sludge and scum must be maintained at a distance of at least 45 cm below and above the slots respectively. The free or clear zone is called neutral zone.

The digestion chamber is made up of two or three inverted cones called hoppers with sides sloping (1 : 1) so as to concentrate the sludge at the bottom of the hopper. The sludge is removed periodically through sludge-pipe, the flow being under a hydrostatic pressure of 1.2 to 1.8 m. All the sludge is not removed, only the lower layers which are completely decomposed are withdrawn, leaving some sludge to keep the tank seeded with anaerobic bacteria.

To permit uniform distribution of settled solids throughout the length of the digestion chamber, so as to utilize the storage capacity in the greatest measure, arrangements for reversing the direction of flow through the tanks are commonly made.

8.3.2 Merits and demerits

Imhoff tanks combine the advantages of both the septic and sedimentation tanks and, as such find use in case of small treatment plants requiring only preliminary treatment. They have better economy and give good results without skilled attention with minimum problems of sludge disposal. They have the following demerits:

(i) greater depth means greater costs and especially where excavation is to be done in quick sands or solids rock, they become uneconomical.

(ii) unsuitable to acidic wastewater exist.

(iii) no adequate control over their operation. This makes them unsuitable for use in large treatment plants where separate sludge digestion tanks are preferred.

8.3.3 Design criteria

In designing Imhoff tanks, following design points may be noted.

(a) Sedimentation chamber:

(i) Retention period = 2 hours (usually)

(ii) flowing through velocity = 30 cm / min

(Iii) surface loading = 30,000 liters/m^2/day.

(iv) length should preferably not to exceed 30 m, so as to provide good sludge distribution. Length to width ratio between 3 : 1 to 5 : 1.

(v) depth should as far as possible be kept shallow, to permit particle falling to the slot before reaching the end of the sedimentation chamber. In practice,a total depth between 9 - 10.5 m for the tank is considered sufficient.

Greater depth involves difficulty of excavation.

(b) Digestion chamber:

(i) the surface area of the scum chamber should be 25 - 30 per cent area of the horizontal projection of the top of the digestion chamber. Ample is for the escape of gases is necessary so as to prevent troubles due to foaming. Width of a vent should be at least 60 cm.

9.1 Introduction to Microbiology

Microorganisms cause a number of chemical transformations in nature. Production of alcohol, making of cheese and retting of flax are some of the processes that have benefited humans for ages.

Antony Van Leeuwenhoek (1632 -1723) was the first to discover the microbial world. Some early scientists propounded 'a spontaneous generation of microbial life'. Pasteuer (in 1862) using sterilized equipment showed that growth of microorganisms was possible only due to outside contamination.

Developments in microbiology has refined the existing processes and introduced new processes to produce organic acids, solvents, vitamins, antibiotics, etc. Pure culture of specific micro-organisms help these processes significantly.

The biological process of wastewater is a secondary treatment involving the components of removing, stabilizing and rendering harmless very fine suspended matter, colloids and dissolved solids of the sewage, that come from the sedimentation tank, where most of the matter in suspension has been removed. In some cases, effluent from sedimentation tank may be good enough for disposal if the dilution is great. However, in most cases, oxidation of the organic putrescible matter is necessary.

9.2 Principle of action

The primary principle of action on which the biological process is based is the availability of a large sewage surface fed by the oxygen from air, where certain type of bacteria, the aerobics, live and use that oxygen to oxidize putrescible matter in the sewage to stable and inoffensive sulfates, nitrates and other compounds.

The sewage filtration, which is the vehicle used for process, can at best cause only the coarser particles of suspended matter to be removed by mechanical straining. This action is only minor and of a secondary nature. The major action takes place at the surface, where the aerobic bacteria oxidizes the finer organic particles of sewage abounding large surface areas, forming a bacterial film. is formed. The film adsorbs more of the finer matter which is then worked upon by the organisms present after which it is released as a coagulated suspended matter, rather heavy and capable of settling readily.

It should be noted that this bacterial film also contains, in addition to the aerobic bacteria, other organisms as protozoa, algae, besides certain species of worms. But their action is somewhat uncertain and the biological action is considered to be mainly due to the aerobic bacteria.

9.3 Classification of microorganisms

Prior to the advent of microscopy and discovery of microorganisms, living beings were either plants or animals. Microbes did not fit into either of the traditional classes. A third classification to accommodate these, protists came into being. Many protists have one cell, but even the multicellular ones have all identical cells. Tissue regions generally recognized as protists include:

- Algae
- Fungi

- Protozoa
- Bacteria
- Cladocera
- Copepods
- Macro invertebrates such as the
    - Nematodes
    - Chironomids
    - Snails

There is another group, which is not visible in the microscope. So, protists can be classified as higher protists (which have a more highly organised cell or eucaryotic cell) and lower protists (which have a simple cellular structure or procaryotic cell).

The eucaryotic cell is present in protozoa, fungi and most groups of algae. The procaryotic cell is the unit of structure in bacteria and blue-green algae. A virus has a still simpler structure (which can not be classified as a cell).

These organisms carry diseases that are public health hazards. They also produce a lot of toxins. For example, one type of blue-green algae releases toxins. Another type is toxic if ingested. Adverse health effects from drinking water thus affected are not common, but such algae are known to produce gastroenteritis. Wherever blue-green algae are known to cause problems, they must be prevented and controlled.

Health problems from these organisms are sure to occur, if untreated, poorly treated, or unprotected water is supplied. However, these organisms also interfere with the operation of water-treatment processes. They spoil the color, turbidity, taste, and odor of finished water. For example, high concentrations of algae in raw water may -

- Clog filters
- Cause taste problems
- Cause odor problems
- Increase the chlorine demand
- Lead to increased concentrations of halogenated organic

compounds that affect public health

A wide range of free-living organisms can appear at the consumer taps. Infections by the aquatic sow bug (asellus) and of midge larvae (chironomus), for example, are by large common. The free-living organisms can be controlled generally by:

- Protection of sources
- Reducing (or preventing) high nutrient levels
- Use of algaecides
- Adequate water treatment
- Including coagulation
- Including sedimentation
- Including filtration
- Including disinfection
- Protecting and covering finished water stored in reservoirs

Toxic algae thrive in surface waters. Copepods may be found in both surface waters and wells. Sand filtration is the best method to remove these organisms. However, the algae toxins already released stays. The algae toxins may also remain following aluminum coagulation, filtration, and chlorination. Activated carbon, at levels usually employed in water treatment, also fails to remove algae toxins.

Mosquito vectors of disease must not be allowed to breed in stored domestic water in the home.

9.3.1 Eucaryotic cell

Eucaryotic cell has a nucleus of chromosomes, which are built with deoxyribonucleic acid (DNA) having the genetic information. The nucleus is contained in a membrane.

Mitochondria and chloroplasts are sites of energy generation. Vacuoles and lysosomes are involved in ingestion and digestion of food. Cytoplasm has a colloidal suspension of proteins, carbohydrates and important organelles such as endoplasmic reticulum, golgi apparatus and ribosomes which are involved in protein synthesis. Cytoplasm is also responsible for locomotion in cells without cell walls. This is also known as amoeboid motion. Flagella provides locomotion of cells which have a rigid cell wall.

9.3.2 Procaryotic cell

These are usually smaller than 5 fm in diameter and have a much simpler structure.

Nucleus has a single long molecule of DNA and is not separated from cytoplasm by any membrane. Cytoplasm is uniform in structure and occupies most of the space. Enzymes for respiration and photosynthesis are housed in the cell membrane which also regulates the flow of materials in and out of the cell. Most cells are surrounded by a rigid cell wall. Procaryotes move by the action of flagella.

9.3.3 Viruses

Viruses have a simpler chemical structure, but are more dangerous to humans. They have only a protein coat around a single kind of nucleic acid, either DNA or ribonucleic acid

(RNA). They lack enzyme activity, so cannot be called cells in the true sense (with the exception of enzymes which aid in penetration of the host cell). Virus injects its nucleic acid into the host cell, takes over the control of the cell and directs it to produce more of it. The cell fills up soon and bursts releasing loads of viruses into the medium where each can infect other host cells and continue the job.

9.3.4 Bacteria

Bacteria are single-cell plants. Bacteria metabolize the organics in wastewaters with the production of new microbial cell mass. The bacteria that can metabolize the maximum amount of the different organics predominate. While most bacteria in wastewater treatment systems utilize organics for their metabolism, there is an important group of bacteria that utilize inorganic compounds for their metabolism. As a net result, the two groups of bacteria do not compete with each other for their nutrients and both grow in the same environment. The bacteria weigh approximately 10 - 12 g each. Normal municipal wastewaters contain between 105 and 107 bacteria/ml.

Bacteria use soluble food to reproduce by binary fission. They are about 0.5 to 1.0 micron in diameter. Their shape falls in three categories:

- Spherical (cocci),
- Cylindrical (bacilli) and
- Helical (spirilli); the spiral forms may be 15 microns long.

Metabolically, most bacteria are heterotrophic. The autotrophic forms obtain energy by oxidation of inorganic substrates such as ammonia, iron and sulfur. There are a few autotrophic photosynthetic bacteria also. Depending on their metabolic reaction, the bacteria may be anaerobic or facultative.

9.3.5 Fungi

Fungi are similar to the bacteria but are multicellular organisms. The fungi are larger than the bacteria and cannot compete with the bacteria for organics under normal environmental conditions. The fungi tend to be filamentous and present too much mass per surface area. Fungi are strict aerobes and cannot grow in the absence of oxygen. Municipal wastewaters contain fungi spores, primarily from the soil.

Fungi have a vegetative structure known as mycelium. The mycelium consists of a rigid, branching system of tubes, through which flows a multinucleate mass of cytoplasm. A mycelium arises by the germination and outgrowth of a single reproductive cell, or spore. Yeasts are exceptional fungi that cannot form a mycelium, so are unicellular. Fungi are heterotrophs and are able to utilize a wide range of organic materials. They are mostly aerobic.

9.3.6 Algae

Algae are true photosynthetic microbes, requiring light for energy while using inorganics for cell protoplasm. Algae do not compete with the bacteria and the fungi for nutrients. Like fungi spores, the algae enter municipal wastewaters from the soil.

Algae maybe unicellular or multicellular. They could be autotrophic, photosynthetic protists. They are classified according to their photosynthetic pigment and taxonomic and biochemical cellular properties. They range in size from tiny single cells to branched forms of visible length. Four classes of algae are of importance:

- Green (chlorophyta) - They are freshwater species, can be unicellular or multicellular.
- Motile green (euglenophyta) They are colonial, unicellular and flagellated.
- Yellow-green (chrysophyta) - Most forms are unicellular. In this group, the most important are diatoms which have shells composed mainly of silica.
- Blue-green (cyanophyta) - They are unicellular, usually enclosed in a sheath and have no flagella. An important characteristic is their ability to use nitrogen in cell synthesis, from the atmosphere as nutrient.

9.3.7 Protozoans

Protozoa are single-cell animals that live on bacteria and small algae, helping to remove the dispersed bacteria and algae from the system. They are much larger than bacteria. Four major groups have been identified:

- Mastigophora, flagellated, usually parasites and some may cause disease, e.g. Giarida lamblia. These Flagellated protozoa are not very efficient energy gatherers and cannot compete with the higher forms of protozoa e.g. Peranema, bodo, oikomonas, and monas.

- Sarcodina, characterised by amoeboid motion, some have flagella. Entamoeba histolytica causes dysentery.

- Ciliata, largest and most varied group, either free-swimming with the help of cilia or stalked, attached to a solid body. The free-swimming ciliated protozoa are the most efficient protozoa and metabolize tremendous quantities of bacteria e.g. Lionotus, paramecium, colpidium, euplotes, aspidiscus and stylonychia. When the energy level of the system decreases, the free-swimming ciliated protozoa give way to stalked ciliated protozoa, which are attached to floc particles and can metabolize bacteria in the nearby vicinity with a lower expenditure of energy than the free-swimming ciliated protozoa e.g. Vorticella, epistlis, opercularia, and carchesium. (Suctoria are a special group of stalked protozoa that eat free-swimming ciliated protozoa rather than bacteria).

- Sporozoa, spore forming oblilgate parasites.

Species of protozoa known to have been transmitted by the ingestion of contaminated drinking water include:

- Entamoeba histolytica (cause of amoebiasis)
- Giardia spp.
- Rarely, balantidium coli

These organisms can be due to human or animal fecal contamination. Standard methods are not available to detect protozoa. When disease outbreaks occur and are associated with drinking water contamination by (pathogenic intestinal) protozoa, boiling of water may provide effective control. It leads to the inactivation of the above three.

9.3.8 Helminths

Many parasitic round worms and flatworms can be transmitted to humans through drinking water. A single mature larva (or fertilized egg) can cause infection and such infective stages should be absent from drinking water. However, the water route needs to be protected only from drcunculus medinensis (the guinea worm) and the human schistosomes cercaria. While there are methods for detecting these parasites, they are not used in routine monitoring. Considering how dracunculus is transmitted, source protection is the best approach. Capping a well and fixing a pump may help. To avoid the disease due to schistosome, the water may be stored for 48 hours and thus rendered safe. Slow sand filters can remove the majority of cercariae (if properly operated) and disinfection with residual chlorine of 0.5 mg/l for 1 hour will kill cercariae of the human schistosomes. A sounder approach is to eliminate host snails which are susceptible to fecal contamination. The grandmother's method of boiling and filtering will always work.

9.3.9 Rotifers

Rotifers are multicellular animals that can eat small particulates as well as bacteria and algae. The rotifers can attach themselves to floc particles and graze on the bacteria on the floc surface. Because of their large size, protozoa and rotifers are easily recognized under the microscope and are often used as indicators of the biochemical characteristics of wastewater treatment systems. The name is due to the rotating motion of the cilia located on the head of the organism. Metabolically, rotifers can be classified as aerobic chemoheterotrophs.

9.3.10 Crustaceans

Like rotifers, crustaceans are aerobic chemoheterotrophs that feed on bacteria and algae. These hard-shelled, multi-cellular animals are a source of food for fish. (Crabs and lobsters are crustaceans).

9.4 Nutritional requirements

To reproduce and to function properly, all organisms must get energy and carbon in order to synthesize new cellular material. Inorganic elements, N and P and other trace elements S, K, Ca and Mg are also important. Organisms may be classified according to their sources of energy and carbon as given below:

Classification	Energy source	Carbon source	Representative organisms
Photoautotroph	Light	Carbondioxide	Higher plants, algae and photosynthetic bacteria
Photoheterotroph	Light	Organic matter	Photosynthetic bacteria
Chemoautotroph	Inorganic matter	Carbondioxide	Bacteria
Chemoheterotroph	Organic matter	Organic matter	Bacteria, fungi, protozoa and animals.

Microorganisms may be further classified as aerobic, anaerobic and facultative depending upon their oxygen demand.

9.5 Microbiology of wastewater treatment

Most wastewaters have putrifying (rotting in due course) organic matter. Biological wastewater treatment systems are to covert the organic matter into easily manageable end products, such as carbon dioxide, methane and humus, which can be utilized or disposed off without affecting the environment. The microorganisms use the organic matter as food to provide energy and carbon for cellular synthesis.

Industrial fermentation uses aseptic techniques to maintain pure cultures and the environment is controlled. Biological wastewater treatment systems are only partially controlled. The wastewater (substrate or food) characteristics may change from time to time, there are changes in temperature and there is always a heterogeneous inoculum of microorganisms from soil and air. This results in a variety of microorganisms participating in the reaction. The fittest survive and dominate the population. When the compounds in wastewater are metabolized, intermediate compounds serve as food for other microorganisms. The population of individual microorganisms and the community structure also changes from time to time reflecting the changes in environmental conditions. It is possible to zero in on groups of microorganisms participating in the process, based on their overall biochemical reactions.

9.5.1 Intermittent sand filters

The treatment involved in the case of intermittent sand filters applies the sewage, that has already undergone preliminary treatment, onto the filter beds of sand at regular intervals. By this, air can enter the interstices of the bed between the dose of sewage to supply the required aerobic bacteria.

9.5.1.1 Construction

The filter consists of a layer of clean, sharp sand, with an effective size 0.2 - 0.5 mm and of uniformly coefficient 2 - 5, 75 to 105 cm deep having underdrains, surrounded by gravel to carry off the effluent. The sewage is applied by means of a dosing tank and siphon; it then flows into troughs laid on the filter bed. The troughs have side openings, which allow the sewage to flow on the sand. To prevent any displacement of sand, blocks may also be used underneath the sewage streams. After an interval of 24 hours, sewage is now applied over a second bed while the first bed rests. Usually, three to four beds may thus be working in rotation. During the resting period, the dried sludge accumulating on the sand surface is the resting period; the dried sludge accumulating on the sand surface is scraped off. The organic loading of the filter bed is not heavy, only 0.825 to 1.1 million liters per hectare per day.

9.5.1.2 Use

It is found that the effluent from an intermittent sand filter is usually better in quality than that resulting from any other type of treatment and can even be disposed off without dilution. However, because of the large land area required, filters of this type are now seldom constructed in cities. They are primarily suited for institutions, hospitals and other small installations.

9.5.2 Contact beds

In this type, the sewage applied on the contact material is allowed to stand undisturbed for some time before, being emptied and an interval is allowed before recharging the bed. During the 'contact period', when the filter is standing full, the fine suspended particles of sewage are deposited on the contact material and worked over by the anaerobic organisms. During the 'empty period' that follows next, the deposited matter is oxidized by the aerobic bacteria. It is then washed off the contact material and carried out with the effluent on the next emptying of the tank.

9.5.2.1 Construction

A contact bed is a watertight tank with masonry walls and very much similar in construction to an intermittent sand-filter. The contact material is made of broken stone called ballast and of 2.5 - 7.5 cm gauge. The tank is filled with the sewage over a period of an hour; allowed to stand full over a period of two hours, then emptied through underdrains. This process takes another hour. The tank is now left empty ffor 3 to 4 hours before admitting the next charge. (Thus with a total working period in a shift of 8 hours, the contact bed can be worked in three shifts daily). The organic loading in this case is about the same i.e., 1.1 million liters per hectare per day.

9.5.2.2 Use

The contact beds method is now only of historical interest and not commonly used. This is mainly because of the loss of efficiency brought about by the exclusion of air when the tank is standing full. For an efficient biological action, it is imperative

That the aeration should be through the mass of sewage. It has therefore, been superseded by more efficient biological methods, as in the case of trickling filters and activated sludge plants. However, the contact beds have some merit when compared to the trickling filters as:

(i) Lesser operating head required

(ii) Freedom from filter (psychoda) flies

(iii) Lesser nuisance due to odor

9.5.3 Activated sludge

When wastewater is aerated sufficiently, its organic matter reduces and a flocculant sludge (consisting of various microorganisms) is formed. In order to improve the process, the flocculant activated sludge is retained in the system as inoculum. This is achieved by settling the wastewater and recirculating the microbial mass. A part of this sludge is wasted periodically as synthesis of new cells continues.

- The organisms involved are aerobic chemoheterotrophic, i.e., those which utilize organic compounds as source for carbon (for cellular synthesis) and energy (by using oxygen as electron acceptor).

- Phase i: initially, the macromolecules are hydrolyzed or broken down into their monomer compounds. These reactions are usually carried out extracellularly. Once their size is reduced they are transported into the cell.

- Phase ii: later, the small molecules produced in phase i are partially degraded, releasing 1/3rd of their total energy to the cell. In the process a number of different products are formed which serve as precursors of both anabolic and catabolic routes of phase iii.

- Phase iii: the catabolic route oxidizes the compounds and produces carbon dioxide and energy. The anabolic route (which requires energy) results in synthesis of new cellular material.

Many microorganisms participate in the above reactions. Both the lower and higher protists have significant roles to play. Generally, the organisms in activated sludge culture may be divided into four major classes (these are not distinct groups and any particular organism may display more than one such behavior):

♦ Floc-forming organisms: these help to separate the microbial sludge from the treated wastewater. Zooglea ramigera and a variety of other organisms flocculate. Flocculation is understood to be caused by the extracellular polyelectrolytes excreted by these microorganisms.

♦ Saprophytes: the saprophytes are micro-organisms that degrade the organic matter. These are mostly gram-negative bacilli such as pseudomonas, flavobacterium, alcaligenes and the floc formers.

♦ Predators: the main predators are protozoa which thrive on bacteria. It has been found that the protozoa can be upto 5% of the mass of biological solids in the systems. Ciliates are usually the dominant protozoa. They are either attached to or crawl over the surface of sludge flocs. Rotifers are the secondary predators. When rotifers occur in plenty, we can be sure of a well stabilized waste, since rotifiers perish in highly polluted waters.

- Nuisance organisms: nuisance organisms interfere with the smooth functioning of the system, when present in large quantities. Most problems arise due to sludge settling (due to presence of filamentous forms which reduce the specific gravity of the sludge). The bacterium sphaerotilus natans and the fungus geotrichium are often responsible for this situation.

9.5.4 Trickling filter

Trickling filters have biomass growth attached to a solid surface over which the wastewater flows in thin sheets, supplying nutrients to the microbial community.

The biochemical reactions are similar to those in an activated sludge, which have a rich mixture of:

- Eucaryotic
- Procaryotic organisms

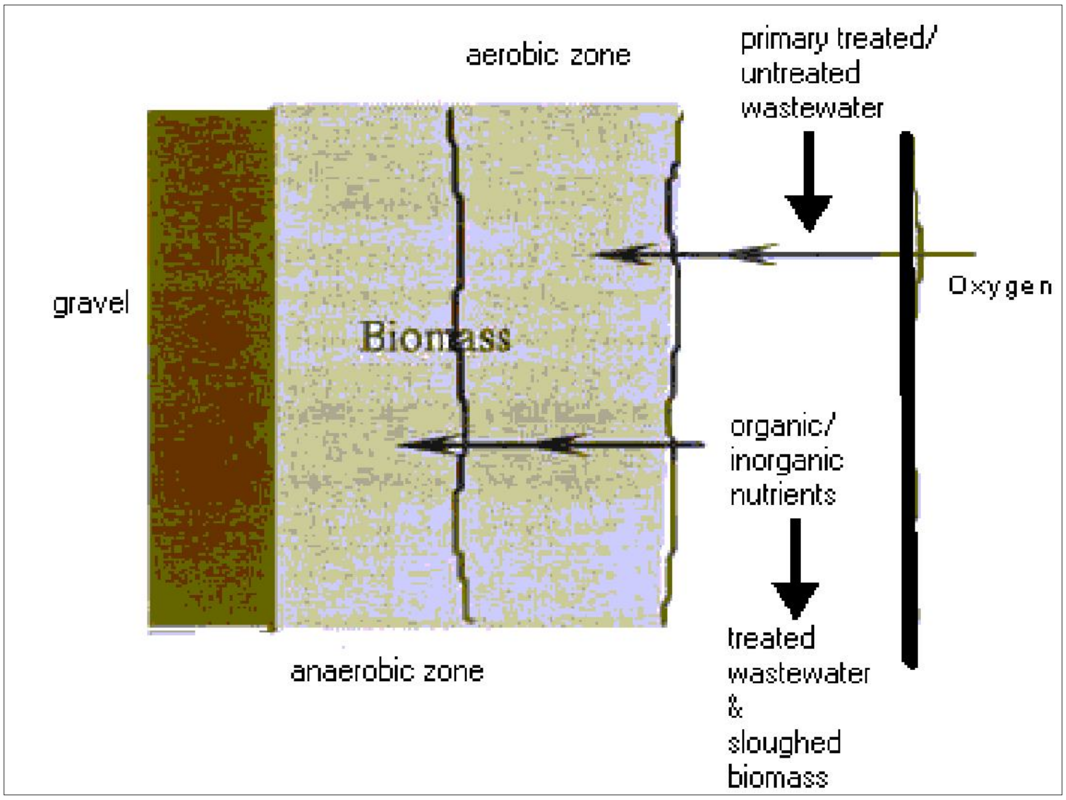
Trickling filters contain these and also higher life forms like:

- Nematodes

- Rotifers
- Snails
- Sludge worms
- Insect larvae
- Filter flies (psychoda)

The complex food chain prevailing in this allows complete oxidation of organic matter and lower quantity of surplus organisms (sludge). The microbial film grows in thickness, due to increased hydraulic shearing and development of an anaerobic layer next to the solid medium. The anaerobic reactions solubilize the anchoring microorganism. Algae can also flourish on the upper surface. However, they do not play significant role in waste stabilization.

Also called percolating filters, the trickling filters are similar to contact beds in construction, but allow constant aeration and the action is continuous. The name is a misnomer since the biological unit neither filters nor it trickles. The main function of a trickling filter is to remove unstable, organic materials in the form of dissolved and finely-divided organic solids and to oxidize these solids biologically to form more stable materials. The biological process involved in the filter is due to the growth of a microbial film on the surface of the filter medium. The film is made up of zoogleal slime, viscous jelly-like substance containing bacteria and other biota. Under favorable environmental conditions, the slime adsorbs and utilizes suspended, colloidal and dissolved organic matter from the sewage. Although classified as an aerobic treatment device, the microbial film is aerobic to a small depth of 0.1 - 0.2 mm. While at the bottom, a larger depth is anaerobic. When the sewage is flowing over the film, the soluble organic matter is rapidly metabolized with the colloidal organics adsorbed onto the surface. As the biota die, they are discharged from the filter with more or less partly decomposed organic matter. This sloughing off of material may occur periodically as in a standard rate filter or continuously as in a high rate filter.



The essential features necessary to the process are:

(1) Sufficient surface area must be provided for biological growth.

(2) Free oxygen must be available at the surface to replenish the dissolved oxygen extracted from the liquid layer.

(3) Sewage, and in particular industrial wastes must be amenable to biological treatment.

9.5.4.1 Construction

A trickling filter consists of a bed of crushed stone or other non-disintegrable contact material viz., granite, limestone etc., 25 cm and 75 cm in size, with the filter depth usually between 2 and 3 m. The larger stones 8 cm - 10 cm. in size are placed in a layer 15 cm - 20 cm thick at the bottom of the bed, while the smaller size stones 2.5 cm size make up the filter bed. The Inside walls of brick masonry may be honey combed (with the idea of securing better aeration of the beds) and provided with air-inlets. In such a filter, air must circulate freely so as to maintain the zooleal flora, which thrives over the stones in the presence of oxygen. The sewage from the sedimentation tank is applied either intermittently through fixed sprays located at the surface of the bed or by what is more favored, i.e., applying sewage continuously through rotary distributors. A rotary distributor consists of two or more arms which are turned in a horizontal plane through the jet action, or sometimes when it is insufficient, moved by the electrical power. The spray nozzles are circular holes 9 mm - 13 mm, and spaced in such a manner that the distribution of applied sewage is more or less in direct proportion to the area of the bed covered by each part of the distributor.

The floor of the trickling filter is made of concrete laid to a slope of 1 in 200. It has a system of underdrains, half-round or v-shaped channels cast into it and making a false bottom with perforated cover to support the coarse media above. The under-drainage system keeps the filter self-cleansing and also assists in the ventilation of beds.

9.5.4.2 Merits and demerits

The advantages of trickling filters are:

(i) They are self-cleaning. Rate of filter loading is much higher.

(ii) No diminishing of capacity even if overdosed, they can recoup after rest.

(iii) They are cheap and simple in operation.

(Iv) Mechanical wear and tear is very small.

The disadvantages are:

(i) High head loss through the filter, making automatic dosing of filters as necessary.

(ii) Odor and fly nuisance due to psychoda which may be carried away into human habitation and may prove a serious nuisance to man. The latter may be overcome by flooding the filter or by the use of DDT or other insecticides.

(iii) Large land area is required. Cost of construction is relatively higher.

(iv) They require preliminary treatment and, therefore, cannot treat raw sewage as such.

9.5.4.3 Filter loading

The loading on the filter may be expressed in two ways:

(1) By volume in terms of the strength of sewage as, kg of 5-day BOD per hectare meter of the material per day. This is also termed as organic loading of the filter.

(2) By surface area of the filter bed as, million liters of sewage

applied per hectare per day (ml/h/d.) This is also termed as hydraulic loading of the filter.

The values of the filter loading are indicated in table.

9.5.4.4 Filter types

Trickling filters are broadly classified as: (a) conventional or standard rate filters and (b) high rate filters. The two types, differ from each other in the filter loading and the method of operation. Thus in case of the high rate filter, loading in terms of the surface area i.e. Hydraulic loading is 5 to 15 times that of the standard rate filter and in terms of the 5-day BOD i.e., organic loading, is 4 to 5 times as much. The high rate filter depends for its operation on recirculation of sewage through the filter by pumping a part of the filter effluent to the primary settling tank, repassing through it and then filters.

Table: given a comparative study of the characteristics of the two types of trickling filters.

