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Wastewater Recovery & Reuse – Part II

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by

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BIOLOGICAL WASTEWATER TREATMENT

All biological-treatment processes take advantage of the remarkable ability of bacteria to use diverse wastewater constituents to provide the energy for microbial metabolism and the building blocks for cell synthesis. This metabolic activity, known as bioremediation, can remove the raw materials, or break down almost all organic compounds.

A total bioremediation treatment process usually consists of the following stages:

Preliminary (Pretreatment) – Screening to remove bulky objects, grit and other large solids.

Primary Treatment – Clarification to allow suspended solids to settle out and oil to rise to the surface.

Secondary Treatment – Biodegradation of biological contaminants utilizing technologies described in this document.

Tertiary Treatment – Final filtration and/or disinfection, dictated by the ultimate use or discharge of the treated effluent. This includes MBR, also detailed in this document.

In the secondary treatment stage of the total bioremediation process, the three types of biological decomposition processes are known as aerobic, anoxic and anaerobic. They are described below. Chemically, organic contaminants, BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) are oxidized by losing an electron to an “acceptor.”

Aerobic

Dissolved molecular oxygen (O_2) is the electron acceptor in this process. The end products are primarily carbon dioxide (CO_2), water and new cell material. This process is capable of breaking down the widest spectrum of organic contaminants of all the decomposition processes. On the other hand, it results in the largest production of new cells (activated sludge).

Aerobic digestion is very effective in the oxidation of ammonia (NH_4^+) to nitrite (NO_2^-) and then onto nitrate (NO_3^-). These particular microorganisms grow more slowly than those used to consume BOD.

Aerobic decomposition is generally not suitable for high strength wastewaters (BOD >1000 mg/L); however, in certain small industrial applications, it may be capable of treating wastewater with BOD concentrations as high as 3000 mg/L.

Anoxic

Microorganisms capable of using nitrate (NO_3^-) as the electron acceptor in the absence of oxygen are utilized in the anoxic process. This is also employed for denitrification, the conversion of nitrate to nitrogen gas (N_2), and sludge production. Nitrate contamination of surface and ground water supplies used in potable applications is a major issue today.

Anaerobic

This process dominates in waters without oxygen and nitrogen electron acceptors. It utilizes sulfate (SO_4^{2-}), carbon dioxide (CO_2) and organic compounds capable of accepting electrons. The reduction of sulfate produces hydrogen sulfide (H_2S) gas (odoriferous and explosive) as well as organic sulfur compounds known as mercaptans. Methane (CH_4) is also produced in the anaerobic process. Sludge volume is low, and the flammable gases, particularly methane, can be collected and used as a source of energy. Anaerobic digestion is most appropriate for wastewater supplies with BOD concentrations above 1000 mg/L.

The following table compares anaerobic and aerobic bioremediation for treatment of wastewater containing 1000 kg COD.

| Parameters | Anaerobic | Aerobic |
|----------------------------------|-----------|---------|
| Power Requirements (kWhr) | 1.5 | 65 |
| Net Production of Biosolids (kg) | 15-100 | 200-600 |
| Useable Energy Produced (kWhr) | 140 | NiL |

APPLICATION OF BIOLOGICAL TREATMENT PROCESSES

Suspended Growth (Activated Sludge)

This process involves air or oxygen being introduced into a mixture of primary treated or screened municipal or industrial wastewater (referred to as “wastewater” from now on), reacting with bacteria to develop a biological floc which reduces the organic content of the sewage. This material (which in healthy sludge is a brown floc) is largely composed of saprotrophic bacteria but also has an important protozoan flora mainly composed of amoebae, Spirotrichs, Peritichs, including Vorticellids, and a range of other filter feeding species. Other important constituents include motile and sedentary rotifers.

