普通高等教育“十三五”规划教材

废水处理原理与技术

WASTEWATER TREATMENT PRINCIPLE AND TECHNOLOGIES

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内 容 提 要

本书以市政废水、农村生活污水、工业废水为对象，介绍了污水水质水量特点、处理机理(活性污泥法、生物膜法和厌氧法)和流程、典型处理技术(A/A/O、氧化沟、SBR、MBR、生物滤池、生物转盘、湿地、氧化塘)、设计参数、典型案例、再生水技术和典型案例。

本书适用于在校研究生和本科生，可作为双语教学或者全英文授课教材或者参考书。

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Chapter 1 Overview of wastewater

1.1 What is wastewater

Wastewater is the flow of used water from a community or industrial process. Most people believe that wastewater is only "sewage" but wastewater also comes from industrial and commercial sources, and from storm and ground water. Generally, each building or home has a drainage system that connects to a network of larger sewers that carry the wastewater to the wastewater treatment plant. Sanitary sewers carry only domestic and industrial wastewater, while combined sewers carry wastewater and storm water runoff. Usually every reasonable effort is made to exclude storm and ground water from the sanitary sewer system. In older sewer systems, however, these efforts are sometimes unsuccessful due to leakage and other design considerations. Typical wastewater contains 99.94% water and 0.06% suspended solids (i.e. particulates). The working process of the wastewater is showed in Fig. 1-1.

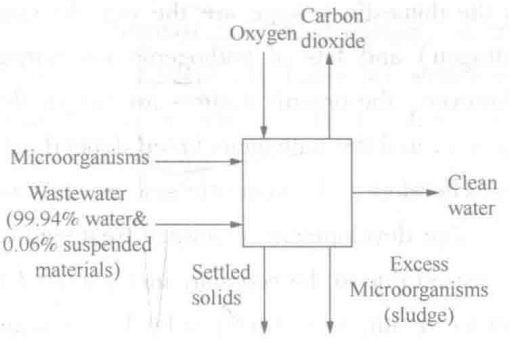

Fig. 1-1 Inputs and outputs in wastewater treatment

Since dissolved oxygen (O_2) is the key element in the life of a body in water, it is important to measure how much oxygen is used by bacteria to consume an amount of wastewater. The measure of the required oxygen is called the biological oxygen demand (BOD). The higher the BOD, the more oxygen will be demanded by the bacteria as they consume the wastes. The removal of BOD is a major goal of wastewater treatment.

Occasionally, wastewater may contain substances that cannot be consumed by micro-organisms, and therefore are not part of the biological oxygen demand. Examples are pesticides, heavy metals such as chromium, lead, and zinc, and nutrients which micro-organisms cannot consume. These substances may have adverse health effects in downstream water supplies. It is therefore necessary to use complex, auxiliary processes to remove what the bacteria cannot consume.

Wastewater contains harmful, pathogenic (i.e. disease-causing) bacteria, viruses and other micro-organisms. The treatment of this water to remove pathogenic organisms through disinfection is critical before the wastewater is discharged.

As we noted earlier, municipal wastewater is about 99.94% water, thus the concentrations of the various contaminants discussed are very low. The concentrations are expressed in milligrams per

litre of water (mg/L). One mg/L of a constituent is equivalent to one part of a constituent (by weight) in one million parts of water or expressed as another often-used term, one part per million (ppm).

Wastewater treatment is designed to remove small quantities of pollutants as the survival or death of fish, for example, depends on the presence or absence of 2~3mg/L of dissolved oxygen in the water. A minimum of 4~5mg/L of dissolved oxygen is usually needed to sustain good fish populations.

1.2 The types of the wastewater

1.2.1 Domestic wastewater

Domestic sewage is thewastewater discharged from the daily life of residents. It mainly comes from the residential buildings and public buildings, such as the apartments, offices, schools, hospitals, markets, other public places and the toilets in the factories. Therefore, the main pollutants in the domestic sewage are the organic matters (protein, carbohydrate, fat, the urea, ammonia nitrogen) and lots of pathogenic microorganism (parasitic worm eggs and intestinal infections). However, the organic matters are not stable, and it is easy to corrupt, resulting in the stench. The bacteria and the pathogens breed depending on the organic matters, resulting in the infectious diseases. Therefore, the domestic sewage must be treated before drainage.