Comparative characteristics of trickling filters

Characteristics	Standard rate filter	High rate filter
(1) Filter loading.		
(i) expressed by surface area	(22 - 44 m.l.h.d.)	(110 - 220 m.l.h.d.)
(ii) expressed by volume	(925 - 2,220 kg of 5 - day BOD per ha.m)	(7,400 - 18,500 kg. Of 5-day BOD per ha.m)
(2) Depth of contact material	1.8 - 2.4 m	1.2 - 1.8 m
(3) Preliminary and final treatment	Necessary for proper functioning of filter.	Also necessary for proper functioning of filter.
(4) Method of operation	Continuous application, less flexible and requires less skill in operation.	Continuous application, more flexible and more of skill is needed in handling the plant.
(5) Type of effluent produced	Effluent is finely divided, very stable being high in nitrate content. BOD removed in filter and subsequent clarifier may be 56 - 98 per cent and the BOD, in effluent	Effluent is more finely divided, but less stable, being deficient in nitrates and hence somewhat inferior. The BOD reduction is 63 - 90 per cent. The results

Characteristics	Standard rate filter	High rate filter
	less than 20 per cent.	of single-stage filtration are not as good as those of the standard rate filter.
(6) Cost of operation		Less, for equal performance.

9.5.5 Anaerobic digestion

Anaerobic digestion happens in a closed reactor. Bacteria act upon the organic waste and release plenty of carbon dioxide and methane. The microbial community has only obligate anaerobic and facultative bacteria. As in aerobic chemohetrotrophic metabolism, initially the macromolecules are hydrolyzed. These products are then converted to volatile fatty acids (mainly acetic acid), and alcohols. The organisms responsible for these reactions are popularly called acid formers. They obtain energy through oxidation of organic compounds, but do not use oxygen as electron acceptor. Instead, another fragment of the substrate is reduced to anaerobic acids and alcohols. These are then metabolized by a second group of obligate anaerobic bacteria (the methane formers), and converted to methane gas. It is estimated that 60 to 70% of methane production is through conversion of acetic acid and the rest through carbon dioxide reduction by hydrogen.

The activities of the methane and acid producing groups of bacteria must be balanced as the former is sensitive to pH changes and works best in pH range 6.8 to 7.5.

9.5.6 Stabilization ponds

Stabilization ponds are large and shallow basins with residence times of 12 to 25 days. A variety of microorganisms inhabit such ponds. In addition to the aerobic and anaerobic chemoheterotrophic organisms, a pond has a large variety of photoautotrophic life forms also. Green and blue-green algae are found in abundance in the top layers, maintaining a symbiotic relationship (I am ok, you are ok!) with the bacteria. At times the pond may also have a significant population of sulfur photosynthetic organisms.

9.6 Microorganisms

9.6.1 Microorganisms removal efficiency (%) by water treatment unit processes

Unit process	Bacteria	Viruses	Protozoa	Helminths
Storage reservoirs	80-90	80-90	-a	-
Aeration	-	-	-	-
Pretreatment b	90-99	90-99	>90	>90
Hardness reduction High lime Low lime	90-99.9 90-99	.90-99.9 90-99	- -	- -
Slow sand filtration Without pretreatment With pretreatment	35-99.5 90-99.9	10-99.9 90-99.9	.59-54 59-99.98	- -
Rapid granular filtration Without pretreatment b With pretreatment except sedimentation b With pretreatment b	0-90 90-99 90-99.9	0-90 90-99 90-99.9	0-90 90-99.9 90-99.9	- - -
Diatomaceous earth filtration with pretreatment and precoating of filter	90-99.9	99-99.96	99-99-999	-
Activated carbon	-	10-99	-	
Disinfection	99-99.99	99	27-78	-
Full and conventional treatment (preteatment, filtration, and disinfection)	99-99.9999	99.9 99.99.	99.9-99-99.98	-

a: not known.

b: pretreatment includes coagulation, flocculation, and sedimentation.

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9.6.2 Disinfection

The final treatment process for drinking water is chemical and physical disinfection to deactivate any coliforms and pathogenic microorganisms that penetrate the filter. The effectiveness is a function of:

The types of organisms to be inactivated.

The quality of the water.

The type and concentration of the disinfectant.

The exposure or contact time.

The temperature of the water.

As stated previously, CT is used to identify the level of removal/inactivation of a given disinfectant for an organism (under a specific environmental condition). These values are useful when comparing biocidal efficiency. The table below provides CT values for several organisms. Most of the available CT data for microorganisms of health concern were developed from laboratory studies, so may not represent actual field conditions.

Water temperature can influence disinfection rates (and hence CT values). Low water temperature decreases microorganism inactivation rates, and is bad for chemical disinfection. Water pH also affects disinfection rates. In most water systems, the pH is kept in the range of 7 - 9. Water pH determines the presence of hypochlorous acid (HOCl) and hypochlorite ion (OCl). Lower pH values (6 - 7) forms HOCl, which is favorable for rapid inactivation. High pH values (8 - 10) form OCl, which results in slower inactivation. For chlorine dioxide (ClO2) which does not dissociate, inactivation is more rapid at higher pH values (9) than at lower pH values (7). Ozone disinfection is not dependent on pH.

Inactivation of microorganisms (99%) by chemical disinfectants

Microorganism	Disinfectant	pH	Temperature (oC)	Concentration (mg/lit)	Contact time(min)	CT (mg.min/lit)
Escherichia coli	HOCl	60	5	0.1	0.4	0.04
	Ocl-	100	5	1.0	0.92	0.92
	$NhCl_2$	90	5	1.0	175	175
		90	15	1.0	64	64
	$NhCl_2$	45	15	1.0	5.5	5.5
	ClO_2	70	5	0.3	1.8	0.54
	O_3	72	1	0.07	0.083	0.006
	O_3	72	1	0.065	0.33	0.022
Poliovirus type 1	HOCL	60	5	0.5	2.1	1.05
	OCl-	10.0	5	0.5	21	10.5
	NH2Cl	90	15	10	90	900
	$NHCl_2$	45	5	100	140	14,000
	ClO_2	45	15	100	50	5000
	O_3	70	5	0.5	12.0	6.0
		70	21	0.3	5.0	1.5
		90	21	0.4	1.0	0.4
		72	5	0.15	1.47	0.22
Giardia lamblia cysts	HOCL	60	5	2.0	40	80
	$NH_2Cl/NHCl_2$	75	3	2.4	220	528
G.nuris cysts	O_3	70	5	0.15	12.9	1.94
Entamoeba histolytica cysts	HOCl	60	5	5.0	18	90

Cell injury is an important factor in bacterial inactivation. Disinfection and other environmental stresses may cause non-lethal physiological injury to water borne bacteria. This phenomenon affects water quality and CT values, because injured bacteria may not grow on selective media normally used to detect and count the bacteria. Thus, the actual number of viable cells may be underestimated. In some cases, injured pathogens remain infective. Problems with detecting injured cells can be mitigated by the use of media and procedures that remain selective, yet permit the injured cells to repair metabolic damage.

9.6.3 Microorganism inactivation

9.6.3.1 Chlorine

Table above shows that enteric viruses, (represented by polivirus type) are more resistant to inactivation by chlorine than bacteria (represented by e.coli). And protozoan cysts are nearly two orders of magnitude more resistant than the enteric viruses. Differences in effectiveness of HOCl and OCl against the viruses and bacteria are also shown.

9.6.3.2 Chloramines

Comparison of chloramines with chlorine for disinfection of microorganisms (table ii) shows that, in general, for all types of microorganisms. CT values for chloramines are higher that CT values for free chlorine species. However, CT values for giardia lamblia cysts are lower, in contrast to the result for free chlorine.

9.6.3.3 Chlorine dioxide

Chlorine dioxide CT values in table ii show that, at pH 7.0, ClO2 is not as strong a bactericide and virucide as HOCl. However, as the pH is increased, the efficiency of ClO2 for inactivation of viruses increases. CT data for protozoan cyst inactivation is not available.

9.6.3.4 Ozone

Overall, comparison of CT values for ozone with those for chlorine and ClO_2 indicates that ozone is a much more effective biocide than the other disinfectants. Escherichia coli is about 10-fold (1 log 10) more resistant to ozone than poliovirus-type 1. Giardia muris cysts are about 10-fold more resistant to ozone than poliovirus type 1. Since ozone is a powerful oxidant, it reacts rapidly with both microorganisms and organic solutes and is very useful as primary disinfectant.

The order of microbial disinfectant effeciency is O_3 > ClO_2 > HOCl > OCl- > NH_2Cl > $NHCl_2$ > rnHCl (organic chloramines). However, for technical reasons, practical handling considerations, cost and effectiveness, the frequency of use of disinfectants by utilities in the united states is generally chlorine >chloramines > O_3 > ClO_2.

9.6.3.5 Ultraviolet light

Sensitivity of the various microbial groups of ultraviolet light is similar to that for chemical disinfectants. Enteric bacteria are most sensitive, followed by enteric viruses; protozoan cysts are least sensitive. Organisms that are sub-lethally injured by UV light exposure may, under appropriate conditions, be able to repair the damage (i.e., Phyto activation or dark repair).

Ranges or UV dosages required for 99.9% inactivation of microorganisms of concern in drinking water are: bacteria, 1400 - 12,000 uw.sec/cm^2; viruses, 21,000 46,800 uw.sec/cm2. The

UV disinfection values given for protozoan cysts are not practical with current UV technology used for water treatment.

10.1 Sludge

Sludges are generated through the sewage treatment process. Primary sludges, material that settles out during primary treatment, often have a strong odor and require treatment prior to disposal. Secondary sludges are the extra microorganisms from the biological treatment processes. The goals of sludge treatment is to stabilize the sludge and reduce odors; remove some of the water and reduce volume, decompose some of the organic matter and reduce volume; kill disease-causing organisms and disinfect the sludge.

Untreated sludges have about 97 percent water. Settling the sludge and decanting off the separated liquid removes some of the water and reduces the sludge volume. Settling can result in sludge with about 96 to 92 percent water. More water can be removed from sludge by using sand drying beds, vacuum filters, filter presses, and centrifuges resulting in sludges having 80 to 50 percent water. This dried sludge is called a sludge cake. Aerobic and anaerobic digestions are used to decompose organic matter to reduce volume. Digestion also stabilizes the sludge to reduce odors. Caustic chemicals can be added to sludge or it may be treated to kill disease-causing organisms. Following treatment, liquid and cake sludges are usually spread on fields, returning organic matter and nutrients to the soil.

Wastewater treatment processes require careful management to ensure the protection of the water body that receives the discharge. Trained and certified treatment plant operators measure and monitor the incoming sewage, the treatment process and the final effluent.

10.1.1 Digestion

This is the process of decomposing organic matter of sewage-sludge anaerobically under conditions of adequate operational control. The sludge is broken up into three different forms:

(i) digested sludge which is a stable humus like solid matter with reduced moisture content

(ii) supernatant liquor which includes liquefied and finely divided solid matter, and

(iii) gases of decomposition like methane (CH), carbon dioxide

4 (CO_2), nitrogen (N_2) etc.

The digested sludge is de-watered, dried up and used as manure while the gases produced are used as fuel or for driving gas engines. The supernatant liquor is retreated at the treatment plant along with the raw sewage. The tanks in which sludge digestion is carried out are called sludge digestion tanks.

10.1.2 Process of sludge digestion

Three stages are known to occur in the biological action involved in the process of sludge digestion. These are (1) acidification (2) liquefaction or a period of acid digestion and (3) gasification or conversion of acids into methane and carbon dioxide.

10.1.2.2 Acidification

As the fresh sewage-sludge begins to decompose anaerobically, bacteria attacks easily available food substances such as carbohydrates (sugars, starches, and cellulose) and soluble nitrogenous compounds. The products of decomposition are acid carbonates, organic acids with gases as carbon dioxide and hydrogen sulfide. Intensive acid production lowers pH value to less than 6. Highly putrefactive odors are evolved.

10.1.2.2 Liquefaction

In this stage, the organic acids and nitrogenous compounds of the first stage are liquefied i.e., transformed from large solid particles to either a soluble or finely dissolved form. The process is brought about by hydrolysis using extra cellular enzymes. It is during this period, that the intermediate products of fermentation viz., acid carbonates and ammonia compounds accumulate and the resulting gasification into H2 and CO2 is at a minimum. The pH value rises a little to about 6.8, odor is extremely offensive and the decomposing sludge entraps gases of decomposition, becomes foam and rises to the surface to form scum. This stage is known to last much longer than the proceeding stage of acidification and hence also termed as acid regression.

10.1.2.3 Gasification

It is the stage when more resistant materials like proteins and organic acids are broken up. Large volumes of methane gas of high calorific value, along with comparatively smaller volumes of carbon dioxide are evolved. The pH value goes to the alkaline range i.e., above 7 and tarry odor appears. Gasification finally becomes very slow; the sludge becomes well adjusted and is stable enough for disposal. This stage is also termed as alkaline fermentation.

10.1.2.4 Control of digestion

In order to have an adequate control over the process of sludge digestion, it is important to maintain a few optimum conditions in the operation of these tanks. These are: (a) maintenance of temperatures most favorable for developing and digesting organisms of sludge, (b) maintenance of the alkaline range of pH of the sludge and (c) seeding of the digested sludge with the raw sludge through proper mixing, dosing and withdrawal of sludge. These conditions are briefly described as below:

(a) temperature: it is observed that the process of digestion is greatly influenced by temperature; rate of digestion is more at higher temperatures. This is indicated in the graph shown in fig. 7.12. Two distinct temperature-zones are indicated.

(i) zone of thermophilic digestion brought about by the heat loving (thermophilic) organisms. The temperature range is 50°C - 55°C.

(ii) zone of mesophilic digestion in which common (mesophilic) organisms are active. The practical range of temperature is 20°C - 40°C. It slows down below 20°C until 10°C, when the bacterial action is practically over. It should be noted that in practice, sludge digestion is never carried to completion but only for a sufficient period of time to render sludge inoffensive, easy to dry and obtain large amount of the sludge gas. The optimum temperature lies in the mesophilic range and is about 35 °C with a digestion period of 4 weeks. Further heating to 49 °C or so would reduce the digestion period to 15 - 18 days, which is the thermophilic range. But, the thermophilic range is not used because of odor and other operating difficulties.

(b) Alkalinity: An alkaline range pH value of 7.2 or 7.4 is desirable especially when raw sludge has to be added daily, which, on undergoing the first and second stage of digestion, would cause lot of acidity which might interfere with the digestion process.

The acidity increases with the overdosing of raw sludge, over withdrawal of digested sludge and with the sudden admission of industrial wastes into digestion tanks. The remedy in such cases is to add hydrated lime in doses of 2.25 - 4.50kg per 1,000 persons. The amount of raw sludge to be added daily, for the maintenance of the optimum value of pH, should be 3 to 4 per cent by weight of the digested sludge.

(c) Seeding: Seeding is the inoculation of the fresh sludge with the previously well-digested sludge under controlled conditions of temperature. Proper seeding results in balanced conditions of reaction or what is called ripening of sludge, the gas bubbles from the decomposing sludge at the bottom of the tank carrying entrapped sludge particles to the surface where they get mixed up with the decomposable particles of fresh sludge. Gases escape while the decomposed sludge particles are carried back to the bottom. In this way, mass of sludge is kept in circulation and bacterial enzymes get every opportunity of attacking the incoming fresh sludge.

Seeding is, therefore, an important requirement in the successful operation of a digestion tank. This is very much assisted through the process of stirring or recirculation. Some tanks are provided with power-driven mechanical mixing devices while others have an arrangement of recirculation of the tank-contents by pumping or agitation set up by the gas evolved. Stirring also helps in transmitting heat from the heating coils to the tank-contents, where it is required to heat up the tank, as in cold countries, to maintain optimum temperature of digestion.

10.1.3 Sludge digestion tanks

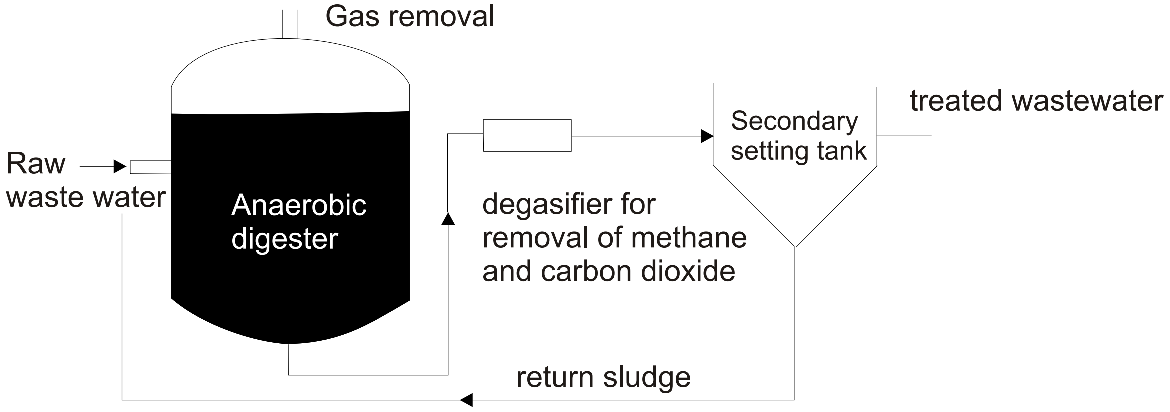
A sludge digestion tank is a R.C.C. tank of cylindrical shape with a hopper bottom and is covered with a fixed or floating type of roof. The latter makes the operation much more effective. The weight of the cover is supported by sludge, and the liquid forced between the tank wall and the side of the cover provides a good seal. The raw sludge is pumped into the tank where it is seeded with digested sludge.

On undergoing anaerobic digestion, gases of decomposition (chiefly Ch_4, CO_2) are given out. The gas rises out of the digesting sludge, moves along the ceiling of the cover and collects in the gas dome. The cover can float on the surface of the sludge between the landing brackets and the overflow pipe. Rollers around the circumference of the cover keep it from binding against the tank wall.

The digested sludge, which settles down to the bottom of the tank is removed under hydrostatic pressure periodically, say, once a week. To maintain optimum temperature, the tank is generally provided with heating coils through which hot water is circulated.

The supernatant liquor i.e., the part of the tank content lying between the scum and the sludge is withdrawn at the optimum level through a number of withdrawal points located at different elevations of the tank. As it is high in BOD and suspended matter contents, it is sent back to the incoming raw sewage for undergoing re-treatment. The scum formed at the surface gets broken up by the recirculating flow or through mechanical rackers called scum-breakers.

The amount of sludge gas produced varies from 0.014 to 0.028 m^3 per capita with 0.017 m^3 being quite common. The gas produced contains 65 per cent of methane with a calorific value 5400 - 5850 kcal. m^3, 30 per cent of carbon dioxide and balance 5 per cent of nitrogen and other inert gases. It resembles natural gas and may be used as a fuel for cooking. Principal uses however, are for driving gas engines, and for heating sludge to promote quick digestion.



10.1.4 Sludge disposal

The disposal of sludge may be carried out by the following Methods:

10.1.4.1 Burial or dumping into the sea or other large bodies of water

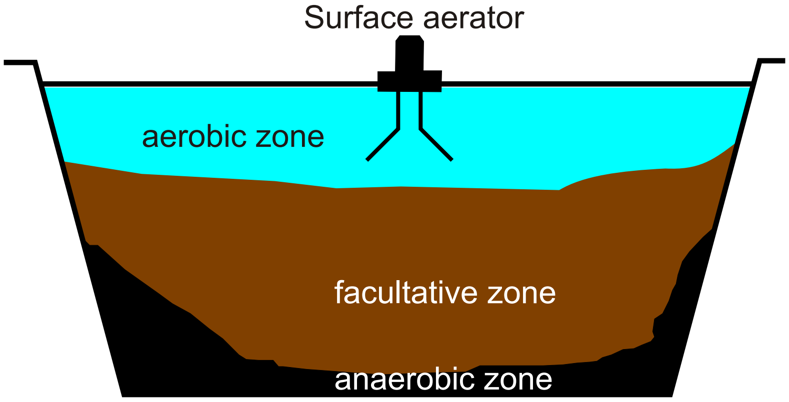
This is possible only in the case of cities situated on the banks of large rivers or tidal waters. Action is through the process of dilution.

10.1.4.2 Shallow burial into the ground

Wet sludge is run into trenches 0.9 m wide x 0.6 m deep and regularly spaced 0.9 to 1.5m apart and in parallel rows. When the sludge has dried to a firm stage, it is covered with a thin layer of soil. After about a month, land is ploughed up with powdered lime and planted with crops. Method of disposal called composting is useful, but the limitation is the area of land required, about 0.84 m[square]2 per person.

10.1.4.3 Lagooning

This involves making earth tanks or ponds 0.6 to 1.2 m deep, and underdraining them with 100 mm. dia agricultural tile drains, spaced at intervals of 2.7 m. Bottom of the tank is covered with a 15 cm layer of clinker or ashes. Sludge is then run in or pumped in and allowed to remain there for a period of 2 to 6 months. When the moisture has been drained or evaporated, contents are dug out to about half of their original volume and used as manure. This method is quite cheap, but its limitation is the nuisance resulting from smell during anaerobic decomposition and files, so that its use is restricted to non-inhabited areas.



10.1.4.4 Mechanical dewatering of sludge

The moisture content is reduced to about 50 per cent and the volume to 20 per cent. Example, filter-pressing, vacuum filtration, centrifuging, heat drying and biological floatation sludge cakes may be sold and used for filling low lands or mixed with house-refuse and then burnt up in incinerators.

10.1.4.5 Drying on beds

This is the most usual method of sludge disposal. The wet sludge, as from the digestion tank, is run into specially prepared sand-beds on which it dries in the open, part of water evaporates and the remaining percolates through the sand to the under-drains and returned to the primary tank for treatment.

A sludge drying bed is made up of 15 to 30 cm of coarse sand, underlain by 7.5 cm fine sand, 22.5 cm of graded gravel of size ranging between 5 cm to 1.5 m at the bottom. At the top, open-joined tile drains, 10 cm dia, laid in coarse gravel are provided at intervals of about 3 to 6 m. The sidewalls project 1.6 m above the sand surface. The top of the beds may be left open. Sometimes, to increase the efficiency of operation and minimize the unfavorable weather-effector fly-nuisance, glass covers or green-houses are installed. This may, however, be costlier.

The drying bed may be 12 to 18 m wide and 30 to 37.5 m long. The sludge is applied on the bed to a depth of 20 cm to 30 cm and at the middle of the shorter side through distribution pipes and troughs. The dried sludge can be removed in 7-10 days. The dried sludge is chiefly used as a fertilizer (its contents are 1.7 per cent nitrogen, 1.5 per cent phosphoric acid and 0.15 per cent potash) in the form of manure. It may also be used for filling up low lands.

10.2 Activated sludge

10.2.1 Definition

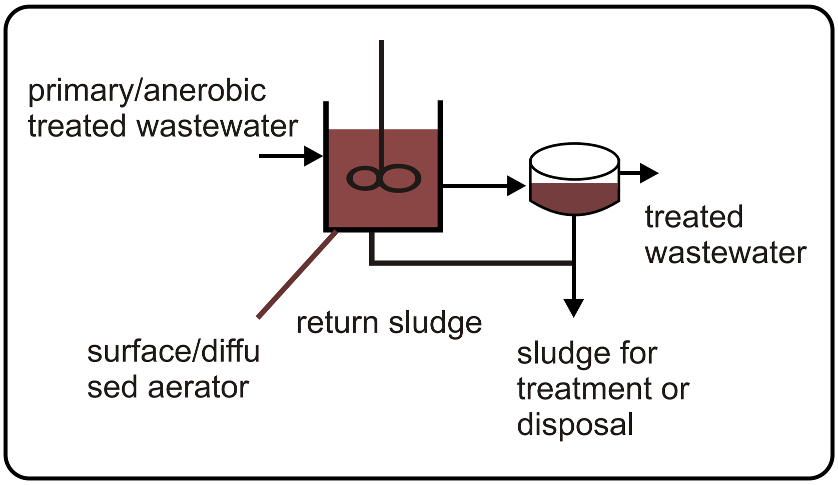
Activated sludge is defined as the sludge settled out of sewage previously agitated in the presence of abundant oxygen.

Activated sludge process is an operation whereby a portion of sludge from the secondary clarifier is returned and in turn added to the effluent from the primary clarifier. From here, it is subsequently aerated and the activated sludge is later removed in the secondary clarifier.

10.2.2 Principle of action

The mechanism of removal of organic material from sewage by the oxidation of organic material under aerobic conditions resulting in respiration and synthesis is the principle of action involved. To accomplish this, the following two actions are necessary:

(1) Adsorption, a physical action where by the finer, suspended particles of sewage combine with bacteria to form a sub-layer of a bacterial film at the surface. This film attracts the finely divided, colloidal and dissolved matter of the activated sludge and thus brings about coagulation resulting in the formation of large sludge flocs. Only a portion of the organic material is thereby stored away (adsorbed).



(2) Oxidation, a bio-chemical action whereby the large flocs so formed act as vehicle for aerobic bacteria, oxidizing the carbonaceous and organic matter of the stored material, resulting in respiration and synthesis and the formation of biological cells. The microorganisms are later settled out of the solution, removed from the bottom of the settling tank and returned to the aeration tank to metabolize additional organic material.

The metabolism of the organic matter results in an increased mass of microorganisms in the system. To maintain a proper balance between the influent sewage (food) and the mass of organisms produced, it becomes necessary to waste the excess microorganisms so formed. This food-to-microorganisms (f/m) ratio also termed, as sludge-loading ratio is an important feature of the aeration tank, which is needed in the operation of activated sludge process.

It is necessary that proper f/m ratio is maintained in the aeration tank in order to have an optimum operation of the activated sludge system. When the f/m ratio is high, microorganisms are in log growth phase, which is characterized by excess food and maximum rate of metabolism. As a result, microorganisms remain in a dispersed state and neither settles out of solution by gravity in the settling tank, nor can be separated easily from the effluent to be returned to the aeration tank.

However, at low f/m ratio, the metabolic activity is in endogenous phase where the rate of metabolism is low. The large mass of microorganisms present then competes for the relatively smaller amount of food available in the influent, and under aerobic conditions rapidly flocculates to settle out of solution by gravity. As such, BOD removal efficiency is quite high in the endogenous phase.

The aerobic organisms in the aeration tank which grow and multiply form an active suspension of biological solids, which is called activated sludge. Since the suspension of biological cells is in a liquid medium containing dissolved oxygen, activated sludge is a truly aerobic treatment process.

10.2.3 Features of operation

The essential features for the operation of activated sludge plants are as follows:

(a) preliminary treatment to remove coarser suspended solids, in order to reduce load on the subsequent process of aeration. This is done by passing the sewage through screens, grit chamber and primary settling tank.

(b) mixing the sewage effluent with a portion of the activated sludge, which are usually 20 to 30 percent by volume of wastewater flow from the secondary clarifier. This is called returned activated sludge.

(c) subjecting the mixture of primary effluent and activated sludge through aeration for a period of 4 - 8 hours (for conventional activated sludge process). This is accomplished in aeration tanks. This enables the microorganisms in the tank to be transformed into activated sludge. The activated sludge combines with the wastewater in the aeration tank to form mixed liquor. During detention in the tank, the organic matter in the liquor stabilizes in the aeration period.

(d) allowing the mixed liquor to flow from the aeration tank to the final settling tank or secondary clarifier to enable the activated sludge solids to settle out by gravity. The detention time in the secondary clarifier is 2 - 2 ½ hours. The clarifier water, which appears near the surface called supernatant, is drawn off to be disposed off usually without treatment. The settled sludge is collected at the bottom and split into two portions. One to be recycled to the inlet end of the aeration tank and the other which is the excess sludge, called waste activated sludge is treated separately for final disposal.

10.2.4 Organic loading parameters

For designing an activated sludge process system, it is necessary to consider the following important parameters:

(1) mixed liquor suspended solids: The sludge solids contained in the mixed liquor are designated as mixed liquor suspended solids (MLSS). Since the volatile portion constitutes about 80 per cent of the mixed liquor suspended solids; it is sometimes also

referred as mixed liquor volatile suspended solids (MLVSS). The MLSS in an aeration tank is an index of the activity of the microorganisms as these metabolize biologically. The value of MLSS in a conventional activated sludge process ranges from 1,500 to 3,000 mg/l and in high rate activated sludge from 4,000 to 5,000 mg/l.

(2) BOD loading: The BOD load in an aeration tank is calculated using the BOD in the influent sewage without regarding that in the return sludge flow. BOD loadings are expressed either in kg of BOD per day per hectare-meter of liquid volume in the aeration tank or in terms of kg of BOD applied per day per kg of MLSS in the aeration tank. The latter is also commonly referred to as sludge loading ratio or food-to-microorganisms (f/m) ratio. The f/m ratio varies between 0.2 - 0.5, in case of conventional activated sludge process and 0.5 - 1.0, in case of high rate activated sludge. It can be computed from the following formula:

$$f/m = \frac{Q \times BOD}{V \times MLSS}$$

where

Q = raw wastewater flow rate, mld

BOD = applied 5-day BOD, mg/l

V = volume of aeration tank, million liters

MLSS = mixed liquor suspended solids, mg/l

(3) Aeration period: The aeration period is the detention time of the raw sewage flow in the aeration tank. It is calculated by dividing the tank volume by the daily average flow of raw sewage without regard to the return sludge. It may be expressed by the relationship:

$$t = \frac{V}{Q} \times 24$$

Where, t = aeration period in hours.

