TECHNOLOGIES THAT TRANSFORM POLLUTANTS TO INNOCUOUS COMPONENTS: CHEMICAL AND PHYSICOCHEMICAL METHODS

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Summary

The basic principles of chemical and physicochemical technologies are to separate pollutants in wastewater, or transform them to innocuous components based on chemical and physicochemical reactions. The technologies include coagulation, chemical precipitation, chemical oxidation, adsorption, ion exchange, disinfection, membrane separation, etc.

Coagulation is the process of mixing chemical coagulants with colloidal particles to destabilize and agglomerate or flocculate the particles with other suspended solids to form relatively larger particles for readily settling with ease. Chemical precipitation processes are mainly used to remove heavy metals or phosphorus from wastewater by way of the addition of chemicals which interact with a dissolved target substance to form an insoluble salt and removed by sedimentation.

Adsorption processes remove solutes from liquids based on their mass transfer from liquids to porous solids. Ion exchange is the exchange of dissolved ions for ions on solid media. The process can be used to remove water hardness and toxic metals during wastewater treatment. Disinfection is the removal or inactivation of pathogenic organisms in wastewater prior to be discharged to the receiving body of water.

Membrane separation processes may remove dissolved and colloidal constituents from wastewater by applying pressure or electrical potential to force water through a semi-permeable membrane. The basic principles, characteristics, and primary applications in water and wastewater treatment of these technologies are reviewed and discussed in this chapter.

1. Introduction

Contaminants in wastewater are notably complex having numerous physical, chemical, and biological characteristics. Consequently, transformation of pollutants to innocuous components requires a combination of different technologies. Chemical and physicochemical technologies commonly used to remove contaminants from wastewater are based on the chemical and physicochemical reactions to separate pollutants in wastewater or transform them to innocuous components respectively.

The processes include neutralization, coagulation and flocculation, chemical precipitation, chemical oxidation and reduction, adsorption, ion exchange, disinfection, membrane separation, etc. By proper selection, they can be applied in water pollution control, water reclamation and conditioning of sludge wastes, and in conjunction with physical or biological processes. The most prevalent chemical and physicochemical technologies and their principal applications are illustrated in Table 1, and several principal technologies are discussed in detail herewith.

Method	Principal Application	Location
Neutralization	Neutralization of industrial wastewater with high or low pH	Pretreatment
Coagulation	Enhancement of removal of colloidal and small particles	Intermediate or advanced treatment

Air flotation	Separation of suspended matter with low density	Pretreatment
Chemical precipitation	Removal of heavy metal or phosphorus	Intermediate or advanced treatment
Chemical oxidation and reduction	Decomposition of odor, color, and dissolved toxic organic compounds.	Intermediate or advanced treatment
Adsorption	Removal of dissolved organics not removed by conventional chemical and biological treatment methods.	Intermediate or advanced treatment
Disinfection	Selective destruction of pathogenic organisms.	Advanced treatment
Ion exchange	Removal of hardness or heavy metal	Advanced treatment
Membrane separation	Removal of ions, large molecular organic matter or small particulates	Advanced treatment
Extraction	Removal of dissolved organic matter	Pretreatment

Table 1: Classification and application of chemical and physicochemical methods in wastewater treatment

2. Coagulation

The main pollutants removed from wastewater via chemical coagulation are colloidal and small particles. Generally, colloidal particles including bacteria, viruses, and proteins have the size in the range of 1 to 100 nm. Such extremely small size is the most significant characteristics responsible for their stability in water. The purpose of chemical coagulation in water and wastewater treatment is to destabilize those colloidal particles by adding some coagulant chemicals and agglomerate them to relatively larger flocs which will settle more readily. Coagulation process is involved with colloidal properties, coagulants, and interactions between colloidal particles and coagulants.

2.1. Colloidal Properties

There are two types of colloids, hydrophilic and hydrophobic. *Hydrophilic* colloids disperse easily in water, and their stability depends on a marked affinity with water, while *hydrophobic* colloids possess no such affinity with water but own their stability due to the electric charge they possess. The double-layer theory and *zeta potential* are generally applied to describe the stability of hydrophobic colloids. A colloidal particle is expected to have a negative charge, and electrostatically attract a fixed covering of positive ions.

This stationary zone of positive ions, referred to as the *Stern Layer*, is surrounded by a movable, diffuse layer of counterions. The boundary surface between the fixed ion layer and the solution serves as a shear plane when the colloidal particle undergoes movement relative to the solution. *Zeta potential* is the magnitude of the charge at the surface of shear, and can be estimated from electrophoretic measurement of particle mobility in an electric field. Typical *zeta potential* magnitudes of hydrophobic colloids, clay and bacteria are -15 ~ -40 mV and -30 ~ -70 mV, respectively. The electrostatic repulsive force between charged colloidal particles disperses them and prevents them from aggregation. The result is that colloidal particles with a high *zeta potential* produce high stability.

