

Benchmarking Waste Water Treatment Systems

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Table of Contents

1.	Abstract	3
2.	Introduction	4
3.	Waste Water Treatment System Overview	5
4.	Pretreatment Units	5
5.	Primary Treatment – Flotation	6
6.	Secondary Treatment – clarification	8
7.	Types Of Activated Sludge Systems	13
8.	Latest Research in Wastewater Treatment Systems	17
9.	Conclusions	18

Abstract

Engineers today have a dual responsibility. There is the responsibility to produce the chemicals needed for food, medicine, and improvements in life style. Coupled with this need for chemical production is the need to produce these requirements with fewer impacts to the environment.

There are two routes to reduce the impacts to the environment. The first route is to develop processes that produce fewer unwanted by-products, the minimization of waste generation. The second route is the transformation of the unwanted by-products to streams of low environmental impact.

Each chemical plant constructed should include each of the routes. The transformation of the unwanted by-products to streams of low environmental impact is called the Waste Water Treatment System. It can process streams of various compositions and transform them to the desired streams of low environmental impact.

The Waste Water Treatment System has a variety of unit operations. They include gravity separators, mechanical separators, filters, stripper towers, aeration and clarifiers basins, as well as others. The transformation of the by-product streams is based of the effectiveness of each of these unit operations.

Each of these unit operations has three values.

- 1) Industry Standard Design Value
- 2) Actual Design Value and
- 3) Present Operating Value

The difference between the values can be benchmarked to establish areas good operation and areas of opportunities for improvements.

An overview of each of the unit operations of a Waste Water Treatment System will be constructed and industry guidelines will be given for individual unit benchmarking.

Introduction

Many industries use large volumes of water in their manufacturing operations. Industrial Waste Water Treatment Systems treat wastewater from an industrial or manufacturing process such as a cooling tower, food or animal processing plant or any type of manufacturing process that generates wastewater. The Pulp and Paper, Steel, Refining, and Chemical industries account for more than 90% of the water used by industries in North America. ⁽¹⁾

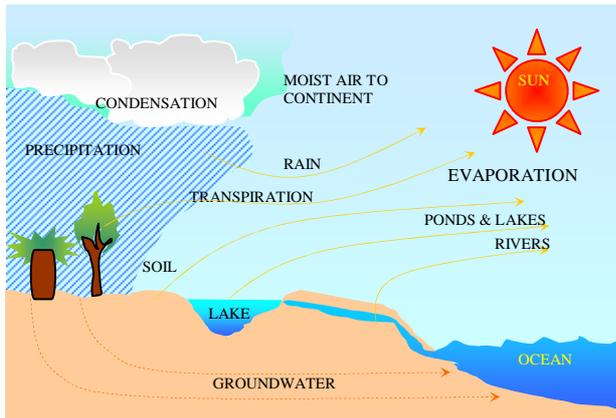


Figure 1- The Water Cycle

The treatment process and equipment is specifically directed to control or remove certain organic or chemical compounds. The flow may or may not contain domestic wastewater and ranges from several hundred to several million GPD. Industrial applications can present challenges that are specific to the plant or process. Maintenance on these systems is always mandatory and contains specific performance parameters.

The amount of organic material that can be discharged safely is defined by the effect of the material on the dissolved oxygen level in the water. Organisms in the water use the organic matter as a food source. In a biochemical reaction, dissolved oxygen is consumed, as the end product of water and carbon dioxide are formed. Atmospheric oxygen can replenish the dissolved oxygen consumption to exceed this re-supply; the dissolved oxygen level drops, leading to the death of fish and other aquatic life.

Under extreme conditions, when the dissolved oxygen concentration reaches zero, the water may turn black and produce odors. Organic compounds are normally measured as chemical oxygen demand (COD) and biochemical oxygen demand (BOD).

Industrial Waste Water Considerations include;

1. Volume of daily flow
2. All biological and chemical characteristics of the wastewater,

3. Including biodegradability, toxic material content and any material covered by specific environmental regulations
4. Regulations of the local health department and federal or state Environmental Protection Agency

The Waste Water Treatment System can be broken down into distinct components. ⁽²⁾

1. Pretreatment Units
2. Primary Treatment
3. Secondary Treatment
4. Tertiary Treatment
5. Sludge Handling (thickening and denaturing)
6. Sludge Disposal

Waste Water Treatment System Overview

Pretreatment Units

Sedimentation - Gravity Separation

Sedimentation is the separation from water of suspended particles that are heavier than water by gravitational settling. The purpose of sedimentation is 1) clarification - to produce clean water, which can be used, recycled or further treated and 2) consolidation - to produce concentrated solids that can be more easily handled and treated.