(4) Sludge volume index. The sludge volume index is the volume occupied by 1 gram of settled sludge and is expressed as million liters per gram (ml / g). It is a measure of the settleability of the activated sludge. A normal sludge with good settling characteristics generally has sludge volume index less than 100.

If more than 100, it indicates some solids get carried over the effluent weir of the clarifier. This may be calculated from the following formula:

$$SVI = \frac{V_s \times 1000}{MLSS}$$

Where,

SVI = sludge volume index, ml / g

V_s = volume of settled sludge (ml/l) over

a period of 30 minutes

(5) Sludge age: The solids retention period in an activated sludge system is termed as sludge age. It is determined from the relationship -

$$\underset{\text{(day)}}{\text{Sludge age}} = \frac{V \times MLSS}{\text{(days)}Q \times SS}$$

Where, SS = suspended solids in influent sewage, mg/l

10.2.5 Methods of aeration

The methods employed for aerating the mixed liquor are (1) diffused air system (2) mechanical aeration or bio-aeration system and (3) combination system.

10.2.5.1 Diffused air system.

In this system, sewage is aerated by blowing compressed air, which is applied through porous diffusers. The diffusers are either porous tubes or porous plates of quartz or aluminum oxide, from which the air is released in the form of fine bubbles. Tube diffusers are suspended along one side of the tank whereas, the plate diffusers are placed at the bottom of the tank. The latter are more commonly used in practice. They are either flat shaped tiles 30 cm x 30 cm x 25 cm thick or dome-shaped tiles 10 cm to 17.5 cm dia. The latter are the more popular these days. In these, about 1/10th of the tank, the diffuser area occupies surface area.

Two arrangements of diffuser tiles are generally adopted:

(i) Ride and furrow method: In this, the floor of the aeration tank is formed in a series of ridges and furrows, usually placed longitudinally, with the diffusers laid on the furrows, and connected to the air main through smaller air pipes. The air is released in the form of fine bubbles, which rise and give impact to the sewage, flowing in a perpendicular direction. In so doing, the air traces out a path as indicated in

(ii) Spiral flow method: In this, the diffusers are placed only at one side of the tank floor. The tank corners are chamfered, so that air bubbles rising at one side are deflected longitudinal displacement of the sewage, produces a helical track. Longitudinal displacement of the sewage, produces a helical track This disperses a certain amount of air across the tank and downwards. This also provides a longer path of travel for both air bubbles and sewage and permits a greater absorption of the atmospheric oxygen at the sewage surface. There is also saving in the number of diffusers and the amount of compressed air. Hence, this method is more economical. It has, however, one defect, and that is the formation of stagnant pockets, which interfere with the aeration process.

10.2.5.2 Mechanical aeration.

It is observed that in the diffused air system, only a small per cent of oxygen, not more than ten is actually used in the oxidation process, the rest, about ninety per cent, is simply required to bring about the required agitation of the sewage-sludge mixture. A great amount of oxygen is invariably obtained from the atmosphere at the surface. The realization of this fact has given rise to mechanical aeration, in which the sewage is constantly stirred by mechanical means in order to bring it into intimate contact with the atmospheric air. This being more economical and better advantageous, is being increasingly followed in modern practice.

Two types of mechanical devices are commonly employed:

(1) Paddle mechanisms

(2) Spray mechanisms

10.2.5.2.1 Paddle mechanisms

Paddle mechanisms circulate the sewage in aeration tanks. The latter are made up of long inter-connected channels such that the sewage has to travel a long distance. the direction of flow being guided by paddle wheels so arranged, as to revolve either about horizontal shafts crossing the channels midway of their lengths. Paddle wheels are placed in a staggered fashion or about vertical shafts partially submerged at the end of each pair of channels in series. Baffles are used to cause overturning motion. In this mechanism, a part of the sewage is also recirculated to the influent end in the first arrangement. Therefore, this has a better advantage to offer.

The channels containing the paddle mechanisms may be about 1.2 m deep x 1.8 m wide with paddle wheels dipping 20 to 30 cm into the sewage and revolving at 0.6 to 0.9 m /sec. Detention periods for complete aeration are somewhat longish (15 hours or even more).

10.2.5.2.2 Spray mechanisms

In spray mechanisms, sewage is drawn to the surface and then thrown in the form of thin sheets or films on the surface. The film formation aids in the absorption of oxygen by exposing large surface of sewage to the atmosphere. The simplex system is a well-known example of this type. This consists of a single square hopper-bottomed tank or a rectangular tank with a series of square hopper-bottomed units, through which sewage flows and which may or may not be equipped with baffles or dividing walls.

Each unit has a central uptake tube, which is widened out at the bottom and has an inverted cone, suspended centrally at top with reference to the uptake tube and driven by a mechanism. The cone has vanes and during its revolutions, sucks up sewage from the bottom and sprays it at the top, thereby setting up a circular motion in the sewage. The cone spins at 60 rpm and contents are turned once in every 20 minutes. Units are 3 to 6 m deep and 1.5 to 2 times as wide. The detention period is 8 hours or more for complete treatment. The spray aeration is well suited for small plants because operation and maintenance are simple.

10.2.5.2.3 Combination system

In this, as the very name implies, the two actions viz. diffusion and the mechanical aeration are combined in one unit. The well-known type is the Dorrco aerator. This consists of a tank, 3 to 4.5 m deep and of equal width. It has two rows of diffusers fixed at the bottom and along one side of the tank. A submerged paddle wheel is at the center of the tank and mounted on a horizontal shaft, that rotates 10 to 12 rpm in a direction opposite to that of the rising air bubbles. Detention period is 2 to 3 hours.

The main advantage of this system is the increase in the diffusion action - 2 to 3 times as much oxygen as in diffused air tanks is absorbed, and consequently there is reduction in the supply of compressed air.

10.2.6 Activated sludge modified systems

Several modifications of the conventional activated sludge treatment system have been developed which serve to increase the efficiency of the activated sludge process. These are briefly discussed as follows:

10.2.6.1 Tapered aeration

As the influent sewage after primary settling (viz. primary effluent with high BOD) enters the top end of the aeration tank, it has a relatively higher oxygen demand. At this distance from the inlet of the aeration tank, the oxygen demand increases. This realization has given rise to modifying the activated sludge process through tapered aeration.

In this, while the influent is taken at one position from the inlet end, the amount of air supplied at the inner end position is greater than that supplied at the outer end. As for example, 45 percent of the total air may be supplied to the first third length of the tank, 30 percent to the next third and 25 percent to the last third.

10.2.6.2 Step aeration

This is another modification, which is based on the same concept i.e., the oxygen demand of the mixed liquor, decreases as the distance from the inlet of aeration tank increases. In this, the returned activated sludge is brought in at the inlet end of the aeration tank but the primary effluent is taken at different positions from the inlet end to some distance away towards the outlet end.

Step aeration is capable of handling shock loadings as well as stabilizing the oxygen demand in the mixed liquor.

10.2.6.3 Control stabilization or sludge re-aeration

This provides for reaeration of the return activated sludge from the secondary clarifier to be carried out in another aeration tank called reaeration tank.

The influent sewage is mixed and aerated with the return activated sludge in the main aeration tank for a short period of half an hour. This process is called contact stabilization. The short period is sufficient for microorganisms to absorb the organic pollutants without stabilization.

However, the activated sludge settles out and is recycled for aeration in the re-aeration tank for a period of 3 hours during which, the absorbed organic material gets decomposed. Since the volume of the activated sludge being stabilized in the aeration tank is considerably less, it is possible to much reduce the size of the main aeration tank. Because of the pre-aeration received by the return sludge, the organisms in the aeration tank have the capacity to handle much larger BOD volumetric loadings. Even the use of primary sedimentation may be dispensed with.

10.2.6.4 Extended aeration

This is characterized by low BOD loadings and is commonly used to treat wastewater from small communities, housing colonies and schools. The aeration period is 24 hours or greater. The extended aeration can accept periodic loadings without becoming upset. Stability of the process results from large aeration volume and complete mixing of the tank contents.

10.2.6.5 High rate aeration

This operates with the highest BOD loading per unit volume of aeration tank. BOD loading is approximately 3 times that of the tapered aeration. Because of high BOD loading, both the aeration period as well as the tank capacity becomes much less. High rate activated sludge system processes a relatively larger amount of the net growth of MLVSS and the sludge disposal as such becomes a major problem. Dorcco aerator is an example of a high rate aeration tank.

10.2.6.6 BOD loadings and operational parameters

The BOD loadings, aeration periods and other operational parameters of the aforesaid modified activated sludge system are given in table for comparison.

Modified system	BOD loading		Aeration period (hrs.)	BOD efficiency (%)	Return sludge (%)
	Kg/day/ha. M	f/m			
Tapered Aeration	4,800-6,400	0.2-0.5	6.0-7.5	95	30
Step aeration	4,800-8,000	0.2-0.5	5.0-7.0	90-95	50
Contact Stabilization	8,000-10,000	0.2-0.5	6.0-8.0	85-90	100
Extended Aeration	1,600-4,800	0.05-0.2	20.0-30.0	85-95	100
High rate	16,000	0.5-1.0	2.5-3.5	85-90	100

10.2.7 Activated sludge process vs. Trickling filter process.

The basic difference between the activated sludge process and the action involved in a trickling filter should be understood. In the case of a trickling filter, the bacterial film coating the contact material is stationary and likely to become clogged after some time. In the activated sludge process, the finer suspended matter of sewage itself contains the bacterial film, which is kept moving because of the constant agitation. The so called sludge flocs are active, free-loving organisms which are being continuously swept through the sewage and which, in their search for food and work, oxidize the organic matter present in the sewage in a much more efficient way. As a result, the efficiency of activated sludge plants is higher than that of trickling filters. Other advantages are:

(1) Lesser land area is required.

(2) The operating head is also comparatively less. As such, little or no pumping is needed.

(3) Higher degree of treatment. The effluent produced is clear,

sparkling and non-putrescible. BOD removal is 80 to 95 percent and coliform (bacteria) removal is 90 to 95 percent.

(4) Greater flexibility of treatment permitting a control over the quality of effluent desired.

(5) Freedom from odor or nuisance as the process operates under water.

The disadvantages are:

(1) Relatively high cost of operation and construction.

(2) Greater skilled attendance is required because of the large mechanical equipment involved. This may make the process unsuitable in case of small cities.

(3) It is more sensitive to change in the quality of influent. Any sudden increase in the strength or volume of which (say due to sudden discharge of strong trade effluent) may adversely affect the operation of the plant. Also the presence of synthetic detergents especially in the case of air-diffusion plants produces foaming difficulties.

(4) Difficulty in handling large amounts of sludge produced. Sludge bulking is a common trouble, which does not allow light, fluffy sludge to be easily removed by settlement.

The important characteristics in the choice of the process are local conditions (availability of land, filter media etc.), cost, nature and strength of sewage, and quality of effluent required. A comparative study of all such characteristics is made in table.

Comparative characteristics of trickling filters and the activated sludge process

S. No	Characteristic	Trickling filter process	Activated sludge process
(1)	Area of land required	Large	Small
(2)	Initial cost	High	Low
(3)	Operating cost	Low	High
(4)	Technical control	Little needed	Much needed
(5)	Nature of sewage	Suitable for strong and difficult industrial sewages	Rather sensitive to shocks of strong trade wastes
(6)	Pumping of sewage	Sometimes necessary since filters need a high head	Little or no pumping needed since only a low head is required.
(7)	Fly and odor nuisance	Considerable	None
(8)	Final effluent	Highly nitrified even if trade wastes are present. Suspended solids are apt to be high.	Usually not so highly nitrified as a filter effluent. Suspended solids low.

S. No	Characteristic	Trickling filter process	Activated sludge process
(9)	Secondary sludge produced	Small in quantity	Large is quantity

11.1 Classification of waste stabilization ponds

There are three commonly used types:

- Anaerobic ponds
- Facultative ponds
- Maturation ponds

Anaerobic ponds have neither dissolved oxygen nor algae. Facultative and maturation ponds are high in algae. They are essential for waste stabilization. Facultative ponds are built after the anaerobic ponds, so receive settled sewage from them. Maturation ponds, placed after facultative ponds, improve the bacterial quality of the final effluent, so are aptly termed as polishing ponds.

The types of ponds are arranged in a series; an anaerobic pond followed by a facultative pond and one or more maturation ponds. Such arrangement helps different types of ponds to perform their natural function in wastewater treatment, so as to produce an effluent of acceptable quality. Anaerobic ponds are very effective for wastewater with high BOD (>300 mg/l) and those with high amount of suspended solids. They and the facultative ponds primarily reduce organic load (BOD) whereas maturation ponds remove excreted pathogens (fecal coliform), plant nutrients (usually nitrogen and phosphorus) and some BOD.

Term	Meaning
Pond	A shallow body of water contained in an excavation in the ground or in a reservoir formed above ground, contained by earth embankments or combination of the two.
Wastewater stabilization pond (WSP)	A man-made pond or series of ponds constructed for treatment of wastewater. The wastewater is allowed to remain in the pond/ponds for a certain period of time where, microorganisms aided by the forces of nature act on the organic matter and thereby an effluent acceptable by the quality standards is produced.
Anaerobic pond	A wastewater stabilization pond where anaerobic bacteria breaks down the organic matter in absence of oxygen. In a combination of pond system, these are generally placed first to receive the raw wastewater directly.
Facultative pond	A wastewater stabilization pond where both anaerobic decomposition at the bottom layer, where dissolved oxygen is absent along with aerobic oxidation at the upper layers takes place simultaneously. In the upper layer algae along with aerobic and facultative bacteria co-exist.
Maturation pond	An aerobic wastewater stabilization pond, which acts as a secondary or tertiary treatment unit after the facultative pond/ponds to primarily improve the bacteriological quality of the effluent, while some reduction of organic load is also accomplished.
Primary pond	A single wastewater stabilization pond or the first unit of a combination of ponds in series, that receive the raw wastewater. These may be anaerobic or a facultative one.

Term	Meaning
Secondary pond	A wastewater stabilization pond that is preceded by a primary pond. It may be an anaerobic, a facultative or a maturation pond.
Tertiary pond	Extensions of above.
Aerobic process	A biological process that essentially needs availability of oxygen.
Anaerobic process	A biological process that takes place in absence of oxygen.

11.1.3 Waste stabilization pond characteristics

11.1.3.1 Anaerobic ponds

They receive wastewater with high organic loading (>100gm BOD5 per m^3 day) and no dissolved oxygen (DO). They function similar to domestic open septic tanks. The settable solids in the raw wastewater settle down as a sludge layer where they are attacked by the acidogenic bacteria first. The bacteria break down the carbohydrates, proteins and fats into fatty acids. When this happens, the organic load does not reduce.

Later, at a temperature above 15°C, the methanogenic bacteria convert the fatty acids into CO_2 and CH_4, which go up into air. BOD removal is from 40% to 60% depending upon ambient temperature. A scum layer forms on the surface which should not be disturbed. It maintains the anaerobic conditions below and also controls the pond temperature. Fly breeding (in summer) may be controlled by clean water sprays or final pond effluent spray, but never use insecticides.

Anaerobic ponds may appear purple or pink, due to sulfide oxidizing by photosynthetic bacteria. They convert hydrogen sulfide to sulfur and their growth is advantageous. Odor release (mainly H_2S) is usually a major disadvantage of anaerobic ponds. If designed for a loading of <400 gm BOD/m^3/day, odor nuisance does not occur. 500 mg of SO_4/l is the limit. The depth of the anaerobic ponds can be 2 - 5m. 1 day is the minimum detention time.

11.3.2 Facultative ponds

In primary facultative ponds (those that receive raw wastewater), two mechanisms reduce BOD:

Sedimentation - settled solids undergo anaerobic digestion.

Upper layers oxidize non-settleable organic solids and the solubilized products of anaerobic digestion. Part of the oxygen comes by surface aeration, but mostly it is provided by the photo-synthetic activities of the micro-algae, which have profuse growth in the pond. The algae in return gets almost all of carbon dioxide from the end product of bacterial metabolism. A symbiotic relationship exists between the heterotrophic bacteria and the autotrophic algae.

In secondary facultative pond (those that receive what comes from the anaerobic pond), the first mechanism (sedimentation) is very little.

BOD removal in both the types of facultative ponds is in the range 70 - 80%. The depth of facultative ponds is 1m to 2 m. A depth of 1.5 m is usually preferred. Depth, less than 0.9 men courage growth of rooted plants (a natural habitat for mosquito breeding).

Due to the photo-synthetic activities of the pond algae, a variation of DO concentration is noticed. After sunrise, the DO level gradually rises to a peak value. From mid-afternoon, it gradually drops drops down and reaches a minimum at night. Oxyphase and pH values change. When algae activity is at its peak, the bi-carbonate ions break to release more carbon dioxide to the algae, so excessive hydroxyl ions that are left over boost pH up to or above 10.

Wind and the churning of pond liquid takes place resulting in an even distribution of DO, BOD, bacteria and algae throughout the depth and hence a better stabilization. When this is absent, the algae population stratifies in narrow bonds (about 20 cm thick), during daylight hours. These bonds move up and down through the top 50 cm of the pond in response to the changes in sunlight intensity. Samples collected from these will show increased BOD, COD and suspended solids, which is not a true representation of everything.

11.3.3 Maturation ponds:

Maturation ponds receive effluents from facultative ponds. The number and size of the maturation ponds depends on the degree of bacterial quality of the effluent desired. These ponds show less vertical qualitative stratification (better churning effect) and are well oxygenated for the whole day. Depths can go up to 3 m, but are usually kept the same as facultative ponds.

The parameters that govern the removal of fecal bacteria are temperature, detention time and organic loading. Removal efficiency improves with a) increasing temperature b) increasing detention time and c) decreasing organic load. However, design is based only on temperature and detention time.

The removal mechanism of virus in the ponds is not well documented. It is believed that the settlement of solids leads to absorption of virus. Sedimentation removes excreted protozoan cysts and helminth eggs. A series of ponds with overall detention time of 11 days or more, normally removes all cysts and eggs.

11.4 Major microbial groups

11.4.1 Examples of Algae genera present in waste stabilization ponds

Algae genera	Facultative Maturation	Maturation
Anabena	Absent	Present
Ankistrodesmus	Absent	Present
Chlamydomonas	Present	Present
Chlorella	Present	Present
Chlorogonium	Present	Present
Coelastrum	Absent	Present
Cryptomonas	Present	Present
Cyclotella	Absent	Present
Dictyosphaerium	Absent	Present
Eudorina	Present	Present
Euglena	Present	Present
Micractinum	Absent	Present
Navicula	Absent	Present
Oocystis	Absent	Present
Oscillatoria	Present	Present
Pandorina	Present	Present
Phacus	Present	Present

Algae genera	Facultative Maturation	Maturation
Pyrobotrys	Present	Present
Rhodomonas	Absent	Present
Scenedemus	Absent	Present
Spirulina	Absent	Present
Volvox	Present	Present

Species diversity in ponds generally decreases as the organic loading increases. So, fewer species are observed in facultative ponds than in maturation ponds. Motile (mobile) genera such as euglena, chlamydomonas dominate in facultative ponds if water is turbid. This is because, they can easily move to the surface. By the same logic, the non-motile forms such as chlorella thrive in clean waters of maturation ponds.

The algae standing crop in a well performing facultative pond is usually in the range of 1000 - 3000 mg/l chlorophyll 'A'- However, it also depends on the BOD surface loading and fluctuates with environmental changes on account of seasonal changes, zooplankton grazing, chemical toxicity etc. The standing crop is lower in maturation ponds (in series), since they are less heavily loaded.

11.5 Nitrogen and phosphorous removal

11.5.1 Removal mechanism in stabilization ponds

Wastewater entering stabilization ponds is exposed to a complex ecosystem and almost all of the physical, chemical and biological activities will determine the form and fate of the nutrients in it. Many transformations take place during the long detention times of the pond systems.

Nitrogen is removed by:

- Blue- green algae
- Biological uptake (algae, plants, bacteria etc.)
- Ammonia volatilization (pH change)
- Nitrification to nitrate and nitrite (aerobic)
- Dentrification to nitrogen gas (anaerobic)
- Retention in benthic sludges
- Biological hydrolysis of organic nitrogen

- Its adsorption to various combinations

Very low concentration of nitrite and nitrate are found in the effluents even though the bacteria for ammonia oxidation and oxygen (through photo-synthesis and natural aeration) are available. Nitrate is rarely found in anaerobic ponds. It is less significant in facultative ponds (may be due to quick conversion to gas by de-nitrifying bacteria pseudomonas and closturdia in benthic sludges). Nitrates however occur in shallow, well-mixed aerobic ponds or in maturation ponds that trail secondary treatment units.

Some studies claim direct sedimentation of particulate matter of benthic sludges cause nitrogen incorporation. Biological intake by plants and bacteria also cause this. Most studies agree that removal is a function of pH (10 - 12), temperature (warmer) and residence time (5 days).

Volatalisation is practiced for permanent removal in high pH ponds. In coastal areas with an average wind velocity of 8km/hr, 90% ammonia can be removed in 15 days by directing lime treated effluent (50-90 mg/l) through a series of 10 ponds.

Phosphorus removal is chemical and/or biological (cell synthesis). There is precipitation at high pH values. Ca(PO)OH separates at pH 8.2. Soluble phosphorus concentration decreases by a factor of 10 for every further increase in pH of 1. Addition of calcium, iron and aluminum salts (200 - 1000 mg/l), remove phosphorus above 95%. Yearly desludging and odor control is necessary.

11.6 Toxicity factors

11.6.1 Heavy metals

Heavy metals do not cause a problem with domestic wastewater since ponds can withstand upto 30 mg/l of heavy metal without any reduction in treatment efficiency.

11.6.2 Algae and bacteria

The performance of a pond system directly depends on its constituent algae and bacterial population. Presence of any toxic substance that affects their metabolism will reduce their performance. The algae are more easily affected than the bacteria. In ponds treating domestic wastewater, the major toxicants are ammonia and sulfide.

11.6.3 Effect of ammonia

If ammonia concentration exceeds 28 mg/l, algae may manage if ponds are within pH range during daylight hours. Ammonia is exponentially more toxic above pH 8, since a larger proportion is then in the unionized state, so can rapidly penetrate the algae cell and inhibit photosynthesis. This can cause the facultative pond to behave like an anaerobic one, even when the BOD surface loading is low. However, this can be reversed in a few hours. Inhibition of photosynthesis also reduces pH and hence toxicity of ammonia.

11.6.4 Effect of sulfide

Sulfide is toxic to algae in its H(subscript)2S stage. Its toxicity increases when pH decreases. In the normal range of pH in ponds, when sulfide concentration exceeds 8 µg/l, the activities of anaerobic heterotrophic bacteria are inhibited. Concentration of 50 - 150 mg/l inhibits methanogenesis in anaerobic ponds.

11.7 Factors affecting treatment in ponds

Several factors may significantly affect or aid, the hydraulic and biological behavior of waste stabilization ponds. Some, not all, can be taken care of during design.

11.7.1 Natural factors

11.7.1.1 Wind

Ponds should be designed to induce churning by wind. We know, this results in uniform distribution of BOD, DO, algae and microorganisms all through the depth of water. It also moves oxygen down. This is particularly important when there is nil or insufficient photosynthetic activity. On the flip side, strong winds may produce high waves and erosion to the embankment slopes.

11.7.1.2 Temperature

Temperature directly influences the physical, chemical and biological activities in a pond system. Rate of photosynthesis and cellular metabolism are directly proportional to the pond temperature. Ponds should be designed for most adverse temperature conditions. At lower temperature, dissolved oxygen present has a tendency to remain in pond longer. As the temperature rises, dissolved oxygen is likely to be liberated to atmosphere, especially under supersaturated conditions. The oxygen production by Algae through photosynthesis is also temperature dependent. All ponds perform well on a sunny, cloudless day at an air temperature above 20°C and mild wind conditions. At a temperature above 35°C, the rate of photosynthesis declines rapidly and at temperatures above 45°C, it altogether stops. High temperatures stimulate growth of blue-green algae at the expense of more efficient green algae. At the same time, aerobic bacteria consume oxygen at higher rate creating conditions to form anaerobic patches in the pond.

Sudden reduction in temperature slows down algae activity and oxygen production. Algae will move to lower layers, the green color will reduce and pond performance will drop.

11.7.1.3 Rainfall

Rainfall influences pond performance. Detention time reduces when it rains. Besides, heavy shower dilutes the contents of shallow ponds reducing the food available to biomass. Rainfall adds oxygen to a pond system by increasing turbulence.

11.7.1.4 Solar radiation

Solar radiation directly relates to photosynthesis by the algae. However, the rate of increase of photosynthesis declines when radiation intensity exceeds certain limits. Oxygen production also reaches a constant level. Actually, light is the factor for oxygen production in low light intensity conditions. And temperature is the guiding factor in areas of high light intensities. Latitude of the location and mean sky clearance factors help in determining the light intensity throughout the year. So, these are important parameters in designing the pond system, particularly the facultative pond. Too much solar radiation has adverse effects on pond performance.

11.7.1.5 Evaporation and seepage

These causes excessive loss of water resulting in increase in solid concentration which upsets the ecological balance. An evaporation rate in excess of 5 mm depth per day (50 m3(superscript)/hectare/day water loss) is excessive and needs special attention. Soil characteristics along with knowledge of ground water, hydrology are important when selecting the site. If ponds have to be built on permeable soils, they must be lined to minimize seepage.

11.7.2 Physical factors:

11.7.2.1 Surface area

The surface area is a function of organic loading (BOD_5) applied per day (especially in case of facultative ponds). In warmer climates, surface loading from 150 - 400 kg BOD has been successfully deployed, though exceeding 250 kg BOD may cause odor problem.

11.7.2.2 Water depth

Stabilization ponds operate at constant depth as designed. Depths, less than 0.9 m cause growth of aquatic plants, surface weeds and mosquitoes. Depths exceeding 2 m in facultative ponds may limit sunlight penetration. So, anaerobic condition at the bottom layer may be created. A design depth of 1.5 m in facultative ponds has shown good results.

11.7.2.3 Short circulating

Incorrect positioning of inlet and outlet and poorly shaped ponds may produce short-circulating (dead or stagnant zones) within the pond. They may also transport the incoming wastewater quickly to the outlets, thus affecting pond performance.

11.7.3 Chemical factors:

11.7.3.1 pH value

Anaerobic and facultative ponds work well under slightly alkaline condition. So, industrial wastewater with high pH values should be appropriately controlled at the source before entry to ponds.

Anaerobic ponds situated in warm climates are usually biased to an alkaline pH value. In facultative ponds, if the pond turns deep green, the pH value can be taken to be in the alkaline range. If the pond water is yellowish green or milky, it is acidic.

However, facultative ponds display a natural diurnal variation in pH value. In the mornings, the pH value is low, due to excess CO_2 while in the late afternoon, the pH value rises due to the consumption of CO_2 by algae.

11.7.3.2 Toxic materials

Stabilization ponds are generally immune to toxic substances and heavy metals. Long detention time allows gradual absorption of the inhibiting substances by the existing biomass, provided there is no shock load. Concentration of 6 mg/l of each of heavy metals like cadmium, chromium, copper, nickel, zinc has not affected the treatment efficiency in a facultative pond.

11.7.3.3 Oxygen

Dissolved oxygen (DO) helps to identify the efficiency of operation in a facultative or maturation pond. A normally functioning facultative pond will be supersaturated with free oxygen at the surface and in the sub - surface layers during the afternoon. However, DO concentration may reduce to below

1.0 mg/l or even zero at dawn. The aerobic (the one that absorbs oxygen) surface layer strips off odor release in well-maintained ponds.

11.8 Design parameters

11.8.1 Anaerobic ponds

Anaerobic ponds must have volumetric loading in the range of 100 to 400 gm/m^3. This will help to maintain anaerobic conditions and minimize odor problems. A BOD contribution of 45 gm per person per day is equivalent to a permissible BOD loading of 100 gm/m3/day.

1.1.1.1 Relationship between temperature, detention time and BOD5 reduction

11.8.1.1 Relationship between temperature, detention time and BOD5 reduction

Anaerobic pond temperature (°C)	Detention time (days)	Expected BOD reduction (%)
10	5	0-10
10-15	4-5	30-40

Anaerobic pond temperature (°C)	Detention time (days)	Expected BOD reduction (%)
15-20	2-3	40-50
20-25	1-2	40-60
25-30	1-2	60-80

The depths of these ponds should be in the range 2 - 5 m. If sludge space is to be provided, its flow may be assumed as 40 liters per person per year.

