

MODULE 1.3

Water Pollution

Synthetic Organic pollutants	2
Soaps And Detergents	2
Pesticides	5
Polychlorinated Dibenzodioxins (PCDDs) And Polychlorinated Dibenzofurans (PCDFs)	8
Polychlorinated Biphenyls	9
Elemental Pollutants	9
Heavy metals	10
Cadmium	10
Lead	11
Chromium	11
Mercury	11
Metalloids	12
Chemical speciation of metal pollutants	13
Other inorganic pollutants	14
Cyanide	14
Ammonia	15
Hydrogen sulfide	15
Nitrite nitrogen	15
Sulfite ion	16
Eutrophication And Algal Nutrients	16
Acid Mine drainage	17
Accumulation of Salts in water	18
Oxygen sag curve	19
Regulation of water quality	22
Secondary standards	24

MODULE 1.3

Water Pollution

The quality of drinking water is an important factor in determining human welfare. It has been noted that polluted drinking water is the cause for waterborne diseases which wiped out the entire populations of cities. The major sources of water pollution are domestic waste from urban and rural areas, and industrial wastes which are discharged into natural water bodies. The rivers and lakes near urban centres emit disgusting odours and fish are being killed in millions along the sea coasts. The meat of some of them is tainted and unsafe to eat because of excessive levels of mercury and pesticides in their bodies. The origin of these problems must be attributed to many sources and types of pollutants. To aid in a systematic discussion of water pollutants they are classified into fourteen categories as described below.

In this chapter the different types of water pollutants are discussed in the following sequence, concluding with an outline of prescription of water quality for drinking.

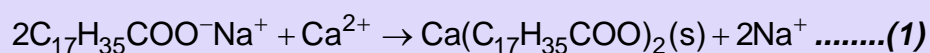
- Synthetic organic pollutants such as detergents, pesticides, polychlorinated biphenyls and other synthetic organic chemicals.
- Inorganic pollutants which include heavy metals, metalloids, speciation, anionic pollutants and ammonia.
- Eutrophication and algal nutrients.
- Acid mine drainage.
- Oxygen sag curve.
- Regulation of water quality.

Synthetic Organic pollutants:

These include detergents, pesticides, polychlorinated biphenyls and other synthetic organic chemicals. These compounds in contrast to the organic wastes, are not biodegradable and may persist for long periods. These are of great concern to environmentalists because most of the synthetic organic compounds are accumulative toxic poisons and ultimately may reach objectionable levels in water or in aquatic life. Analysis of polluted waters show the presence of a wide variety of these compounds and many others are probably not being detected. Of these, detergents, pesticides, polychlorinated biphenyls have been subjected to intensive study since these degradation resistant organics are not efficiently removed from the treatment processes and disposal of inadequately treated sewage can cause severe problems.

Soaps And Detergents:

Soaps are salts of long chain fatty acids such as sodium stearate . The cleaning action of soap results largely from its emulsifying power caused by the dual nature of the soap anion. In the presence of oils, fats, and other water insoluble organic materials, the "tail" of the anion tends to dissolve in the organic matter, whereas the carboxyl "head" remains in aqueous solution. Thus the soap emulsifies, or suspends, organic material in water. All sodium and potassium salts of soap are soluble in water. If the water is hard, the calcium, magnesium and any other ions causing hardness precipitate the soap as shown by the following equation.



These insoluble products, are not at all effective as cleaning agents. In addition, the insoluble "curds" form dirty deposits on clothing and in washing machines.

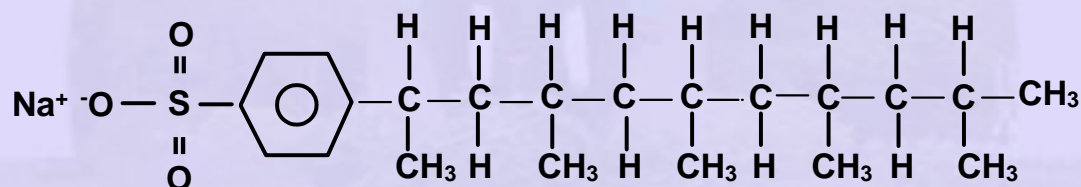
However soap has a distinctive advantage from the environmental stand point. As soon as soap gets into sewage or an aquatic system, it generally precipitates as calcium and magnesium salts. Hence any effects that soap might have in solution are eliminated. As it is eventually biodegrades, the soap is completely eliminated from the environment. Thus soap does not cause any substantial pollution problems.