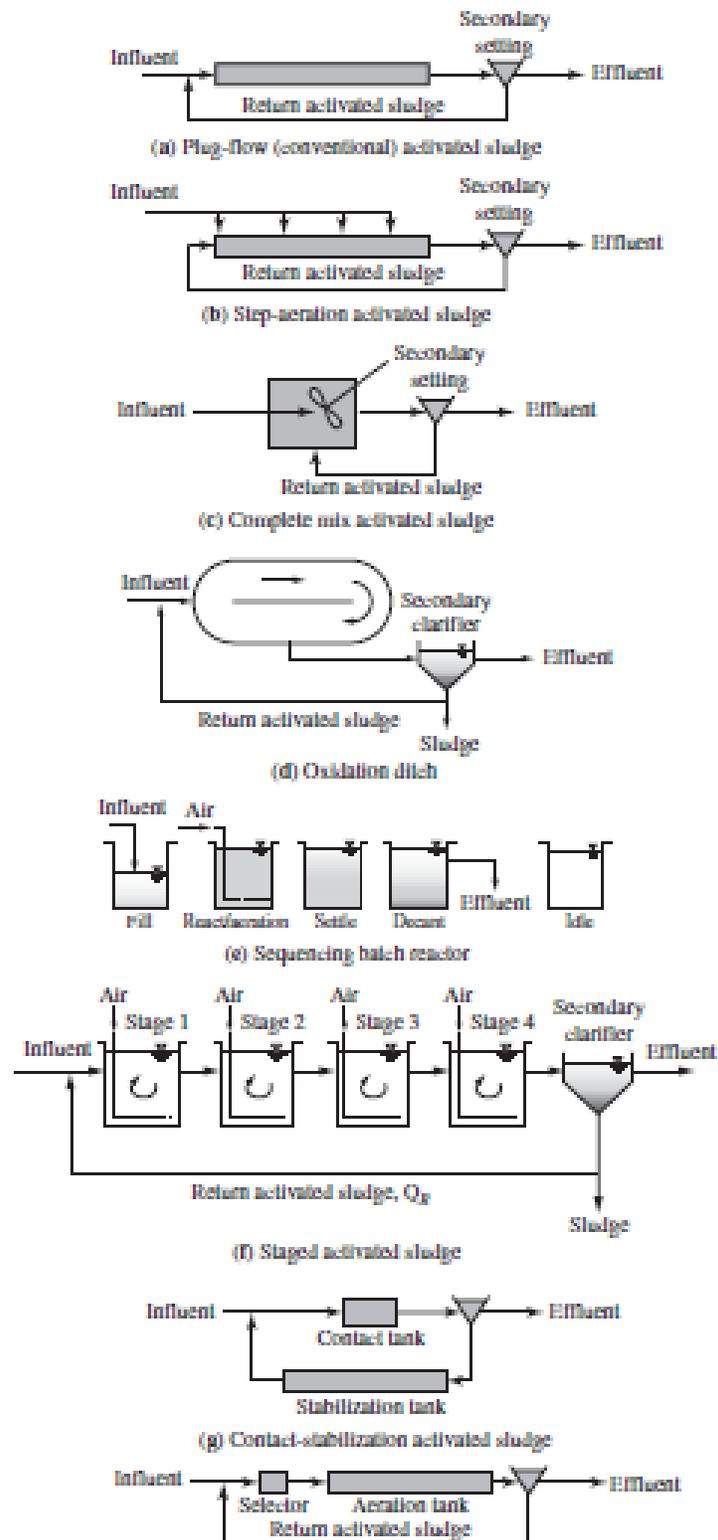
The combination of wastewater and biological mass is commonly known as *mixed liquor*. In a typical activated sludge plant, once the wastewater has received sufficient microbial treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. The remainder is discharged to the sludge handling system for treatment and disposal.

The solids retention time (SRT) is defined as the average amount of time that microorganisms are kept in the system.

In conventional activated sludge systems, the wastewater is typically aerated for six to eight hours. Sufficient air is provided to keep the sludge in suspension. The air is injected near the bottom of the aeration tank through a system of diffusers. The volume of sludge returned to the aeration basin is typically 20 to 30% of the wastewater flow.

The following list is an indication of the numerous configurations for the activated sludge process, and these are illustration below.

- Plug flow (conventional)
- Step feed (step aeration)
- Complete mix
- Oxidation ditch
- Sequencing batch reactor
- Staged activated sludge
- Contact stabilization
- Conventional with selector



(Sources: Adapted from Rittmann and McCarty, 2001 and Metcalf & Eddy, 2003)
M.L. Davis, Water & Wastewater Engineering Design Principles & Practice (2010)

Attached Growth (Fixed Film)

In this process, the microorganisms attach themselves to inert media and generate a biofilm layer (lipopolysaccharide). As the medium contains void spaces, air can circulate to allow oxygen to contact the microorganisms for aerobic digestion. As layers of growth accumulate, they slough off the media and form sludge in the bottom of the vessel.

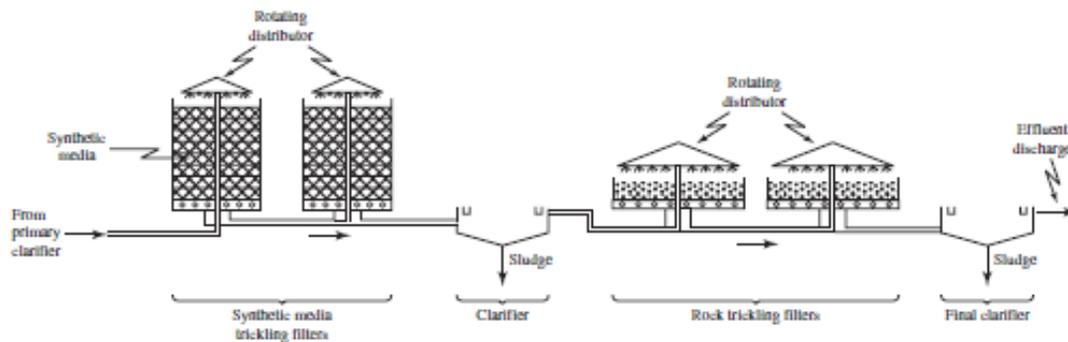
The most common designs are trickling filters, rotating biological contactors (RBCs) and moving bed biofilm reactors (MBBRs).