11.9 Pond location

11.9.1 Geo-technical consideration

Soil characteristics and maximum level of ground water table are important parameters. Organic such as peaty and plastic soils and medium to coarse sand are not good for embankment construction. If required, suitable soil will have to be brought from outside to construct a stable and impermeable embankment core. Ideally, embankment should be constructed from local soil from the site and there should be a balance between cut and fill. The soil in the embankment should to be compacted in layers of 250 cm thick to attain a permeability of less than 10 - 7 m/s. Embankment slopes are commonly 1 in 2 or flatter internally and 1 in 1.5 on the outside. Embankment stability should be ascertained according to standard soil mechanics procedures. Planting of grass on the slopes increase stability of embankment against erosion. Stone ripraps and pre-cast slabs protect the inner embankment against erosion by wave action.

If ,

Seepage loss < (inflow net evaporation)

then, the water level in the pond will not reduce. If the permeability of the soil exceeds the maximum permissible limit, the pond must be lined suitably. The following will provide a general guideline on the basis of local soil characteristics:

Permeability	Action suggested
> 10 - 9 m/s	No risk of ground water contamination.
> 10 - 8 m/s	The pond will seal naturally.
> 10 - 7 m/s	Some seepage may occur, but no need to worry.

Permeability	Action suggested
> 10 - 6 m/s	Too permeable; must be lined.

11.10 Preliminary treatment

Small ponds serving less than 1000 people do not need pretreatment. If the ponds are fed by a pumping station, screens may be already available in the pumping station, so are not required here. Otherwise, a coarse screen (50 cm pitch) may have to be placed at entry to the ponds. In sea coasts and areas using combined sewerage system, loads of sand and grit accompany the influent wastewater. Opinions vary widely about placing a grit removal facility ahead of the ponds.

Some designers have a grit chamber fitted with velocity control device to minimize pond silting. This is particularly relevant when the influent carry industrial waste from washing machines or glass and marble polishing units. If the incoming sewerage system is of separate type having only sanitary sewage, very little slit is expected (1 - 3 liters/year) and a grit chamber in such a case can be avoided. Some designers believe that a primary anaerobic pond with an additional sludge depth can conveniently replace the grit chamber. Where the grit chambers are inevitable, conventional manually cleaned twin grit channel with suitable velocity control mechanism is preferred.

Having a combined sewer inlet (storm water is mixed with sanitary sewage), helps to provide a storm water overflow, after the pretreatment units, set at 6 times the capacity of dry weather flow. A parshall or venturi fluxe can be installed to measure the wastewater influent and log it for future redesign.

11.11 Operation and maintenance of anaerobic ponds

11.11.1 Functioning

An anaerobic pond functions properly if:

- No plants or weeds collect on the wet slope.
- The surface of the pond is covered by layer of scum which helps to:
- Maintain anaerobic condition.
- Prevent atmospheric oxygen transfer.

- Check heat loss.
- Daily check should be on
- No seepage though embankment.
- No clogging of inlet particularly when it is submerged.
- No floating scum should pass into facultative pond.
- No fly breeding.
- Periodical check must be on sludge layer thickness.

11.11.2 Operational problems and remedies

11.11.2.1 Anaerobic ponds

11.11.2.1.1 Odor problem

Possible reasons:

Excessive loading rate

(i) Presence of toxic substances and inhibitors in influent.

(a) Sudden drop of temperature.

(1) Low influent pH value.

Possible remedies:

(1) Allow scum (natural floating cover) to form.

Reduce influent flow by by-passing a portion to facultative ponds.

(1) Avoid chlorine and other chemicals.

11.11.2.1.2 Mosquitoes and other insects

Possible reasons:

(i) Removed screenings and grits lie at site.

(ii) Weeds or grass on the wet slope touch or dip into the liquid.

(iii) No floating scum layer.

Possible remedies:

(i) Dispose off screenings and grits.

(i) Remove all vegetation from wet slopes.

(1) Install spray water jets.

11.12 Routine maintenance

Do the following periodically:

- Remove screening and grit from pretreatment units
- Look for growth of grass and weeds on the wet slope. If found, cut and remove.
- Remove floating scum and floating macrophytes (e.g. Lemna) algae patches from the surface of facultative and maturation ponds.
- Spray the scum on anaerobic pond with clean water or plant effluent.
- Remove blocks if any from inlet, outlet and interconnections.
- Check for damage to the embankment by rodents, rabbits and other animals.
- Check the depth of liquid in ponds.

Operators must be instructed on the frequency of performing these tasks and their work must be regularly inspected. It would be of much help, if they are provided with a pond maintenance manual and a log book to record their activities. The operators must also collect samples and carry out some routine measurements.

11.13 Evaluation of pond performance

This is a time-consuming and expensive process.

Samples should be taken and analyzed at least 5 times over a five week period at both the hottest and coldest times of the year. Samples should be collected on:

- Monday in the 1st week.
- Tuesday in the 2nd week.
- Wednesday in the 3rd week.
- Thursday in the 4th week.
- Friday in the 5th week.

If the load is likely to be different on a holiday, that must be taken into consideration. For example, industrial wastewater from factories will not come on a holiday. On the contrary, household wastewater may increase on the same day.

12.1 Immobilized cell reactor

Amongst the technologies, immobilized cell oxidation process has been used more successfully for the treatment of wastewater. Immobilized cells have been defined as cells that are entrapped within or associated with an insoluble matrix. Mattiasson discussed six general method of immobilization: covalent coupling, adsorption, biospecific affinity, entrapment in a three dimensional polymer network, confinement in a liquid-liquid emulsion, and entrapment within a semi permeable membrane.

Under many conditions, immobilized cells have an advantage over either free cells or immobilized enzymes. By preventing washout, immobilization allows a high cell density to be maintained in a bio-reactor at any flow rate. Catalytic stability is greater for immobilized cells and some immobilized microorganisms tolerate higher concentration of toxic compounds than do their non-immobilized counterparts.

One partial disadvantage of immobilization is the increased resistance of substrates and products to diffusion through matrices used for immobilization. Owing to the low solubility of oxygen in water and the high local cell density, oxygen transfer often becomes the rate limiting factor in the performance of aerobic immobilized cell systems. Thus when aerobic cells are used, aeration technique bears a very important consideration in bioreactor design technology.

Advanced 'Immobilized Cell Reactor' employing aerobic cells, has been recommended for the treatment of tannery wastewater. This technology comprises of immobilization of chemo-autotrophs, oxidation of dissolved organics in water and filtration of treated water. The activated carbon serves as a matrix to facilitate selective solute transfer, enhanced bio film attachment or restricts the permeation of microorganisms to the downstream.

12.2 Advanced 'Immobilized Cell Reactor' technology for treatment of wastewater

The concepts reinforced in this technology are:

1. immobilisation of organisms in the carrier matrix will prevent
2. accessibility of enzymes to the substrate is increased by reducing the mean free path of the bio catalyst to the substrate
3. reduce the cellular synthesis by using the organisms with low-yield coefficient

In Advanced 'Immobilized Cell Reactor' technology, the carrier matrix used is activated carbon of low surface area. The characteristics of carbon is presented in table 1.

The bacteria immobilized in anoxic zone can fragment the organics into simpler compounds and the bacteria in oxic zone perform oxidation of organics. In addition to bacterial oxidation, catalytic oxidation is also facilitated at the active sites of the carbon matrix. The heat of combustion of organics released at the active sites will be used for excitation of organic molecules to cross over the activation energy barrier, which normally determines the rate of any chemical reaction.

The freedom of movement of molecules is also restricted at the surface of adsorbent as they are anchored at the sites. Thus energy expenditure towards translational motion, which is considered to be the major component in the orientation of molecule, is lowered to maximum extent. The partially oxidized organic molecule is aerobically oxidized with low heat of combustion by aerobic organisms immobilized at the mouth of the pores. Thus, the energy available for cellular synthesis is decreased and consequently the biomass production is decreased. Since the organisms are in immobilized state, the expenditure of energy towards diffusion of organic molecules and oxygen from the bulk liquid to cellular matrix is very minimum compared to that in suspended growth system.

Hence, the conservation of energy in the immobilized state, enhances the rate of degradation of organics in wastewater is much greater than in suspended growth system. The elimination of micropores in the carrier matrix avoids the loss of active sites by irreversible bonding with organic molecules in aqueous environment. Therefore, the number of active sites available for oxidation of organic compounds remains a constant. Thus, the rate of removal of dissolved pollutants in wastewater is nearly constant.

12.2.1 Advanced 'Immobilized Cell Reactor' technology applied to leather industry

The Advanced 'Immobilized Cell Reactor' system performs at a credible level for the removal of organics estimated as BOD and COD from wastewater generated in garment leather manufacturing industry. The maintenance cost of the effluent treatment plant was reduced by $2000 per annum, through savings on electricity and chemicals. The treated water supported the growth of vegetative plants and aquatic bred animals.

12.2.2 Advanced 'Immobilized Cell Reactor' technology applied to textile industry

Advanced 'Immobilized Cell Reactor' system was applied for the treatment of wastewater discharged from textile-yarn-dyeing industry. The wastewater contains the dissolved organics classified under dyestuff, starch, EDTA, citrate etc. The treated wastewater met the discharging standards reused within the industry or used for irrigation purposes.

12.2.3 Advanced 'Immobilized Cell Reactor' technology applied to sago industry

Tapioca, the commercial crop is a source for production of starch. The potential use of starch is manifold mainly in pharmaceutical, explosives, alcohol fermentation, food industries etc. The industries are engaged in processing of raw tapioca into starch powder through peeling, crushing, washing and settling the milk of starch and drying in solar evaporation pans.

12.2.4 Advanced 'Immobilized Cell Reactor' technology applied to chemical industry

The industry is engaged in manufacturing certain type of monomers that discharge only 3500 liters per day. The wastewater was of high COD in the range of 70-90 g/l. The treated wastewater was expected to meet the discharging standard of Dubai municipality i.e. COD 3000 mg/l and BOD 1000 mg/l. The suggested treatment technology for the treatment of wastewater was anaerobic treatment followed by Advanced 'Immobilized Cell Reactor' treatment.

The anaerobic system used was anaerobic contact filter filled with polymeric material of void ratio 0.5. The reactor was of height 5.5 m and dia 1.5 m. The anaerobically treated wastewater was treated further in Advanced 'Immobilized Cell Reactor' reactor of height 5 m and dia 1 m. The treated wastewater from Advanced 'Immobilized Cell Reactor' reactor was able to meet the discharging standards prescribed by the regulatory agencies in Dubai.

12.2.5 Advanced 'Immobilized Cell Reactor' technology applied to pharmaceutical industry

The wastewater discharged is 20 m^3/day and widely varying in its characteristics. Aerobic biological consortia generally used in conventional treatment units are exposed to shock load applications as highly fluctuating organic loads are applied.

Hence, aerobic biological system requires a supporting device to offset the shock load application. This system has been proved to be resistant to shock load applications.

The treated wastewater from Advanced 'Immobilized Cell Reactor' based effluent treatment plant could be utilized for irrigation of the crops raised within the premises. Our previous experience on treated wastewater shows that the treated wastewater supports the growth of blue-green algae. This would in turn increase C/N ratio of soil and thus fertility of the soil will be increased.

12.2.6 Advanced 'Immobilized Cell Reactor' technology applied to treatment of domestic wastewater

Domestic wastewater discharged from domestic sector is complex in nature due to the presence of organic, inorganic chemicals, wide spectrum of organisms that are pathogenic and non-pathogenic in nature. Conventional biological treatment systems fail to accomplish removal of dissolved organics and microorganisms to the satisfactory level. Moreover, the systems are not efficient enough to recover the water for reuse purpose.

Domestic wastewater collected from the staff quarters was screened and passed through a pressure sand filter to remove the suspended solids. The screened domestic wastewater was treated in anaerobic reactor. The anaerobic treated wastewater was applied over the surface of the Advanced 'Immobilized Cell Reactor' reactor. Advanced 'Immobilized Cell Reactor' reactor has an integrated biological and chemical oxidation incorporated in a single reactor. The reactor consists of a tall column (0.6 m height and diameter 0.15 m) packed with activated carbon. The activated carbon is immobilized with chemo autotrophs of capacity 3.5×10^7 cells/gm. Oxygen required for the oxidation of organics in wastewater is supplied in the form of compressed air at a pressure 1 - 3 kg/cm^2 from the bottom of the reactor. The counter current movement of the liquid and air streams enables the dissolved organics to undergo oxidation and desorb the converted products, so that the activated carbon maintains its activity throughout the operation. The domestic wastewater treated through Advanced

'Immobilized Cell Reactor' system has removed BOD by 94%, COD by 90% and sulfide by 100%.

12.2.7 Merits and demerits of Advanced 'Immobilized Cell Reactor' technology

The treatment of domestic wastewater through Advanced 'Immobilized Cell Reactor' system has many advantages as listed below:

- Less land requirement
- Less electrical and mechanical equipment
- Less detention period (1 - 4 hrs.)
- Less power consumption (about 30% of the conventional consumption)
- Aeration tank is not required
- No foaming problem
- No addition of micro / macro nutrients
- No biomass production

- No secondary settling
- Tertiary treatment is not required
- Positive response to achieve discharging standards (BOD < 30 mg/l, COD < 250mg/l)
- Complete removal of color and odor
- Possibilities to reuse the treated effluent
- Provisional to handle the additional load by adding more number of modules
- Need not work on holidays
- Treated effluent can be used for agricultural / recreational purposes
- Investment cost for domestic wastewater treatment is only 75 % of the conventional one
- Payback period of Advanced 'Immobilized Cell Reactor' system is 26 months towards savings on electrical power and chemical consumption

- The treated wastewater supports the growth of vegetative plants

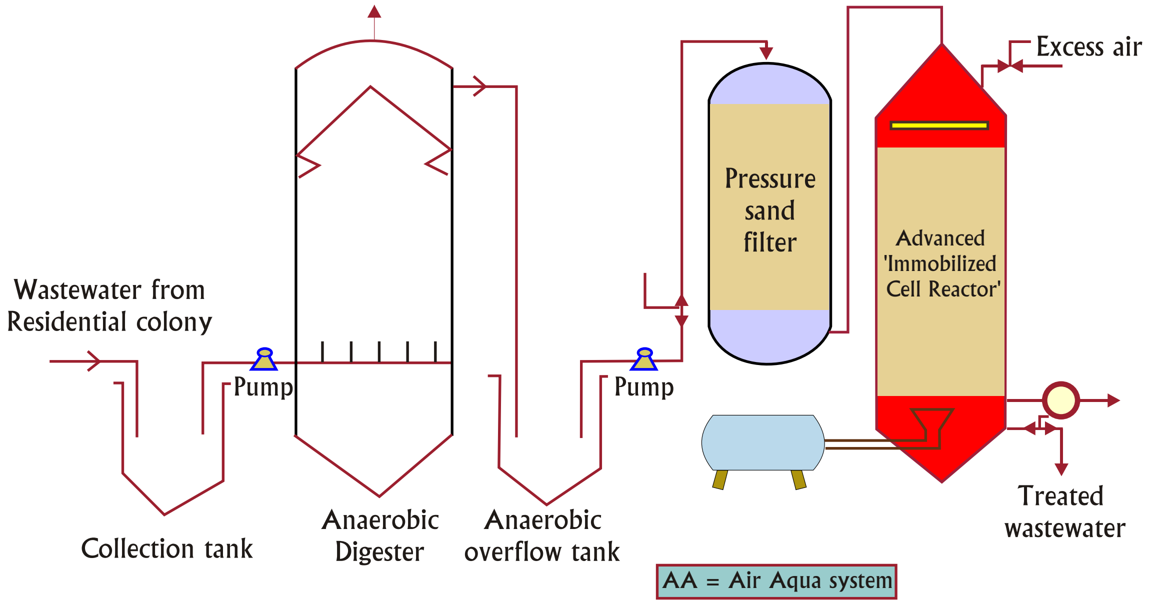
Demerits of Advanced 'Immobilized Cell Reactor' technology

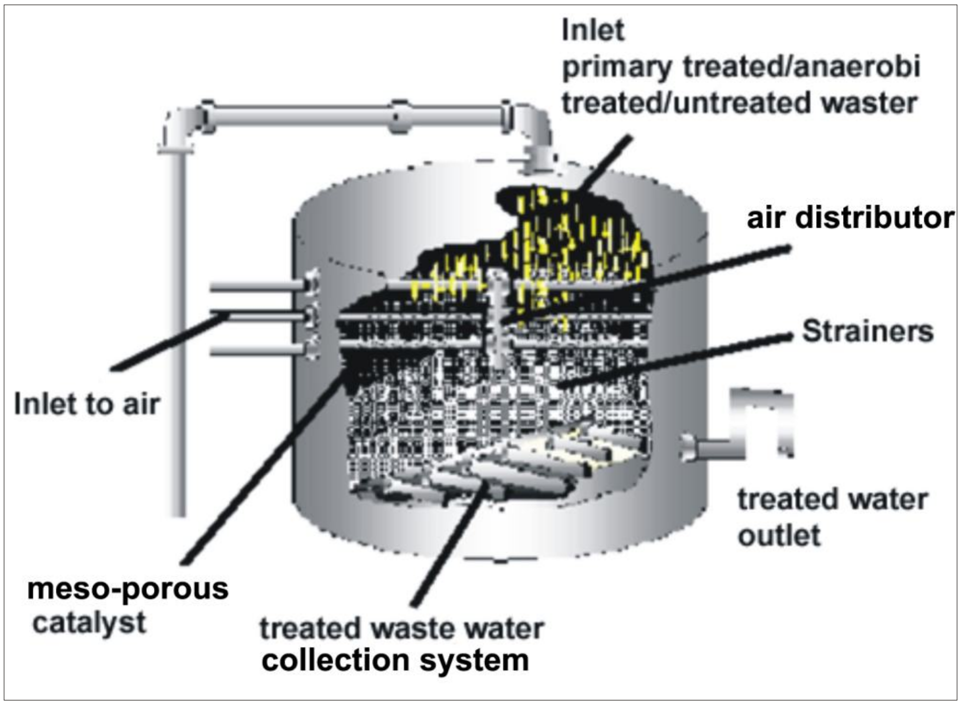
- Permeability index is less than that of sand filters
- Maximum organic loading rate allowed is only 1.2 kg COD/m^2 of Advanced 'Immobilized Cell Reactor' reactor.
- Performance of Advanced 'Immobilized Cell Reactor' reactor is limited by the presence of suspended solids in wastewater.
- Anaerobic treatment is an essential unit of operation before proceeding to Advanced 'Immobilized Cell Reactor' reactor. This is to reduce the viscosity of wastewater and eliminate colloidal solids.
- Multiple modules is required to handle huge volumes instead of a single module.

12.2.8 Catalysts used in Advanced 'Immobilized Cell Reactor'

Characteristics of catalysts used in Advanced 'Immobilized Cell Reactor' :

Elemental analysis	
C	48.45 (%)
H	0.70 (%)
N	0.10 (%)
Ash	50.75 (%)
Bulk density	0.69 (g/m^3)
Specific surface area	218 (m^{2}g)


Wastewater from
Residential colony
Pump
Collection tank
Anaerobic
Digester
Anaerobic
overflow tank
Pump
Pressure
sand
filter
Advanced
'Immobilized
Cell Reactor'
Excess air
Treated
wastewater
AA = Air Aqua system


Inlet
primary treated/anaerobi
treated/untreated waster
air distributor
Strainers
Inlet to air
treated water
outlet
meso-porous
catalyst
treated waste water
collection system

13.1 Oxidation pond

An oxidation pond (also called stabilization pond) is an artificial pond in which sewage can be retained for a sufficient time to satisfy the biochemical oxygen demand (BOD), and thereby make the sewage non-putrescible.

The purifying action in an oxidation pond can be explained because of a unique relationship between bacteria and algae in shallow ponds. The bacteria metabolize organic matter releasing nutrients like nitrogen, phosphorous and carbon dioxide.

Algae use these compounds along with energy from sunlight for synthesis of food releasing oxygen into solution. Bacteria take up oxygen released by algae, thus closing the cycle. This type of relationship between bacteria and algae is called symbiosis. This is common among organisms living in small ponds and streams, where two or more species live together for mutual growth and development. Besides these, other microorganisms like protozoa, rotifers etc., also live in these waters and feed on algae and bacteria.

Because of the shallow depth, generally less than 2 m, the oxidation ponds act as facultative ponds in which both aerobic as well anaerobic biochemical reactions take place. As the raw sewage without primary treatment enters the pond, the organic solids settle to the bottom and decompose anaerobically forming a sludge zone at the bottom and producing intermediate products. The latter are acted upon by facultative and aerobic bacteria, and in the process converted into stabilized nutrient form. Oxygen is added to the wastewater in the pond by wind action at the surface and from daylight metabolism of algae.

Oxidation ponds can successfully treat either raw or settled sewage. The latter is more often applied. The loading in terms of 5-day BOD may vary from 55 kg per day per hectare for tropical regions like our country. The pond area required per 1,000 persons may vary roughly from 0.2 to 0.4 hectares. It is claimed that the BOD removal is as much as 90 per cent and coliform removal is even higher, 99 per cent, which speaks of the great efficiency of these ponds.

Oxidation ponds which are rectangular shaped (l / b = (3/2))

i) having side slopes (1: 1.5) are constructed by building embankments of earth. Usually more than one in number, these are operated in parallel or series. Operating ponds in series generally causes increased BOD reduction by preventing short-circuiting.

On the other hand, parallel operation may be desirable to distribute the raw BOD load and avoid potential odor problems. They are of shallow depth usually 0.9 to 1.5 m and as such effective in permitting penetration of sunlight to all parts of the sewage, encouraging algae growth. Influent is applied in the middle of the pond and allowed to be spread by the action of wind currents, which prevents any odor nuisance due to concentration.

Oxidation ponds are suitable in case of small cities where relatively large land areas are easily and cheaply available, and in tropical countries having dry climate and warm temperatures. They possess such advantages as low cost, quickness of construction, easy maintenance and high efficiency of BOD removal. Disadvantages are nuisance due to mosquito breeding and odors.

13.2 Oxidation ditch

Oxidation ditch is a modified form of activated sludge process (extended aeration type), which is economical, highly efficient involving simple waste treatment principles and is comparable in performance with the oxidation pond. The process involves a single unit treatment in an endless channel equipped with a special type of rotor, which serves the dual purpose of oxygenation and circulation. The ditch comprises of a trapezoidal cross-section of relatively shallow depth (0.9 to 1.5 m) forming a continuous circuit.

There is normally no primary tank and the raw sewage passes directly through a bar screen to the ditch. The oxidation ditch forms the aeration basin where the raw sewage is mixed with the active organisms in the ditch. The cage rotor entrains the necessary oxygen into the liquid and keeps the contents of the ditch mixed and moving. The ditch entails a physical-cum-biological process in which a small portion of the organic matter undergoes direct chemical oxidation, while the bulk of the organic matter is stabilized by the biochemical activities of the microorganisms previously formed in the system.

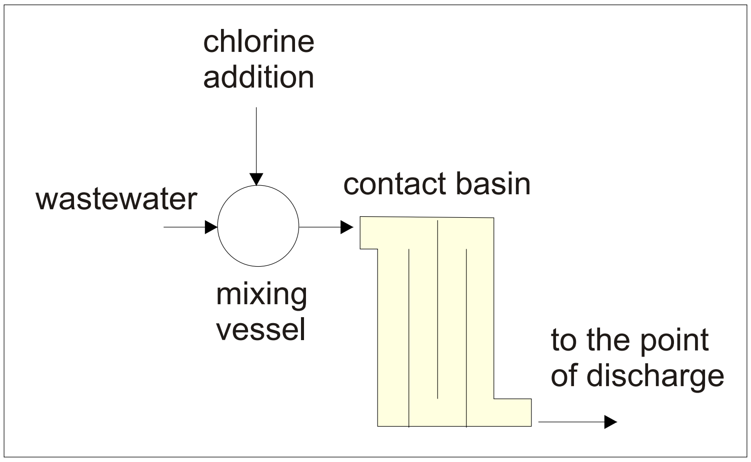
The mixed liquor in the ditch flows to the clarifier for separation. The clarified liquid passes over the effluent weir for disposal into the receiving stream, while the settled sludge from the bottom of the clarifier is removed by pumping and returned to the ditch for further treatment.

The oxidation ditch normally employs a detention period upto 24 hours and is designed to carry mixed liquor suspended solid concentration of 3000 to 8000 mg/l with a minimum circulation speed of 25 cm per se in the ditch. The plant can be operated either intermittently or continuously. These ditches have been found to treat quite efficiently wastes having BOD as high as 8000 mg/l. These are being used at a number of industrial plants in Canada and Australia. In some places, oxidation ditch process has been used to treat domestic as well as industrial wastes.

13.3 Chlorination

Disinfection by chlorination: is it a viable technology?

The chlorination of sewage by the addition of chlorine or chlorine compounds is required to achieve the following purposes:-



(a) To disinfect sewage, especially where the effluent is to be discharged into a body of water to be used for bathing, recreation or water supply.

(b) To control the odors due to hydrogen sulfide (H_2S) by either preventing its formation or reducing or neutralizing the amount after it has been produced.

(C) To reduce the BOD, 10 to 35 per cent by oxidizing the organic matter and killing the microorganisms necessary for decomposition.

(d) To kill the filter (psychoda) flies.

(e) To reduce ponding in the case of trickling filters.

(f) To form floc by coagulation in combination with other chemicals.

The action of the various forms of chlorine and the methods of application of chlorine is mostly similar to those used for disinfecting water. However, the amount of chlorine required is much larger because, a great amount of organic matter in sewage tends to neutralize the chlorine.

13.3.1 Applied chlorine dose

Type of effluent	Dose in mg/l
Settled sewage (fresh)	10
Settled sewage (septic)	20
Imhoff-tank effluent	10
Trickling filter effluent	3 to 7
Intermediate sand filter effluent	2
Activated sludge effluent	5

Recommended doses are given in the table. Chlorine residual is 0.15 mg/l with a contact period of 15 - 30 minutes. It is, however, more usual to regulate the dosages by reduction in coliform organisms, instead of obtaining the chlorine residuals. Thus, a 99.9 per cent reduction in coliforms may be considered as having eliminated the less resistant bacteria. But, it should be understood that chlorination is not effective in killing all types of bacteria, as for instance, certain spores and bacteria protected in the organic matter are not penetrated by chlorine and thus escape its disinfecting effect.

13.4 Intermittent sand filters.

Can sand filtration of sewage solve the pollution problems?

The treatment involved in the case of intermittent sand filters is by applying the sewage, having undergone preliminary treatment, on the filter beds of sand at regular intervals. By this, air can enter the interstices of the bed between doses of sewage, to supply the required aerobic bacteria.

13.4.1 Construction

The filter consists of a layer of clean, sharp sand, with an effective size 0.2 to 0.5 mm and of uniform coefficient 2 - 5, 75 to 105 cm deep under-drains, surrounded by gravel to carry off the effluent. The sewage is applied by means of a dosing tank and siphon; it then flows into troughs laid on the filter bed. The troughs have side openings, which allow the sewage to flow on the sand. To prevent any displacement of sand, blocks may also be used underneath the sewage streams.

After an interval of 24 hours, sewage is now applied over a second bed while the first bed rests. Usually, three to four beds may thus be working in rotation. During the resting period, the dried sludge starts accumulating on the sand surface and later it is scraped off. The organic loading of the filter bed is not heavy, only 0.825 to 1.1 million liters per hectare per day.

13.4.2 Use

It is found that the effluent from an intermittent sand filter is usually better in quality, than that resulting from any other type of treatment and can even be disposal of without dilution. However, because of the large land area required, filters of this type are now seldom constructed in cities. They are primarily suited for institutions, hospitals and other small installations.

14. Treatment (Natural water)

Even naturally available water cannot be readily used. It requires some treatment. Primarily, pathogenic organisms need to be removed for controlling water borne diseases and hence protect public health.

Additionally, we may have to make it 'potable' (drinkable). So, some physical and chemical factors and the presence of toxic substances may make water treatment essential. Water treatment depends on many needs such as:

a. Aesthetic reasons such as 'the removal of taste, odor, color and turbidity'.

b. Economic reasons like 'softening for minimizing laundry costs'.

c. Industrial needs including 'the preparation of boiler feed water'.

d. Recreational needs like filling a swimming pool.

e. Occasionally for other purposes like, ' to reduce corrosiveness' or 'to combat fluorosis', etc.

14. Treatment (Natural water)

The objective of treatment is to ensure potable water which is of safe sanitary quality. Stated differently, we want to supply water that is:

a. Free from significant concentrations of toxic substances.

b. Of attractive nature, so far as tastes and odors are concerned.

c. Reasonably soft and yet non-corrosive.

d. With a very low content of iron and manganese, so that it is non-staining to laundry and plumbing fixtures.