A wide variety of synthetic **detergents**, commonly called syndets have been accepted as a substitute for soap. Their major advantage is that they do not form insoluble precipitates with the ions causing hardness. As marketed most of them contain from 20 to 30 percent surfactant, and 70 to 80 percent builders. The builders are usually sodium sulphate, sodium tripolyphosphate, sodium silicate and other materials that enhance the detergent properties of the active ingredient. Of these polyphosphates undergo fast biodegradation by hydrolysis giving HPO_4^{2-} and H_2PO_4^- . Eventhough these hydrolysis products do not pose any threat to aquatic animal life, they act as nutrients for plants and thus cause eutrophication by excessive growth of plants. The synthetic surfactants are of three major types: anionic, nonionic and cationic of which anionic surfactants are widely used.

The anionic surfactants are all sodium salts and ionise to yield Na^+ plus a negatively charged, surface active ion. The common ones are all sulphates and sulphonates.

Long chain alcohols when treated with sulphuric acid produces sulphates (inorganic esters) with surface-active properties. Dodecylalcohol or Lauryl alcohol is commonly used. The sulphated alcohol is neutralised with sodium hydroxide to produce the surfactant. (e.g: $C_{12}H_{25}OSO_3Na$, sodium lauryl sulphate).

The principal sulphonates of importance are derived from esters, amides and alkyl benzenes. The esters and amides are of organic acids with 16 to 18 carbon atoms. In the past the alkyl benzene sulphonates (ABS) were derived largely from polymers of propylene, and the alkyl group, which averaged 12 carbon atoms, was highly branched.



Structure of ABS

The environmental problem associated with ABS was that it had the disadvantage of being only very slowly biodegradable because of the branched chain structure of the alkyl groups and because the benzene rings are attached principally to tertiary carbon of the branched chain groups.

Because of this resistance, these detergents persisted even after biological treatment of the effluent and have contaminated both surface water and ground water with objectionable foaming properties.

one of the most potent toxins known) and 2,4-D (dichlorophenoxyacetic acid) are common water pollutants.

The most well known organochlorine pesticide is DDT (dichlorodiphenyltrichloroethane) which has been widely used to control insects that carry such diseases such as malaria, typhus, and plague. By contributing to the control of these diseases, DDT is credited with saving literally millions of lives worldwide. In spite of its more recent reputation as a dangerous pesticide, in terms of human toxicity, DDT is considered to be relatively safe. It was its impact on food chains, rather than human toxicity, that led to its ban. Organochlorine pesticides, such as DDT, have two properties that cause them to be particularly disruptive to food chains. They are persistent, which means they last a long time in the environment before being broken down into other substances and they are quite soluble in lipids, which means they easily accumulate in fatty tissue.

The accumulation of organochlorine pesticides in fatty tissue means that organisms at successively higher trophic levels in a food chain are consuming food that has successively higher concentrations of pesticide. At the top of food chain body concentrations of these pesticides are the highest, and it is there that organochlorine toxicity has been most recognisable. Birds, for example, are high on the food chain and it was the adverse effect of DDT on their reproductive calcium metabolism in birds, resulting in eggs with shells that are too thin to support the weight of the parent. The resulting difficulty to reproduce has been shown to affect a number of species, including falcons, bald eagles, ospreys, and brown pelicans.

Other widely used organochlorines included methoxychlor, chlordane, heptachlor, aldrin, dieldrin, and chlordane produce liver cancers, and aldrin,

dieldrin, and endrin have shown to cause birth defects in mice and hamsters. One of the great environmental disasters that had resulted from pesticide manufacture users in the production of kepone at virginia, USA. This pesticide was used for the control of banana-root borer, tobacco wire-worm, ants and cockroaches during mid 1970's. However the plant was ultimately closed since worker's exposure to kepone in the manufacturing unit showed severe neurological damage. Given the ecosystem disruption, the toxicity, and the biological resistance to these pesticides that many insect species have developed, organochlorines have largely been replaced with organophosphates and carbamates.

The organophosphates, such as parathion, malathion, diazinon, TEPP (tetraethylpyrophosphate), and dimethoate, are effective against a wide range of insects and they are not persistent. However, they are much more toxic than the organochlorines that they have replaced. They are rapidly absorbed through the skin, lungs, and gastrointestinal tract and, hence, unless proper precautions are taken they are very hazardous to those who use them. Humans exposed to excessive amounts have shown a range of symptoms including tremor, confusion, sturred speech, muscle twitching, and convulsions.

Propoxur, carbaryl, and aldicarb are some of the popular carbamate pesticides. Acute human exposure to carbamates has led to a range of symptoms, such as nausea, vomiting, blurred vision, and in extreme cases convulsions.