Trickling filters

Historically, these have utilized a 10 to 20 m diameter bed of stones, one to three m deep, with a rotating arm to distribute the effluent over the surface. The stones range from 25 to 100 mm in diameter, and provide the surface area necessary for the bacteria to establish biofilm and metabolize the BOD. To provide for higher surface area and lower weight (to allow taller systems – up to 12 m), plastic media, with a choice of many shapes and materials, are now usually employed.

Most designs provide for the recirculation of a portion of the treated effluent back through the filter.

Below is an illustration of two-stage trickling filter plant utilizing both synthetic media and rock media.

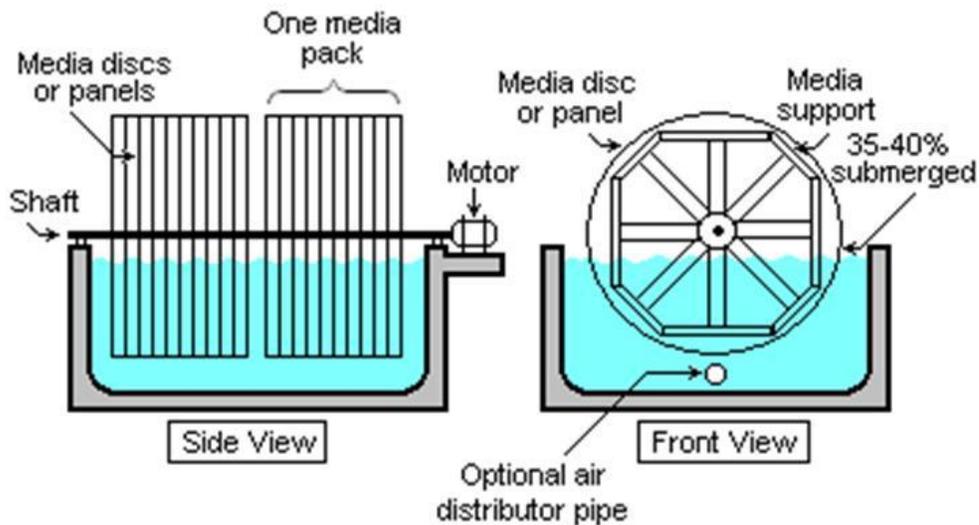


(Sources: M.L. Davis, Water & Wastewater Engineering Design Principles & Practice (2010))

Rotating Biological Contactors (RBCs)

RBCs consist of a series of vertical disks about three meters in diameter and all mounted on a horizontal shaft positioned near the top of the tank containing the effluent to be treated. Roughly one half of the disks are immersed in the effluent, and they are slowly rotated to allow the attached microorganisms to be alternatively exposed to the wastewater and the air. The biofilm is one to three mm thick and excess growth sloughs off into the tank.

An illustration of the RBC process is below.



Wikipedia "Sewage Treatment"

Moving Bed Biofilm Reactor (MBBRs)

These systems utilize small plastic elements (7-22 mm diameter) loosely contained in the reactor tank. Air is usually directed into the tank from below and agitates the suspended growth. Mechanical mixers may also be employed. The tank contains a screen to contain the media.

The following table compares these fixed film designs with activated sludge technology.

| SUSPENDED GROWTH | FIXED FILM | | |
|---|--|---|--|
| Activated Sludge | Trickling Filter | RBC | MBBR |
| Requires residual suspended solids (MLSS) | No residual. Suspended solids returned. | No residual suspended solids returned | No residual suspended solids returned |
| Operator adjusts MLSS levels | Self regulating, no operator adjustments | Self regulating, no operator adjustments | Self regulating, no operator adjustments |
| MLSS sludge recycled back through plant | Single pass flow through | Single pass flow through | Single pass flow through |
| MLSS can be flushed out with high flows | Not affected by high flows | Biology stripped of media with high flows | Not affected by high flows |
| Moderate mechanical equipment | Low mechanical equipment | High mechanical equipment | Low mechanical equipment |
| Unstable nutrient removal | Stable nutrient removal | Unstable nutrient removal | Stable nutrient removal |

A Word of Caution

Knowing the composition of the wastewater is essential for planning a treatment process. In petroleum refineries, for example, excessive amounts of spent caustic can quickly overwhelm a wastewater treatment system due to the normally high COD of the caustic. Another issue can be a significant increase in ammonia and sulfide loads that result from upsets in the operation of sour-water strippers. These loads can, in turn, upset the biological treatment system if it is not designed to handle ammonia and sulfide.

In addition to understanding the source and composition of the wastewater, it is important to recognize when pretreatment steps are needed to provide adequate protection for a biological treatment system. In most petroleum and petrochemical facilities, for example, raw wastewater normally contains free oil, which can have serious, detrimental effects. Oil can coat and kill bacteria, causing a drop in microbial activity, and can interfere with oxygen-transfer efficiency. Another cause for concern in refineries is the potential upset in desalter operations that can lead to oil/water emulsions in the wastewater and thereby negatively impact the biological treatment system. To prevent these types of problems, process steps prior to biological treatment are normally included. Pretreatment for this industry typically includes the use of oil/water separators, and an equalization tank to mediate spikes in wastewater composition.