Popular methods of water treatment include:

a. Sedimentation (plain or with coagulation).

b. Filtration through sand.

c. Miscellaneous methods, which have: -

1. Aeration
2. Prevention of tastes and odors.
3. Disinfection

4. Removal of iron, manganese and other minerals.

5. Softening and demineralization.

6. Correction for corrosiveness etc.

14.1 Pretreatment

Pretreatment of water precedes regular treatment through filters when necessary. It may include one or more of the following processes:

a. Screening

b. Plain sedimentation

c. Aeration

d. Chemical dosing and mixing

e. Coagulation followed by flocculation

f. Sedimentation

g. Prechlorination at the appropriate stages.

14.1.1 Screening

Coarse screens are placed at the entrance of the intakes to keep off weeds, reeds and floating debris. Screening is usually of steel/rough iron, round/flat bars positioned in a frame. These are coarse screens. In addition, fine screens can be included in the intake structure or installed in a separate screen house, adjacent to the pumping station.

14.1.2 Plain sedimentation

This results when the suspended impurities are separated from the water by the action of natural forces (like gravity) alone. The settling particles may or may not be separated at once. If no further filtration is carried out, the basins are usually constructed as large storage reservoirs, having one to several days settling before the water is used.

If filters are also present, water will not be turbid. Then, a period of approximately 4 hours will be sufficient time for settling to take place in the storage reservoirs.

Filters are of two types: a. Slow sand filters and b. Rapid sand filters. The former require a longer settling time.

14.1.3 Aeration

Aeration is 'exposing to the atmosphere'. This usually results in:

a) Removal of objectionable tastes and odors.

b) Expulsion of dissolved gases like carbon dioxide and hydrogen sulfide (water from deeper layers of impounding reservoirs is rich in these).

c) Precipitation of impurities like iron and manganese which are in ferrous and manganous states (water from some underground sources is guilty of these).

d) Addition of oxygen to water for imparting freshness (water from ground sources will gain from this).

e) Removal of ammonia (if ground water, you can bet there will be ammonia).

Excellent aeration is achieved by:

A) Increasing the area of contact between water and air (water sprayed in small droplets as done in cooling towers gives good exposure).

b) Agitating the surface of the liquid constantly to minimize the thickness of liquid film.

c) Increasing the contact time of water with air (for example, we can increase the height of the jet in a spray aerator).

There are many devices to create aeration. The popular ones are:

a) Cascades

b) Splash trays

c) Shallow beds of coke or similar crushed material on which water will fall (which effects both adsorption and aeration).

d) Perforated pipes or porous plates through which, water is diffused.

'Local conditions', 'quality of water to be treated' and 'what is sought to be removed from or added to the water', determine aeration method to be followed.

Aeration however increases the oxygen content of water, which may not be always desirable. For example, the increased oxygen may accelerate corrosion and algae growth. Aeration has also been found to be not so effective in improving taste and odor. These days, there are some good chemical methods available to achieve a better taste and odor. For example, adding chlorine or activated carbon to the aeration systems is found to be very effective.

14.1.4 Chemical dosing and mixing

Chemicals are introduced into the water to aid the following:

a) Coagulation

b) Flocculation

c) Disinfection

d) Softening

e) Algae control

f) Corrosion control

g) Fluoridation

Chemicals are added continuously as solutions or dilute suspensions, with the help of chemical feeders (solution feed type or dry feed type).

14.1.5 Coagulation and flocculation

Suspended solids are of two types: a. Coarse and b. Fine material. Whereas the former settles down by itself, the latter may coalesce naturally (or with the help of a coagulant forcibly) and precipitate. The precipitating solids formed by coagulation undergo the following:

a) They are finely divided (this is fine only if all suspended solids are coarse, which is unlikely).

b) They are coagulated into larger solids (well developed floc) by agitation of the water which will settle in sedimentation basins or removed by filtration.

Coagulation and flocculation must be completed, before the treated water enters sedimentation basins.

Coagulation is the effect produced by the addition of a chemical to result in colloidal dispersion and hence particle destabilization. Flocculation is bringing together of micro floc particles into larger rapidly settleable flocs due to rapid mixing (or controlled agitation). First, a coagulating chemical is applied to water. Rapid agitation also helps to distribute the chemical evenly. Complex chemical reactions facilitate coagulation and formation of microscopic particles. Gentle agitation of water usually helps in agglomeration of fine particles into settleable floc.

There is a definite relationship between the turbidity of raw water and the coagulant dosage. The dosage is a function of the character of water, its temperature, pH etc. The optimum quantity is determined with the help of jar tests. Alum (aluminum sulfate) and copperas (ferrous sulfate) are popular coagulants. Quicklime or calcium oxide can be added to alum or copperas to facilitate water softening by increasing its alkalinity.

Rapid mixing to distribute the coagulant throughout the water is known as "flash mixing". This can be provided in special basins in which electric motors drive small propellers to achieve a flow of about a minute. A hydraulic jump (or standing wave got by a channel with sloping and widening sections) can also be used for flash mixing.

14.1.6 Sedimentation and flocculation

Sedimentation aids settleable floc to be deposited and reduce the load on the filters.

The following factors influence sedimentation:

a) Size, shape and weight of the floc.

b) Temperature of water.

c) Available detention period.

d) Effective depth of basins.

e) Area of the basins.

f) Surface overflow rate

g) Velocity of flow.

h) Inlet and outlet design.

14.1.7 Prechlorination

Gaseous chlorine or chlorine compounds help in disinfecting potable water, globally. The goal is to destroy any bacteria that may be present (chlorine is a very effective germicide). Chlorinating also helps in:

a) Oxidation of iron, manganese and hydrogen sulfide.

b) Destruction of some taste and odor producing compounds.

c) Control of algae and slime organisms in treatment plants

Chlorine also aids coagulation.

If chlorinating precedes filtration, it is prechlorination. This may lead to a higher demand for chlorine since some of it will get filtered. 5 ppm or more of chlorine may have to be added to a heavily polluted water, so that 0.2 to 0.5 ppm of chlorine may remain in the end. Prechlorination by its ability to prevent the growth of algae, easy removal of algae (by coagulation and sedimentation) and destroy slime organisms, thus prolongs the life of filter beds and facilitates easy filter washing.

14.2 Slow sand filters

Recommended standards of performance:

a) The filtrate should be clear with turbidity in the range 1 ppm (1 JTU - Jackson Turbidity Unit) to 3 ppm.

b) The filtrate should be color-free and read below 3 in the cobalt scale.

c)With the raw water turbidity inside 30 ppm (30 JTU), the filter run should exceed 6 to 8 weeks with the filter head loss below 0.6 m.

d) If the initial loss of head exceeds .02 to .05 cm, the entire sand bed needs overhauling.

The relative advantages and disadvantages of slow sand filters over rapid sand filters are:

14.2.1 Advantages

- Can be without coagulation.
- Simple design for the equipment

- Suitable sand will be usually readily available.
- Simple supervision is possible.
- Less corrosive and more uniform effluent.
- Effective removal of bacteria.

14.2.2 Disadvantages

- Size is bigger, so cost is more.
- Operational flexibility is less.
- If not accompanied by preliminary plain sedimentation, not economical for raw waters with turbidity above 30.
- Color removal is less effective.
- If no pretreatment, poor results for water with high algae content.

14.3 Pressure filters

14.3.1 Disadvantages

- Complicates effective feeding, mixing and flocculation of water to be filtered.

- It may not be possible to provide adequate chlorine contact time, if supply is direct from pressure filter.
- It is not possible to observe the effectiveness of the backwash, since the water, sand bed etc ., are not in sight.
- Effective design of water gutter is impossible due to the inherent shape of the pressure filter.
- To inspect, clean and replace the sand, gravel and under drains of pressure filters is difficult, since access is not easy.
- Sometimes, results can be disastrous due to sudden pressure differentials of the two sides of the filters.
- Condition of the sand bed may be difficult in ascertaining.
- Pressure filters are used only for small industrial needs and swimming. This is because, the disadvantages outweigh the advantages.

14.4 Postchlorination

Postchlorination is done after filtration and is normally used to treat moderately polluted waters. It is also done in small doses after prechlorination, to provide a factor of safety and maintain residual chlorine level. The chlorine is added when the filtered water enters clear water reservoirs to maximize the retention period. The usual practice is to maintain 0.2 to 0.4 ppm free-residual chlorine throughout the distribution system.

Contact period must exceed 30 minutes and the levels of residual chlorine must satisfy the following table:

PH value	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11
Residual of chlorine in ppm (or mg/l)	0.2	0.2	0.4	0.8	0.8

14.5 Domestic water treatment methods

'Safe water' does not contain harmful chemicals or micro organisms in concentrations that cause illness. 'Adequate water supply' provides safe water in quantities sufficient for drinking, culinary, domestic and other household needs, in order to maintain personal hygiene of the household members.

WHO 1987, Technology for water supply and sanitation in developing countries, WHO, Geneva, technical report series no.742.

14.5.1 Commercial devices:

The point-of-use commercial devices for drinking water treatment are increasingly becoming popular in many developing countries.

Two commercial domestic water treatment devices are tap attachable filters and candle filters.

In tap attachable filters, water passes through a cotton wad held on a coarse sintered silica crucible (or a sponge type wad placed over a micro porous bed held on a porous bulchner type funnel). These filters are capable of filtering out fine particulate and clusters of bacteria.

The candle filters comprise a top chamber with one or more micro porous ceramic filter candles and a bottom chamber with a tap. These filters trap microorganisms, dirt and other suspended impurities.

A series of three zero-b (zero-bacteria) water purifiers incorporating ion-exchange technology has also been in the market for more than 10 years. These purifiers eliminate all water-borne bacteria, hence produce water fully free of typhoid, cholera, diarrhea, dysentery, gastroenteritis and other disease-causing bacteria.

The three purifiers are:

- Tumbler: provides bacteria-free water at office or during travel. Recommended life is one year for one person or 700 liters of water filtered.
- Filter tap attachment: a device with refill cartridges that can be directly attached to a candle filter tap. Recommended life of cartridge is 6 months for a family or 3,000 liters of water filtered.
- Basin: a basin with refill cartridge, which purifies water while it is poured. Recommended life of cartridge is 6 months

for a family of 6 or 3,000 liters of water filtered.

Another device is a tap attachable ultraviolet water purifier with an electronic eye to indicate any malfunction. It is claimed to produce 100% bacteria-free water at 2 liters/minute.

The public water supply systems do not function as expected by the local residents. The adequacy of water, quality at end-user point creates loss of confidence in the public supply prompting a search for an alternative drinking water source.

Alternate solutions are perceived to be spring water, private wells and bore wells bottled water and home treatment devices. Home treatment devices known as point-of-use devices receive much interest because of advertising claims for treatment of specific problems and consumer's fears of exposure to carcinogenic agents.

There are a number of devices that have been developed for home treatment of public water supplies. Such devices use a variety of basic process concepts such as filtration, adsorption, ion exchange, reverse osmosis and distillation to achieve a revised contaminant reduction.

Filtration devices have been designed to remove turbidity, particulate materials (such as asbestos) and certain type of colloidal color in water.

Adsorption by granular activated carbon is used to remove tastes and odors associated with chlorine residuals, certain organic chemicals and chemical compounds produced by various micro organisms including actinomycetes, iron and sulfur bacteria, fungi and algae.

Ion exchange resins are used to exchange their 'soft' sodium ions for the calcium, magnesium and iron ions in 'hard' waters. These systems may also remove nitrates and sulfates by freeing the water of mineral cations and anions.

Distillation units heat the water to a vapor, vents volatile impurities and separate solids. Cooling condenses the purified water vapor back to liquid. Heating the water to boiling and inclusion of an air gap between the raw supply and the product water provides an effective barrier to microbial migration from contaminated source into the processed water. Generally, seawater was used in distillation process to obtain fresh water to use.

Reverse osmosis (RO) is another popular treatment principle in which the dissolved solids are separated from the water supply by applying a pressure difference across a semi-permeable membrane. The semi-permeable membrane allows the water to flow through but prevents dissolved ions, molecules, solids and also many organisms and imparts a higher quality to the product water.

Water purifiers are treatment devices that must remove all types of pathogenic organisms from the water so that the processed water is safe for drinking.

To accomplish this objective, devices have been designed to include one or more of the following:

- Membrane filters with small pore sizes that are a barrier to organism passage.
- Silver salts impregnated in gac to serve as a bacterial

inhibitor.

- Halogen based disinfectants imbedded in contact resins.
- Ultra violet light exposure; or
- Generated ozone contact of product water processed by point-of-use treatment units.

In an effort to minimize the deterioration of water quality by point-of-use treatment devices, the use should apply the following recommendations.

a) Use the point-of-use device only on a micro-biologically safe water supply, unless specifically recommended by the manufacturer. For other applications.

b) After a prolonged quiescent period (several houses or overnight), the home treatment device should be allowed to run to waste for 30 seconds or longer at full flow. Longer flushing is disabled after a prolonged non-use period such as a vacation.

c) Change the filter cartridges at least as frequently as recommended by the manufacture.

d) Adhere to the manufacture's maintenance recommendations of the filter cartridges.

There is a limit to the service life of filter cartridges in the home treatment units, which will vary, with the characteristics of the water being processed, daily water use and the treatment capacity of the unit selected.

Microbial proliferation relates to the species present in the tap water influent to the filter devices, the presence or absence of a free-chloride residual, seasonal changes in water temperatures, ambient air temperatures around the device and the service duration for a given carbon cartridge.

Static water conditions overnight or for longer intervals provide an opportunity for continued growth of organisms colonizing carbon filters. Ambient air temperatures that translated into static water temperatures, coupled with available nutrients in the carbon particles and no flushing, were the prime factors favorable to increase microbial growth i.e., The heterotrophic plate count (hpc) heterotropic bacteria.

The occurrence of pigmented bacteria (forming yellow, organic pink, brown, or black colonies) often found in treated distribution water, will be potentially useful markers in interpreting the changes in the microbiological quality of the product water from the house treatment devices.

On the basis of the data presently available in various tests, it is understood that most of the pathogenic or opportunistic bacteria will generally not colonize and \ or be present for long in the carbon filter devices that already have bio-film population of non-pathogenic heterotropic bacteria. However, source organisms such as k.preamoniae, a.hydrophila and l.prevnophila can colonize and could prove to be health hazards for some consumers.

14.6 Miscellaneous methods and its applications

Point-of-use methods for reduction or removal of contaminants in water supply:

Method / Water treatment devices	General removal applications.
Filtration	Turbidity, particulates, color
Adsorption	Chlorine, organic substances, odors
Ion exchange Cationic Anionic	Calcium, mercury, magnesium iron Arsenic, selenium

Method / Water treatment devices	General removal applications.
Distillation	Inorganic substances, dissolved solids
Reverse osmosis	Metals, total dissolved solids
Water softening	Barium
Lime softening	Cadmium
Water porifiers Filtration barrier Disinfection barrier	Giardiamunis or giandia camblia bacteria, viruses

14.7 Household water treatment and storage (handling of water)

Treatment of the water supplied to houses is required when the water is contaminated. The contamination of already treated water may be due to faulty distribution system, faulty household storage and handling of water.

The aesthetic quality of water (turbidity, temperature, etc) and reduced fecal contamination can be achieved through simple household treatment and hygienic storage. Improvement to the chemical quality using household treatment is not common.

In rural areas and even in urban areas water is often carried from a well, spring, stand posts during supplies through tankers. If the water supply is intermittent, water must be stored in homes. Treated water sometimes gets re-contaminated when transported or stored unhygienically. This leads to general risk in the public health. The water supplied which is microbiologically safe become grossly contaminated with fecal material before consumption because of poor handling.

Fecal contaminated water can be treated by:

(a) Boiling

(b) Filtration

(c) Chemical disinfection

(d) Cloth filtration

14.7.1 Boiling:

Any ova, cysts, bacteria and viruses present in the contaminated water could be killed by boiling the water by heating until it comes to a “rolling boil” and maintained for minimum of one minute.

When the attitude increases, then extra boiling time of 1 minute for every additional 1000 meters above sea level.

The main disadvantages of boiling are:

(a) It requires large amount of fuel.

(b) It may give unacceptable and unpleasant taste to the water.

(c) It may again get decontaminated after it has cooled.

14.7.2 Filtration:

Simple household filters are produced commercially and some manufactured locally. High proportion of solids, silts are removed by most filters

15.1 Origin and composition of hazardous waste effluents

Every activity of humans and others generates waste. This is especially true for industrial processes (table below). Industrial (non-medical) wastes may be roughly ranked with respect to degree of hazard. Examples of each follow.

Examples of hazardous wastes

Origin (industry)	Waste components
Chemicals	Arenes, phenols, carbon disulfide, carbon tetrachloride, cyanides, Pb, As, Hg, Cd
Pulp/paper	Lignosulfonates, chlorolignins, formaldehyde, mercaptans, phenols
Leather/tanning	Phenols, Cr, Fe
Metal finishing	Cyanides, Cu, Ni, Zn, Cr, Fe
Rubber/plastic manufacture	Trichlorothlene, anilines, arenes
Explosives	Trichlorothylene, nitroguanidine RDX, picric acid, Cu
Pharmaceuticals	Anilines, phenols, formaldehyde
Petroleum/petrochemicals	Hydrocarbons (including polycyclic aromatics), mercaptans, H_2S
Agriculture	Pesticides (herbicides, insecticides, fungicides), phenols, As, Pb
Coal	Hydrocarbons (inc.polycyclic aromatics), pyridines
Combustion(general)	Sulfur oxides, nitrogen oxides, carbon monoxide

15.2 Characteristics of effluents

15.2.1 Tannery effluent

Effluent	Volume, liters per 100 kg. of hide or skin tanned	pH	Total solids mg/l	Suspended solids mg/l	BOD (5 day, 20°C)mg/l
1. Soaking	250-400	7.5 to 8.0	8000 to 28000	2500 to 4000	500 to 3000
2. Liming	650-1000	10.0 to 12.5	16000 to 45000	4500 to 6500	6000 to 9000
3. Delim ing	700-800	3.0 to 9.0	1200 to 12000	200 to 1200	1000 to 2000
4. Vege table tanning	200-400	5.0 to 6.8	8000 to 50000	5000 to 20000	6000 to 12000
5. Chrome tanning	400-500	2.6 to 3.2	2400 to 12000	300 to 1000	800 to 12000
6. Compo site (including washings)	3000-3500	7.5 to 10.0	10000 to 25000	1250 to 6000	2000 to 3000

15.2.2 Sugar factory effluents (excluding condenser water)

Characteristics	Analysis value
1. pH	4.6 to 7.1
2. Solids	
A. Total solids (mg/l)	870 to 3500
B. Suspended solids (mg/l)	220 to 800
C. Volatile solids (mg/l)	400 to 2000
3. BOD (5-day, 20 °C),mg/l	300 to 2000
4. Chemical oxygen demand (mg/l)	600 to 4380
5. Total nitrogen (mg/l)	10 to 40

15.2.3 Distillery spent wash

Characteristics	From literature	Data from 15 factories
pH	4.5 to 5.0	3.0 to 5.4
Total (%)	5 to 9	0.15 to 10.4
Volatile solids (%)	5.3 to 6.0	0.11 to 7.5
Ash (%)	2.7 to 3.0	0.02 to 2.2
Calcium (CaO) (%)	0.26 to 0.40	...
Potash (as K2O) (%)	0.6 to 1.5	0.03to 0.72 (7 factories)
Sodium salts (as Na2O) (%)	0.15 to 0.20	...
Iron etc.hydroxides (%)	0.01 to 0.03	...
BOD (5day, 20 °C)mg/l	30000 to 70000	10000 to 73000
Phosphorus (as P) (%)	...	0.1 to 1.0
Nitrogen (as N) (%)	...	0.1 to 1.5

15.2.4 Combined waste from a pulp and paper mill

Parameter	Values (all values except pH are in mg/l)
pH	7.3 - 7.8
Total solids	560 - 1720
Suspended solids	210 - 660
BOD	135 - 200
COD	340 - 630
Total nitrogen (N)	0.8 (ave)
Phosphorus	0.3 (ave)

15.2.5 Combined wastes from cotton processing mill

Parameters	Values
1. pH	9.8 to 11.8
2. Total dissolved solids	3620 - 5230
3. Suspended solids	1500 - 1950
4. BOD	680 - 840
5. COD	1160 - 1790
6. Chloride	300 - 570
7. Sulfate	660 - 1600
8. Phosphate	20 - 25
9. Total nitrogen	45 (ave)

15.2.6 Wastes from a fertilizer industry

Parameters	Value
pH	7.0 to 10.2
Total solids	1790 - 10,420
Total nitrogen	364 - 5320
Ammonia nitrogen	313 - 1932
Urea nitrogen	28 - 3388
Phosphate	20 - 250
Fluoride	1.7 - 36.0
Arsenic	0.27 - 3.0

15.2.7 Wastes from a large dairy

Parameters	Receiving and pasteurization units	Cheese plant	Butter&ghee units	Casein plant	Combined effluent
pH	8.2	6.7	7.1	7.7	8.0
Color	White	White	Brown	Clear	White
Total solids	3640	2300	3460	680	1690
Volatile solids %	77	29	72	62	67
Suspended solids	1320	600	2240	160	690
Alkalinity (as $CaCO^3$)	500	490	350	490	590
Oxygen absorbed	437	483	90	9	120
BOD	1820	2150	1377	200	816
COD	2657	3188	3218	372	1340

Parameters	Receiving and pasteurization units	Cheese plant	Butter & ghee units	Casein plant	Combined effluent
Total nitrogen	-	-	-	-	84
Phosphates	10	12	2	5	12
Oil & grease	690	520	1320	Nil	290
Chlorides	105	105	105	70	112
COD : BOD	1.46	1.48	2.33	1.86	1.65

All parameters except pH, color, volatile solids and COD : BOD are in mg/

15.2.8 Wastes from refinery

Parameters	Range (mg/l)
Free oil	2000 - 3000
Emulsified oil	80 - 120
H_2S and RSH	10 - 220
Phenol compounds	12 - 30
BOD	100 - 300
Suspended solids	200 - 400

16.1 Significance of chemical parameters

- Aluminum: causes Alzheimer's disease.

- Arsenic: the pathogenicity of arsenic is thought to be due to the binding of sulphydril enzymes, that interrupts cellular metabolism. The symptoms of acute poisoning are initially gastrointestinal. Two to three hours after an oral dose, there is sudden vomiting and copious watery diarrhea, which may be bloody. If death does not occur, jaundice and renal failure may develop after a couple of days. The fatal dose may be as low as 100 mg. Chronic poisoning is manifest by anorexia, diarrhea and weight loss. If poisoning continues, other features include typical skin changes such as bronzing and hyperkeratosis of the palms and soles, peripheral neuritis, and cardiac, renal and liver changes.

Blackfoot disease is the name given to a peripheral vascular disease caused by arsenic. The disease usually begins with numbness or coldness in the feet. Cumulative exposure to arsenic is associated with hypertension. The cutaneous signs of arsenism include hypopigmentation, hyperpigmentation, palmoplantar keratosis, papular keratosis, and ulcerative zones. The exposed population is likely to suffer from nausea, epigastric pain, colic, diarrhea, headache and oedema.

Chronic arsenism, due to consumption of artesian drinking water, has been reported to be endemic in the southwest coast of Taiwan. Arsenical dermatitis is seen in the rural Asia, where it is associated with water from tube wells. This problem was first identified in 1983. The arsenic concentrations in tube well water associated with affected families ranged from 0.20 to 2.00 mg/l.

- Barium: the soluble salts of barium are acutely toxic. Features of acute poisoning include gastroenteritis, weakness, paralysis, convulsions and myocarditis. The fatal dose for an adult is between 500 and 1000 mg. Barium ion affects muscle cell membranes so that the muscle fibre is stimulated indiscriminately. Treatment involves supportive care and the use of the antidote, sodium sulfate.

- Copper: although copper is considered as non-toxic, high concentrations can have both acute and chronic effects. Excess copper in water causes vomiting and abdominal pain. Copper levels in the hair of the affected persons may elevate. The water may become acidic and corrosive. In severe cases micronodular liver cirrhosis may occur.

- Fluoride: acute ingestion of excess fluorides results in salivation, nausea, vomiting, abdominal pain and diarrhoea followed by weakness, muscle spasm and convulsions. Death is by respiratory paralysis. Chronic poisoning, with the ingestion of more than about 6 mg of fluorine per day, results in a condition known as fluorosis. Fluorosis results in weight loss, anaemia, brittle bones, joint stiffness and mottling of teeth. Treatment of acute poisoning is by giving intravenous calcium gluconate with oral milk of magnesia. If this form of calcium is not available, then any soluble oral form of calcium such as, milk or calcium gluconate or lactate solution plus magnesium sulphate is suitable. Supportive measures include treatment of shock and giving milk or cream every few hours to reduce oesophageal pain. Treatment of fluorosis is the removal of the patient from continuing exposure.

- Hardness: calcium and magnesium, the chief chemical components of hardness, are not in themselves acutely toxic at anywhere near the doses that could be dissolved in water. However, the health effects of hardness have received more interest than most other topics in water chemistry. Many studies have identified a negative association between water hardness and deaths from cardiovascular disease. Cardiovascular mortality in soft water areas (25 mg/l) is found to be higher than in areas with medium hard water (170 mg/l). Increased hardness above this latter level had no further protective effect. The exact mechanism for this small but consistent protective effect of water hardness on cardiovascular death rates is not fully proven.

- Lead. the features of lead poisoning include experience of a metallic taste, vomiting, abdominal pain and diarrhoea. Features of chronic poisoning include a metallic taste in the mouth, constipation, abdominal pain and peripheral nerve palsies. Severe cases, especially in children, may be present with encephalopathy, leading to coma and convulsions. Typical blue lead lines may be seen on the gums. Chronic lead poisoning requires chelation therapy with calcium disodium edetate. Dimercaprol may also be added in severe cases and in cases of encephalopathy.

- Ammonia: Ammonia is a by-product of the decay of plant and animal proteins and fecal matter. It is also formed from the decomposition of urea and uric acid in urine.

On dissolution in water, ammonia forms the ammonium cation; hydroxyl ions are formed at the same time. The equilibrium constant of this reaction, kb is $1.78x10-^{5}$. The degree of ionization depends on the temperature, the pH, and the concentration of dissolved salts in the water.

The environmental cycling of nitrogen relies mainly on nitrate, followed by ammonia and the ammonium cation, which predominates. The ammonium cation is less mobile in soil and water than ammonia and is involved in the biological processes of nitrogen fixation, mineralization and nitrification.

Ammonia has a toxic effect on healthy humans only if, the intake becomes higher than the capacity to detoxify.

If ammonia is administered in the form of its ammonium salts, the effects of the anion must also be taken into account. With ammonium chloride, the acidotic effects of the chloride ion seem to be of greater importance than those of the ammonium ion. At a dose of more than 100 mg/kg of body weight per day (33.7 mg of ammonium ion per kg of body weight per day), ammonium chloride influences metabolism by shifting the acid-base equilibrium, disturbing the glucose tolerance, and reducing the tissue sensitivity to insulin.

By testing for ammonia you are able to indicate if there is sewage or sewage sludge entering the body of water.

Ammonia is very poisonous to fish and other aquatic organisms even in very low concentrations. When the level reaches 0.06 mg/l, fish can suffer gill damage and when levels reach 0.2 mg/l, sensitive fish like trout begin to die. When level nears 2.0

even the hardy, pollution tolerant fish like carp begin to die. Levels greater than about 0.1 mg/l usually indicate polluted water. The danger ammonia poses for fish also depends on the temperature and pH of the water, the amount of dissolved oxygen and carbon dioxide present. Ammonia is much more poisonous to fish and aquatic life when water contains very little dissolved oxygen.

Ammonia and its derivatives significantly accelerate the process of eutrophication in waterways.

- Nitrites: Nitrites are the inorganic free-state of nitrogen. They are usually short lived being quickly converted into nitrates by bacteria. Nitrate should be discussed in terms of NO_2 + NO_3 since it is after conversion from NO_3 to NO_2, that it becomes harmful. However, NO_2 will seldom be present in any appreciable level in natural waters.

(a) Nitrites cause brown blood disease in populations of fish, even though they exist as nitrites for only a short period of time. Nitrite levels below 0.5 mg/l do not appear to have an effect on warm-water fish. Cold-water fish however seem to be more sensitive to the amount of nitrite content in water.

(b) Nitrites can also affect humans due to the fact that it reacts directly with hemoglobin in the blood, which in turn causes methemoglobinemia. Nitrites oxidise the haemolobin of the blood to methamoglobin, which is incapable of absorbing oxygen.

(c) Because nitrites are quickly converted to nitrates, they indirectly accelerate the process of eutrophication. Eutrophication is the process whereby bodies of water become fertilized, allowing rapid plant growth to occur. The process of eutrophication causes reduced oxygen levels, increased carbon dioxide levels and eventual fish die-offs if left untreated. For this reason levels of nitrites in waters should not exceed. 0.6 mg/l.

(d) Nitrites ingested as such or formed from ingested NO_3 may react in the body with amines and amides derived from food to produce nitrosoamines. The reaction takes place in the acidic condition of the adults' stomach. Nitrosoamines are considered to be carcinogenic.

