ELSEVIER

Desalination 167 (2004) 55–63

DESALINATION

www.elsevier.com/locate/desal

Developments in wastewater treatment methods

Amit Sonune*, Rupali Ghate

Water and Land Management Institute, PO No. 504, Paithan Road, Aurangabad 431005 (MS), India
email: amitsonune@yahoo.com

Received 10 February 2004; accepted 19 February 2004

Abstract

Wastewaters are waterborne solids and liquids discharged into sewers that represent the wastes of community life. Wastewater includes dissolved and suspended organic solids, which are "putrescible" or biologically decomposable. Two general categories of wastewaters, not entirely separable, are recognized: domestic and industrial. Wastewater treatment is a process in which the solids in wastewater are partially removed and partially changed by decomposition from highly complex, putrescible, organic solids to mineral or relatively stable organic solids. Primary and secondary treatment removes the majority of BOD and suspended solids found in wastewaters. However, in an increasing number of cases this level of treatment has proved to be insufficient to protect the receiving waters or to provide reusable water for industrial and/or domestic recycling. Thus, additional treatment steps have been added to wastewater treatment plants to provide for further organic and solids removals or to provide for removal of nutrients and/or toxic materials. There have been several new developments in the water treatment field in the last years. Alternatives have presented themselves for classical and conventional water treatment systems. Advanced wastewater treatments have become an area of global focus as individuals, communities, industries and nations strive for ways to keep essential resources available and suitable for use. Advanced wastewater treatment technology, coupled with wastewater reduction and water recycling initiatives, offer hope of slowing, and perhaps halting, the inevitable loss of usable water. Membrane technologies are well suited to the recycling and reuse of wastewater. Membranes can selectively separate components over a wide range of particle sizes and molecular weights. Membrane technology has become a dignified separation technology over the past decennia. The main force of membrane technology is the fact that it works without the addition of chemicals, with relatively low energy use and easy and well-arranged process conduction. This paper covers all advanced methods of wastewater treatments and reuse.

Keywords: Wastewater; Primary treatment; Secondary treatment; Membrane technology; Recycle; Reuse; Advanced water treatment

*Corresponding author.

Presented at the EuroMed 2004 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and Office National de l'Eau Potable, Marrakech, Morocco, 30 May–2 June, 2004.

doi;10.1016/j.desal.2004.06.113

1. Introduction

Water covers 71% of the earth's surface and makes up 65% of our bodies. Everyone wants clean water — to drink, for recreation, and just to enjoy looking at. If water becomes polluted, it loses its value to us economically and aesthetically, and can become a threat to our health and to the survival of the fish living in it and the wildlife that depend on it.

The pollution of rivers and streams with chemical contaminants is one of the most crucial environmental problems. Waterborne chemical pollution entering rivers and streams causes tremendous amounts of destruction. Although some kinds of water pollution can occur through natural processes, it is mostly a result of human activities. We use water daily in our homes and industries. The water we use is taken from lakes and rivers and from underground (groundwater); and after we have used it — and contaminated it — most of it returns to these locations. This used water is called "wastewater". If it is not treated before being discharged into waterways, serious pollution is the result.

Wastewater may be defined as a combination of liquid or water-carried waste removed from residences, institutions, and commercial and industrial establishments, together with ground water, surface water and storm water. It generally contains a high load of oxygen demanding wastes, pathogenic or disease-causing agents, organic materials, nutrients that stimulate plant growth, inorganic chemicals and minerals and sediments. It may also contain toxic compounds [1].

Wastewater may be classified into four categories:

- domestic: wastewater discharged from residences and commercial institutions and similar facilities;
- industrial: wastewater in which industrial waste predominates;
- infiltration/inflow: extraneous water that enters the sewer system through indirect and direct means such as through leaking joints, cracks, or porous walls. Inflow is storm water that enters the sewer system from storm drain connections, roof headers, foundation and basement drains or through manhole covers;
- storm water: runoff resulting from flooding due to rainfall.