The development of sewage treatment in China is late. But the demand on the sewage treatment increased due to the economy increase after the reform and opening. The growth of the demand on the sewage treatment in China is far higher than the demand of the whole world after the 1990s.

From the 1990s, the growth of the demand on the sewage treatment in the whole world is up to 6% (average). While in China, the average growth is up to 17.73% during the decade of the 1990s. It is 2.9 times of the average growth of the whole world. It is coming into the 21st century, the demand on the sewage treatment increases very fast. The wastewater consumption increased from 1.88 million tons to 4.47 million tons from 2000 to 2004. It is calculated that the average growth of the demand is up to 27%. In addition, the apparent consumption of the sewage was up to 2.25 million tons at 2001, while China has become the world's largest consumer of sewage, more than the USA. China's sewage treatment imports 1 million tons at 1998 and China has become the world's largest importer of sewage at the same year. Making a comparation between 2004 and 1998, the average growth of the import on the sewage treatment is up to 27.14%.

1.2.1.1 The pollutants

(1) Pathogen contamination

Mainly from urban sewage, hospital sewage, garbage and surface runoff, etc...The characteristics of pathogenic microorganisms are: the quantity is large; the wide distribution; the longer survival time; the propagation speed; easy to produce resistance, it is difficult to eliminate; after the

traditional two stage biochemical sewage treatment and chlorine disinfection, some pathogenic microorganisms and the virus can still survive a lot; such pollutants can enter the body through a variety of ways and, result in deceases.

(2) Aerobic organic pollution

The common characteristics of organic matter are these substances can directly get into the water, and be decomposed into simple inorganic substances, such as carbon dioxide and water, dissolved oxygen in the decomposition process need to be consumed in the water, in anoxic conditions, corruption decomposition will occur, water quality will be deteriorated.

(3) Eutrophication pollution

It is a phenomenon of water pollution caused by excessive content of nutrients such as nitrogen and phosphorus. The eutrophication of aquatic ecosystems by chemical pollutants caused by two ways: one is the increasing amount of inorganic nutrients in plants in normal condition; another is increasing in decomposer organic matter.

(4) Stench

Odor is a common pollution hazard, it also occurs in polluted water. People can smell up to more than 4000 kinds of odor, there are dozens of harmful. Harmful: 1, interfere with the normal respiratory function, digestive dysfunction; mental irritability, decreasing work efficiency, judgment, memory decline; 2, in the long-term work and living environment will cause the stench of olfactory dysfunction, cerebral cortex damaged the central nervous, excited and adjusting function; It can produce hydrogen sulfide, formaldehyde and the other toxic hazard.

1.2.1.2 Wastewater quality index

(1) Physical Index

① Temperature

The effluent fromthe houses has high temperature, which is discharged into the water body to increase the temperature of the water and causes the heat pollution of the water body. The increase of water temperature affects the survival of aquatic organisms and the use of water resources. The solubility of oxygen in water decreases with the increase of water temperature. The dissolved oxygen content decreases. On the other hand, the water temperature rises and accelerates the consumption of oxygen, which leads to the water body's anoxia or the deterioration of water quality. The temperature of surface water varies with season and climate. At 0.1 ~ 30℃, the temperature of underground water is relatively stable.

② Color

Color has euchroic and allochromatic color. Euchroic is caused by the dissolved substance or colloidal substance in the water. Therefore, the color is presented after removing the suspended matter in the water. Allochromatic color consists of the color that is caused by the dissolved substance, the colloid substance and the suspended substance. Generally, pure natural water is clear and transparent, that is, colorless. It only determines euchroic of natural water and drinking water, but the sewage containing metallic compounds or organic compounds and other colored pollutants has various colors.

③ Odor and taste

Odor and taste, like color, are also sensory indicators, which can qualitatively reflect the amount of a certain amount of pollutants. Natural water is odorless and tasteless. When a body of water is polluted, it produces a peculiar smell. The odor of water is derived from compounds such as reductive sulfur and nitrogen compounds, volatile organic compounds and chlorine gas. Different salt can bring different odors in water supply. For example, sodium chloride with salty taste, magnesium sulfate with bitter taste, calcium sulphate with a slight sweetness and so on.