The oral lethal dose for humans ranges from 33 to 250 mg of nitrite per kg of body weight, the lower doses applying to children and elderly people. Toxic doses give rise to methaemoglobinaemia range from 0.4 to 200 mg/kg of body weight.

Another source of nitrite toxicity in humans is the use of sodium nitrite as medication for vasodilation or as an antidote in cyanide poisoning.

- Nitrate: nitrates are widely distributed in soil, water and plants and are found in most foods and drinking waters. The excess nitrate in water may come from agricultural sources, because nitrates form the basis of many fertilizers. They can also come from domestic and industrial effluents, and decaying animal and vegetable matter. Symptoms of acute poisoning include headache, vomiting, flushing of the skin, hypotension, collapse, convulsions and coma. In infants, methaemoglobinaemia can develop after exposure to high levels of nitrate. Methaemoglobinaemia occurs when the ferrous ion of haemoglobin is oxidized to the ferric form. This form of haemoglobin is less effective at carrying oxygen. The earliest clinical feature is cyanosis, but after 30 - 40% of haemoglobin has been converted to methaemoglobin, there is weakness and excertional dyspnoea. After about 60% has been converted, respiratory depression and stupor develop. Death may follow soon after. Diagnosis of acute nitrate poisoning is aided by the demonstration of methaemoglobin in blood samples. Treatment is by giving oxygen and possibly the antidote, which is methylene blue or ascorbic acid.

- Sodium: the relative importance of drinking-water sodium depends on the sodium concentration in water and the total sodium intake from all sources. In adults acute poisoning from sodium chloride is virtually unheard of due to the efficient way that the kidneys handle sodium. Salt has been used therapeutically as an emetic, and large oral intakes will usually induce vomiting, with the ejection of the salt. However, hypernatraemia may develop in the very young and in those with impaired renal function. Clinical features of hypernatraemia may include cerebral and pulmonary oedema with convulsions, muscle twitching and breathlessness. For most healthy adults, drinking-water sodium contributes only marginally to daily sodium intake. Nevertheless, for the very young and those on severely reduced sodium intakes for medical reasons, water-sodium levels can cause problems when moderately elevated.

- Biochemical oxygen demand (BOD): For this parameter, no standard has been set for drinking water use. The BOD value is an indication of the degree of pollution of a source by biodegradable organic substances.

The biochemical oxygen demand test (BOD) is an empirical one that determines the relative oxygen requirements for the various organic substances present in water, as they are biodegraded by aquatic microorganisms. The study of the biochemical consumption of oxygen provides information on the processes of the degradation of organic compounds. This process can be assessed by the measurement of the amount of oxygen used up and the rate of oxygen consumption. The process is a complicated one, and depends on the various organic compounds present in water, the types of microorganism available and on many other parameters such as pH, DO content, nutrient levels, the presence of toxic substances, the adaptation of the microorganisms to the organic substances etc.

Thousands of different organic compounds may occur in water because the environmental conditions vary so much. For this reason, the process is very difficult to express mathematically.

Usually, the kinetics of the processes is summarized in the form of first order equations (unimolecular reactions). These equations are used to describe many chemical reactions.

The reactions of biochemical degradation of organic
bacteria
compounds may be expressed by the general equation:

$$\text{Organic substances} + O_2 \longrightarrow CO_2 + H_2O + \text{more bacteria}$$

Radium: radium is derived from the radioactive decay of uranium and itself decays into radon and eventually into stable lead:

$^{234}U \rightarrow {}^{230}Th \rightarrow {}^{236}Ra \rightarrow {}^{222}Rn \rightarrow \ldots \rightarrow {}^{206}Pb$

Radium causes lung and bladder cancer in males and breast and lung cancer among females. Radium may also cause leukemia.

16.2 Major uses

16.2.1 Ammonia

Ammonia is used in fertilizer and animal feed production and in the manufacture of fibres, plastics, explosives, paper, and rubber. It is used as a coolant in metal processing, and as a starting product for many nitrogen-containing compounds , ammonia and ammonium salts are used in cleansing agents and as food additives and ammonium chloride is used as a diuretic.

16.2.2 Antimony

Antimony is used in semiconductor alloys, batteries, antifriction compounds, ammunition, cable sheathing, flameproofing compounds, ceramics, glass, pottery, type castings for commercial printing, solder alloys, and fireworks. Some antimony compounds are used for the treatment of parasitic diseases and as pesticides.

16.2.3 Arsenic:

Arsenicals are used commercially and industrially as alloying agents in the manufacture of transistors, lasers, and semiconductors, as well as in the processing of glass, pigments, textiles, paper, metal adhesives, wood preservatives, and ammunition. They are also used in the hide-tanning process and, to a limited extent, as pesticides, feed additives, and pharmaceuticals.

16.2.4 Asbestos:

Asbestos, particularly chrysolite, is used in a large number of applications, particularly in construction materials, such as asbestos-cement (a/c) sheet and pipe, electrical and thermal insulation, and friction products, such as brake linings and clutch pads.

16.2.5 Barium

Barium compounds, including barium sulfate and barium carbonate, are used in the plastics, rubber, electronics, and textile industries; In ceramic glazes and enamels, in glass-making, brick-making, and paper-making, as a lubricant additive; In pharmaceuticals and cosmetics, in case-hardening of steel, and in the oil and gas industry as a wetting agent for drilling mud.

16.2.6 Beryllium

Beryllium and its alloys have a number of important uses, mostly based on their heat resistance. these include uses in space vehicles, x-ray equipment, and electrical components.

16.2.7 Boron

Elemental boron and its carbides are used in composite structural materials, high-temperature abrasives, special-purpose alloys, and steel-making. Boron halides are used as catalysts in the manufacture of magnesium alloy products, metal refining, and rocket fuels. Boron hydrides are used as reductants, to control heavy metal discharge in wastewater, as catalysts, and in jet and rocket fuels.

Boric acid and borates are used in glass manufacture and as wood and leather preservatives, flame retardants, cosmetic products, and neutron absorbers for nuclear installations. Boric acid, borates, and perborates have been used as mild antiseptics or bacteriostats in eyewashes, mouthwashes, burn dressings, and nappy rash powders, although boric acid is not now regarded as effective for this purpose. Borax is used extensively as a cleaning compound, and borates are applied as agricultural fertilizers. Boron compounds are also used as algicides, herbicides and insecticides.

16.2.8 Cadmium

Cadmium metal is used mainly as an anticorrosive, electroplated onto steel. Cadmium sulfide and selenide are commonly used as pigments in plastics. Cadmium compounds are used in electric batteries, electronic components and nuclear reactor.

16.2.9 Chloride

Sodium chloride is widely used in the production of industrial chemicals such as caustic soda, chlorine, sodium chlorite, and sodium hypochlorite. Sodium chloride, calcium chloride, and magnesium chloride are extensively used in snow and ice control. Potassium chloride is used in the production of fertilizers.

16.2.10 Chromium

Chromium and its salts are used in the leather tanning industry, the manufacture of catalysts, pigments and paints, fungicides, ceramic and glass industry, photography, for chrome alloy and chromium metal production, chrome plating, and corrosion control.

16.3 Basic chemistry

(1) Element: an element is a pure substance that cannot be broken down into simpler substances e.g. Hydrogen, oxygen, gold, iron, sulfur.

(2) Atom: the smallest particle of an element which cannot be further broken down without losing its properties is called an atom.

(3) Compound: a compound is a pure substance of two or more elements combined chemically e.g. Water, sugar, sodium chloride, chloroform.

(4) Molecule: the smallest particle of a compound which cannot be further broken down without losing its properties is called a molecule.

(5) Mixture: the substance that contains two or more substances in variable amounts. The components of the mixture can be separated by physical processes e.g. Air

(6) Bonding:

(a) Covalent bonding

(b) Ionic bonding

(c) Hydrogen bonding

(7) Atomic number: the number of protons or the number of electrons present in an atom of an element is called its atomic number.

(8) Equivalent weight of an element: equivalent weight of an element is the atomic weight divided by valency.

Molecular weights and equivalent weights of substances:

No.	Substance	Molecular weight	Equivalent weight
1.	Sodium oxalate	134.00	67.00
2.	Benzoic acid	122.13	122.13
3.	Borax	381.44	190.72
4.	Potassium ferrocyanide	422.41	422.41
5.	Potassium nitrate (KNO_3)	101.10	101.10
6.	Lead sulfate ($PbSO_4$)	303.27	303.27
7.	Ammonium thiocyanate (NH_4CN_s)	76.00	76.00
8.	Arsenious oxide (As_2O_3)	197.82	49.45
9.	Conc. Hydrochloric acid (HCl)	36.50	36.50
10.	Conc. Sulphuric acid (H_2SO_4)	98.00	49.00
11.	Conc. Nitric acid (HNO_3)	63.00	63.00
12.	Copper sulfate ($CuSO_4.5H_2O$)	249.71	249.71
13.	Ferrous ammonium sulfate {$FeSO_4(NH_4)2SO_4.6H_2O$}	392.10	392.10

No.	Substance	Molecular weight	Equivalent weight
14.	Iodine (I_2)	253.84	126.92
15.	Oxalic acid ($C_2H_2O_4.2H_2O$)	126.08	63.04
16.	Potassium chloride (KCl)	74.56	74.56
17.	Potassium hydroxide (KOH)	56.00	56.00
18.	Potassium dichromate ($K_2Cr_2O_7$)	294.21	49.03
19.	Potassium permanganate ($KMnO_4$)	158.03	31.60 (acidic medium)
20.	Potassium thiocyanate (KCNS)	97.16	97.16
21.	Sodium chloride (NaCl)	58.46	58.46
22.	Sodium carbonate (Na_2CO_3)	106.00	53.00
23.	Sodium hydroxide (NaOH)	40.00	40.00
24.	Sodium thiosulfate ($Na_2S_2O_3.5H_2O$)	248.20	248.20
25.	Silver nitrate ($AgNO_3$)	169.89	169.89
26.	Sodium bicarbonate ($NaHCO_3$)	84.00	84.00

(9) Gram equivalent weight: it is that weight of a substance which will react with or displace 1.008 g of hydrogen or 8 g of oxygen or 35.45 g of chlorine or that quantity of any element which reacts with these weights of hydrogen, oxygen and chlorine.

(10) Solution: when a substance is dissolved in a solvent, it is called a solution.

(11) Molar solution: a molar solution (1 M) is one which contains one gram molecular weight (formula weight) i.e one mole of solute per liter of solution.

Eg:

1 M sodium chloride = 58.45 g $NaCl$/ 1 liter of solution.

1 M sulphuric acid = 98.08 g H_2SO_4/ 1 liter of solution.

1 M oxalic acid = 126.1 g $H_2C_2O_4.2H_2O$/ 1 liter of solution.

(12) Normal solution: a normal solution (1 N) is one that contains one gram equivalent weight of solute per liter of solution.

(13) Simple salt: a simple salt is formed by the neutralization of an acid and a base.

$$\underset{\text{alkali}}{NaOH} + \underset{\text{acid}}{Hcl} \rightarrow \underset{\text{salt}}{Nacl} + \underset{\text{water}}{H_2O}$$

(14) Double salt: when two or more normal salts are mixed in requisite proportions and allowed to crystallize together, a → double salt is formed.

$FeSO_4$(simple salt) + $(NH4)_2SO_4$(simple salt) + $6H_2O$

$FeSO_4.(NH4)_2SO_4.6H_2O$(double salt ferrous ammonium sulfate)

Double salt gives in aqueous solution, the test of all its constituent ions.

(15) Complex salt: a complex salt is formed by the combination of two or more simple salts. But the new salt formed has entirely new physical and chemical characters. The complex ion in the new complex salt has charged radical, which is formed by the combination of a simple cation with one or more neutral molecules or one or more complex other simple ions.

$FeSO_4 + 6KCN \rightarrow K_4[Fe(CN)_6] + K_2SO_4$

Complexes may be either chelated or non-chelated. In chelation, cyclic structures are formed by union of metallic atoms with organic or inorganic molecules. Normally chelated complexes are more stable than the simple non-chelated complexes.

Buffer solution: a buffer solution is one whose pH does not change either on dilution or on keeping for a long time. pH of such a solution is not altered by a small addition of either an acid or alkali.

Eg :

(1) $CH_3COOH + CH_3COONa$

(2) $NH_4OH + NH_4Cl$

Strength for some concentrated acids:

Name	Specific gravity	Normality (approximate)
Hydrochloric acid (HCl)	1.19	12 n
Sulphuric acid (H_2SO_4)	1.84	36 n
Nitric acid (HNO_3)	1.42	16 n
Acetic acid (CH_3COOH)	1.05	16 n

pH values of some liquids/solutions:

Liquid/solution	pH
Hydrochloric acid, 0.1 N	1.1
Sulfuric acid, 0.1 N	1.2
Oxalic acid, 0.1 N	1.6
Tartaric acid, 0.1 N	2.2

Liquid/solution	pH
Citric acid, 0.1 N	2.2
Acetic acid, 0.1 N	2.9
Benzoic acid, 0.1 N	3.1
Boric acid, 0.1 N	5.2
Sodium hydroxide, 0.1 N	13.0
Sodium carbonate, 0.1 N	11.6
Ammonia 0.1 N	11.1
Borax, 0.1 N	9.2
Sodium bicarbonate, 0.1 N	8.4
Grape fruit juice	3.1
Soda water	4.0
Blood	7.2

Body fluid buffers

Body fluids contain three major buffer systems: the carbonic acid/bicarbonate buffer, the $H_2PO_4^-$ - HPO_4^{--} buffer, and the protein buffer. The body uses each of these to regulate pH.

Dissolved carbon dioxide gas from metabolism combines with water in blood plasma to form unstable carbonic acid (H_2CO_3).

$$CO_2(g) + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$$

carbonic acid is a weak acid that dissociates:

$$H_2CO_3 \rightarrow H^+_{(aq)} + HCO_3^-{}_{(aq)}$$

Carbonic acid is capable of neutralizing base added to the solution; bicarbonate ion can neutralize hydrogen ions from an acid added to the solution (e.g. Lactic acid). Because of their ability to neutralize hydrogen ions, bicarbonate ions are occasionally called the alkaline reserve of the body fluids. Bicarbonate is present in higher concentration than other buffer conjugate bases. The enzyme carbonic anhydrase catalyzes the breakdown of the carbonic acid formed into water and carbon dioxide. The lungs expel the latter.

pH and oxygen transport

To meet normal metabolic demands, the human body requires an enormous amount of oxygen on a continuous basis. The maintenance of a relative constancy of 7.4 of blood pH is vital for oxygen transport. The oxygen transport is a pH-controlled process; deoxygenation into active cells require H+

ions.

O_2 + HHB → $HHBO_2$ → H^+ + HBO_2^- (in lungs & red blood cells)

H_2O + CO_2 → H_2CO_3 → H^+ + HCO_3^- (in hemoglobin)

Qualitative analysis

Detection of the constituents (an ion or a pure substance) in a substance (mixture or compound) is known as qualitative analysis. The quantity of the ion or the substance present will not be known.

Quantitative analysis

Determining by weight or volume the exact quantities of the different constituents present in a substance is known as quantitative analysis.

Quantitative analysis can be done by any one or more of the following methods:

(i)Volumetric analysis

(a) Acid-base titration

(b) Oxidation-reduction titration

(c) Iodimetry-iodometry titration

(d) Precipitation titration

(e) Complexometric titration

(f) Conductometric titration

(g) Potentiometric titration

Formula used :– (1) $V_1N_1 = V_2N_2$

where, V_1 – volume of reagent 1

V_2 – volume of reagent 2

N_1 – strength of reagent 1

N_2 – strength of reagent 2

(2) Normality = (W x 1000)/(E x V)

where,

W- weight of substance taken

E - equivalent weight

V - Volume

Indicators used:- (1) internal indicator

- (a) Acid-base indicator
- (b) Precipitation indicator
- (c) Redox indicator
- (d) Adsorption indicator

(2) external indicator

(3) self indicator

Standard atomic weights, 1993

[scaled to $a_r(^{12}c) = 12$]

Name of the element	Symbol	Atomic number	Atomic weight
Actinium*	Ac	89	
Aluminium	Al	13	26.981539
Americium*	Am	95	
Antimony	Sb	51	121.760
Argon	Ar	18	39.948
Arsenic	As	33	74.92159
Astatine*	At	85	
Barium	Ba	56	137.327
Berkelium*	Bk	97	
Beryllium	Be	4	9.012182
Bismuth	Bi	83	208.98037
Boron	B	5	10.811
Bromine	Br	35	79.904
Cadmium	Cd	48	112.411
Calcium	Ca	20	40.078
Californium*	Cf	98	
Carbon	C	6	12.011
Cerium	Ce	58	140.115
Cesium	Cs	55	132.90543
Chlorine	Cl	17	35.4527
Chromium	Cr	24	51.9961

Name of the element	Symbol	Atomic number	Atomic weight
Cobalt	Co	27	58.93320
Copper	Cu	29	63.546
Curium*	Cm	96	
Dysprosium	Dy	66	162.50
Einsteinium*	Es	99	
Erbium	Er	68	167.26
Europium	Eu	63	51.965
Fermium*	Fm	100	
Fluorine	F	9	18.9984032
Francium*	Fr	87	
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.723
Germanium	Ge	32	72.61
Gold	Au	79	196.96654
Hafnium	Hf	72	178.49
Helium	He	2	4.002602
Holmium	Ho	67	164.93032
Hydrogen	H	1	1.00794
Indium	In	49	114.818
Iodine	I	53	126.90447
Iridium	Ir	77	192.217
Iron	Fe	26	55.845
Krypton	Kr	36	83.80
Lanthanum	La	57	138.9055

Name of the element	Symbol	Atomic number	Atomic weight
Lawrencium*	Lr	103	
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Lutetium	Lu	71	174.967
Magnesium	Mg	12	24.3050
Manganese	Mn	25	54.93805
Mendelevium*	Md	101	
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.1797
Neptunium*	Np	93	
Nickel	Ni	28	58.6934
Niobium	Nb	41	92.90638
Nitrogen	N	7	14.00674
Nobelium*	No	102	
Osmium	Os	76	190.23
Oxygen	O	8	15.9994
Palladium	Pd	46	106.42
Phosphorus	P	15	30.973762
Platinum	Pt	78	195.08
Plutonium*	Pu	94	
Polonium	Po	84	
Potassium	K	19	39.0983

Name of the element	Symbol	Atomic number	Atomic weight
Praseodymium	Pr	59	140.90765
Promethium*	Pm	61	
Protactinium*	Pa	91	231.03588
Radium*	Ra	88	
Radon*	Rn	86	
Rhenium	Re	75	186.207
Rhodium	Rh	45	102.90550
Rubidium	Rb	37	85.4678
Ruthenium	Ru	44	101.07
Samarium	Sm	62	150.36
Scandium	Sc	21	44.955910
Selenium	Se	34	78.96
Silicon	Si	14	28.0855
Silver	Ag	47	107.8682
Sodium (natrium)	Na	11	22.989768
Strontium	Sr	38	87.62
Sulfur	S	16	32.066
Tantalum	Ta	73	180.9479
Technetium*	Tc	43	
Tellurium	Te	52	127.60
Terbium	Tb	65	158.92534
Thallium	Ti	81	204.3833
Thorium*	Th	90	232.0381
Thulium	Tm	69	168.93421

Name of the element	Symbol	Atomic number	Atomic weight
Tin	Sn	50	118.710
Titanium	Ti	22	47.867
Tungsten	W	74	183.84
Uranium*	U	92	238.0289
Vanadium	V	23	50.9415
Xenon	Xe	54	131.29
Ytterbium	YB	70	173.04
Yttrium	Y	39	88.90585
Zinc	Zn	30	65.39
Zirconium	Zr	40	91.224

* element has no stable nuclides.

Ref: Standard methods for the examination of water and wastewater, 19th edition, 1995 Apha AWWA

Acid-base indicators:

Indicator	Transition pH range	Color change	
		Acid	Base
Methyl violet	0.5 - 1.5	Yellow	Blue
Thymol blue	1.2 - 2.8	Red	Yellow
Methyl yellow	2.9 - 4.0	Red	Yellow
Methyl orange	3.1 - 4.4	Red	Yellow
Methyl red	4.2 - 6.3	Red	Yellow

Indicator	Transition pH range	Color change	
		Acid	Base
Bromocresol green	3.8 - 5.4	Yellow	Blue
Phenol red	6.4 - 8.0	Yellow	Red
Cresol purple	7.4 - 9.0	Yellow	Purple
Cresol purple	1.2 - 2.8	Red	Yellow
Phenolphthalein	8.0 - 9.6	Colorless	Red
Thymolphthalein	9.3 - 10.5	Colorless	Blue
Alizarin yellow R	10.1 - 12.0	Colorless	Violet

(ii) Gravimetric analysis

E.g. Testing of TDS (total dissolved solids)

Formula:

Weight in mg/l of a dissolved substance

$$= \{[w2-w1] \times 1000\}/V$$

Where,

W1 - initial weight

W2 - final weight

V - volume of water/solution

(Iii) Colorimetric analysis

E.g. Use of colorimeter, spectrophotometer, UV-visible Spectrophotometer for testing of Fe, NO_3, F, PO_4, NH_3, NO_2 etc.

Formula:

Substance mg/l = o.d x slope x dilution factor

(iv) Instrumentation analysis

E.g. pH meter, flame photometer

Reference:

(A) Subash-Satish, Advanced Inorganic Chemistry, Pragathi Prakashan, Meerut, India, Seventh Edition, 1989.

(b) Curtis T.Sears/Conrad L.Stanitski, Chemistry for health-related sciences, concepts and correlations, Second Edition, Prentice Hall, 1983.

(c) Standard methods for examination of water and wastewater 20th edition, APHA, AWWA

17.1 Significance of water quality parameters and source

Sl.no	Parameter	Source	Significance
1.	Turbidity	(i) Silt, clay, finely divided organic matter, planktons and other organisms (ii) Ferric iron in ground water/surface water	(i) Objectionable from the point of appearance
2.	Color	(i) Iron and manganese (ii) Decayed vegetable matter (iii)Pollution due to industrial waste	(i) Aesthetically not acceptable (ii) Discoloring of clothes
3.	Odor	(i) Decomposed organic matter (ii) Metabolic activity of organism (iii) Hydrogen sulfide (iv) Algae (v) Earthy odor due to actinomycetes (vi) Polluting substances	(i) Aesthetically not acceptable
4.	Taste	(i) Decomposition of organic matter (ii) Metabolic activity of organisms (iii) Phenol & other pollutants (iv) Earthy taste due to actinomycetes (v) High levels of chloride & sulfate	(i) Aesthetically not acceptable
5.	Total dissolved solids	(i) Salts present in water (ii) Mixing of industrial effluents	(f) Undesirable taste (g) Laxative effects (h) Gastro intestinal irritations

Sl.no	Parameter	Source	Significance
6.	PH	(i) Presence of limestone deposits (ii) Presence of dissolved Co_2 and alkalinity (iii) Decomposition of vegetation	(i) Affects mucous membrane (ii) Low pH causes corrosion
7.	Alkalinity	(i) Presence of carbonate, bicarbonate and hydroxide (ii) Presence of borates, phosphates and silicates	(i) Boiled rice is yellowish (ii) Boiled dhal is rubbery
8.	Total hardness	(i) Presence of calcium and magnesium	Scale formation in boilers Cardio vascular disease
9.	Calcium	(i) Dissolution of soils and rock	(i) Incrustation in pipes (ii) In combination with chloride, becomes corrosive and causes pitting of boilers
10.	Magnesium	(i) Dissolution of soils and rock	(I) In combination with chloride becomes, corrosive (ii) In combination with sulfate causes laxative effect
11.	Iron	(i) Ferrous bicarbonate in ground water (ii) Ferric and organically bound iron	(i) Taste, color, turbidity and staining problems (ii) Causes bitter taste above 2 mg/l (iii) Iron bacteria (crenothrix) in the distribution system causing slime and objectionable odor.

Sl.no	Parameter	Source	Significance
12.	Manganese	(I) Present as manganese bicarbonate along with iron (ii) Industrial and mine effluent pollution	(iii) Taste, color, turbidity & staining of cloth (iv) Black slime coating formed in distribution systems in the presence of oxygen and chlorine
13.	Aluminum	(i) Overdosing in treatment plants (ii) Effluent from aluminum based industries	(i) Neurological disorders (ii) In the form of antacids, leads to loss of phosphate
14.	Copper	(i) Industrial and mine effluent pollution (ii) Copper sulfate used as algaecide (iii) Dissolution of copper pipes	(i) Imparts taste (ii) High concentration causes sickness and liver damage (iii) Large doses cause mucosal irritation, renal damage and depression
15.	Zinc	(I) Pollution from industrial and mine effluent (ii) Dissolution of galvanized pipes (iii) Dezincification of brass fittings	(e) Astringent taste (f) Opalescence in water (g) Gastro intestinal irritation (h) High doses cause vomiting, dehydration, abdominal pain, nausea and dizziness.
16.	Ammonia	(I) Degradation of nitrogenous organic matter (ii) Sewage pollution (iii) Reduction of nitrate in ground water	(i) Corrosion in pipes (ii) Promotes growth of organisms (iii) Growth of algae in presence of phosphate

Sl.no	Parameter	Source	Significance
17.	Nitrite	(i) Pollution in the near past	(i) Ingested nitrite reacts with secondary and tertiary amines to turn nitrosamine which may be carcinogenic
18.	Sulfate	(i) Dissolution of soil and rock gypsum (ii) Salt water intrusion (iii) Industrial effluents dealing with sulfate and sulfuric acid	(i) Taste (ii) Laxative effect (iii) Gastro intestinal irritation (iv) Anaerobic condition releases hydrogen sulfide
19.	Chloride	(i) Dissolution of rocks (ii) Salt water intrusion (iii) Mixing of tannery waste	Salty taste Corrosive Causes pitting in boilers
20.	Hydrogen sulfide	(i) Reduction of sulfate (ii) Decomposition of organic matter (iii) Industrial pollution	(i) Rotten egg smell (ii) Corrosive (iii) Promotes sulfur bacteria and clogging of pipes
21.	Anionic detergents	(i) Mixing of domestic waste water	(i) Undesirable foaming
22.	Fluoride	(i) Fluorospar in sedimentary rock (ii) Cryolite in igneous rock	(I) Low fluoride causes dental caries (ii) High fluoride causes dental fluorosis, skeletal fluorosis and other non-skeletal manifestations
23.	Nitrate	(i) Sewage pollution (ii) Use of fertilizers (iii) Leaching of nitrates from soil	(i) Infantile methemoglobinemia (ii) Irritation of mucous membrane in adults

Sl.no	Parameter	Source	Significance
24.	Arsenic	(i) Industrial effluent and mine waste pollution (ii) Spraying of insecticides and pesticides (iii) Volcanic action	(i) Toxic effect (ii) Affects central nervous system (iii) Chronic poisoning causing muscular weakness.
25.	Chromium	(i) Industrial waste pollution (ii) Tannery waste pollution	(i) Carcinogenic (ii) Ulcer and dermatitis
26.	Cyanide	(2) Electroplating industry (3) Photo film industry (4) Mining industry	(i) Toxic
27.	Mercury	(i) Industrial pollution	(i) Neurological impairment and renal disturbances (ii) Mutagenic (iii) Disturbs cholesterol metabolism
28.	Cadmium	(i) Metal finishing industrial waste	(i) Affects cardio vascular system (ii) Gastro intestinal upsets and hyper tension (iii) Teratogenic, mutagenic and carcinogenic
29.	Lead	(i) Dissolution from lead plumbing (ii) Leaching out of plastic pilpe in which lead compounds are used as stabilizer	(i) Tiredness, lassitude, abdominal discomfort and irritability, anemia (ii) Cumulative poisoning effect
30.	Pesticides	(i) Use of pesticides in agriculture	(i) Affects central nervous system (ii) Toxic

17.2 WHO Guidelines

S.No	Physical	
1.	Color (Pt-Co scale)	15
2.	Appearance	-
3.	Odor	Not offensive
4.	Taste	Not offensive
5.	Turbidity NTU	5
6.	Total dissolved solids	1000

S.No	Chemical	
7.	ph	6.5 - 8.5
8.	Alkalinity as $CaCO_3$, mg/L, max	-
9.	Total hardness as '$CaCO_3$'	500
10.	Calcium as 'Ca'	-
11.	Magnesium as 'Mg'	-
12.	Sodium as 'Na'	200
13.	Potassium as 'K'	-
14.	Iron as 'Fe'	0.3
15.	Manganese as 'Mn'	0.1
16.	Ammonia as 'NH_3'	-
17.	Nitrite as 'NO_2'	-
18.	Nitrate as 'NO_3'	45
19.	Chloride as 'Cl'	250
20.	Fluoride as 'F '	1.5
21.	Sulfate as 'SO_4'	400
22.	Phosphate as 'PO_4'	-
23.	Boron as 'B'	-
24.	Aluminium as 'Al'	0.2

S.No	Chemical	
25.	Zinc as 'Zn'	5
26.	Copper as 'Cu'	1.0
27.	Mercury as 'Hg'	0.001
28.	Cadmium as 'Cd'	0.005
29.	Selenium as 'Se'	0.01
30.	Arsenic as 'As'	0.05
31.	Lead as 'Pb'	0.05
32.	Chromium as 'Cr'	0.05
33.	Cyanide as 'CN'	0.1
34.	Anionic detergent	-
35.	Mineral oil	-
36.	Pesticide	-
37.	Phenol compounds	-
38.	Residual free chlorine, (min)	-
39.	Poly nuclear aromatic compounds, PAHs (Polycyclic Aromatic Hydrocarbons)	-

S.No	Radio activity	
40.	Gross alpha activity pCi/lit	-
41.	Gross beta activity pCi/lit	-

17.3 Undesirable effects of water quality parameters:

The constituents in water should be well within the safe limits for human usage and consumption. The water supplied should be aesthetically good, chemically potable and without any contamination by bacteria.