For many years the main goal of treating municipal wastewater was simply to reduce its content of suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria. In recent years, however, more stress has been placed on improving means of disposal of the solid residues from the municipal treatment processes. The basic methods of treating municipal wastewater fall into three stages: primary treatment, including grit removal, screening, grinding, and sedimentation; secondary treatment, which entails oxidation of dissolved organic matter by means of using biologically active sludge, which is then filtered off; and tertiary treatment, in which advanced biological methods of nitrogen removal and chemical and physical methods such as granular filtration and activated carbon absorption are employed [2].

The characteristics of industrial wastewaters can differ considerably both within and among industries. The impact of industrial discharges depends not only on their collective characteristics such as biochemical oxygen demand and the amount of suspended solids, but also on their content of specific inorganic and organic substances. Three options are available in controlling industrial wastewater. Control can take place at the point of generation in the plant; wastewater can be pre-treated for discharge to municipal treatment sources; or wastewater can be treated completely at the plant and either reused or discharged directly into receiving waters.

Industrial wastewaters are the discharge of industrial plants and manufacturing processes. Industrial wastewaters can represent, collectively, an important part of community wastewaters and must be considered for successful wastewater treatment plant operation. In some locations industrial wastewater discharge is collected together with other community wastewaters and the mixed wastes are treated together. In other instances, industries may provide some pretreatment or partial treatment of their wastewaters prior to discharge to the municipal sewers. In still other situations, the volume and character of the industrial waste are such that separate collection and disposal are necessary.

Industrial wastewaters vary widely in composition, strength, flow and volume, depending on the specific industry or manufacturing establishment in the community. The specific composition and volume of the industrial waste will, of course, depend on the use to which the water has been put. Typical industries which produce significant volumes of wastewaters include paper and fiber plants, steel mills, refining and petrochemical operations, chemical and fertilizer plants, meat packers and poultry processors, vegetable and fruit packing operations and many more. Industrial discharges may consist of very strong organic wastewaters with a high oxygen demand or contain undesirable chemicals that can damage sewers and other structures. They may contain compounds, which resist biological degradation, or toxic components, which interfere with satisfactory operation of the wastewater treatment plant. A less obvious source, which must be considered an industrial waste, is thermal discharge since it lowers dissolved oxygen values. Many industries use large quantities of cooling water, with the electric power industry being the largest user. However, the primary metal and chemical industries also use substantial quantities of cooling waters.

2. Conventional wastewater treatment processes

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment.

2.1. Preliminary treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Preliminary treatment helps to remove or to reduce in size the large, entrained, suspended or floating solids. These solids consist of pieces of wood, cloth, paper, plastics, garbage, etc., together with some fecal matter. Removed are heavy inorganic solids such as sand and gravel as well as metal or glass. These objects are called grit and excessive amounts of oils or greases.

2.2. Primary treatment

Primary treatment is designed to remove organic and inorganic solids by the physical processes of sedimentation and flotation. Approximately 25–50% of the incoming biochemical oxygen demand (BOD_5), 50–70% of the total suspended solids (SS), and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation, but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is referred to as primary effluent. Table 1 provides information on primary effluent from three sewage treatment plants in California along with data on the raw wastewaters.

2.3. Secondary treatment

The objective of secondary treatment is the further treatment of the effluent from primary

Table 1
Quality of raw wastewater and primary effluent at selected treatment plants in California

Quality parameters, mg/l	City of Davis		San Diego		Los Angeles County joint plant	
	Raw wastewater	Primary effluent	Raw wastewater	Primary effluent	Raw wastewater	Primary effluent
BOD_5	112	73	184	134	—	204
TOC	63.8	40.6	64.8	52.3	—	—
SS	185	72	200	109	—	219
Total nitrogen	43.4	34.7	—	—	—	—
NH_3-N	35.6	26.2	21.0	20.0	—	39.5
NO-N	0	0	—	—	—	—
Org-N	7.8	8.5	—	—	—	14.9
TDS	—	—	829	821	1404	1406
Alkalinity ($CaCO_3$)	—	—	—		322	332
Hardness ($CaCO_3$)	—		—		265	

Source: International Desalination Association [3].

treatment to remove the residual organics and suspended solids. In terms of the size of the solids, the distribution is approximately 30% suspended, 6% colloidal and about 65% dissolved solids. The function of primary treatment is to remove as much of the suspended solids as possible. Primary treatment utilizes clarifiers or settling tanks, which remove the settleable organics and settleable inorganic solids from the wastewater. The effluent from primary treatment, therefore, contains mainly colloidal and dissolved organic and inorganic solids. Recent effluent standards and water quality standards require a greater degree of removal of organics from wastewater than can be accomplished by primary treatment alone. Additional removal of organics can be accomplished by secondary treatment.