Most waste treatment system employ a gravity separation step for suspended particle or oil removal. The settling rate of a particle is defined in terms of “free” versus “hindered” settling. A free settling particle’s motion is not affected by that of other particles, the vessel’s wall, or turbulent currents. A particle has a hindered settling rate if there is any interference from these effects. ⁽²⁾

Table 1 - Effect of Particle Size on Settling

Unit	Size (microns)	Time to fall 1 meter	Settling (m/h)
Gravel	10,000	1 sec	3600
Sand Course	1,000	10 sec	360
Sand Fine	100	125 sec	28
Silt	10	108 min	0.5
Bacteria	1	180 hr	
Colloidal matter	0.1	2 years	
Color Particles	0.001	200 years	

Gravity settling is employed primarily for removal of inorganic suspended solids, such as grit and sand. The equipment employed for gravity separation for waste treatment is normally either a rectangular basin with moving bottom scrapers for solids removal or a circular tank with a rotating bottom scraper.

Rectangular tanks are normally sized to decrease horizontal fluid velocity to approximately 1 foot per minute. Their lengths are three to five times their width and their depths are three to eight feet.

Circular clarifiers are ordinarily sized according to the surface area, because velocity must be reduced below the design particle's terminal velocity. The typical design provides a rise rate of 600-800 gpd/ft².

API Separator

When wastewater contains appreciable amount of hydrocarbons, removal of these contaminants become a problem. Oil is commonly lower in density than water; therefore, if it is not emulsified, it can be floated in a separate removal stage or in a dual-purpose vessel that allows sedimentation of solids.

For example, the refining industry uses a rectangular clarifier with a surface skimmer for oil and a bottom rake for solids as standard equipment. Stokes' Law expresses the basic principle governing the separation of oil from water by gravity differential as follows: ⁽⁴⁾

$$U_p = \frac{g(\rho_p - \rho_w)d_p^2}{18\mu}$$

Where:

- v_p = particle settling velocity
- g = acceleration due to gravity, 9.81 m/s²
- ρ_p = density of particle
- ρ_w = density of water
- d_p = diameter of particle
- μ = dynamic viscosity

Primary Treatment – Flotation

Air Flotation

Where the density differential is not sufficient to separate oil and oil-wetted solids, air flotation may be used to enhance oil removal. In this method, air bubbles are attached to the contaminant particles and thus the apparent density difference between the particles is increased.

Dissolved air flotation (DAF) is a method of introducing air to a side stream or recycle stream at elevated pressures in order to create a super saturated stream. When this stream is introduced into the waste stream, the pressure is reduced to atmospheric, and the air is released as small bubbles. These bubbles attach to contaminants in the waste, decreasing their effective density and aiding in their separation.

The most important operation parameters for contaminant removal by dissolved air flotation are; ⁽¹⁾

- Air pressure
- Recycle or slip stream flow rate
- Influent total suspended solids (TSS) including oil and grease
- Bubble size
- Dispersion

As in gravity settling, air flotation units are designed for a surface-loading rate that is a function of the waste flow and rise velocity of the contaminants floated by air bubbles. The retention time is a function of the tank depth.

DAF units can be rectangular in design by are usually circular, resembling a primary clarifier or thickener. They are often single stage units.

Induced Air Flotation (IAF) is another method of decreasing particle density by attaching air bubbles to the particles, however the method of generating the air bubble differs. A mechanical action is employed to create the air bubbles and their contact with the waste contaminants. The most common methods use high-speed agitators or recycle a slipstream through venturi nozzles to entrain air into the wastewater.

In contrast to DAF units, IAF units are usually rectangular and incorporate four or more air flotation stages in series. The retention time per stage is significantly less than in DAF circular tanks.

As in gravity settling, the diameter of the particle plays an important role in separation. Polyelectrolytes may be used to increase effective particle diameters. Polymers are also used to destabilize oil / water emulsions, there by allowing the free oil to be separated from the water. Polymers do this by charge neutralization, which destabilizes an oil globule surface and allows it to contact other oil globules and air bubbles. Emulsion breakers, surfactants, or surface-active agents are also used in air flotation to destabilize emulsions and increase the effectiveness of the air bubbles.