Polychlorinated Dibenzodioxins (PCDDs) And Polychlorinated Dibenzofurans (PCDFs):

Polychlorinated dibenzodioxins are highly toxic and are the by-products in the manufacture of chlorophenoxy herbicides and hexachlorophene. The chlorophenoxy herbicides including 2,4,5-trichlorophenoxyacetic acid, were manufactured on a large scale for weed and brush control and as military defoliants. The best known member of the PCDDs group is 2,3,7,8-tetrachlorodibenzo-p-dioxin (often referred to simply as dioxin) which shows very acute toxicity for some species in laboratory tests. Also of concern is the related polychlorinated dibenzofuran group of compounds (PCDFs), the most toxic member once again being 2,3,7,8 tetrachlorinated compound. These compounds are found in the environment in complex mixtures containing PCDDs and PCDFs with all possible substitution patterns. The two group of compounds are formed during the combustion of organic material containing chlorine such as chemical and municipal incinerators, coal-fired power stations and domestic coal fires. They are also found as contaminants in some chlorinated chemical products as described previously.

The solubility of 2,3,7,8-tetrachlorodibenzodioxin(molecular mass=322) is $5.9 \times 10^{-5} \mu \text{ mol l}^{-1}$ at 25°C . It is a solid with a vapour pressure of $6.2 \times 10^{-7} \text{ pa}$ at normal temperature. The bioconcentration factor for this pollutant is extremely high. In addition the compound is also likely to accumulate in sediments. There are few investigations of dioxin concentrations in natural water samples (concentrations would be at or below lower detection limits), but many in sediments and living organisms.

Polychlorinated Biphenyls:

Polychlorinated biphenyls, PCBs, are among the most hazardous human made substances. PCBs are extremely stable to heat, chemical, and biological decomposition. They are excellent insulating and cooling fluids, extensively used for many years in manufacture of transformers and capacitors. PCBs are also used in hydraulic fluids, lubricating oils, paints, adhesive resins, inks, fire retardants, wax extenders, and numerous other products. The chemical and physical properties of PCBs make the remediation of the pollution sites difficult. They resist the degradation and adsorb into soils and colloidal materials in water. Some persist with half-lives of 8-15 years in the environmental compartments. This stability contributes to their dispersion in the environment and long-range air pollution. Because they are lipophilic, these species are stored in fatty tissues and accumulate in food webs.

The physical and toxicological properties and molecular structures of PCBs are related to their degree of chlorination. Substitution of electronegative chlorines at one or more ortho--positions lead to rotation about the bond between phenyl rings. The three most toxic congeners are 3,4,3,4'- tetrachlorobiphenyl, 3,4,3,4',5' - pentachlorobiphenyl and 3,4,5,3,4',5' -hexachlorobiphenyl. Because these have no chlorines at the ortho-positions, the biphenyl rings can be coplanar and structurally resemble dioxin, which is the most toxic organic compound.

Elemental Pollutants:

Trace elements are those that occur at very low levels of a few parts per million or less in the environment. Some of these trace elements are recognized as nutrients required for animal and plant life. There are some elements which are essential at low levels but toxic at higher levels. The most harmful of these

elements have been found to be heavy elements. These elements include essential elements like iron as well as toxic elements like lead, cadmium and mercury. Most of these have tremendous affinity for sulfur and sulfur bonds in enzymes, thus immobilizing the enzymes. The carboxylic acid and amino groups from protein are also chemically bound by heavy metals. Cadmium, copper, lead and mercury ions bind to cell membranes, hindering transport processes through the cell wall. Heavy metals may also precipitate phosphate biocompounds or catalyze their decomposition. Most of these substances produce physiological poisoning by becoming attached to the tissues of aquatic organisms and accumulate. Consequently, their increasing concentrations can build up in food chains. The metals of particular concern in industrial waste waters are cadmium, chromium, lead and mercury. The following paragraph give an account of the toxicity of these heavy metals. More details however are given under chapter "Toxicological chemistry".

Heavy metals

Cadmium

Cadmium is generated in waste streams from pigment works, textiles, electroplating chemical plants etc. In rivers polluted by cadmium, the metal may be undetectable in filtered water, although it is present in high concentration in particulate fraction. The itai-itai disease in Japan was probably due to the transport of cadmium containing particulates in water to the irrigation fields. Chemically cadmium is very similar to zinc and both are found in water in +2 oxidation state. Cadmium causes acute poisoning in humans resulting in kidney damage, destruction of testicular tissue and destruction of red blood cells. Because of its chemical similarity to zinc, cadmium replace zinc in some enzymes, thus altering the stereo structure of the enzyme and impairing its

catalytic activity. It has been found that 0.1 mg l^{-1} cadmium can be lethal to both oysters and aquatic plants.