④ Turbidity and transparency

The water is turbidity due to the impurity of the suspension and colloid state. The turbidity of water can be expressed with turbidity. The content of suspended matter in water is one of the basic indexes of water quality, which shows the insoluble suspended and floating substances in water, including inorganic and organic matter. The part of the suspended substance that can be precipitated within 1 to 2 hours is called a settling solid, which can roughly represent the amount of suspended matter in the water body. The precipitated substances in domestic sewage are usually called sludge; the precipitated particles in industrialwastewater are called sediment.

(2) Chemical Index

Organic Matter

Organic matter such as carbohydrates, proteins, fats and other organic matter in sewage and some industrialwastewater is decomposed into simple inorganic substances, carbon dioxide and water under the metabolism of microorganisms. These organic matters need to consume a large amount of oxygen in the process of decomposition, so they are oxygen consuming pollutants. Oxygen consumption is one of the main causes of black and odorous water body.

(3) Inorganic Index

① Plant Nutrient Elements

N and P in sewage are plant nutrient elements. From the perspective of crop growth, plant nutrient elements are valuable substances, but too many N and P are easy to lead to eutrophication. The content of nitrogen and phosphorus in water is closely related to the degree of eutrophication. The role of phosphorus is much greater than that of nitrogen in the eutrophication of sewage.

② pH value

pH value is mainly to indicate the acidity and alkalinity of water samples.

③ Heavy metals

Heavy metals are mainly toxic elements such as Hg, Cd, Pb, Cr, Ni and metal arsenic. They also include toxic heavy metals such as Zn, Cu, Co and Sn.

(4) Biological Index

① Total Number of Bacteria

The total number of bacteria in the water reflects the degree of bacterial contamination in the water body. The total number of bacteriacannot explain the source of pollution, it must be combined with the number of coliform to determine the source and safety of water pollution.

② Escherichia Coli

Water is an important medium for the spread of intestinal diseases, and coliform bacteria is regarded as the most basic feces indicator flora. The value of coliform group can indicate the degree of water pollution in water samples by feces, which indirectly indicates the possibility of enteric pathogens (typhoid, dysentery, cholera, etc.).

(5) Comprehensive Index

① Chemical Oxygen Demand (COD)

COD refers to thecontent of oxidants consumed in water samples treated with a strong oxidizer under certain conditions, represented by the milligram/liter of oxygen. Chemical oxygen demand reflects the degree of pollution of the reducing substances in water.

② Biochemical Oxygen Demand (BOD)

BOD refers to the amount of dissolved oxygen consumed by microorganisms in the biochemical process of certain oxidizable substances, especially in the biochemical process of organic matter, under the specified conditions. Biochemical oxygen demand (BOD) reflects the content of biodegradable organic matter in the water body.

③ Suspended Solids (SS)

SS, which is the total non-filterable residue dried at 103 to 105℃. The presence of suspended matter in the water will make the water body cloudy, reduce the transparency, and affect the respiration and metabolism of aquatic organisms. In the treatment of water and wastewater, suspended solids have specific significance.

④ Total Nitrogen (TN)

When a certain amount of nitrogen is contained in the water body, it will lead to the vigorous reproduction of plankton and a eutrophic state. Therefore, the total nitrogen is one of the important indexes to measure the water quality.

⑤ Ammonia Nitrogen (NH_3-N)

NH_3-N, in the form of free ammonia or ammonia salt in the water. The main source of ammonia nitrogen in water is the decomposition product of nitrogen containing organic matter in the sewage. The determination of the content of ammonia nitrogen in water helps to evaluate the pollution and "self purification" of the water body.

⑥ Total Phosphorus (TP)

Phosphorus is one of the essential elements of biological growth, but the high phosphorus content in water can cause algae overproduction and cause eutrophication.

1.2.1.3 The standard for domestic sewage drainage

Standards for the discharge of the domestic sewage are the control standards for the pollutants and toxic factors on the environment due to the discharge of domestic sewage. According to the water quality of the receive waterbody, the standard was formulated, combing the environmental characteristics, social, economic and technology conditions. The standards consist the national discharge standard, the local discharge standards.