The World Health Organization defines unsafe water to have any/all of the following constituents:

(1) Those influencing the potability:

- Total dissolved solids
- Iron
- Manganese
- Calcium
- Magnesium
- Copper
- Zinc
- Chloride

- ✶ Sulfate
- ✶ pH

(2) Those having effects upon health:

- ✶ Nitrate
- ✶ Fluoride

(3) Those with toxic effects:

- ✶ COD
- ✶ BOD
- ✶ Total Kjeldahl Nitrogen (TKN)
- ✶ NH_3

17.4 Drinking water standards and significance of parameters

Drinking water standards

Guidelines for drinking water, Vol I - WHO Recommendations, 1984.

No	Radio activity	Requirement	
		Grade i	Grade ii
1.	Insoluble matter, percent by mass, (max)	0.5	0.5
2.	Soluble iron compounds (as Fe), percent by mass, max	0.7	0.7
3.	Water soluble aluminum compounds (as Al_2O_3), percent by mass, (max)	17.0	15.0
4.	pH (of aqueous solution,	2.7	2.9
5.	Basicity (as Al_2O_3), percent by mass, (max)	0.5	0.5
Additional requirements for material required for purification of water			
6.	Lead (as Pb), ppm, (max)	40	40
7.	Arsenic (as As_2O_3), ppm, (max)	8	8

Packaged mineral water specification

No	Characteristic	Requirement
	Organoleptic and physical parameters	
1.	Color, color units, max	2
2.	Odor	Agreeable
3.	Taste	Agreeable

No	Characteristic	Requirement
4.	Turbidity, ntu, max	2
5.	Total dissolved solids, mg/l, max	500
6.	pH value	6.5 - 8.5
7.	Barium (as Ba), mg/l, max	1.0
8.	Copper (as Cu), mg/l, max	0.05
9.	Iron (as Fe), mg/l, max	0.1
10.	Manganese (as Mn) mg/l, max	0.1
11.	Nitrate (as NO_3), mg/l, max	45
12.	Nitrite (as NO_2), mg/l, max	0.02
13.	Fluoride (as F), mg/l, max	1.0
14.	Zinc (as Zn), mg/l, max	5
15.	Silver (as Ag), mg/l, max	0.01
16.	Aluminum (as Al), mg/l, max	0.03
17.	Chloride (as Cl), mg/l, max	200
18.	Selenium (as Se), mg/l, max	0.01
19.	Sulfate (as SO_4), mg/l, max	200
20.	Alkalinity (as HCO_3), mg/l, max	75
21.	Calcium (as Ca), mg/l, max	75
22.	Magnesium (as Mg), mg/l, max	30
23.	Sodium (as Na), mg/l, max	200
24.	Residual free chlorine, mg/l, max	0.2
25.	Phenol compounds (as C_6H_5OH), mg/l, max	0.001

No	Characteristic	Requirement
26.	Mineral oil , mg/l, max	0.01
27.	Anionic surface active agents (as MBAS), mg/l, max	0.2

17.5 Collection and preservation of samples

The sample should be exactly as per the requirement of the sampling program. It must not deteriorate nor become contaminated before it reaches the laboratory. Care should be taken to ensure that analytical results match the actual sample composition. Important factors affecting results are:

- The presence of suspended matter and turbidity.
- The method chosen for their removal.
- Physical and chemical changes brought about by storage or aeration.

It is essential to ensure sample integrity from collection to data reporting. This includes the ability to trace possession and handling of the sample from the time of collection through analysis and final disposition. One method is to fix sampling locations by detailed description by maps or with aid of stakes, buoys or landmark in a manner that will permit their identification by other persons, without depending on memory or personal guidance.

(I) Type of sample

(a) **Grab or catch sample:** a sample collected at a particular time and place.

(b) **Composite sample:** a sample of grab samples collected at the same sampling point at different times. A composite sample representing a 24 hour period is considered standard for most determinations. Individual portions are collected in a wide-mouth bottle having a diameter of at least 35 mm at the mouth and a capacity of at least 120 ml. Collect these portions every hour; in some cases every half an hour or even every 5 minutes and mix at the end of the sampling period in a single bottle. If preservatives are used, add them to the sample bottle initially so that all portions of the composite are preserved as soon as they are collected.

(c) **Integrated sample:** it is a mixture of samples collected from different points simultaneously.

(II) Method of collection:

(a) **Collection from distribution system:** flush the lines sufficiently to ensure that the sample is representative of the supply. For determining the extent of flushing, the diameter and length of the pipe and the velocity of flow should be taken into account.

(b) **Collection from wells:** collect samples after sufficient pumping, to ensure that the sample represents the ground water source. It is necessary to pump at a specified rate to achieve a characteristic draw down. Record the pumping rates and draw down.

(c) **Collection from a river or stream:** take integrated sample from top to bottom in the middle of the stream or from side to side at mid depth. If only a grab or catch sample is collected, take it in the middle of the stream and at mid depth.

(d) Collection from reservoir: choose location, depth and frequency of sampling depending on local conditions and the purpose of the investigation and sample testing. Avoid surface scum. Avoid areas of excessive turbulence. Avoid sampling at weirs. Generally collect samples beneath the surface in quiescent areas. Lakes and reservoirs are subject to considerable variations from normal causes such as seasonal stratification, rainfall, run off, and wind.

(III) Sample container:

Except for dissolved oxygen, for analysis of other parameters, use one-liter white polythene container for collection of sample. For analysis of metals, use container rinsed with 1 : 1 HNO. For 3 samples containing organic content, avoid plastic containers.

(IV) Filling the container:

(a) Before filling, rinse sample bottle two or three times with the water being collected. Rinsing is not required if the bottle contains a preservative or dechlorinating agent.

(b) Fill the container full without leaving any air space. Even the handle of the container should be filled with water. Close the inner cap, place polythene sheet (10 cm x 10 cm) in between the inner and outer caps and screw the outer cap. Place another polythene sheet over the outer cap and tighten the neck with a rubber band.

(V) Labelling:

Use labels to prevent a sample misidentification. The label should contain the following particulars:

(a) Name of the scheme

(b) Scheme type

(c) Source

(d) Programme name

(e) Tapping point (source or distribution)

(f) Location (address/identification)

(g) Habitation with code

(h) Panchayat with code

(i) Census village

(j) Union/block

(k) District

(l) Depth of well

(m) Water level below ground

(n) Remarks on surroundings & pollution of source

(o) Previous reference, if any

(p) Date & time of collection

(q) Collected by

(VI) Dispatching: the sample should reach the lab within 24 hours from the time of collection.

(VII) Preservation of sample for ferrous iron: a portion of sample is preserved for testing of ferrous iron as follows:

Ferrous iron: for testing ferrous iron, separately filter 100/200 ml of sample at site and collect it in a separate container. Add 5 drops of conc. HNO_3 as preservative.

17.5.1 Sampling technique for bacteriological examination

A. Preparation of source for sampling:

1. Care must be exercised to take samples that will be representative of the water being tested and to avoid contamination of the sample at the time of collection and in the period before examination.

2. When samples are collected from a tap, the tap should be opened fully and the water allowed running to waste for 3 to 5 minutes or for a time sufficient to permit cleaning of the service line. The flow from the tap should then be restricted to one that will permit filling the bottle without splashing. Leaking taps must be avoided as sampling points.

3. When collected from a tap and when the tap is not clean, apply a sodium hypochlorite (100 mg NaOCl/l) to faucet and allow water to run for 2-3 minutes.

4. For sampling in a river, stream, lake, reservoir, spring or shallow well. The location of sampling should be very nearer to the draw off point.

5. If the sample is to be collected from a well, fitted with a hand pump, water should be pumped to waste for about 5 minutes before the sample is collected. If the well is equipped with a mechanical pump, the sample should be collected from a tap on the discharge. If there is no pumping machinery, sample can be collected by lowering a sterilized bottle (fitted with a weight at the base) directly into the well.

B. Collectionof sample:

1. A pre sterilized 250 ml bottle obtained from any one of the laboratory is to be used for collection of bacteriological samples.

2. Bottles with 'hypo' are used for collection of chlorinated waters.

3. The time and date of handing over the sample for testing may be prefixed with the laboratory so as to keep the necessary bacterial media ready in the lab for testing on that day.

4. The sterilized bottle for sample collection is covered with a brown paper (kraft paper). First cut the kraft paper at the

marked level indicated around the bottle. Remove the stopper along with the top portion of the cut out paper. Hold the bottle at the base, fill it with sample without rinsing. Replace the stopper with cut out portion of the paper. Cover the stopper and neck with a polythene sheet and tie with a rubber band. Then place the whole bottle inside a polythene bag and fold it and tie with a twine thread or rubber band and make it air and water proof.

5. While filling the water, some air space (about 2.5 cm below from mouth) is left within the bottle.

6. The sampling bottle received from the laboratory should never be opened till the actual sampling is commenced.

7. When collecting the running water, hold the bottle near its base and plunge it, neck downward below the surface. The bottle is then turned until the neck points slightly and the mouth is directed towards the current and the water is allowed to collect.

8. When depth samples are used, the sampler covered with

brown paper is to be pre sterilized. When sampling is made, the mouth is opened using some external arrangement after immersing the bottle in the water to be collected. The mouth is then closed and the bottle is lifted to the surface.

C. Labelling:

The label should furnish all source particulars.

D. Preserving:

If the period for dispatch to the lab exceeds 6 hours, the sample has to be preserved in an icebox (thermocole box).

E. Dispatching:

1. After collecting, the samples should reach the laboratory within 6 hours and the testing started immediately.

2. In any case if this time is to be exceeded, preserve the samples in an icebox send it within 24 hours from the time of collection and analysis started immediately.

17.6 Water quality formulae

Ref: Gabriel, Formula handbook for environmental engineers

and scientists, a Wiley-interscience publication, John Wiley & Sons, inc., 1998.

17.6.1 Terms

1. Application factor

2. Autotropic index

3. Beer-lambert law

4. Biochemical oxygen demand (BOD)

5. Bio-concentration factor (BCF)

6. Birth rate (daphnia)

7. Chemical oxygen demand (COD)

8. Chlorophyll a,b,c

9. Concentration of contaminant in receiving water

10. Disinfection (concentration-time product)

11. Disinfection (inactivation rate microrganisms (chick's law)

12. Disinfection (lethality coefficient)

13. Exponential growth of microrganisms

14. Fecal coliform/fecal streptococci ratio

15. Food-to-microrganism ratio

16. Median lethal concentration (LC_{50})

17. Mixed liquor suspended solids (MLSS)

18. Mixed liquor volatile suspended solids (MLVSS)

19. Most probable number (MPN)

20. Osmotic pressure

21. Sludge density index (SDI)

22. Sludge volume index (SVI)

23. Sodium adsorption ratio (SAR)

24. Tolerable daily intake (TDI)

25. Water budget

17.6.1.1 Application factor (AF)

In environmental toxicology, the application factor (AF) is the ratio of the maximum acceptable toxicant concentration (MATC) to the median lethal concentration (LC_{50}). MATC is obtained via chronic toxicity tests, where, as LC_{50} is obtained via acute toxicity tests. AF is relatively constant for a given chemical.

$$AF = [MATC/LC_{50}]$$

Where,

MATC = maximum acceptable toxicant concentration (mg or g/l)

LC_{50} = median lethal concentration (mg or g/l)

In effluent monitoring, the application factor AF is used to extrapolate from LC_{50} concentrations to no-effect concentration, and ranges between 0.1 and 0.01, depending on the persistence and bioaccumulation potential (higher af is allowed when the waste does not persist or bioaccumulate)

(Mount, 1977;NAS/NAE, 1972; Tebo, 1986)

Sometimes, the *acute/chronic ratio* (ACR) is used and is the reciprocal of the application factor (Macek, 1985).

Ref:

Macek.K.J. 1985. Effluent evaluation, pp. 636-649. In: fundamentals of aquatic toxicology, g.m. Rand and S.R.Petrocelli, Eds., Hemisphere, Washington, D.C.

Mount,d.i. 1977. An assessment of application factors in aquatic toxicology, epa-600/3-77-085, U.S. Environmental protection agency, Washington, D.C.

NAS/NAE (national academy of sciences and national academy of engineering). 1972. Water quality criteria, 1972, epa-r3-73-033, U.S., Environmental protection agency, Washington.D.C.

17.6.2 Autotrophic index (AI)

The autotrophic index (AI), the ratio of total biomass to chlorophyll a, is a water quality indicator. This ratio increases when the water is enriched with organic matter, a situation that leads to an increase in the numbers of heterotrophic microorganisms (e.g. Bacteria, fungi, protozoa).

$$AI = \frac{\text{total biomass (ash-free weight of organic matter) (mg/m}^3\text{)}}{\text{chlorophyll a (mg/m}^3\text{)}}$$

weber (1973)

Sample	Autotrophic index (ai)
Algal culture	40-96
Marine phytoplankton	76-200
Pond water	44-221
Marine seston	40-146
Lake seston	457

Ref:

Weber, C.I. 1973. Recent developments in the measurement of the response of plankton and periphyton to changes in their environment, pp. 119-138. In: Bioassay techniques and environmental chemistry, G.Glass, Ed., Ann Arbor Science, Ann Arbor, Mi.

17.6.3 Beer-Lambert law:

$$A = \log \frac{Io}{I} = KCZ$$

Where,

I_o - intensity of incident light

I - intensity of transmitted light

K is the molar extinction coefficient (cm^3/ mol).

C - concentration of absorbing medium (mol/l)

Z - thickness of the absorbing medium (cm)

The Beer-Lambert relationship is valid only for dilute solutions.

17.6.4 Biochemical oxygen demand (BOD):

BOD is the amount of dissolved oxygen (DO) used by microorganisms in the biochemical oxidation of organic and inorganic matter. It is measured by incubating a sample at a standard temperature (usually 20°C) for a set period of time (commonly 5 days). The sample must be diluted if the BOD is high.

$$BOD\ (mg/l) = (D_1 - D_2) \times D.F$$

Where,

D_1 - initial DO

D_2 - final day DO and

D.F - dilution factor.

I. Typical BOD values in domestic wastewater varies between 110 and 400 mg/l (Metcalf and Eddy, 1979)

II. For typical untreated domestic wastewater, the BOD_5 / COD ratio varies from 0.4 to 0.8, and the BOD_5 / TOC ratio varies from 1.0 to 1.6.

The ultimate BOD value depends on the carbonaceous phase and nitrogeneous phase.

Ref:

Metcalf and Eddy, inc. 1979, Wastewater Engineering: treatment, disposal and reuse, 2nd Ed., Mcgraw-hill, New York).

17.6.4.1 Carbonaceous biochemical oxygen demand) (CBOD):

CBOD is the amount of dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter only. It is measured by preventing nitrification during the incubation period of the BOD test. Methods for preventing nitrification include pre-treating the sample by adding inhibitory agents such as ammonia, methylene blue, thiourea, allylthiourea, 2-chlor-6 (trichloromethyl) pyridine (TCMP), or proprietary products.

17.6.4.2 Nitrogeneous biochemical oxygen demand (NBOD):

Autotrophic bacteria such as nitrifying bacteria require oxygen to oxidize NH_4+ to NO_3. The oxygen demand exerted by nitrifiers is called autrotrophic BOD or nitrogeneous biochemical oxygen demand (NBOD).

$$NBOD = BOD - CBOD$$

Where

NBOD - nitrogeneous biochemical oxygen demand

BOD - biochemical oxygen demand

CBOD - carbonaceous biochemical oxygen demand

The theoretical nitrogeneous oxygen demand is 4.57 g oxygen used per gram of ammonium oxidized to nitrate. However, this value is actually lower and must be corrected due to incorporation of some of the nitrogen into the microbial cells. Thus NBOD is as follows (Verstraete, W., and E. VanVvaerenbergh, 1986):

NBOD (mg/l) = (available N - assimilated N) x 4.33

It is necessary to carry out an inhibited BOD test to distinguish between carbonaceous and nitrogeneous BODs. It is recommended to add 2-chloro-6(trichloromethyl) pyridine at a final concentration of 10 mg/l for nitrification inhibition.

Ref:

Verstraete, W., and E. Van Vaerenbergh, 1986. Aerobic activated sludge, pp. 43-112. In: Biotechnology, vol.8, Microbial Degradations, W.Schonborn, Ed., Vch, Weinheim, Germany)

17.6.5 Bio concentration factor (BCF)

In toxicology, the bio concentration factor expresses the bioaccumulation of hydrophobic compounds that tend to assimilate in the fat of animals. It is the ratio of the concentration of a chemical in an organism to that in water. Chemicals with a high partition coefficient K_{ow} (measured in an octanol-water mixture) are greatly prone to bioaccumulation in organisms. There is a good relationship between the bio concentration factor and the octanol-water partition coefficient.

$$BCF = C_a \; / \; C_w$$

where,

BCF - bio concentration factor

C_a - toxicant concentration in an organism (g/g)

C_w - toxicant concentration in water (μg/ml)

17.6.6 Birth rates (daphnia)

Birth rate of daphnia is determined according to the following equation:

$$b = \frac{\ln(1+e/n)}{d}$$

Where

b - birth rate (day-1)

e - total number of eggs

e/n - the egg ratio

d - development time of eggs (days)

d - 2.8 days at 20°c (Elster and Schworbel, 1970)

Ref:

Elster, H.J., and J.Schworbel. 1970. Beitrage zur biologie and populationdynamik der daphnia in bodensee. Arch. Hydrobiol. Suppl. 38: 18-72.

17.6.7 Chemical oxygen demand (COD)

Chemical oxygen demand (COD) is the amount of oxygen necessary to oxidize the organic carbon completely to CO_2 and H_2O. Some organic chemicals are not completely oxidized. However, COD is measured in approximately 3 hours via oxidation with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid and silver sulphate. During the COD test, other reduced substances (e.g., Sulfides, sulfites, Fe^{++}) are also oxidized and included in the COD. Furthermore, reduced forms of organic nitrogen are converted to ammonia in the COD test and more oxidized forms of nitrogen (e.g., Nitrite) are converted to nitrate. If the COD value is much higher than the BOD value, it means that the sample contains large amounts of organic compounds that are not easily biodegraded. For some wastewaters, COD can be correlated with BOD. For example, COD of a 500 mg/l solution of phenol (C_6H_6O) is 1191.5 mg/l.

$$C_6H_6O + 7O_2 \rightarrow 6CO_2 + 3H_2O$$

$$COD = \{[7(32)x500]/94\}\ mg/l = 1191.5\ mg/l$$

17.6.7.1 Relationship with ultimate BOD:

For wastewaters with readily degradable organics (e.g: Dairy wastes), the COD is given by

$$COD = BOD_{ult} \ / \ 0.92$$

where, BOD is the ultimate BOD (mg/l).

I. For untreated domestic wastewaters: COD range = 250 - 1000 mg/l (Metcalf and Eddy, 1991).

Ii. Industrial wasterwaters: COD range = 200 - 350,000 mg/l (Eckenfelder, W.W.Jr., 1989).

Ref:

I. Metcalf and Eddy, inc.,1991. Wastewater Engineering: treatment, disposal and reuse, 3rd Ed., Mcgraw-hill, New York).

Ii. (Eckenfelder, W.W.Jr., 1989. Industrial water pollution control, 2 Ed., Mcgraw-hill, New York).

17.6.8 Chlorophyll a,b,c

The water sample is passed through a membrane filter and then extracted with 90% aqueous acetone. The optical density of the extract is read at wavelengths of 664, 647 and 630 nm for determination of chlorophyll a, b and c, respectively. The three optical densities are corrected for turbidity by subtracting the absorbance at 750 nm.

$$c_a\ (mg/l) = 11.85\ (od_{664}) - 1.54\ (od_{64}7) - 0.08\ (od_{630})$$

$$c_b\ (mg/l) = 21.03\ (od_{647}) - 5.43\ (od_{664}) - 2.66\ (od_{630})$$

$$c_c\ (mg/l) = 24.52\ (od_{630}) - 7.60\ (od_{647}) - 1.67\ (od_{664})$$

Where,

c_a, c_b, c_c - concentrations of chlorophylls a,b and c, respectively (mg/l)

od_{664}, od_{647}, od_{630} - turbidity-corrected optical densities (1-cm light path) at wavelengths 664, 647 and 630 nm, respectively.

The chlorophyll concentration in a given water sample is given by the following (chlorophyll a is given as an example):

$$\text{chlorophyll a (mg/m3)} = \frac{\text{ca (mg/l) x extract volume (l)}}{\text{volume of sample (m3)}}$$

17.6.9 Concentration of contaminant in receiving waters

The discharge of wastewater into receiving water increases the concentration of any pollutant above the ambient concentration. The increment of pollutant concentration above background is decreased by the dilution factor s, or is increased by the relative wastewater concentration p.

$$C = C_s + (1/S)\,(C_d - C_s)$$

Where

C_s - background concentration of substance x in ambient water

C_d - concentration of x in the wastewater discharge

S - dilution factor

17.6.10 Disinfection: concentration - time product CT

Waston's law deals with the relationship between disinfectant concentration and contact time. Disinfectant effectiveness may be expressed as Ct, C, being the disinfectant concentration and t, the time required to inactivate a given percentage of the population under specific conditions (pH and temperature).

$$K = C^{N}T$$

Where

K = constant for a given microorganism exposed to a disinfectant under specific conditions (mg/l . min)

C = disinfectant concentration (mg/l)

N = empirical constant, also called the coefficient of dilution

T = contact time required to kill a certain percentage of the population (min)

When T is plotted against C on double logarithmic paper, N is the slope of the straight line. The value of N determines the importance of the disinfectant concentration or contact time in microorganism inactivation. However, in engineering practice, N value is often assumed to be close to unity.

Ref:

Baumann, E.R., and D.D Ludwig. 1962. Free available chlorine residuals for small nonpublic water supplies. J.Am. Water works assoc. 54:1379-1388.

Clark, R,M., E.J. Read and J.C. Hoff. 1989. Analysis of inactivation of giardia lamblia by chlorine, J.Environ. Eng.div.asce 115: 80-90.

Rubin, A.J., J.P. Engel, and O.J. Sproul, 1983. Disinfection of amoebic cysts in water with free chlorine. J. Water pollut. Control. Fed. 55:1174-1182.

17.6.11 Disinfection: inactivation rate microorganisms (Chick's law)

As per Chick's law, for a given disinfectant and concentration, the death of microorganisms follows first order kinetics with respect to time. $-dx/dt = kx$

where,

x - concentration of living microorganisms at time t

k - first-order decay rate (1/time)

The integrated form of Chick's law is as follows:

$$\ln (x / x_o) = - kt$$

where,

x - concentration of living microorganisms at time t (number/ unit volume)

x_o - initial concentration of living microorganisms (number/ unit volume)

k - decay rate (1/time)

t - time

Chick's law is represented graphically as a straight line when plotting $\log_{10}$ or $\ln (x / x_o)$ versus time t. Chick's law, however assumes a constant concentration of disinfectant, uniform susceptibility of all microbial species present, and the absence of interfering substances. A deviation from first-order kinetics is therefore noticed.

17.6.12 Disinfection: lethality coefficient

The lethality coefficient expresses the relative efficiency of a disinfectant.

$$\lambda = 4.6 \ / \ C \ T99$$

Where

4.6 = natural log of 100

C = residual disinfectant concentration (mg/l)

T_{99} = contact time to achieve 99% destruction of microorganisms (min)

The value of λ for destruction of various microorganisms by ozone varies with the type of microorganism (cf. Table below).

Values of lethality coefficient 8 and residual O_3 to destroy 99% of microorganisms in 10 minutes at 10 - 15° C

Microorganisms	Value of λ	Residual O_3 (mg/l)
Escherichia coli	500	0.001
Streptococcus fecalis	300	0.0015
Poliovirus	50	0.01
Bacillus megaterium spores	15	0.03
Entamoeba histolytica cysts	5	0.1

λ also varies with the type of disinfectant, as shown in the table below:

Values of for 99% destruction of four groups of organisms in 1 minute at 50°C by ozone and three chlorine compounds.

Disinfection agent	Escherichia coli	Enterovirus	Amoebic cysts	Bacterial spores
O_3	50	5	0.5	1.5
HOCl	20	1	0.05	0.05
Ocl	0.2	0.02	0.0005	0.0005
NH_2Cl	0.1	0.005	0.02	0.001

Ref:

Chang.S.I. 1982. The safety of water disinfection. Annu. Rev. Public health 3: 393-418.

17.6.13 Exponential growth of microrganisms

In a batch culture, microbial populations undergo a lag phase, an exponential phase, a stationary phase, and a death phase.

During the exponential growth phase, microbial growth is given by the equation:

$$dx / dt = \mu x \implies X = Xo\, e^{\mu T}$$

where,

X = biomass concentration (g/l or cell numbers) at time t

μ = specific growth rate (h^{-1})

X_o = biomass concentration (g/l or cell numbers) at time = 0

T = time (h)

The doubling time T_d of the culture is given by:

$$T_d = \ln 2/\mu = 0.693/\mu$$

Ref:

Drew, S.W.1981. Liquid cultures, pp.151-178. In : Manual of methods for general bacteriology, P.Gerhardt et al., Eds., American soceity for microbiology, Washington.D.C

17.6.14 Fecal coliforms/ fecal streptococci (fc/fs) ratio

The relative quantities of fecal coliforms and fecal streptococci discharged by humans are different from the relative quantities discharged by animals. Thus the fecal coliform to fecal streptococci ratio is indicative of the source of fecal contamination (human versus animal)

Typical fc/fs ratios

Source	fc/fs
Chicken	0.4
Cow	0.2
Duck	0.6
Pig	0.04
Sheep	0.4
Turkey	0.1
Human	4.4

17.6.15 Food-to-microorganism (f/m) ratio

f/m ratio is the ratio between the organic loading rate to an activated sludge system and the mass of sludge in the system. Organic loading rate is expressed in terms of biochemical oxygen demand or chemical oxygen demand. Sludge mass is expressed in terms of total dry weight or ash-free dry weight. The f/m ratio indicates the organic load in the activated sludge system and is given by (Curds and Hawkes, 1983; Nathanson, 1986).

$$f/m = [Q \times BOD] \ / \ [MLVSS \times V]$$

where,

f/m = kg BOD/kg MLVSS per day

Q = flow rate of sewage (m^3 / day)

BOD = 5-day biochemical oxygen demand in influent (mg/l)

MLVSS = mixed liquor volatile suspended solids (mg/l)

V = volume of aeration tank (m^3)

f/m is controlled by the rate of activated sludge wasting. The higher the wasting rate, the higher the f/m ratio. For conventional aeration tanks the f/m ratio is 0.2-0.5 kg BOD5 / kg MLVSS.day, but can be higher (up to 1.5) for activated sludge using high-purity oxygen (Hammer, 1986). A low f/m ratio means that the microorganisms in the aeration tank are starved, leading to a more efficient wastewater treatment.

Food to microorganisms ratio in some activated sludge system

Process	f / m ratio (kg BOD / kg MLVSS.days
Conventional	0.2 - 0.4
Step aeration	0.2 - 0.4
Contact stabilization	0.2 - 0.6
Extended aeration	0.05 - 0.15
Pure oxygen system	Up to 1.5

Source : data from Hammer (1986), Metcalf and Eddy (1991).

Reference

Curds, C.R., And H.A Hawkes, Eds. 1983. Ecological aspects of used-water treatment, vol.2, academic press london.

Hammer, M.J., 1986 water and wastewater technology, Wiley, New York.

Metcalf and Eddy, inc.1991. Wastewater engineering : treatment, disposal and reuse, 3rd Ed., Mcgraw-hill, New York.

Nathanson, J.A. 1986. Basic environmental technnology: water supply, waste disposal and pollution control, Wiley, New York.

