TECHNOLOGIES FOR WATER POLLUTION CONTROL

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Contents

Summary

The pollutants in water and wastewater can be removed by means of physical, chemical and biological treatment methods. The specific methods are classified as physical unit operation, chemical unit processes, and biological unit processes.

A variety of methods have been developed for treatment of water and wastewater. In most situations, a combination or sequence of methods will be needed. The specific sequence required will depend on the quality of the influent water or wastewater and the desired quality of the effluent.

There are many organic compounds, chiefly synthetic ones, are not amenable to biological treatment either because they are toxic to the microorganism population at the concentrations present or because of their metabolic inertness. It is in the treatment of organic material of this nature and in the treatment of certain inorganic pollutants that chemical oxidation processes are used to their greatest advantages. Integration of chemical and biological treatment processes is the optimal approach, and it is easy to find lots of examples in practice.

Bioremediation and soil vapor extraction (SVE) are by far the most commonly technologies applied for the remediation of contaminated underground water and soils. Their principle is to use microorganisms to transform harmful substances into nontoxic compounds. They are one of the most promising new technologies for the treatment of chemical spills and hazardous wastes and have been used to degrade petroleum products and hydrocarbons.

1. Introduction

Water is the most important natural resource in the world. It is an essential element in the maintenance of all forms of life. Without it life cannot exist and most industries could not operate. The presence of a safe and reliable source of water is thus an essential prerequisite for the establishment of a stable community. Water, as a natural resource, requires careful management and conservation.

Although nature often has great ability to recover from environmental damage, the growing demands on water resources necessitate the professional application of fundamental knowledge about the water cycle to ensure the maintenance of quality and quantity.

A series of physical, chemical and biological treatment methods have been developed to remove the pollutants in water and wastewater. Although several of these operations and processes are combined in most treatment systems, they are usually considered separately.

2. Physical, Chemical and Biological Characteristics of Water

Water quality measures can be classified in a number of ways, but most often are grouped as physical, chemical and biological. To provide a perspective for considering the characteristics of water it will be instructive to consider first the hydrologic cycle and its relationship to those characteristics, and then review the methods used to quantify them.

2.1 The Hydrologic Cycle and the Characteristics of Water

From a global point of view, the hydrologic cycle of water is closed (i.e., no water is lost). In individual regions, however, considerable deviations from the theoretical mean values for the mass fluxes occur due to long-range transport and climatic differences.

Water is "pure" only in the vapor state, and impurities begin to accumulate as soon as condensation occurs. Upon reaching the surface, water either percolates into the soil, becoming groundwater, or runs off along the surface in rivulets, streams, and rivers. Minerals dissolve in both groundwater and surface water, but the greater contact with soil and minerals generally results in a higher dissolved-salt concentration in groundwater.

Chemical impurities commonly found in water in significant quantities include calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and nitrate. Trace amounts of other ions such as lead, copper, arsenic, manganese, and a wide spectrum of organic compounds are also common. The organic compounds originate from four principal sources: decaying plant and animal matter, agricultural runoff, wastewater, and the improper management of hazardous wastes discharge.

The compounds themselves range from humic materials to the synthetic organic compounds used as detergents, pesticides, herbicides, and solvents.

Groundwater

In many groundwater basins, the amount of groundwater withdrawn for agricultural irrigation considerably exceeds the rate of recharge. Because water lost during consumptive use, evapotranspiration, and surface runoff, the level of the groundwater is dropping.

At the same time, the concentration of impurities in the groundwater is increasing because of evapotranspiration, the leaching of salts from the soil, and the application of fertilizers.

Surface water

Surface water characteristics also change with time and space. Concentrations of impurities increase because of mineral pickup from surface runoff, silt and debris are carried out by surface waters, often resulting in muddy or turbid streams.

2.2. Measurement of Organic Pollutants

Over the years, a number of tests have been developed to measure the organic matter content of water. In general, the tests may be divided into those used to measure concentrations of organic matter greater than 1 g/m^3 and those used to measure trace concentrations in the range of 10^{-12} to 10^{-3} g/m^3. The former is used to measure the mixtures of organic compounds found in water. The latter is used to measure the presence of trace quantities of anthropogenic organic compounds.