Even properly pretreated wastewater can still contain a wide variety of compounds which may or may not be biodegradable. There may also be a significant concentration of compounds that require modifications to the treatment process in order to meet discharge regulations. The types of compounds present, the concentration of each and the ultimate discharge requirements are key to selecting the proper biological treatment system. This is true whether the wastewater is being discharged directly to the environment or to a publicly owned treatment works (POTW), or if it is to be reused within the facility.

MBR

Introduction

With regard to bioremediation wastewater reuse, the most widely used technology is MBR (Membrane Bioreactor).

Municipal wastewater treatment plants are designed to accept wastewater from all sources: residences, commercial establishments, institutions and industrial plants. Generally known as POTW (Publically Owned Treatment Works), they are usually located in or near a municipality, city or town.

In addition to municipal sewage, this discussion also addresses industrial facilities that produce wastewater high in biodegradable organic compounds (BOD).

Likewise, as septic systems utilize the same bioremediation process as municipal wastewater plants, this discussion applies to these “decentralized” applications.

MBR is particularly unique because it combines one of the newest technologies, crossflow pressure-driven membrane separation, with the oldest wastewater treatment technology, biological degradation (bioremediation).

MBR technology normally utilizes activated sludge treatment as the bioremediation process and membranes to “dewater” the biological sludge and produce a permeate (treated effluent) stream with very low BOD and COD, and almost no particles (TSS) and bacteria. The membrane basically replaces the final clarifier used in conventional activated sludge treatment, which achieve solids separation by gravity only. The physical barrier imposed by the membrane system accomplishes this removal. MBR also enables operation at higher sludge concentrations, thereby reducing the required footprint and/or sludge production.

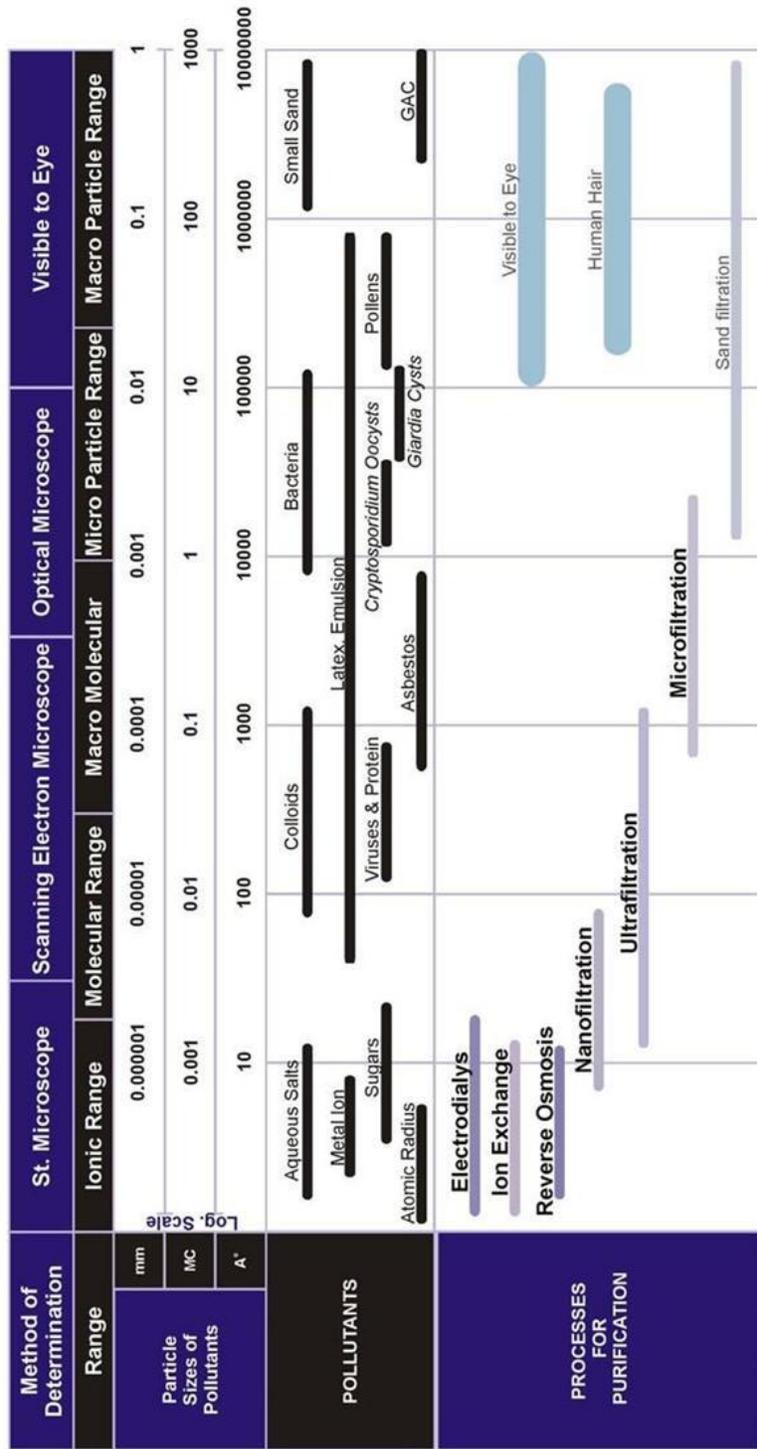
Some estimates indicate that MBR is growing at a rate of 25% per year. When considering the huge number of bioremediation applications and current emphasis on wastewater recovery and reuse, this figure is not unrealistic.