2.2. Destabilization of Colloids

In counteracting to electrostatic stability, the factors which tend to destabilize colloids are *Van der Waals* forces and *Brownian movement*. *Van der Waals* forces derived from the molecular attractive forces are negligible when the particles are slightly separated but become a dominant force when particles are approaching each other. *Brownian movement* is the random motion of colloids caused by water molecule bombardment, and this movement has a destabilizing effect on colloids because aggregation may result.

In addition, destabilization of hydrophobic colloids could be accomplished by adding electrolytes to the solution. Counterions of the electrolyte can sufficiently suppress the double-layer charge of the colloids to permit contact among particles. Further, as particles approaching, *Van der Waals* forces become dominant and aggregation results. It has been found that the most effective electrolytes are multivalent ions whose charge is opposite to that of the colloidal particles.

Colloids may also be destabilized by a polymer. The charged polymer may suppress the diffuse double layer much the same as electrolytes. For most cases, however, bridging appears to be the primary mechanism. The long polymer molecule attaches to the absorbent surfaces of colloidal particles, either by chemical or physical interaction, causing aggregation.

2.3. Water Coagulation Process

Two basic mechanisms define water coagulation processes: *Coagulation* reduces the net electrical repulsive force at colloidal particle surfaces and destabilizes particles via exposure to coagulant chemicals, whereas *flocculation* is the agglomeration of destabilized particles by chemical joining and bridging. Coagulation is distinctly characterized by rapid mixing to disperse coagulant chemicals into the water being treated, and flocculation is by gentle agitation for a much longer time period, allowing small destabilized particles to agglomerate into well-defined flocs.

The primary purpose of chemical coagulation is to agglomerate particulate matters and colloids into floc that can be separated from the water by sedimentation and filtration. In water treatment, coagulation and flocculation are used to destabilize turbidity, color, odor-producing compounds, pathogens, and other contaminants.

In wastewater reclamation, coagulation precedes tertiary filtration necessary to clarify a biologically treated effluent. The removal of contaminants by coagulation depends on their natural property and concentration, use of both coagulants and coagulant aids, and other characteristics of water, including pH, temperature, and ionic strength.

2.4. Coagulants

Coagulant is classified into two categories: inorganic coagulant and organic polymer coagulant. The most widely used inorganic coagulants for water and wastewater treatment are aluminum and iron salts.

The most common metal coagulant is aluminum sulfate which is an effective coagulant for water containing organic matter. Iron coagulants are effective over a wider pH range and are generally more effective in removing color from wastewater.

Synthetic polymers are water-soluble organic compounds with high-molecular-weight which have multiple electrical charges along a backbone of the polymer. If ionizable groups have net positive charge, the compound is referred to be a cationic polymer, for net negative charge, it is an anionic polymer, and if no charges are exhibited, it is then a nonionic polymer.

For certain kind of water, polymers are effective as primary coagulants, they are, however, applied more readily as coagulant aids with aluminum and iron coagulants.

Following destabilization of colloidal particles via inorganic coagulants, polymers promote larger and more durable floc through a bridging mechanism. Use of polymers can reduce the dose of inorganic coagulant that would otherwise be required.

3. Chemical Precipitation

Chemical precipitation in wastewater treatment involves the addition of certain chemicals, to be referred as precipitants, to interact with dissolved target substances to form insoluble salts which can be removed by sedimentation. These processes have been developed for removal of heavy metals or phosphorus from wastewater.

3.1. Removal of Heavy Metals by Chemical Precipitation

A number of different substances have been used as precipitants. Technologies including the processes of precipitation for hydroxide, sulfide and carbonate have been developed.

The hydroxide method precipitates heavy metals contained in wastewater through the addition of hydroxides, for example calcium hydroxide. Its performance depends on the pH value of the wastewater being treated.

Sulfide precipitation creates heavy metal sulfides through the addition of sulfide compounds, such as H_2S, Na_2S, K_2S, and formation of metal sulfides also depends on pH value due to the influence of pH on sulfide hydrolysis.

Generally, sulfide particles are too small to settle, and consequently the addition of coagulant to enhance precipitation is necessary. Application of sulfide precipitation is not extensive, and often supplementary to hydroxide precipitation.

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Biographical Sketch

HUANG Xia obtained her Ph.D. in 1988 from Tokyo Institute of Technology, Japan. She is now a professor and deputy director of the State Key Joint Laboratory of Environment Simulation and Pollution Control at Department of Environmental Science and Engineering, Tsinghua University, Beijing, China. Professor Huang was a visiting professor from April 1994 to July 1994 at the Dept. of Civil Eng., University of Cincinnati, USA; associate professor from 1995 to 1997 at the Dept. of Ecological Eng., Toyohashi Institute of Technology, Japan; visiting professor from December 1998 to March 1999 at the Tokyo Institute of Technology, Japan. Her major research interests include water pollution control technologies, with the emphasis on membrane bioreactor process, hybrid processes of biological and chemical methods for treating refractory organic pollutants, and novel processes for phosphorous and nitrogen removals. More than 60 research papers have been published during 1990-2000.