(1) The national discharge standard

The nationaldischarge standard is the standard formulated by the national competent administra-

tive department of environmental protection and applied nationwide or within a specific region. 《Comprehensive wastewater discharge standard of the People's Republic of China》(GB 18918—2002) is suitable nationwide (Table 1-1~1-3).

(2) The local discharge standard

The local discharge standards are approved by the people's governments of provinces, autonomous regions, and municipalities, applicable in specific administrative regions.

For example, Shanghai Municipal Wastewater IntegratedDischarge Standard (DB31/199—2009) is applicable to Shanghai City.

(3) The relationship between the national discharge standard and the local discharge standard

Article 10 in the 'Environmental Protection Law' said: if the items are not specified in the national discharge standard, the people's governments of provinces, autonomous regions, and municipalities can formulate the local discharge standard. If the items are specified in the national discharge standard, the local discharge standard can be stricter than that in the national discharge standard. When two kinds of standards coexist, it performs the local standard.

Table 1-1 The maximum allowable discharge concentration of basic control items in national standard (mean a day)

Number	Basic control item	First grade		Second grade	Third grade
		A	B		
1	COD/(mg/L)	50	60	100	120
2	BOD/(mg/L)	10	20	30	60
3	SS/(mg/L)	10	20	30	50
4	Animal and vegetable oils/(mg/L)	1	3	5	20
5	Petroleum/(mg/L)	1	3	5	15
6	Anionic surfactant/(mg/L)	0.5	1	2	5
7	Total N (nitrogen)/(mg/L)	15	20		
8	NH_3-N/(mg/L)	5 (8)	8 (15)	25 (30)	
9	Total P (phosphorus)/(mg/L)	0.5	1	3	5
10	Color	30	30	40	50
11	pH	6~9			
12	Number of fecal coliforms/(CFU/L)	10^3	10^4	10^4	

Annotation: the value is for the water temperature less than 12 degrees in the bracket, while outside the bracket is for the water temperature higher than 12 degrees.

Table 1-2 The maximum allowable discharge concentration of first kind pollutants in national standard (mean a day)

Number	Item	Standard value
1	Totalmercury/(mg/L)	0.001
2	Alkylmercury /(mg/L)	Not detectable

续表

Number	Item	Standard value
3	Total cadmium/(mg/L)	0.01
4	Total chromium/(mg/L)	0.1
5	Cr VI/(mg/L)	0.05
6	Totalarsenic/(mg/L)	0.1
7	Totallead/(mg/L)	0.1

Table 1-3 The maximum allowable discharge concentration of selective control pollutants in national standard (mean a day)

No.	Item	Standard value/(mg/L)	No.	Item	Standard value/(mg/L)
1	Total Ni	0.05	23	Trichloroethylene	0.3
2	Total Be	0.002	24	Tetrachloroethylene	0.1
3	Total Ag	0.1	25	Benzene	0.1
4	Total Cu	0.5	26	Total benzene	0.1
5	Total Zn	1.0	27	O-xylene	0.4
6	Total Mn	2.0	28	P-xylene	0.4
7	Total Se	0.1	29	M-xylene	0.4
8	Benzopyrene	0.00003	30	Ethylbenzene	0.4
9	Volatile penol	0.5	31	Chlorobenzene	0.3
10	Total cyanide	0.5	32	1, 4-dichlorobenzene	0.4
11	Sulfide	1.0	33	1, 2-dichlorobenzene	1.0
12	Methanal	1.0	34	P-nitrchlorobenzene	0.5
13	Anilines	0.5	35	2, 4-dinitrochlorobenzene	0.5
14	Total N nitroso compounds	2.0	36	Phenol	0.3
15	Organophosphorus pesticide (P)	0.5	37	M-Cresol	1.0
16	Malathion	1.0	38	2, 4-dichlorophen	0.6
17	Dimethoate	0.5	39	2, 4, 6-trichlorophenol	0.6
18	Parathion	0.05	40	Dibutyl phthalate	0.1
19	Parathion-methyl	0.2	41	Dioctyl phthalate	0.1
20	Pentachlorophenol	0.5	42	Acrylonitrile	2.0
21	Trichloromethane	0.3	43	Adsorbable organic halides	1.0
22	Tetrachloromethane	0.03			

1.2.1.4 The treatment method for domestic sewage

Generally, the biotechnical processes are used in the treatment of domestic sewage. The main reason is that the biodegradability of the domestic sewage is high, up to 0.5. In addition, there are some processes for the treatment of domestic sewage (Table 1-4).