Lead: Of all the toxic metals in the environment lead is the most pervasive; it poisons many thousands of people yearly especially children in urban areas. Unlike cadmium, lead is not taken up actively by plants; nevertheless it contaminates the food supply because it is abundant in dust and is deposited on food crops or on food as it is being processed. Food and direct ingestion of the dust account for most of the average lead intake by humans. The sources for lead pollution are industry and mining in which lead is present in +2 oxidation state.

Lead pollution from leaded gasoline which used to be a major source of atmospheric and terrestrial lead has been stopped because of the use of other environmental friendly antiknock agents. Acute lead poisoning in human causes malfunctioning of kidneys, reproductive system, liver, and the brain and central nervous systems.

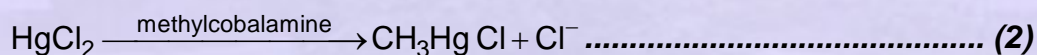
Chromium

Chromium is found in two forms in waste waters - hexavalent and trivalent. Hexavalent is present in waste waters of plating operations, aluminium anodising, paint and dye operations, and leather industries. Trivalent chromium is present in waste waters from textile dyeing, the ceramic and glass industry, and photography. As the effluent flows downstream, the dissolved oxygen can oxidise Cr^{3+} to $\text{Cr}_2\text{O}_7^{2-}$. Cr(III) has low toxicity, but in the hexavalent form it is both toxic and carcinogenic to humans.

Mercury

Mercury is discharged into natural waterways from various industrial effluents

such as those of manufacture of paint, paper, chlorine and caustic soda, fertilisers and pesticides. Among the more severe toxicological effects of mercury is neurological damage, chromosome breakage; and birth defects. The toxicity of mercury was tragically illustrated in the minamata bay area of Japan during the period 1953-1960. The level of metal in the contaminated sea food was 5-20 ppm. Unexpectedly high concentrations of mercury was found in water and fish tissues in the US and Canada around 1970. They were attributed to the formation of soluble monomethyl mercury ion CH_3Hg^+ , and volatile dimethyl mercury, $(\text{CH}_3)_2\text{Hg}$ by anaerobic bacteria in sediments. Mercury from these compounds becomes concentrated in fish lipid tissue and the concentration factor from water to fish may exceed 10^3 . The methylating agent by which inorganic mercury is converted to methyl mercury compound is methylcobal amine, a vitamin B12 analog;



It is believed that the bacteria that synthesise methane, produce methyl cobal amine as an intermediate in the synthesis. In neutral or alkaline waters, the formation of dimethyl mercury, $(\text{CH}_3)_2\text{Hg}$ is favoured. This volatile compound can escape to the atmosphere. One aspect of mercury poisoning that is causing concern is its effect on the rate of photosynthesis of phytoplanktons. There is some evidence that the oxygen producing activities of phytoplankton can be inhibited at mercury levels as low as 0.001 mg l^{-1} .

Metalloids:

Among the metalloids arsenic is the most significant water pollutant. Although arsenic is in the same column of periodic table as phosphorous, and has similar chemistry, it is more easily reduced from V to III oxidation state. As (III)

(arsenite, AsO_3^{3-}) is more toxic than As(V) (arsenate, AsO_4^{3-}), probably because it binds more readily to sulfhydryl groups on proteins. Toxicity of As(V) probably results from its reduction to As(III) in the body. Arsenic occurs with phosphate minerals and enters into the environment along with some phosphorous compounds. Arsenic produced as a by-product of copper, gold and lead refining, greatly exceeds the commercial demand for arsenic, and it accumulates as waste material. Like mercury, arsenic may be converted to more mobile and toxic methyl derivatives by bacteria such as methyl arsenic acid ($\text{CH}_3\text{AsO}(\text{OH})_2$) and dimethyl arsinic acid $\{(\text{CH}_3)_2\text{AsO}(\text{OH})\}$ and dimethyl arsenic acid $\{(\text{CH}_3)_2\text{AsO}(\text{OH})\}$ which are highly reactive and damage DNA atleast in cultured human cells. In another recent discovery low levels of arsenic were found to inhibit activation receptors of glucocorticoid hormone, receptors that turn on many genes that suppress cancer and regulate blood sugar.