MBR applications include:

- Residential development projects
 - Single dwellings
 - Housing clusters
 - Apartment buildings/condominiums
- Commercial projects
- Mining camps and other remote installations
- Emergency response installations
- Military installations
- Sports facilities
- Recreation parks
- Schools
- Shopping centers
- Office parks
- Industrial plants
 - Food processing
 - Abattoir facilities
 - Animal feed lots

The following chart illustrates the sizes of various water contaminants and treatment technologies employed to remove them.

Water Contaminants, Sizes and Treatment Technologies



1 Angstrom(A³) = 10⁻¹⁰Meter(m) = 10⁻⁴Microns(MC) = 10⁻⁷Millimeter(mm)

Courtesy Val S. Frenkel, Ph.D., P.E., D.WRE., Kennedy/Jenks Consultants

History

The MBR process was introduced in the late 1960s, as commercial scale microfiltration and ultrafiltration membranes became available. The original process was introduced by Dorr-Oliver, Inc. and combined the use of an activated sludge bioreactor with an external crossflow membrane filtration loop. The flat sheet membranes used in this process were polymeric and featured pore sizes ranging from 0.003 to 0.01 μ . Due to the poor economics of the first generation MBRs, they only found applications in niche areas with special needs, such as isolated trailer parks or ski resorts.

The breakthrough for MBR came in 1989 with the idea of Yamamoto and co-workers in Japan to submerge the membranes in the bioreactor. Until then, MBRs were designed with the membrane device located external to the reactor (sidestream MBR) and relied on high transmembrane pressures (TMP) to maintain filtration. With the membrane immersed into the bioreactor, submerged MBR systems are usually preferred to the external configuration, especially for municipal sewage treatment. The submerged configuration relies on bubble aeration to produce mixing and limit fouling. The energy of the submerged system can be up to 2 orders of magnitude lower than that of the sidestream systems, but submerged systems operate at lower flux, requiring more membrane area. Aeration maintains solids in suspension, scours the membrane surface and provides oxygen to the biomass, leading to improved biodegradability.

The lower operating cost provided by the submerged configuration along with the steady decrease in membrane cost has resulted in a significant increase in MBR plant installations from the mid 90s. Since then, further improvements in the MBR design and operation have been introduced and incorporated into larger plants. While early MBRs were operated at solids retention times (STR) as high as 100 days and with mixed liquor suspended solids (MLSS) levels up to 30 g/L, the recent trend is to apply lower solids retention times (around 10-20 days), resulting in more manageable MLSS levels (10-15g/L). Thanks to these new operating conditions, the oxygen transfer and pumping costs have tended to decrease and overall maintenance has been simplified. Typical hydraulic retention times (HRT) range between 3 and 10 hours. In terms of membrane configurations, hollow fiber and flat sheet membranes are utilized in most MBR applications; however, tubular and even spiral wound device configurations are being used to a limited extent.

The following table compares several of the processes with MBR in a number of parameters.

Biological Treatment Processes

| Evaluation Parameter | Activated Sludge | Trickling Filter | Rotating Biological Contractor (RBC) | Membrane Bioreactor (MBR) |
|--|------------------|------------------|--------------------------------------|---------------------------|
| Effective BOD Removal | X | | | X |
| Effective COD Removal | X | | | X |
| Low O&M Costs | | | X | |
| Low Sludge Production | | X | X | X |
| Low Sludge Disposal Costs | | X | X | X |
| Good Operability: Winter | X | | | X |
| Good Operability: Summer | X | X | X | X |
| Good Performance: High Water Temperature | | X | | X |
| Good Performance: Low Water Temperature | X | | | X |
| Minimal Operator Attention | | | X | |
| Quick Upset Recovery | X | X | X | |
| Easy Expandability | | | X | |
| Efficient Nitrification | X | | | X |
| Easy Installation | | | X | |
| Energy Efficient | | X | X | |
| Minimal Space Requirements | X | | | X |

Comparisons are made based on wastewater with a COD of 600 mg/L and BOD of 250 mg/L

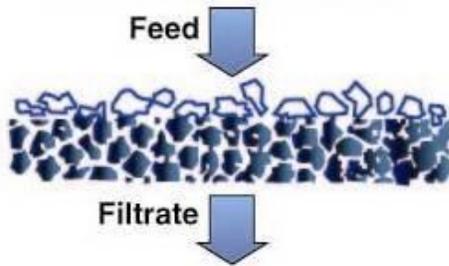
MBR TECHNOLOGY

Introduction

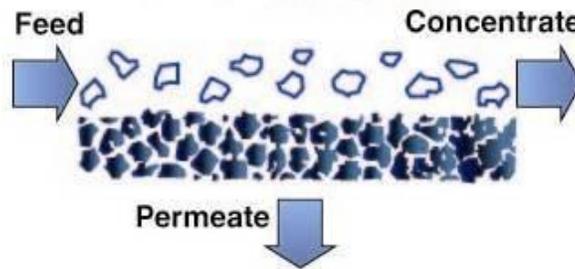
MBR involves the utilization of either microfiltration (MF) or ultrafiltration (UF) membrane technology to treat the water from or in a bioremediation tank to continuously remove TSS (total suspended solids), BOD, COD and bacteria. This treated water then can be used in many non-critical applications, or can be “polished” by reverse osmosis or other deionization processes, followed by disinfection.