Laboratory tests commonly run to measure gross amounts of organic matter (greater than 1 g/m^3) include tests for:

- Chemical oxygen demand (COD)
- Total organic carbon (TOC)
- Total oxygen demand (TOD)
- Biochemical oxygen demand (BOD)

The COD test is a chemical test, the TOC and TOD tests are instrumental tests, and the BOD test is a biochemical test involving the use of microorganisms.

The BOD test was developed to determine the depletion of oxygen that would occur in a stream due to utilization by living organisms as they degrade organic matter. That is to say, it is used to determine the amount of biodegradable contents in a sample of wastewater. The test simulates the conditions as close as possible to those that occur naturally.

Often the BOD is used as the sole basis for determining the efficiency of the treatment plant in stabilizing organic matter. The ammonium-nitrogen present in wastewater poses an analytical problem in measuring BOD. At 20 ^{0}C, the nitrifying bacteria in raw domestic wastewater usually are significant in number and normally will not grow sufficiently during the 5-day BOD test to exert a measurable oxygen demand.

To obtain a true measure of the treatment plant performance in removing organic matter, the BOD test may require correction for nitrification. For this reason, and to avoid possible confusion, it is better to use the term CBOD to denote carbonaceous biochemical oxygen demand. The oxygen required to the biological oxidation of ammonia to nitrate is termed the nitrogenous biochemical demand (NBOD).

In addition, the BOD test depends on the control of such environmental and nutritional factors as pH and osmotic conditions, essential nutrients, temperature, and population of organisms representative of natural conditions.

Although it theoretically takes an infinite amount of time for all the oxidizable material in a sample of water to be consumed, it has been empirically determined that a period of 20 days is required for near completion. Because the 20-day test period is too long to wait in most cases, a 5-day incubation period (the time in which 70-80% of available material is usually oxidized) has been adopted as standard procedure. This shorter test is referred to as BOD_5.

While the BOD test is the only presently available that gives a measure of the amount of biologically oxidizable organic matter present in a body of water, it does not provide an accurate picture of the total amount of overall oxidizable material and thus the total oxygen demand. For such measurements, the COD test is used, a very strong oxidizing chemical, usually potassium dichromate, is added to samples of different dilution.

To ensure full oxidation of the various compounds found in the samples, a strong acid and a chemical catalyst are added. The COD test is more reproducible and less time-consuming. The COD test and BOD test can be correlated, but the correlation ultimately gives a qualitative value. The COD test measures the non-biodegradable as well as the ultimate biodegradable organics. A change in the ratio of biodegradable and non-biodegradable organics affects the correlation between COD and BOD.

The TOC test is another method used for measurement of the organic matter present in a wastewater. The test is carried out, by placing a sample into a high-temperature furnace or chemically oxidizing environment, in which organic carbon is oxidized to carbon dioxide.

The carbon dioxide that is produced can then be measured. While the TOC test does directly measure the concentration of organic compounds, it does not provide a direct measurement of the rate of reaction or the degree of biodegradability. For this reason, the TOC test has been accepted as a monitoring technique but has not been utilized in the establishment of treatment regulations.

The BOD, COD and TOC tests provide estimates of the general organic content of a wastewater. However, because the particular composition of the organic compounds remains unknown, these tests do not reflect the response of the wastewater to various types of biological treatment technologies. It is necessary to separate the wastewater into its specific components.

Trace organic compounds in the range of 10^{-12} to 10^{-3} g/m^3 are determined using instrumental methods including gas chromatography (GC), high performance liquid chromatography (HPLC) and mass spectroscopy (MS).

2.3. Types of Pollutants

Contaminants behave in different ways when added to water. Non-conservative materials including most organic compounds, some inorganic compounds and many microorganisms are degraded by natural self-purification process so that their concentrations reduce with time. The rate of decay of these materials is a function of the particular pollutant, the receiving water quality, temperature and other environmental factors. Many inorganic substances do not affected by the natural process, so that these conservative pollutants can only have their concentrations reduced by dilution. Conservative pollutants are often unaffected by normal water and wastewater treatment processes so that their presence in a particular water source may limit its use.