The secondary treatment process consists of the biological treatment of wastewater by utilizing many different types of microorganisms in a controlled environment. Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

3. Developments in wastewater treatment methods

Primary and secondary treatment removes the majority of BOD and suspended solids found in wastewaters. However, in an increasing number of cases this level of treatment has proved to be insufficient to protect the receiving waters or to provide reusable water for industrial and/or domestic recycling. Thus, additional treatment steps have been added to wastewater treatment plants to provide for further organic and solids removals or to provide for removal of nutrients and/or toxic materials.

Therefore, advanced wastewater treatment is defined as: any process designed to produce an effluent of higher quality than normally achieved by secondary treatment processes or containing unit operations not normally found in secondary treatment. The above definition is intentionally very broad and encompasses almost all unit operations not commonly found in wastewater treatment today.

3.1. Types of advanced wastewater treatment

Advanced wastewater treatment may be divided into three major categories by the type of process flow scheme utilized:

- tertiary treatment
- physicochemical treatment
- combined biological–physical treatment

Tertiary treatment may be defined as any treatment process in which unit operations are added to the flow scheme following conventional secondary treatment. Additions to conventional secondary treatment could be as simple as the addition of a filter for suspended solids removal or as complex as the addition of many unit processes for organic, suspended solids, nitrogen and phosphorous removal. Physicochemical treatment is defined as a treatment process in which biological and physical–chemical processes are intermixed to achieve the desired effluent. Combined biological–physical–chemical treatment is differentiated from tertiary treatment in that in tertiary treatment any unit processes are added after conventional biological treatment, while in combined treatment, biological and physicochemical treatments are mixed.

Another way to classify advanced wastewater treatment is to differentiate on the basis of desired treatment goals. Advanced wastewater treatment is used for:

- additional organic and suspended solids removal
- removal of nitrogenous oxygen demand (NOD)
- nutrient removal
- removal of toxic materials

In many, if not most instances today, conventional secondary treatment gives adequate BOD and suspended solids removals. But advance wastewater treatment is necessary because advanced wastewater treatment plant effluents may be recycled directly or indirectly to increase the available domestic water supply.

Advanced wastewater treatment effluents may be used for industrial process or cooling water supplies. Some receiving waters are not capable of withstanding the pollutional loads from the discharge of secondary effluents. Secondary treatment does not remove as much of the organic pollution in wastewater as may be assumed.

The performance of secondary treatment plants is almost always measured in terms of BOD and SS removal. A well-designed and operated secondary plant will remove from 85% to 95% of the influent BOD and SS. However, the BOD test does not measure all of the organic material present in the wastewater. An average secondary effluent may have a BOD of 20 mg/L and a COD of 60 to 100 mg/L. The average secondary plant removes approximately 65% of the influent COD. Thus, when high-quality effluents are required, additional organic removal must be accomplished. In addition to the organic materials remaining in most secondary effluents, there is an additional oxygen demand resulting from the nitrogen present in the wastewater.

3.2. Emergence of membrane treatment technology

Biological and chemical treatment methodologies have been developed to handle different treatment scenarios. Yet these applications are often limited by the expensive cost of treatment, continuous additions of toxic chemicals, extensive space required for installation, side effects of secondary pollution, etc. As a result, physical, membrane-based separations of liquids from solids have enjoyed increasing popularity over the last 20 years and are becoming the promising technology for the 21st century. It is a means of purifying and/or concentrating a wide variety of fluids from water and wastewater to pharmaceutical and chemical products. It is also a pressure-driven process that relies on the pore size of the membrane (typically thin films or sheets of plastic with an accurately sized micropore structure resembling that of a sponge) to separate feed stream components according to their pore sizes. The use of membranes is not uncommon to human beings; air filters, water filters, and even drinkable water retraction system for astronauts travelling in space are some of the typical applications.