Membrane separation technologies have been around for about 60 years. These technologies utilize a membrane to separate contaminants from water streams and are based on the engineering principle of “crossflow filtration.” The illustration below compares the crossflow mechanism with conventional filtration.

Conventional Filtration

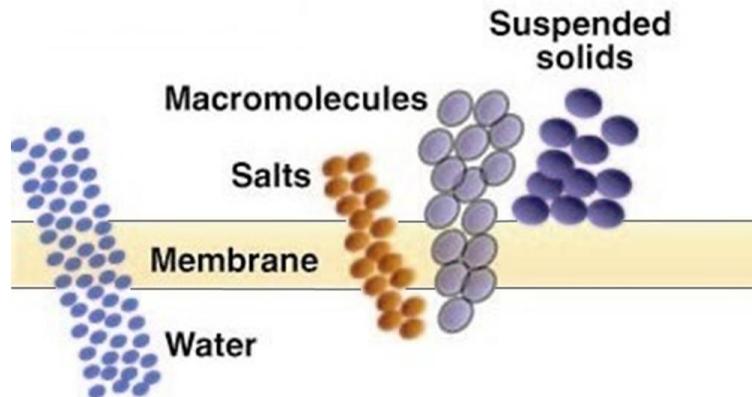


Crossflow Filtration



Microfiltration (MF)

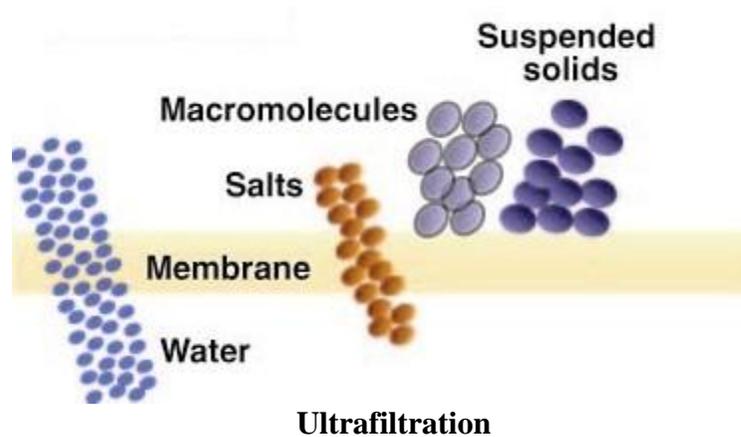
The following figure depicts the mechanism of microfiltration. Generally, microfiltration involves the removal of suspended materials ranging in size from approximately 0.01 to 1 microns (100 to 10,000 angstroms).



Microfiltration

Ultrafiltration (UF)

The illustration below depicts ultrafiltration, which is used to separate materials typically smaller than 0.01 microns (100 angstroms). The removal characteristics of UF membranes can be described in terms of "molecular weight cutoff" (MWCO), the maximum molecular weight of compounds that will pass through the membrane pores. MWCO terminology is expressed in Daltons. Basically, ultrafiltration is used to remove dissolved, non-ionic contaminants while suspended solids are removed by microfiltration.