The pollutants existing in the waters can be classified into following categories:

- Toxic compounds which result in the inhibition or destruction of biological activity in the water. Most of these materials originate from industrial discharges and would include heavy metals from metal finishing and plating operations, moth repellents, herbicides and pesticides etc.
- Anything which may affect the oxygen balance of the water, including
- Substances which consume oxygen: these may be organic matters that are biochemically oxidized or inorganic reducing agents;
    - Substances, which hinder oxygen transfer across the air-water interface. Oils and detergents can form protective films at the interface which reduce the rate of oxygen transfer and may thus amplify the effects of oxygen-consuming substances;
    - Thermal pollution, which can upset the dissolved oxygen (DO) balance because the saturation DO concentration reduces with increasing temperature.
- Inert suspended or dissolved solids in high concentrations can cause problems.

2.4. Characteristics of Wastewater

Any body of water is capable of assimilating a certain amount of pollutants without serious effects because of the dilution and self-purification factors which are present. If additional pollution occurs, the nature of the receiving water will be altered and its suitability for various uses may be impaired. Understanding of the effects of pollution and of the control measures that are available is thus of considerable importance to the efficient management of water resources.

Municipal wastewater consists of a mixture of dissolved, colloidal, and particulate organic and inorganic materials. Municipal wastewater contains 99.9 % water. The remaining materials include suspended and dissolved organic and inorganic matter as well as microorganisms. These materials make up the physical, chemical, and biological qualities that are characteristics of residential and industrial waters.

The physical quality of wastewater is generally reported in terms of its temperature, color, and turbidity. The temperature of wastewater is slightly higher than that of the water supply. This is an important parameter because of its effect upon aquatic life and the solubility of gases. The temperature varies slightly with the seasons, normally remaining higher than air temperature during most of the year and failing lower only during the hot summer months.

The color of a wastewater is usually indicative of age. Fresh water is usually gray, septic wastewater imparts a black appearance. Odors in wastewater are caused by the decomposition of organic matter that produces offensive-smelling gases such as hydrogen sulfide. Wastewater odor generally can provide a relative indication of its condition.

Turbidity in wastewater is caused by a wide variety of suspended solids. Suspended solids are defined as the material which can be removed from water by filtration through prepared membranes.

Chemical characteristics of wastewater are expressed in terms of organic and inorganic constituents. Different chemical analyses furnish useful and specific information with respect to the quality and strength of wastewater.

Organic compounds in the wastewater are the most significant factor in the pollution of many natural waters. The principal groups of organic matter found in municipal wastewater are proteins, carbohydrates, and fats and oils. Carbohydrates and proteins are easily biodegradable.

Fats and oils are more stable and can also be decomposed by microorganisms. In addition, wastewater may also contain small fraction of synthetic detergents, phenolic compounds, and pesticides and herbicides. These compounds, depending on their concentration, may create problems such as non-biodegradability, foaming, or carcinogenicity. The concentrations of these toxic organic compounds in wastewater are very small. Their sources are usually industrial wastes and surface runoff.

The inorganic compounds most found in wastewater are chloride, hydrogen ions, alkalinity-causing compounds, nitrogen, phosphorous, and sulfur compounds, and heavy metals. Trace concentrations of these compounds can significantly affect organisms in the receiving water through their growing-limiting characteristics.

The quality and species of micro- and macroscopic plants and animals, which make up the biological characteristics in a receiving water body, may be considered as the final test of wastewater treatment effectiveness. Within the treatment facility, the wastewater provides the perfect medium for microbial growth, whether it is aerobic or anaerobic. Bacteria and protozoa are the keys to the biological treatment process used at most treatment facilities, and to the natural biological cycle in receiving waters. In the presence of sufficient dissolved oxygen, bacteria convert the soluble organic matter into new cell tissues, carbon dioxide and water.