Chemical speciation of metal pollutants:

Natural waters are extremely complex chemical environments. Not only do they contain almost every element in the periodic table, but also dissolved organic matter of largely unknown composition (fulvic acid and humic acid) and colloidal and particulate material, both inanimate and living. The range of chemical process affecting pollutant metals can be illustrated by the case of copper in natural waters. Copper dissolved at trace levels in distilled water is present as hydrated Cu^{2+} ion. In natural water this cation is subjected to range of interactions as shown in fig 1.

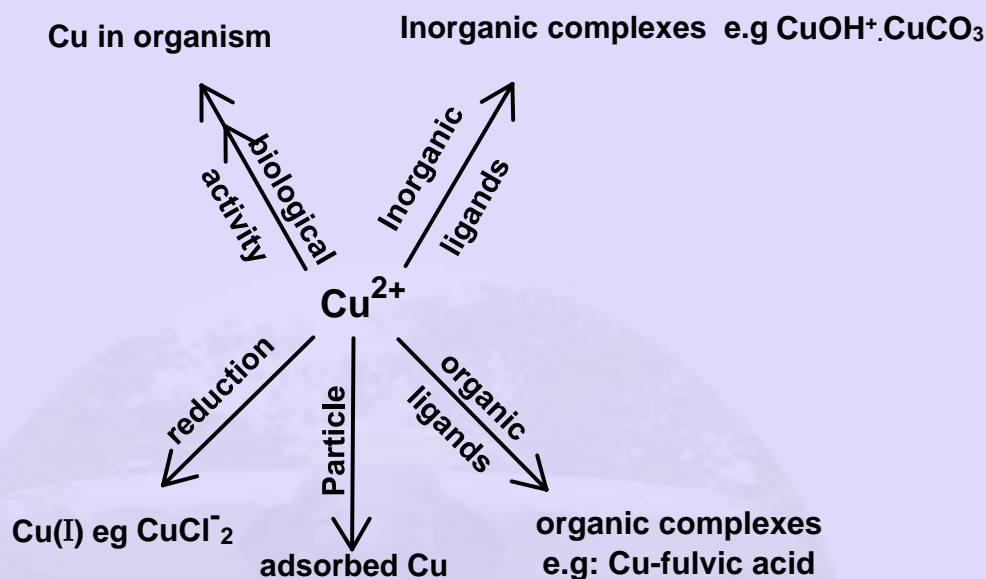


Fig.1 Major processes involving trace metals in water, taking sea water as example

The distribution of copper between the different chemical species and forms shown in fig.1 is termed chemical speciation, and it is chemical speciation which holds key to understanding the geochemical and biological reactivity of trace metals. Metal organic interaction may increase or decrease the toxicity of metals in aquatic ecosystems, and they have strong influence on the growth of algae in water.

Other inorganic pollutants:

Cyanide

Cyanide is a deadly poisonous substance, that exists in water as HCN; It is a very weak acid. Cyanide ion forms stable complexes with metal ions and these complexes are relatively less toxic. The cyanide ion has a strong affinity for many metal ions forming relatively less toxic complexes. For example with iron (II) it forms less toxic $[\text{Fe}(\text{CN})_6]^{4-}$ where as volatile HCN is toxic. Especially metal

cleaning and electroplating industry use large quantities of cyanides. The presence of cyanide in water is indicative of a serious pollution problem.

Ammonia :

Ammonia is formed during the microbial degradation of decaying biomass and organic matter in soil and water. Nitrogenous compounds like proteins are ammonified to release ammonia into the surroundings. Sometimes it is added to drinking water during chlorination where it reacts to provide residual disinfectant chlorine.

Hydrogen sulfide:

The anaerobic decay of organic matter containing sulphur leads to the production of H_2S . Anaerobic reduction of sulphate in water by microorganisms is also a natural source for hydrogen sulphide. H_2S is evolved as a gaseous pollutant from geothermal waters. Wastes from chemical plants, paper mills, textile mills, and tanneries may also contain H_2S . It is a weak diprotic acid and S^{2-} is not present in normal natural waters. The sulphide ion has tremendous affinity for many heavy metals and precipitation of metallic sulphides often accompanies production of H_2S .

Nitrite nitrogen:

Nitrite nitrogen seldom appears in concentrations greater than 1mg l^{-1} , even in waste treatment plant effluents. Its concentration in surface and groundwaters is normally much below 0.1 mg l^{-1} . Nitrite is added to some industrial process water to inhibit corrosion; it is rarely found in drinking water at levels over 0.1 mg l^{-1} .