(1) Physical processes

The processes are referred to the separation and recovery of insoluble pollutants (including oil film and oil beads) in wastewater by physical methods. Gravity separation method, centrifugal separation and filtration are the main methods. Additionally, the method, based on the heat exchange, is attributed to the physical process.

(2) Chemical processes

The processes are referred to the separation and removal of the soluble pollutants or transformation of the pollutants from toxic forms to nontoxic forms. The units based on the chemical reaction of adding chemicals are as followed, coagulation, neutralization and Oxidation-reduction, and so on. The units based on the mass transfer effect are as followed, extraction, stripping, blowoff, adsorption, ion exchange, electrodialysis and hyperfiltration. It is noticeably, the units based on the mass transfer effect are related to the chemical mechanism and physical mechanism, therefore, the process could be separated from the chemical processes. It is named physical-chemical processes.

(3) Biological processes

The processes are referred to thetransformation of the soluble, colloidal, superfine suspended pollutants from toxic forms to nontoxic and stable forms under the metabolism of the microorganisms. According to the microorganisms, biological processes can be separated to aerobic processes and anaerobic processes. Nowadays, the wastewater treatment plant mainly uses the aerobic processes. The aerobic processes can be divided into activated sludge and biofilm methods. For the former, it is a treatment unit and has many running modes. For the latter, it consists the biofilter, rotating biological disk, biological contact oxidation pond, biological fluidized bed, and so on. The method of biological ponds is named natural biological processes. Anoxic processes are also named biological reduction process. It is mainly used for the treatment on the organic wastewater with high concentration and sludge.

(4) Biological contact oxidation process

The filters were filled into the bioreactor. and they were submerged by the wastewater with the oxygen and the water passed the fillers with some flow rate. The biofilms covered the fillers, and the wastewater contacted completely with the biofilms. The pollutants can be removed under the metabolism of the microorganisms. The process is in the middle of the activated sludge and the biofilter.

Table 1-4 The selection of the wastewater treatment according to the pollutants

Pollutants	Treatment processes
Suspended solids	Screen, grinding, screen, filter, sedimentation, flotation, centrifugation, coagulation
Biodegradable organic matters	Activated sludge, biofilm, stable ponds, land treatment system.
Nonbiodegradable organic matters	Physical-chemical system, activated carbon, ozone or other advanced oxidation, land treatment system
Pathogene	Disinfection; chlorination, ozone, chlorine dioxide, ultraviolet ray, bromine or iodine, radiation; land treatment system
Nitrogen	Biological nitrification and denitrification, nitrogen blowoff, ion exchange, land treatment system

续表

Pollutants	Treatment processes
Phosphorus	Chemical treatment: aluminium salt, ferric salt, lime; biological-chemicalmethods, A/A/O process, land treatment system
Heavy metals	Coagulation and sedimentation, flotation, ion exchange, electroosmosis, reverse osmosis, activated carbon, ferriter technique
Dissolved inorganic solids	Ion exchange, electroosmosis, reverse osmosis, evaporation
Oil	Oil separator, flotation, coagulation and filtration, coarse graining, electrolysis
Heat	Cooling tower, cooling tank
Acid, alkali	Neutralization, dialysis, evaporation
Radioactive contamination	Coagulation and filtration, ion exchange, evaporation, storage

1.2.2 Industrial wastewater

Generally, industrial wastewater is referred to the wastewater during the industrial processes. The main pollutants are the industrial production materials, process products, by-products, and those pollutants during the processes. The types of the wastewater are rich and the constituents are complex. For example, the mercury is the main pollutant in the electrolysis brine wastewater. The lead and the cadmium are the main pollutants in the heavy metals smelt wastewater. The cyanide and the chromium are the main pollutants in the electroplate wastewater. The phenol is the main pollutant in the petroleum refining wastewater. Therefore, the industrial wastewater consists many toxic materials and harms the environment and the health.