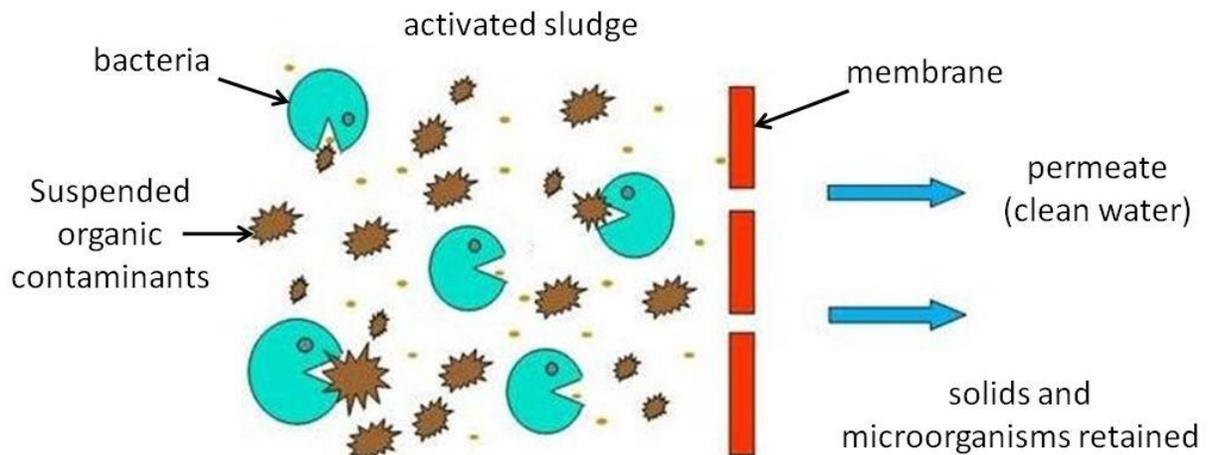


MBR PROCESS

Introduction

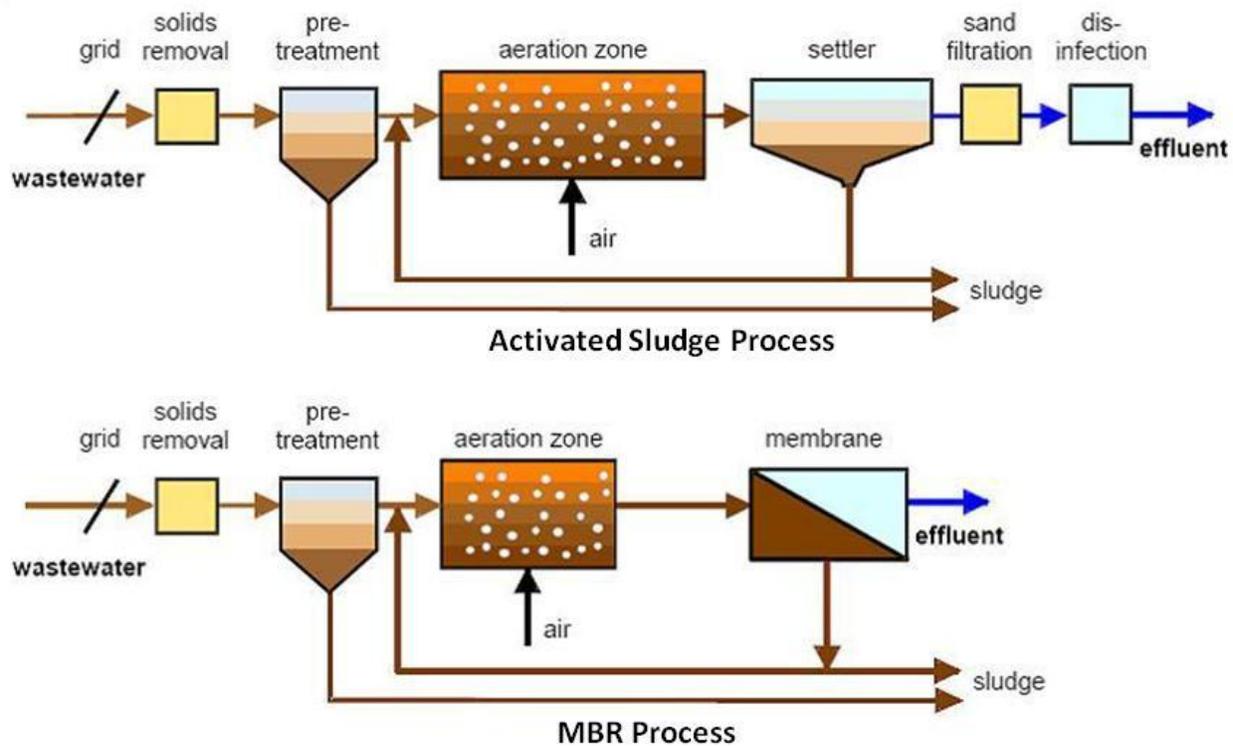
The wastewater is pumped against a membrane surface. The membrane is selected to hold back suspended solids, microorganisms such as bacteria and a high percentage of BOD and COD, while allowing water to pass through.

The following illustration depicts the MBR process.



MBR Process

Below, typical aerobic activated sludge and MBR processes are illustrated.



MBR Advantages (over traditional bioremediation processes)

- High-quality effluent, almost free from suspended solids
- The ability to disinfect without the need for chemicals
- Complete independent control of HRT (Hydraulic Retention Time) and SRT (Sludge Retention Time), which allow more complete reduction of BOD and COD, and improved stability of such processes as nitrification
- Reduced sludge production
- Process intensification through high biomass concentrations with MLSS (Mixed Liquor Suspended Solids) over 25,000 mg/L
- Ability to treat high strength wastes
- More compact systems, resulting in a smaller footprint
- Process unaffected by solids settling
- Longer retention time for more complete nitrification
- Reduction in post treatment disinfection requirements

MBR Disadvantages

- Higher capital cost, primarily resulting from the membrane unit and pump costs
- Higher operating costs associated with the energy requirements of the air blower and pump
- Operation at high SRTs may increase levels of inorganic chemicals that are harmful to the microbial populations

Membrane Configurations

The two most common types of membranes used in the MBR process are plate and frame and hollow fiber configurations.

Plate & Frame

In the plate and frame design, the permeate is drawn perpendicularly through the membrane sheet. The panel between the membrane sheets is grooved to channel the permeate flow to an opening at the top of the panel or to an integral pipe between panels.