Sulfite ion

Some industrial wastes contain sulphite ions where sodium sulphite is added to boiler feed waters as an oxygen scavenger:



Since pKa₁ of sulfurous acid is 1.76 and pKa₂ is 7.20, sulfite exists as either HSO₃⁻ or SO₃²⁻ in natural waters, depending upon its pH.

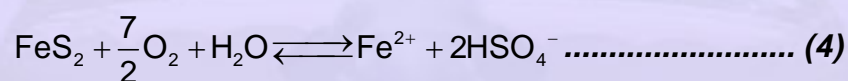
Eutrophication And Algal Nutrients:

Eutrophication is a process of providing a water body with nutrients for the aquatic life it supports. A lake starts its life as a clean body of water. Small amounts of nitrates and phosphates occur in all aquatic systems and these are sufficient to maintain a balanced biological growth (a balance between the production of aquatic life and its destruction by bacterial decomposition). With the introduction of nutrients through land run off and growth and decay of aquatic life, the lake collects good amount of organic substances. Thus when unusually large concentrations of nutrients are present in water bodies, there is an excess of growth of algae known as algal bloom. This produces an unsightly green slime layer over the surface of water body. This slime layer reduces the penetration of light and restricts atmospheric reoxygenation of the water. The dense algal growth eventually dies and the subsequent biodegradation produces oxygen deficit which can result in foul smelling anaerobic conditions. The anaerobic conditions created by rotting algae can present health hazard to aquatic systems. Thus with large inputs of nutrients from human sources, the bacterial decomposition cannot keep pace with the productivity and sedimentation is accelerated, whereby eutrophication only is favoured. Lakes can be protected

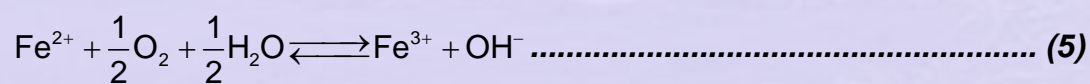
from eutrophication only by providing measures for sewage treatment and preventing the sewage from entering the water bodies.

Acid Mine drainage:

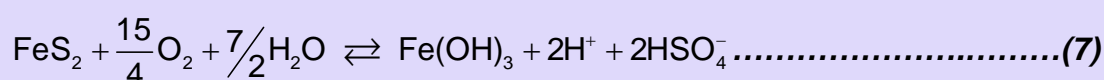
Coal mines, especially those that have been abandoned, are known to release substantial quantities of sulphuric acid and iron hydroxide into local streams. The first step in the process is the oxidation of pyrite (FeS_2), which is common in underground coal streams.



This step is mediated under aerobic conditions by the bacterium thiobacillus ferro oxidans, which oxidises FeS_2 as an energy source much the same way that other aerobic bacteria oxidise organic carbon (CH_2O) in respiration reactions. The oxidation step occurs spontaneously at ambient temperatures once iron sulphide, which is stable in the absence of air is exposed to atmosphere. In the second step, the ferrous iron (Fe^{2+}) formed from reaction (3) combines with oxygen and water in the overall reactions.

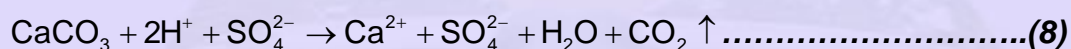


The sum of reactions (3), (4) and (5) yields the following reaction:



Thus one mole of pyrite produces 2 moles of sulphuric acid and one mole of ferric hydroxide, which is removed from the solution as a brown precipitate. The pH of the streams receiving this drainage can be as low as 3.0

Environmental chemists have a tough challenge in the prevention of water pollution from acid mines. Even though at the first instance, it may appear that this problem can be remedied by using carbonate rocks to neutralise the acid as per the following equation.



this reaction is inhibited after sometime since the formed ferric hydroxide form an impermeable layer with the calcium carbonate particles.

Accumulation of Salts in water:

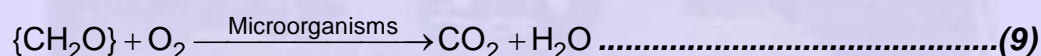
Water naturally accumulates a variety of dissolved solids, or salts as it passes through the soils and rocks on its way to the sea. A more commonly used measure of salinity is to determine the concentration of total dissolved solids in the water sample. All naturally occurring water has some amount of salt in it. While human activities may increase salinity by adding salts to a given volume of water, it is more often the opposite process, the removal of fresh water by evaporation, that causes salinity problems. When water evaporates, the salts are left behind, and since there is less remaining fresh water to dilute them, their concentration increases.