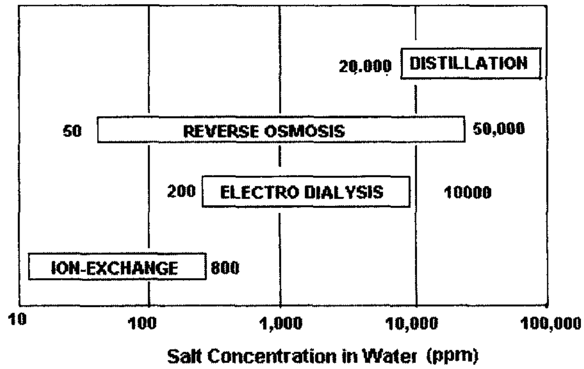

Fig. 1. Salt concentration of seawater.

3.3. Desalination technologies

Desalination is a process that removes dissolved minerals (including but not limited to salt) from seawater, brackish water, or treated wastewater. There are five basic techniques that can be used to remove salt and other dissolved solids from water: distillation, reverses osmosis (RO), electrodialysis (ED), ion exchange (IX), and freeze desalination. Distillation and freezing involve removing pure water, in the form of water vapor or ice, from salty brine. RO and ED use membranes to separate dissolved salts and minerals from water. IX involves an exchange of dissolved mineral ions in the water for other, more desirable dissolved ions as the water passes through chemical resins. The relative percentages of different types of desalination plants worldwide are shown in Table 2.

Over the last few decades desalination technologies have been used increasingly throughout the world to produce drinking water from brackish groundwater and seawater, to improve the quality of existing supplies of fresh water for drinking and industrial purposes, and to treat industrial and municipal wastewater prior to discharge or reuse. In the early 1950s there were about 225 land-based desalination plants worldwide with a combined capacity of about 27 mgd. Of the more than 7,500 desalination plants in operation worldwide, 60% are located in the Middle East. The world's largest plant in Saudi Arabia produces 128 mgd of desalted water. In contrast, 12% of the world's capacity is produced in the Americas, with most of the plants located in the Caribbean and Florida [4]. Fig. 1 shows the salt concentration of seawater.

3.3.1. Reverse osmosis (RO)

In RO, feed water is pumped at high pressure through permeable membranes, separating salts from the water (Fig. 2). The feed water is pretreated to remove particles that would clog the membranes. The quality of the water produced depends on the pressure, the concentration of salts in the feed water, and the salt permeation constant of the membranes [5]. Osmosis depends only on the solute concentration and not on its type [6].

3.3.2. Electrodialysis (ED)

With this technique, brackish water is pumped at low pressures between several hundred flat, parallel, ion-permeable membranes that are assembled in a stack. Membranes that allow cations to pass through them are alternated with anion-permeable membranes [7]. A direct electrical current is established across the stack by

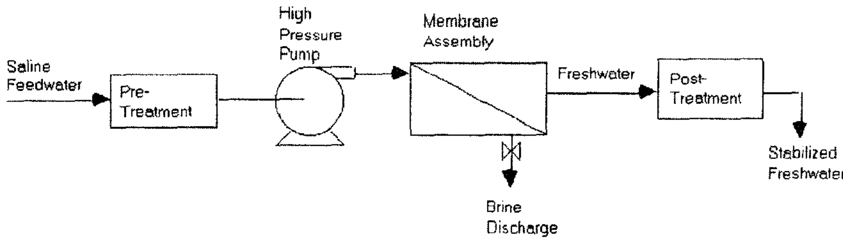

Fig. 2. Flow diagram of a reverse osmosis system.