Filtration

Filtration is employed in waste treatment whenever suspended solids must be removed. In practice, filtration is most often used to polish wastewater following treatment. In primary waste treatment, filters are often employed to remove oil and suspended solids prior to biological treatment. More commonly, filters are used following biological treatment prior to final discharge or reuse.

Filtration is also widely used as a tertiary treatment for suspended solids removal. The fundamental requirement is that the suspended particles are of sufficient size or capable of being increased in size by flocculation. In cases when it is not possible to flocculate such particles, more advanced techniques such as ultra-filtration is more practical.

Some of the advantages of filtration are as follows: ⁽³⁾

1. Simple to operate and easy to control
2. Can be used for almost any type of free-flowing liquid stream containing suspended solid particles

3. Relatively cost competitive with regard to sludge dewatering processes
4. Lower energy consumption as compared to others
5. Can be integrated easily with other treatment trains
6. Great potential for recovery as the process will not chemically change the characteristics of the materials treated.

Some of the disadvantages, among others are: ⁽³⁾

1. Not capable of producing a high purity effluent as both the liquid product and dewatered sludge still contain a certain fraction of the liquid and solid phase
2. Not capable of separating chemical components especially when they are present in the same phase.
3. Not capable of destroying or chemically changing the toxicity of materials
4. Will produce a liquid waste stream that requires further treatment prior to disposal.

Ultra-filtration

Ultra-filtration, by definition, is a membrane filtration process that separates high molecular weight solutes or colloids from a solution or suspension. The process has successfully been applied to both homogeneous solutions and colloidal suspensions that are difficult to separate practically by other techniques.

The types of membrane used for ultra-filtration are similar to reverse osmosis membranes that are made of cellulose acetate and nylon. It has demonstrated unique capabilities in the treatment of industrial wastewaters such as the separation of oil from water, reduction of toxic compounds present in the wastewater and recovery of valuable byproducts. Nevertheless, the process is unattractive to small-scale industries due to high operating and capital costs. ⁽³⁾

Secondary Treatment - clarification

The Secondary Treatment consists of at least two types of systems. The first is Fixed Film / Media System and the second is Suspended Growth Systems.

The Fixed Film / Media Biological Oxidation System has a media in which the Biological Film is attached to a Media. The Waste Water is slowly passed through the Media and the Biological Film degrades the organics to non-organic products. The fixed film system include Trickling filters, Rotating Biological Contactor (RBC), etc.

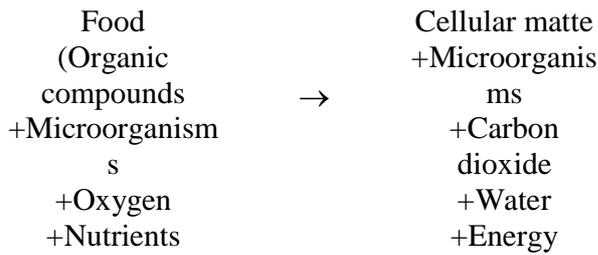
The Suspended Growth Biological Oxidation System includes Stabilization Ponds, Single Pass Aerated Lagoons and Activated Sludge Systems

Biological Oxidation

One of the most common ways to convert soluble organic matter to insoluble matter is through biological oxidation. Soluble organics metabolized by bacteria are converted to carbon dioxide and bacterial floc, which can be settled from solution.

The biodegradable contaminants in water are usually measured in terms of biochemical oxygen demand (BOD). BOD is actually a measure of the oxygen consumed by microorganisms as they assimilate organics.

Bacteria metabolize oxygen along with certain nutrients and trace metals to form cellular matter, energy carbon dioxide, water and more bacteria. This process may be represented in the form of a chemical reaction. ⁽¹⁾



The purity of the water depends on minimizing the amount of organic compounds that remain after secondary treatment. Factors that affect biological oxidation are shown in Table 2. ⁽¹⁾

Table 2 - Factors Affecting Biological Oxidation

Factor	Affect
Food, BOD	To maintain control with efficient BOD removal, the proper amount of food must be supplied
Dissolved Oxygen	Insufficient oxygen levels inhibit BOD removal
pH, toxicants	With time, bacteria adapt to change in conditions. Rapid changes in pH or type of waste organic inhibit the process
Time	The degree of degradations varies with time
Nutrients	Bacteria require trace amounts of nitrogen and phosphorus for cell maintenance.
Temperature	Low Temperature result in slow reaction rates, higher temperature may kill many strains of bacteria