Irrigated agriculture, especially in acid areas, is always vulnerable to an accumulation of salts due to this evaporation on the cropland itself. The salinity is enhanced by the increased evaporation in storage reservoirs that typically

accompany irrigation projects. In addition irrigation drainage water may dissolve more salt from soils with which it comes in contact further increasing its salinity. As a result, irrigation water is always higher in salinity than the supply water and with every reuse, its salt concentration increases even more. In rivers that are heavily used for irrigation, the salt concentration progressively increases downstream as the volume of water available to dilute salts decreases due to evaporation and diversions.

Oxygen sag curve:

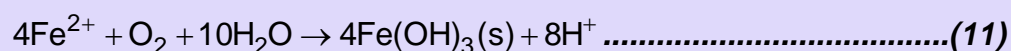
Oxygen which is present in water is vitally important. If the water contains organic matter (CH_2O), the oxidation of this compound is mediated by microorganisms as shown below.



When the river water is turbulent, it gets reaerated quickly. With the introduction of organic loaded polluted water into the river, the dissolved oxygen content in the water body rapidly gets depleted and it cannot support higher forms of aquatic life. In addition to microorganism mediated oxidation of organic matter, oxygen may be consumed by the oxidation of nitrogenous material,



Or by chemical reducing agents present in water may consume oxygen for their chemical or biochemical oxidation as shown below:





All these processes involve the removal of dissolved oxygen in water. The measure of oxygen utilised by microorganisms during the oxidation of organic materials is called the biochemical oxygen demand or the biological oxygen demand (BOD). This parameter is commonly measured by determining the quantity of oxygen utilized by suitable aquatic micro organisms during a five-day period. The five day BOD test is empirical and semiquantitative. But it still remains a respectable measure of the short-term oxygen demand exerted by a pollutant.

The discharge of wastes into a body of river stream results in the depletion of dissolved oxygen level as the wastes are oxidised by the bacteria. Opposing this drop in dissolved oxygen is reaeration which replaces oxygen through the surface, at the rate which is proportional to the depletion of oxygen below the saturation value. The simultaneous action of deoxygenation and reaeration produces a typical pattern in the dissolved-oxygen concentration of the aquatic system. This pattern is known as the oxygen sag curve which is shown in fig 2.

To begin with a well – aerated unpolluted stream is relatively free from oxidisable material; the oxygen level is high; and the bacterial population is relatively low.

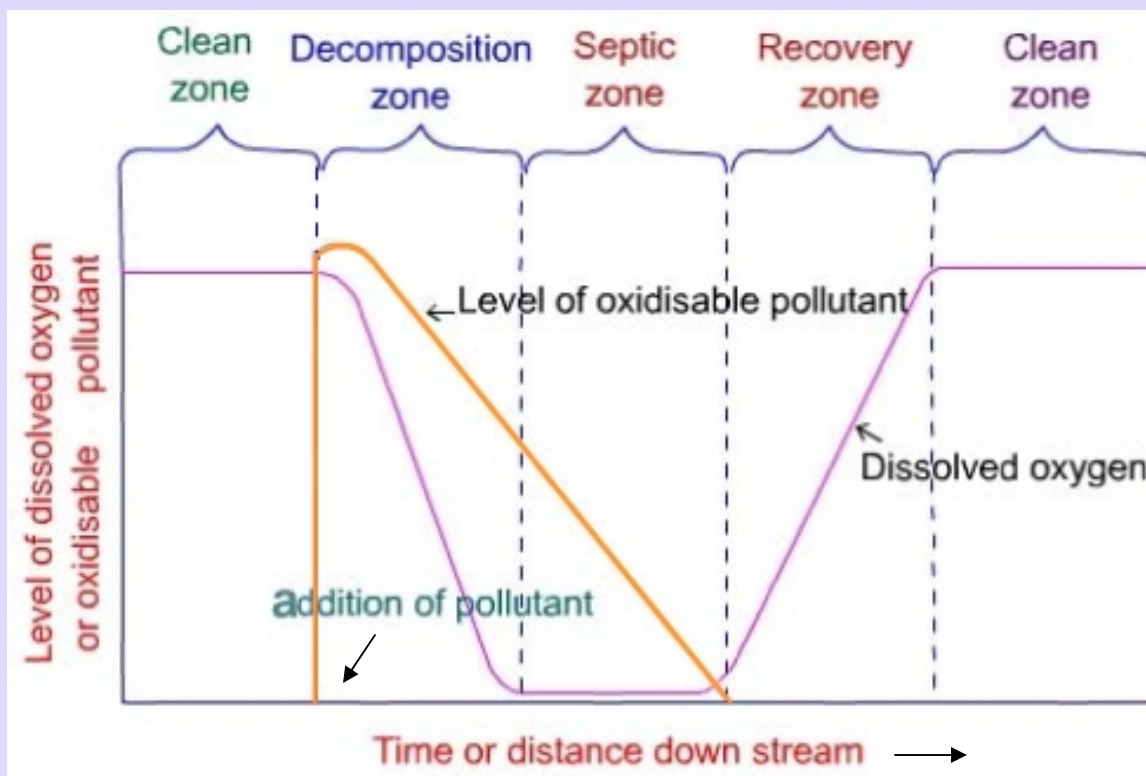


Fig. 2 Oxygen sag curve resulting from the addition of oxidisable pollutant to a stream