Table 2
Relative distribution of different types of desalination plants worldwide

Process	No. of plants	Percent of total	Capacity (mgd)	Percent of total
Distillation				
MSF	532	15.1	1955	64.5
ME	329	9.3	145	4.8
VC	275	7.8	65	2.2
Membrane				
RO	1742	49.4	709	23.4
ED	564	16.0	139	4.6
Other	95	2.4	19	0.6
Total	3527	100.0	3032	100.1

Source: International Desalination Association [3].

electrodes positioned at both ends of the stack. This electric current ''pulls' the ions through the membranes and concentrates them between each alternate pair of membranes. Partially desalted water is left between each adjacent set of membrane pairs. Scaling or fouling of the membranes is prevented in most ED units by operationally reversing the direction of the electrical current around the stacks at 15–30-min intervals. This reverses the flow of ions through the membranes so that the spaces collecting salty concentrate begin collecting less salty product water. Alternating valves in the water collection system automatically direct the flow in the appropriate direction. Typical freshwater recovery rates for ED (reversal) range from 80–90% of the feed water volume.

3.3.3. Ion exchange (IX)

In this process undesirable ions in the feed water are exchanged for desirable ions as the water passes through granular chemicals, called ion-exchange resins. For example, cation-exchange resins are typically used in homes and municipal water treatment plants to remove calcium and magnesium ions in "hard" water and by industries in the production of ultra-pure water. The higher the concentration of dissolved solids in the feed water, the more often the resins will need to be replaced or regenerated. With rising costs for resins and for disposing of regeneration solutions, IX is now competitive with RO and ED only in treating relatively dilute solutions containing a few hundred ppm of dissolved solids.

3.3.4. Freeze desalination

When saltwater freezes, ice crystallizes from pure water, leaving the dissolved salt and other minerals in pockets of higher salinity brine. In fact, freeze desalination has the potential of concentrating a wider variety of waste streams to higher concentrations with less energy than any other distillation process. Traditional freezing processes involve five steps:

- precooking of the feed water
- crystallization of ice into slush
- separation of ice from the brine
- Washing the ice and
- melting the ice.

New research efforts are attempting to reduce the number of steps, especially the need to wash the ice crystals. Although small-scale commercialisation of freezing was attempted in the late 1960s, there were still significant operational problems. Only a few isolated commercial freezing plants now exist.

4. A new system designed for wastewater neutralization

Green Turtle Technologies Limited (GTT) has developed an innovative flow-through acidic wastewater treatment system known as PHIX [8]. The system is designed to treat acidic wastewater in process and/or prior to discharge into a water body or municipal sewer system. The pH can be adjusted to by-law limits, or specific levels if required, resulting in the elimination of sewer surcharges or fines. The system was designed to allow better control over the effluent pH and to do so with the use of all-natural and safe media that eliminate the need for special storage or handling. The system replaces the need for large tanks, caustic injectors and mixers, and replaces them with a very small-automated system.

5. Conclusions

The pollution of rivers and streams with chemical contaminants is one of the most crucial environmental problems. Waterborne chemical pollution entering rivers and streams causes tremendous destruction. Thus it is essential to treat the wastewater before it is discharged into the environment. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Irrigation with wastewater is possible and indeed is an effective form of wastewater disposal (as in slow-rate land treatment). However, some degree of treatment must normally be provided to raw municipal wastewater before it can be used for industrial/agricultural purposes.

Advanced wastewater treatment can be used to achieve any level of treatment desired. Advanced treatment is necessary in some treatment systems to remove nutrients from wastewater. Advanced wastewater treatment plants utilize sophisticated processes and equipment. They are relatively expensive to run and operating costs as well as effluent quality are sensitive to the quality of operation.

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

The ultimate goal of wastewater treatment should be managing wastewater effectively, economically, and ecologically.

References

[1] Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal, Reuse.

[2] D. Krantz and B. Kifferstein, Water Pollution and Society.
[3] IDA, Plant inventory, 1987.
[4] S.E. Pantell, Seawater desalination in California, 1993.
[5] I. Cabasso, Membrane Encyclopedia Polymer Science Engineering, 1987.
[6] Vapor pressure, boiling and freezing temperatures of a solution, http://urila.tripod.com/colligative.htm., 1998.
[7] W.S. Ho and N.N. Li, Membrane processes, in: Perry's Chemical Engineering Handbook, 6th ed., New York, 1984.
[8] New system designed for wastewater neutralization, Industrial Water World, November 2003.