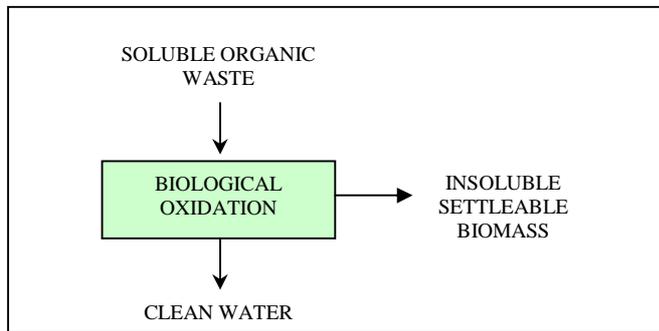


Figure 2 - Biological oxidation converts soluble waste to clean water and insoluble biomass

Fixed Film / Media Systems

Fixed Film / Media Oxidation passed influent wastewater across a substructure laden with fixed biomass. Fixed media allow a biological layer to grow on a substructure continually exposed to raw wastewater. As the layer grows in thickness oxygen transfer to the inter-most layers is impeded. Eventually, some of the layer is removed. This phenomenon is called sloughing. In a continuous process this material is carried to a sedimentation stage, where it is removed.

Media plugging and lack of oxygen transfer are the primary difficulties encountered with fixed media designs. Plugging problems can be alleviated by increase wastewater shear. This is normally accomplished by recycling a portion of the wastewater. The graphical representation of bio-film formations in the fixed film/media system is shown in Figure 3.

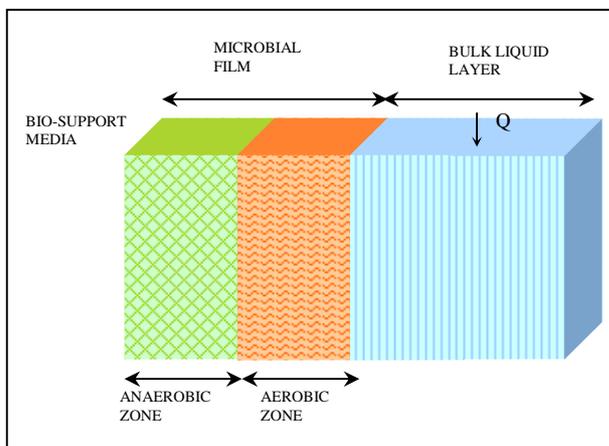


Figure 3 - Volumetric element for Microbial film and Bulk Liquid Layers in the fixed film/media system

Suspended Growth Biological Oxidation Systems

Activated Sludge Systems

Activated sludge system is a biological process that is characterized by the suspension of aerobic microorganisms being maintained in a relatively homogenous state by the mixing or turbulence induced from the aeration process ⁽³⁾.

The microorganisms oxidize the soluble and colloidal organics in the presence of molecular oxygen. In the oxidation process, a part of the organic material is transformed into new cells that subsequently undergo auto-oxidation in the aeration basin. In the conventional activated sludge process, the typical hydraulic retention time (HRT) is in the range of 6 to 10 hours, and the volumetric loading rate (VLR) of the reactor is in the range of 0.32 to 0.64 kg BOD /m³.day.

In the process, the flocs generated from the oxidation process are separated in a clarifier and partly recycled into the aeration basin with some removed for disposal off site or further treatment. The supernatant overflows from the clarifiers as final discharge. The process has been widely used throughout the world as one of the most proven method to treat, not only sewages but also highly toxic industrial wastewaters. Since its invention, the process has been modified to improve its efficiency and reduce the capital and operation costs. ⁽³⁾

The advantages of the activated sludge process are as follows:

- Requires limited space – HRT is 3 to 36 hour range
- MLSS is in the range of 1500 to 10,000 mg/l
- Reliable operator control capability
- Can handle shock loads better with less recovery time required
- Can handle high loaded waste streams
- Excellent solids removal capability

The disadvantages, among others, are as follows:

- Requires highly trained operators
- Requires substantial monitoring
- Requires high operation and maintenance costs
- Sensitive to toxic discharges or load fluctuations
- Generates waste sludge products that are difficult to dewater

The control of contaminate oxidation at high BOD loading requires a bacteria population that is equal to the level of food. The need is the basis for the activated sludge process. In the activated sludge process, reactants, food, and microorganism are mixed in a controlled environment to optimize BOD removal. The process incorporates the return of concentrated microorganisms to the influent waste.