3. Wastewater Treatment Processes

3.1. Basic Concept

Wastewater treatment plants utilize a number of individual or unit operations and processes to achieve the desired degree of treatment. The collective treatment schematic is called a flow sheet or flow scheme. Many different flow schemes can be developed from various unit operations and processes for the desired level of treatment. Unit operations and processes are grouped together to provide what is known as primary, secondary and tertiary (or advances) treatment. The term primary refers to physical unit operations, secondary refers to chemical and biological unit processes, and tertiary refers to combination of all three.

Treatment methods in which the application of physical forces predominates are known as physical unit operations. These were the first methods to be used for wastewater treatment. Screening, mixing, flocculation, sedimentation, flotation, and filtration are typical unit operations.

Treatment methods in which the removal or conversion of contaminants is brought about by the addition of chemicals or other chemical reactions are known as chemical unit processes. Precipitation, gas transfer, adsorption, and disinfection are the most common examples used in wastewater treatment.

Treatment methods in which the removal of contaminants is brought about by biological activity are known as biological unit processes. Biological treatment is used primarily to remove the biodegradable organic matter (colloidal or dissolved) in wastewater. Basically these substances are converted into gases that can escape to the atmosphere or into biological cell tissue that can be removed by settlement. Biological treatment is also used to remove nitrogen and phosphorous in wastewater. With proper environmental control, wastewater can be treated biologically in most cases.

3.2. Stages of Treatment Processes

Wastewater treatment is essentially a mixture of settlement and biological or chemical unit process.

Unit treatment processes can be classified into five stages:

- Preliminary treatment: the removal and disintegration of gross solids, the removal of grit. Oil and grease are also removed at this stage if present in large amounts.
- Primary (sedimentation) treatment: the first major stage of treatment following preliminary treatment, which usually involves the removal of settleable solids, which are separated as sludge.
- Secondary (biological) treatment: the dissolved and colloidal organic compounds are oxidized in the presence of microorganisms.
- Tertiary treatment: further treatment of a biologically treated effluent to remove BOD_5, bacteria, suspended solids, specific toxic compounds or nutrients to enable the final effluent to comply with a standard more stringent before discharge.
- Sludge treatment: the dewatering, stabilization, and disposal of sludge.

Depending on the quality of the final effluent required, not all the stages may be utilized. Preliminary treatment only may be given to effluents which are discharged to coastal or marine waters to prevent floating debris and gross solids being washed ashore later, whereas primary treatment is generally given to wastewater discharged to estuaries with the sludge often dumped at sea from special vessels. Most effluents discharged to rivers receive secondary treatment while tertiary treatment is often required if water is abstracted for potable supply downstream of a discharge.

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Biographical Sketch

Wang Jianlong is an Associate Professor in Department of Environmental Science and Engineering at Tsinghua University, Beijing, Peoples' Republic of China. He received his Ph.D degree in Environmental Chemical Engineering from Harbin Institute of Technology in 1993 and carried out the postdoctoral work in Tsinghua University. He gives lectures on Environmental Microbiology for undergraduate students and lectures on Modern Environmental Biotechnology for graduate students. He carries out the research work in the State Key Joint Laboratory of Environmental Simulation and Pollution Control. His research interests are mainly in the following areas: (1) novel technology of biological wastewater treatment which is high efficiency, low cost and suitable for Chinese practical conditions; (2) nitrogen removal of high-concentrated nitrogen-containing industrial wastewater; (3) application of bioadsorption technique to the removal of heavy metal ions from wastewater; (4) application of bioaugmentation technique to remediation of contaminated soil and improving the removal efficiency of recalcitrant organic compounds from industrial wastewater; (5) BOD biosensor. He has done much research on the biodegradation of refractory organic compounds by immobilized microbial cells. He was or is in charge of several projects supported by: National Natural Science Foundation of China; International Foundation for Science, National High Technology Development Plan (863 Project), State Commission of Science and Technology; State Education Commission and the like. His present researches are focused on modern environmental biotechnology, such as the separation, purification and characterization of enzymes relating to the degradation of recalcitrant compounds, application of molecular biology techniques to detection and monitoring of specialized microorganisms in the bioreactor or in the field. He is also interested in environmental ethics, such as the relationship between human beings and the nature. He is the author or co-author of over 100 technical papers and research reports. He has published two books and has written several chapters in other books.