(Redrawn by permission of Lewis Publishers, Chelsea, Michigan 48118, USA from Fundamentals of Environmental Chemistry, S.E.Manahan, p.428,1993)

However with the addition of oxidisable pollutant, the oxygen level drops because reaeration cannot keep up with oxygen consumption. In the decomposition zone, the bacterial population rises. The bacterial population is very high and the dissolved oxygen levels are very low in the septic zone. When the oxidisable pollutant is exhausted, the septic zone terminates and then the recovery zone begins. The bacterial population decreases in the recovery zone and the dissolved oxygen level increases until the water regains its original conditions.

Regulation of water quality:

Governments around the world try to regulate water quality in the interest of public health and environmental protection. In the U.S. the legal instruments for regulation are two basic laws, the Clean Water Act (CWA), of 1972 and Safe Drinking Water Act (SDWA) of 1974, both of which have been amended several times. Under this act, the Environmental Protection Agency (EPA) is required to set standards that protect from harmful effects of contaminants. Similar initiatives have been undertaken in most of the industrially advanced countries. These measures have helped to produce marked reductions in pollutant discharges to water bodies.

With regard to the drinking water standards, it falls into two categories: **primary standards** which specify maximum contamination Levels (MCLs) based on health related criteria and **secondary standards**, which are unenforceable guidelines based on both aesthetic such as taste, odour and colour of drinking water, as well as non aesthetic characteristics such as corrosivity and hardness. In setting MCLs, the EPA is required to balance the public health benefits of the standard against what is technologically and economically feasible.

Primary standards: Contaminants for which MCLs are established are classified as being **inorganic chemicals, organic chemicals, radionuclides, or microbiological contaminants**. A list of standards for inorganic chemicals have been prescribed which included many metallic cations and anions with their permissible levels.

Organic chemical contaminants for which MCLs are being promulgated are classified conveniently using the following **three** groupings.

Synthetic organic chemicals :These are used in the manufacture of a wide variety of agricultural and industrial products. They include primarily pesticides and herbicides.

Trihalomethanes: These are the products of water chlorination. They include chloroform (CHCl_3), bromodichloromethane (CHBrCl_2), dibromochloromethane (CHBr_2Cl), and bromoform (CHBr_3).

Volatile organic chemicals (VOCs) : These are synthetic chemicals that readily vaporise at room temperature. These include degreasing agents, paint thinners, glues, dyes, and some pesticides. Representative chemicals include benzene, carbontetrachloride, 1,1,1-trichloro ethane (TCA), trichloroethylene (TCE), and vinyl chloride.

Radioactivity in public drinking water supplies is the **third** category of contaminants regulated by safe water drinking act. Some radioactive compounds, or radionuclides, are naturally occurring substances such as radon and radium-226 (which are often found in ground water) while others such as strontium-90 and tritium are surface water contaminants resulting from atmospheric nuclear weapons testing fall out. The most significant radionuclide associated with drinking water is dissolved radon gas. It is an unusual contaminant because the danger arises not by drinking radon contaminated water, but from breathing the gas which is believed to be the cause for lung cancer.

The **fourth** category of primary MCLs is **microbiological contaminants**. While it would be desirable to evaluate the safety of a given water supply by individually testing for specific pathogenic microorganisms, such tests are too

difficult to perform on a routine basis. Instead a much simpler technique is used, based on testing water for evidence of any fecal contamination. In this test coliform bacteria are used as indicator organisms whose presence suggests that the water is contaminated.

Secondary standards:

Secondary standards are non enforceable, maximum contaminant levels based on aesthetic factors such as taste, colour, and odour, rather than on health effects. The limits suggested for chloride, copper, total dissolved solids and zinc are in large part based on taste. Excessive sulphate is undesirable because of its laxative effect; iron and manganese are objectionable because of taste and their ability to stain laundry and fixtures. Foaming and colour are visually upsetting and odour from various dissolved gases may make water unacceptable for drinking.