When bacteria are separated from wastewater leaving an aeration basin and reintroduced to the influent, they continue to thrive. The re-circulated bacteria continue to oxidize wastewater contaminants, and if present in sufficient quantity, produce a relatively low BOD effluent water. Because the

activated sludge process incorporates the return of concentrated microorganisms, it must include a process for microorganism concentration and removal. This process includes an aeration stage and a sedimentation stage.

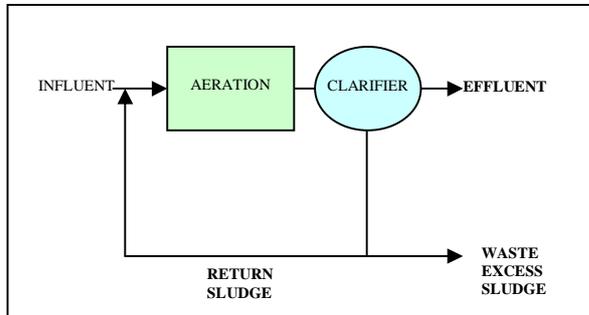


Figure 4 - Activated sludge process returns active biomass to enhance waste removal

The operating parameters that affect the performance of any activated sludge process are BOD, microorganism, dissolved oxygen, retention time, nutrient concentration, and external influences of temperature and pH. In order to understand the various activated sludge designs, it is necessary to examine the relationship between available food and bacteria population.

Initially, excess food is present; therefore the bacteria reproduce in a geometric fashion. This is termed the “log growth phase”. As the population increase and food decrease a plateau is reached in population. From the inflection point on the curve to the plateau, population is increasing but at a decreasing rate. This is called the “declining growth phase”.

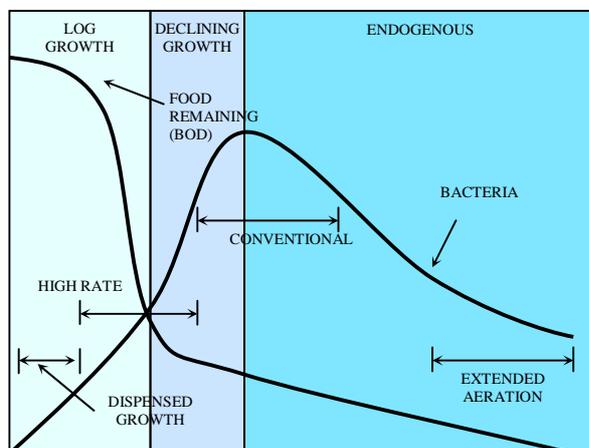


Figure 5 - Model of bacteria population as a function of time and amount of food

Once the plateau is crossed, the bacteria are actively competing for the remaining food. The bacteria begin to metabolize stored materials, and the population decreases. This area of the curve is termed “endogenous respirations”. Eventually, the bacterial population and the DOD are at a minimum.

Because activated sludge is a continuous, steady state process, each plant operates at some specific point on the curve, as determined by the oxidation time provided. The point of operation determines the remaining bacteria population and BOD of the effluent.

Optimization of an activated sludge plant requires the integration of mechanical, operational and chemical approaches for the most practical overall program. Mechanical problems can include excessive hydraulic loading, insufficient aerations, and short-circuiting. Operational problems may include spill and shock loads, pH shocks, failure to maintain correct mixed liquor concentrations, and excessive sludge retention in the clarifier. Because activated sludge depends on microorganism recirculation, sedimentation is the key stage. The settle ability of the biomass is a crucial factor. As bacteria multiply and generate colonies, they excrete natural biopolymers. These polymers and the slime layer that encapsulates the bacteria influence the flocculation and settling characteristics of the bacteria colonies.

It has been determined empirically that the natural settle ability of bacteria colonies is also a function of their position on the time chart. Newly formed colonies in the log growth phase are relatively non-settle able. At the end of the declining growth phase and the first part of the endogenous phase, natural flocculation is at an optimum. As the endogenous phase continues, colonies break up and floc particles are dispersed, decreasing the biomass settle ability.

Although microbes are eventually able to break down most complex organics and can tolerate very poor environments, they are very intolerant of sudden change in pH, dissolved oxygen and the organic compounds that normally upset an activated sludge system. These upsets normally result in poor BOD removal and excessive carry over of suspended solids (unsettled microorganisms) in the final effluent.