1.2.2.1 The types of the industrial wastewater

(1) According to the chemical materials

The wastewater can be called inorganic wastewater due to the main inorganic pollutants, while the water can be called organic wastewater due to the main organic pollutants. For example, the water can be called inorganic wastewater if it comes from the electroplating and mineral processing. On the contrary, the water can be called organic wastewater if it comes from the food processing or petroleum refining. But the water can be called mixed sewage if it comes from the printing and dyeing. Therefore, the component in the different wastewater from different industry was different completely.

(2) According to the materials in the processing and the product

The wastewater includes many types, such as papermaking, metallurgy, coking, metal pickling, chemical fertilizer, printing and dyeing, leather making, pesticides, electric power station, and so on.

(3) According to the main pollutants in the wastewater

The wastewater includes many types, such as acid wastewater, alkali wastewater, cyanide wastewater, chromium wastewater, mercury wastewater, phenol wastewater, aldehyde wastewater, oil wastewater, sulfide-bearing wastewater, organic phosphorus wastewater, radioactivity wastewater.

1.2.2.2 The typical industrial wastewater

Thecomponents are very complex in the industrial wastewater. Nowadays, the industrial wastewater could be divided into some kinds according to the main pollutants.

(1) Pesticide wastewater

There are many kinds of pesticides, and the quality of pesticide wastewater is complicated. Its main features are as followed:

The concentration of pollutants is high, and chemical oxygen demand (COD) can reach tens of thousands of milligrams per litre.

It is highly toxic. In addition to containing pesticides and intermediates, wastewater also contains toxic substances such as phenol, arsenic and mercury as well as substances that are difficult to degradeby many microorganisms.

It has a foul odor and is irritating to the human respiratory and mucous membrane.

The quality and quantity of the wastewater are not stable. Therefore, the pollution of pesticide wastewater to the environment is very serious. The purpose of the treatment on the pesticide wastewater is to reduce the concentration of pollutants, improve recycling efficiency, and strive to achieve harmless. The methods for treating pesticide wastewater include activated carbon adsorption, wet oxidation, solvent extraction, distillation, and activated sludge. However, the new pesticides that are highly efficient, low-toxic, and low-residue is the development direction of pesticides. Some countries have banned the production of organic chlorine and organic mercury pesticides such as BHC, and actively researched and used microbial pesticides. This is a new way to fundamentally prevent pesticide wastewater from pollution on the environment.

(2) Phenolic wastewater

The phenolic wastewater mainly comes from coking plants, gas plants, petrochemical plants, insulating material plants and other industrial sectors. Decontamination of high concentration ammonia nitrogen industrial wastewater and production of ethylene, synthetic phenol, polyamide fibers, synthetic dyes, organic pesticides and phenolic resins. Phenolic wastewater mainly contains phenolic compounds such as phenol, cresol, xylenol, and nitrocresol. Phenolic compounds are protozoal poisons that can make proteins coagulation. When the concentration of phenol in water reaches 0.1~0.2mg/L, the smell of the fish is odor and cannot be eaten; if the mass concentration increased to 1mg/L, fish spawning will be affected. The amount of phenol in the water reaches 5~10mg/L, and fish will die in large numbers. Phenol in drinking water can affect human health. Even if the concentration of phenol in the water is only 0.002mg/L, chlorophenol odor will be produced when chlorine is used for disinfection. Phenolic wastewater with a concentration of 1000mg/L is often referred to as high-concentration phenolic wastewater. This wastewater must be treated after phenol recovery. Phenolic wastewater with a mass concentration of less than 1000mg/L is called low-concentration phenolic wastewater. This kind of wastewater is usually recycled and the phenol is concentrated and recovered before being processed. The methods for recovering phenol include solvent extraction, steam stripping, adsorption, closed loop, and so on. Wastewater containing phenol at a concentration of less than 300mg/L can be discharged or recovered after being treated by