17.6.16 Median lethal concentration (LC50)

Toxicant dose-response relationship is one of the most basic concepts in toxicology. In safety evaluation of chemicals, one must be able to measure the toxicity of a given chemical. Plotting the percent response (e.g. Mortality) against the concentration of the test chemical gives a typical sigmoidal curve.

The median lethal concentration (LC_{50}) is the chemical concentration that produces mortality in 50% of the test population over a certain period of time. When effects other than mortality are used (e.g. Behavioral or physiological effects), the term median effective concentration (EC_{50}) is used.

Ref:

Rand, G.M., and S.R.Petrocelli. 1985. Fundamentals of aquatic toxicology, hemisphere, Washington.D.C..

17.6.17 Mixed liquor suspended solids (MLSS)

Mixed liquor suspended solids (MLSS) is the particulate solid concentration (measured as dry weight) in the mixed liquor. It is total amount of organic and mineral suspended solids, including microorganisms, in the mixed liquor. MLSS is determined by filtering an aliquot of mixed liquor, drying the filter at 105 °C and determining the weight of solids in the sample.

Range of MLSS in some activated sludge processes

Process	MLSS (mg/l)
Conventional	1,500 - 3,000
Step aeration	2,000 - 3,500
Extended aeration	3,000 - 6,000
Pure oxygen system	6,000 - 8,000
High rate aeration	4,000 - 10,000

Source: adapted from Metcalf and Eddy (1979).

Reference

Metcalf and Eddy, inc.,1979. Wastewater engineering: treatment, disposal and reuse, 2nd ed., Mcgraw-hill, New York.

17.6.18 Mixed liquor volatile suspended solids (MLVSS)

Mixed liquor volatile suspended solids (MLVSS) is the particulate solid concentration (measured as ash-free dry weight) in the mixed liquor. The organic portion of MLSS is represented by MLVSS which comprises non-microbial organic matter as well as dead and live microorganisms, and cellular debris (Nelson and Lawrence, 1980). MLVSS is determined following heating of dried filtered samples at 600 - 650 °c. The ratio MLVSS/MLSS in activated sludge ranges typically between 0.65 and 0.90.

References:

Metcalf and Eddy, inc.,1991. Wastewater tengineer: treatment, disposal and reuse, 3rd ed. Mcgraw-hill, New York.

Nelson, P.O., and A.W.Lawrence. 1980. Microbial viability measurements and activated sludge kinetics. Water res. 14:217-225.

17.6.19 Most probable number

The most probable number (MPN) method helps estimate the number of organisms in a sample, using probability tables. Decimal dilutions of a given sample are incubated in a specific growth medium, and positive tubes (e.g. Growth and gas production) are scored. Mpn is given in tables or by using a formula.

The Thomas's formula is based on positive and negative tubes:

$$\text{MPN/100 ml} = \frac{[\text{number of positive tubes x 100}]}{(\text{ML sample in negative tubes x ML sample in all tubes})^{1/2}}$$

17.6.20 Osmotic pressure

Osmotic pressure is the difference in pressure between two solutions at equilibrium of varying salinities which are separated by a semipermeable membrane. It is a measure of the potential energy difference of the water molecules between the two solutions.

$$\pi = \frac{RT}{V_a} \ln \frac{P^o_a}{P_a}$$

Where,

π = osmotic pressure (atm)

R = 0.082 (l . Atm / (mo l .k)

T = temperature (k)

V_a = volume/mole of solvent (l/mol) (v_a = 0.018 l for water)

P^o_a = vapor pressure of solvent in the dilute solution (atm)

P_a = vapor pressure of solvent in the concentrated solution (atm)

For dilute solutions, the osmotic pressure is given by (tinoco et al., 1995)

$$\pi = CRT$$

Where C is the concentration of solute (mol/l).

References

Sawyer, C.N., and P.L. Mccarty, 1978. Chemistry for environmental engineering, Mcgraw-hill, New York.

Sundstrom, D.W., and H.E. Klei. 1979, Wastewater treatment, Prentice Hall, Upper Saddle River, NJ.

Tinoco, I. Jr., K.Sauer, and J.C.Wang. 1995. Physical Chemistry: principles and applications in biological sciences, Prentice Hall, Upper Saddle River, NJ.

17.6.21 Sludge density index (SDI)

Sludge density index is the density of settling sludge after a 30-minute settling period. Sludge density index is essentially the reciprocal of the sludge volume index (SVI)

$$SDI = MLSS/V$$

Where,

SDI = sludge density index (g/ml)

MLSS = mixed liquor suspended solids concentration (g/l)

V = settled sludge after 30 minute settling time (ml/l)

The SDI varies from about 0.02 g/ml for a sludge that settles well to about 0.005 g/ml or less for a bulking sludge.

Reference

Institute of water pollution control, 1987. Unit processes : activated sludge, IWPC, Maidstone, Kent,England.

17.6.22 Sludge volume index (SVI)

The sludge volume index (SVI) is the volume occupied by 1 g of sludge after a 30-minute settling. It is used as an index for assessing the settleability of activated sludge or other suspensions. It is well known that overgrowth of filamentous bacteria in activated sludge leads to an increase in sludge volume index. This phenomenon is called filamentous bulking.

$$SVI = V/(V_o \times MLSS)$$

where,

SVI = sludge volume index (ml/g)

V = settled sludge volume after a 30-minute settling (ml)

V_o = initial volume of sludge tested (l)

MLSS = mixed liquor suspended solids (g/l)

An acceptable range for sludge SVI is between 35 and 100 ml/g.

Ref: Sundstrom, D.W., and H.E. Klei. 1979. Wastewater treatment, Prentice Hall, Upper Saddle River, NJ

17.6.23 Sodium adsorption ratio (SAR)

Sodium ions alter soil permeability. The sodium adsorption ratio indicates whether or not the sodium content of a wastewater is high enough to cause infiltration problems in soils.

$$SAR = [Na^+] \ / \ [0.5\ (Ca^{++} + Mg^{++})]^{0.5}$$

$[Na^+]$, $[Ca^{++}]$, and $[Mg^{++}]$ are expressed in milliequivalents/l.

The higher the SAR, the higher the tendency of sodium to absorb to the cation exchange sites (Donahue et al., 1977). Soil permeability is affected when $SAR>9$ (Rich, 1980). High sodium levels are also toxic to plants.

References

Donahue, R.L., R.W.Miler, and J.C.Shikluma. 1977. Soils: An Introduction to soils and plant growth, Prentice Hall, Upper Saddle River, NJ

Rich, L.G.1980. Low-maintenance, mechanically simple wasterwater treatment systems, Mcgraw-hill, New York).

17.6.24 Tolerable daily intake (TDI)

For most kinds of toxicity, it is generally believed that there is a dose below which no adverse effects will occur. For chemicals that give rise to such toxic effects, a tolerable daily intake (TDI) can be derived as follows:

$$\text{TDI} = \frac{\text{NOAEL or LOAEL}}{\text{UF}}$$

where,

NOAEL - no-observed-adverse-effect level,

LOAEL - lowest-observed-adverse-effect level,

UF - uncertainty factor.

The guideline value (GV) is then derived from the TDI as follows:

$$GV = \frac{TDI \times BW \times P}{C}$$

where,

BW - body weight (60 kg for adults, 10 kg for children, 5 kg for infants),

P - fraction of the tdi allocated to drinking-water,

C - daily drinking-water consumption (2 litres for adults, 1 litre for children, 0.75 litre for infants).

17.6.25 Water budget

The sum of water inputs (i.e. Precipitation) into a system is equal to the sum of water outputs (i.e., Evapotranspiration, run off, infiltration, storage).

$$P = ET + R + I + S$$

where,

P - precipitation (cm)

ET - evapotranspiration (cm)

R - runoff (cm)

I - infiltration (cm)

S - storage (cm)

Ref:

B.t. 1995, environmental engineering, pws, boston.

17.7 Principles of water chemistry reactions

17.7.1 Color

Metallic ions, humous and peat materials, plankton, weeds and industrial wastes impart color to water. Normally color increases with pH. The color obtained by mixing potassium chloroplatinate and $COCl_2$ is used for comparison of color with that of samples. 'true color' is the color from which turbidity has been removed. 'apparent color' is determined on the original sample without filtration or centrifugation. In some highly colored industrial wastewaters, color is contributed principally by colloidal or suspended material. In such cases, both true color and apparent color should be determined.

17.7.1.1 Visual comparison method

The platinum-cobalt method of measuring color is the standard method, the unit of color being that produced by 1 mg platinum/l in the form of chloroplatinate ion.

17.7.1.2 Spectrophotometric method:

The color of a filtered sample is expressed in terms that describe the sensation realized when viewing the sample. The hue (red, green, yellow, etc.) is designated by the term "dominant wavelength", the degree of brightness by "luminance", and the saturation (pale, pastel, etc.) by "purity". These values are best determined from the light transmission characteristics of the filtered sample by means of a spectrophotometer.

17.7.2 Turbidity

Suspended matter like clay, silt, finely divided organic matter, soluble colored organic compounds, plankton and other microscopic organisms contribute for turbidity.

A light source from tungsten filament lamp at a color temperature of 2200 - 3000 °k, scattered at 90 °C is measured using a photoelectric detector. The instrument used for measurement of turbidity by the above principle is called Nephelometer. Normally 40 NTU = 40 JTU. For other ranges, it slightly differs.

17.7.3 Solids

Residue dried at 180 °C will lose almost all mechanically occluded water. Some water of crystallization may remain, especially if sulfates are present. Organic matter may be lost by volatalization, but not completely destroyed. Loss of CO_2 results from conversion of bicarbonates to carbonates, and carbonates may be decomposed partially to oxides or basic salts. Some chloride and nitrate salts may be lost. Dissolved solids obtained at 180 °C yield results to those obtained through summation.

17.7.4 pH

pH is the intensity factor of acidity. Pure water is ionized and at equilibrium the ion product is:

$(H^+)\ (OH^-) = K_w$

$= 1.01 \times 10^{-14}$ at 25°C

Where,

$(H^+) = (OH^-) = 1.005 \times 10^{-7}$.

By definition, pH = $-\log 10 AH^+$ (AH^+ is the activity of hydrogen ion)

The neutral point is temperature dependent,

at 0 °C, it is 7.5

at 25 °C, it is 7.0

at 60 °C, it is 7.5

The activity of H^+ ions is measured by the potential difference between a standard hydrogen electrode and a reference electrode. Because of difficulties in using a H^+ electrode, a glass electrode is used. The pH measuring instrument is calibrated potentiometrically with an indicating electrode (glass) and a reference electrode.

17.7.5 Alkalinity

CO_3, HCO_3, OH, borate, phosphate, silicate and other bases contribute for alkalinity. Alkalinity is measured at two end points namely 8.3 (phenolphthalein end point) and 4.5 (methyl orange end point).

Level of different alkalinities

Result of titration	OH	OH	HCO_3
P=0	0	0	T
P< ½ T	0	2P	T - 2P
P= ½ T	0	2P	0
P> ½ T	2P - T	2(T - P)	0
P= T	T	0	0

Note: P = phenolphthalein alkalinity

T = methyl orange (total) alkalinity

I. In alkalinity, the acid base reactions are the main reactions.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

$H_2SO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + CO_2 + H_2O$

$H_2SO_4 + 2NaHCO_3 \rightarrow Na_2SO_4 + 2CO_2 + H_2O$

II. At less than 8.3 pH, the H ions in acid medium suppress ionization of phenolphthalein (HpH) which is a weak acid. In the presence of OH ions, H^+ in HpH combine to form water. The pH is pink in colour.

$NaOH \rightarrow OH + Na$

HpH (colourless) → H + pH (pink)

$H + OH \rightarrow H_2O$

III. Methyl orange (CH_3OH) is a weak base, presence of OH ions suppress ionization of CH_3OH. This is yellow in color. In presence of acid, H combines with OH in CH_3OH to create water. CH_4 (methane), which is red in color is released:

$CH_3OH \rightarrow CH_3^+ + OH$

(Yellow)

17.7.6 Hardness

I. Titrant: EDTA as H_4y is having limited solubility. Na_4y is extensively hydrolyzable and its solution is highly alkaline. Na_2H_2y is obtained in a high state of purity as the dehydrate $C_{10}H_{14}O_8N_2Na_2 \cdot 2H_2O$ and is used as the titrant.

The structure of EDTA is

$HOOC.\ H_2C \rightarrow CH_2COOH$

$N\text{-}CH_2\text{-}CH_2N$

$HOOC.\ H_2C \qquad CH_2COOH$

with divalent Ca or Mg, it forms a chelated complex.

II. Indicator: at pH 10.0 + 0.1, in presence of indicator Ca & Mg react with the indicator and the solution turns wine red. As EDTA is added with Ca + Mg, the more stable EDTA chelate complex is formed. At the end point, all the Ca & Mg are consumed by the EDTA, and the free indicator (blue) is released.

$H_2R + Ca^{++} \rightarrow CaR + 2H^+$

(blue) (wine red)

$CaR + Na_2H_2y \rightarrow CaNa_2y + H_2R$

(EDTA salt) (chelate - blue)

III. Definite end point: to get a satisfactory end point, Mg ions must be present. To ensure this, a small amount of complexometrically neutral Mg salt of EDTA is added to the buffer. The sharpness of end point increases with increasing pH. However, at a high pH, $CaCO_3$ or $Mg(OH)_2$ is precipitated. The dye will also change its color to yellowish orange (above pH 11.5).

IV. $CaCO_3$ precipitation: titration should be finished within 5 minutes to minimize the tendency towards $CaCO_3$ precipitation. Dilution can reduce $CaCO_3$ concentration and therefore sample is always diluted before adding reagents and conducting titration.

V. Titration: conduct titration at or near normal room temperature. Indicator decomposes in hot water.

17.7.7 Aluminum (eriochrome cyanine r method)

With eriochrome cyanide r dye, dilute aluminum solution buffered to a pH of 6.0, produces a red to pink complex that exhibits maximum absorption at 535 nm. The intensity of developed color depends on aluminum concentration, reaction time, temperature, pH, alkalinity and concentration of other ions in the sample.

	$H_4I^+ \rightarrow$	$H_3I \rightarrow$	$H_2I^- \rightarrow$	$HI^- \rightarrow$	I^-
	pink	orange	red	yellow	violet
pH	~ 0.0	~ 1.0	~ 2.0	~ 6.0	~ 12.0

eriochrome cyanine r

17.7.8 Arsenic

Silver diethyldithiocarbamate is a reagent used for the determination of arsenic. The method involves evolution of arsine (A_sH_3) and its absorption in a pyridine solution of the reagent. The red reaction product is described as colloidal silver formed according to the reaction equation:

$A_sH_3 + 6AgI \rightarrow 6Ag + 3HI + AsI_3$

Where HI - diethyldithiocarbamic acid

The absorption peak is 522 nm. The method is sensitive due to the large change in the oxidation state of as (-3 → +3). A 0.25% solution of Ag diethyldithiocarbamate in chloroform containing 0.165% l-ephedrine can be used instead of the unpleasant-smelling pyridine solution.

17.7.9 Calcium

At high pH of 12 - 13, Mg is precipitated as hydroxide. The indicator used combines only with Ca to form orange-red color. As EDTA is added, chelated EDTA complex is formed and at the end point, free indicator is released and pink color is noted.

Eriochrome blue-black r [sodium - 1 (2 -hydroxy-1-naphthyl azo)-2napthol-4- sulfonic acid] gives a better end point than murexide indicator.

17.7.10 Chromium

In acid solution, sym-diphenylcarbazide (1,5-

diphenylcarbohydrazide) gives a soluble strongly colored red-violet product with sexivalent chromium. The colored species is believed to be a chelate cation of Cr(iii) (formed by reduction of Cr(vi) by diphenylcarbazide) and diphenylcarbazone. A 1:2 (metal : ligand) chelate has been proposed. The direct reaction between Cr(iii) and diphenylcarbazone takes place only in an acetone medium, forming a 1 : 1 complex. The stoichiometry and the structure (N-bonding or N^- and O^- bonding) of the colored species remain to be established.

Diphenylcarbazide: $C_6H_5.NH.NH.CO.NH.NH.C_6H_5$

Diphenylcarbazone: $C_6H_5.NH.NH.CO.N{=}N.\ C_6H_5$

17.7.11 Iron (thiocyanate method)

Iron forms a series of complexes with thiocyanate ion, represented by $Fe(SCN)_n^{3-n}$ (n = 1,....,6). The various Fe^-SCN^- species are controlled by the thiocyanate concentration in acid medium. When $[SCN^-] = 0.01$, ~50% of the iron is present as $FeSCN^{++}$, the reminder mostly as Fe^{+++}. At 0.3 m SCN^-, a commonly used thiocyanate concentration, most of the iron is present in the form of $Fe(SCN)_3$ and $Fe(SCN)_2^+$, but some $FeSCN^{++}$ and $Fe(SCN)_4^-$ are also present.

The color intensity of an iron-thiocyanate solution depends upon a number of factors such as the excess of thiocyanate, the kind of acid present, and the time of standing. A relatively large excess of thiocyanate is desirable. Not only is the sensitivity increased by increasing the thiocyanate concentration, but the color intensity also remains nearly constant when the acidity is varied. Moreover, a high concentration of thiocyanate reduces the errors due to chloride, phosphate, and other ions forming complexes with iron (iii) in acid solution.

A final concentration of 0.3 m is generally satisfactory. Care must be taken to have the same concentration of thiocyanate in the unknown and the standards because, a relatively small difference leads to a fairly large change in color intensity. The acidity of the solution plays a minor role in determining the color strength, provided enough acid is present to prevent appreciable hydrolysis of the iron, and the acid does not form a complex with iron (iii). When the solution is exposed to light, the iron (iii) thiocyanate color fades due to thiocyanate or its decomposition products.

17.7.12 Iron (1, 10-phenonthroline method)

Boiling acid and hydroxylamine reduce ferric iron to ferrous iron. At pH 3.2 to 3.3, three molecules of 1, 10-phenanthroline chelates with one atom of ferrous iron to form an orange-red complex.

$$Fe(OH)_3 + 3H^+ \rightarrow Fe^{+++} + 3H_2O$$

$$4Fe^{+++} + 2NH_2OH \rightarrow 4Fe^{++} + N_2O + H_2O + 4H^+$$

17.7.13 Manganese

Persulphate oxidation converts soluble Mn to $KMnO_4$, which is pink in color. Oxidation is done in presence of $AgNO_3$ catalyst. $HgSO_4$ is used to complex Cl_- to avoid its interference (dissociation constant of Hg_2Cl_2 is 2.6×10^{-15})

$$2Mn^{++} + 5S_2O_8^- + 8H_2O \xrightarrow{2Ag} 2MnO_4^- + 10SO_{4-}^- + 16H^+$$

17.7.14 Na & K

The sample is sprayed into a gas flame and excitation is carried out under controlled and reproducible conditions. The desired spectral line is isolated by use of interference filters. The intensity is measured using a photo tube potentiometer.

K is measured at 766.5 nm.

Na is measured at 589 nm

17.7.15 Boron

When a sample containing boron is acidified and evaporated in the presence of curcumin, a red colored product called rosocyanine is formed.

17.7.16 CO_2

Carbon dioxide combines with H_2O to form weak carbonic acid. This acid is titrated with strong base i.e., NaOH. Phenolphthalein is used as indicator.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + NaOH \rightarrow NaHCO_3 + H_2O$$

17.7.17 Cyanide

CN is converted to CNCl by chloramine - t, at pH<8.0. After the reaction is complete, CNCl forms a red - blue dye on addition of pyridine barbituric acid reagent.

17.7.18 Chloride

Silver nitrate reacts with chloride to form silver chloride. At end point, it reacts with K_2CrO_4 to form silver chromate, a red precipitate.

$$AgNO_3 + Cl \rightarrow AgCl + NO_3$$

$$2AgNO_3 + K_2CrO_4 \rightarrow \underset{\text{(red)}}{Ag_2CrO_4} + 2KNO_3$$

The solubility product for AgCl is 1.78×10^{-10}. For Ag_2CrO_4 is 1.1×10^{-12}

17.7.19 Fluoride (ion selective method)

The f electrode is an ion-selective sensor. The key element in the fluoride electrode is the laser-type doped lanthanum fluoride crystal across which a potential is established by fluoride solutions of different concentrations. The crystal contacts the sample solution at one face and an internal reference solution at the other. The cell may be represented by

Ag / AgCl, Cl (0.3m), F (0.001 m) La f3/ test solution / reference electrode

The f electrode can be used with a std. Calomel reference electrode and almost any modern pH meter having an expanded milli volt scale can be used.

The f- electrode measures the ion activity of f in solution rather than concentration. f-ion activity depends on the solution, total ionic strength and pH and on fluoride complexing species. Adding an appropriate buffer provides a nearby uniform ionic strength background, adjusts pH, and breaks up complexes so that, in effect the electrode measures concentration.

17.7.20 Fluoride (spands method)

It is based on the reaction between f and a zirconium-dye lake. F reacts with the dye lake, dissociating a portion of it in to a colorless complex anion (ZrF^{62}) and the dye. As the amount of F increases, the color produced becomes progressively lighter.

The reaction between f and zirconium ion is influenced greatly by the acidity of the reaction mixture. The proportion of the acid in the reagent increase and the reaction is made almost instantaneous.

17.7.21 Ammonia

The nessler-ammonia reaction produces yellow to brown colour.

$$HgI_2 + 2KI \rightarrow K_2HgI_4 \text{ (complex)}$$

$$2K_2HgI_4 + NH_4OH \rightarrow 3KOH + \ldots$$

Pretreatment before direct nesslerisation with 1 ml $ZnSO_4$ + $7H_2O$ (10% of solution) and (0.5 ml 6 N NaOH), Precipitates Ca, Fe, Mg and S.

$ZnSO_4 + 2NaOH \rightarrow Zn(OH)_2 + Na_2SO_4$

$Zn(OH)_2 + Ca^{++} = Ca(OH)_2 + Zn^{++}$

$Zn(OH)_2 + S = ZnS + 2OH$

Addition of rochelle salt inhibits precipitation of Ca & Mg ions in the presence of alkaline nessler reagent.

17.7.22 Nitrite

Nitrite forms a reddish purple azo-dye at pH 2.0 to 2.5 by coupling diazotised sulphanilamide with n-(l-naphthyl)-ethylene diamine dihydrochloride.

By the action of HNO_2 as aromatic amines, the so called diazo compounds are formed. This is known as greiss reaction.

17.7.23 Nitrate (u-v method)

Nitrate has a u-v spectral peak at 220 nm. Organic matter also interferes at this wave length. For this a second measurement at 275 nm is used to correct the nitrate value.

17.7.24 Nitrate (electrode method)

Nitrate ion electrode is a selective sensor that develops a potential across a thin, porous, inert membrane that holds in place a water immiscible liquid ion exchanger. The electrode responds to nitrate ion activity between 10 m at 10'm.

Ag_2SO_4 in the buffer removes interference due to Cl, Br, I, S and CN. The sulfanic acid removes interference due to NO_2. PH_3 removes interference due to $HCO_{3-}Al_2(SO_4)_3$ removes interference due to complex organic acids.

17.7.25 Dissolved oxygen

In presence of KOH and O_2, manganous sulfate forms a brown manganic hydroxide precipitate which dissolves in H_2SO_4 to give manganic sulfate. Manganic sulfate reacts with KI to liberate iodine. This is titrated with hypo in presence of starch indicator.

$MnSO_4+2KOH \rightarrow Mn(OH)_2+K_2SO_4$(in the absence of O2, white ppt)

$2Mn(OH)_2+O_2$ → $2MnO(OH)_2$ (in the presence of O2, brown ppt)

$MnO(OH)_2+2H_2SO_4 \rightarrow Mn(SO_4)_2+3H_2O$

$Mn(SO_4)_2+2KI \rightarrow MnSO_4+K_2SO_4+I_2$

$2Na_2S_2O_3+I_2 \rightarrow Na_2S4O_6+2NaI$

17.7.26 Phosphate

Molybdophosphoric acid is reduced by stannous chloride to intensely colored molybdenum blue.

$PO_4 + 12(NH_4)2MoO_4+24H_2O \rightarrow (NH_4)3PO_4.1_2MoO_3 + 21NH_4 + 12H_2O$ Ammonium phospho molybdat

$(NH_4)_3PO_4.12MoO_3 + Sn_4$ is molybdenum blue + Sn_4

17.7.27 Silicon

Ammonium molybdate at about pH 1.2, reacts with silica and PO_4 to produce yellow colored heteropoly acids. Oxalic acid is added to destroy molybdophosphoric acid, but not the molybdosilicic acid. The yellow molybdosilicic acid is reduced by means of amino napthol sulphonic acid to hetero poly blue.

17.7.28 Sulfide

Sulfide reacts with I2, excess iodine is titrated with thio.

$$I_2 + S^{-} 2H_4 \rightarrow 2HI + S$$

17.7.29 Sulfate

Sulfate ion is precipitated in an acetic acid medium with $BaCl_2$ to form $BaSO_4$. Light absorbance of $BaSO_4$ suspension is measured by a photometer.

17.7.30 COD

Organic substances are oxidized by potassium dichromate in 50% H_2SO_4 at reflux temperature. The excess dichromate is titrated with ferrous sulfate in the presence of ferroin indicator.

$$K2Cr_2O_7 + 6FeSO_4 + 8H_2SO_4 \rightarrow 2KHSO_4 + Cr_2(SO_4)_3 + 3Fe_2(SO_4) + 7H_2O$$

(orange) (cream)

Silver sulfate acts as a catalyst. Mercuric sulfate forms complex mercurous chloride (Hg_2Cl_2) with chloride and prevents interference. The ferroin indicator is a red complex of ferrous iron with o-phenanthroline $(Fe(C1_2H_8N_2)\}_2+$

Initially, iron in this complex reacts with dichromate and free o-phenanthroline is released. At the end point, excess iron reacts & ferroin is again formed.

17.7.31 Tidy's test

In acid solution potassium iodide reduces the oxidising agent setting free an equivalent quantity of sulfate using starch as indicator.

$$2KMnO_4 + 6KI + 8H_2SO_4 \rightarrow 4K_2SO_4 + 2Mn(SO_4)_2 + 8H_2O + 3I_2$$

$$2Na_2S_2O_3 + I2 \rightarrow Na_2S_4O_6 + 2NaI$$

$$I_2 + \text{starch} \rightarrow \text{Starch iodide (blue)}$$

17.7.32 Residual chlorine

Ortho toluidine is oxidized in acid solution by chlorine to produce a yellow colored compound.

17.7.33 Available chlorine in bleaching power

Bleaching powder in presence of acetic acid liberates chlorine. Chlorine liberates iodine from KI.

$CaOCl_2 + 5C_3COOH \rightarrow (CH_3COO)_2Ca + Cl_2 + H_2O$

$Cl_2 + 2KI \rightarrow 2KCl + I_2$

$2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI$

Ref:

(1) Hiroshi Onishi, Photometric determination of traces of metals, Part ii a: Individual metals, aluminium to lithium, John Wiley & Sons, 1986, 4th Edition.

18.1 Future trend

What will be the future trend on wastewater discharge? Population growth and continued urbanization will continue to increase the quantity of wastewater discharged to municipal wastewater treatment plants (MWTPs). Public expectations will increase demand on municipalities to provide greater levels of treatment for wastes, on the premise that improved receiving water quality will benefit human and environmental health. These expectations for wastewater treatment are likely to evolve faster than municipalities are able to respond through infrastructure programs. Additionally, mwtps were designed to remove solids, oxygen-demanding material and, in some cases N or P but may not adequately remove all constituents identified in wastewater. New technologies are becoming available, but may be very expensive.

Many municipalities face problems related to aging infrastructure. Sewer collection networks deteriorate allowing non-wastewater inflow into sewers, thereby adding to the volume of water that must be treated. Mwtps may not have been expanded to keep up with population growth and may be hydraulically overloaded, particularly during wet weather. Significant expenditure may be required simply to maintain existing levels of treatment, let alone meet higher levels of treatment. For municipalities to justify substantial investments in infrastructure, renewal or upgrades to higher treatment levels requires an understanding of the environmental implication of these discharges, on water quality health and the benefit to be gained by the investment.

18.2 Adages/proverbs

- "Three billion years of life, three million years of man-like creatures, ten thousand years of civilization and mere two hundred years of industrial revolution have brought us to the brink of disaster" - Prof. George Wald, Heritage.
- "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy" - Paracelsus (1493-1541).
- It is necessary to bear in mind that all {pesticides} are

biocides, and that at a sub cellular level most organisms are dependent on similar chemical processes. Consequently, it is inevitable that most pesticides will continue to have adverse effects in foe and friend alike - Unknown scientist.

- Infectious diseases caused by pathogenic bacteria, viruses, and protozoa or by parasites are the most common and widespread health risk associated with drinking-water - Guidelines for drinking-water quality, Volume I recommendations, Second Edition, WHO, Guidelines for drinking-water quality, Second Edition, 1988, page-8.

- “Science is built up of facts as a house is with stones, but a collection of facts is no more a science than a heap of stones a house" - Poincare (1854-1912)