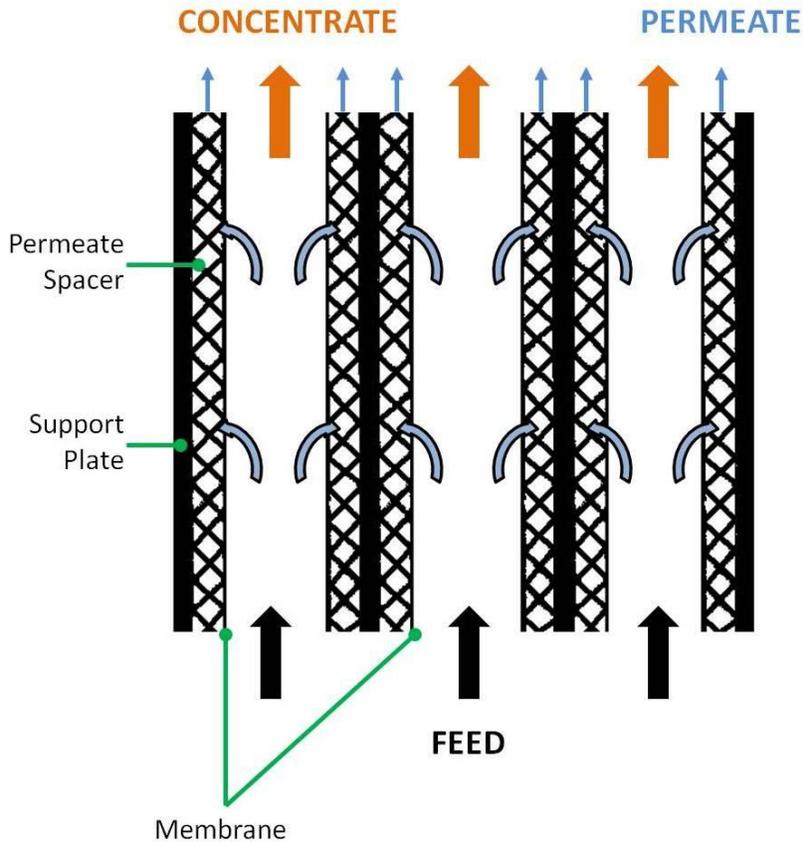


Plate & Frame Element

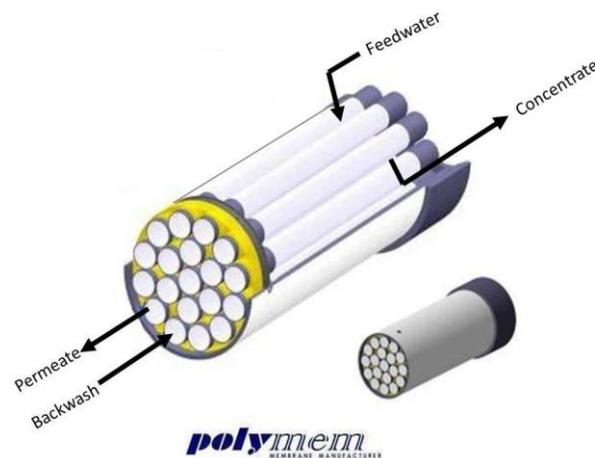
There are significant variations exist between the different plate and frame membrane suppliers. These include:

- Panel size
- Panel material
- Membrane material
- Pore size
- Operating pressure
- Membrane to panel attachment method

Hollow Fiber MBR

Hollow fiber membranes are long, small diameter strands of a hollow fiber polymer, often coated with a protective coating. These products are manufactured by an extrusion or spinneret process rather than the coating process used for the other membrane configurations. The strands are usually bundled and secured at the top and bottom when submerged in the activated sludge tank. The permeate is drawn through the membrane wall into the center of the strand, and then travels to one or both ends before discharging to the main permeate header.

A hollow fiber element is illustrated below.



Hollow Fiber Element

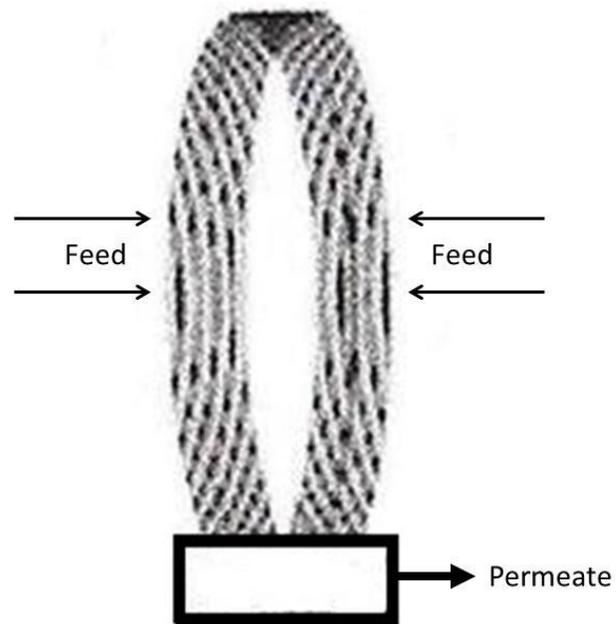
Variations between hollow fiber manufacturers include the following:

- Fiber diameter
- Method used to bundle the strands
- Number of strands per bundle
- Membrane material
- The method in which air is applied to the bundle
- Wall thickness

There are a number of types of bundles available, as described below:

U shaped bundle:

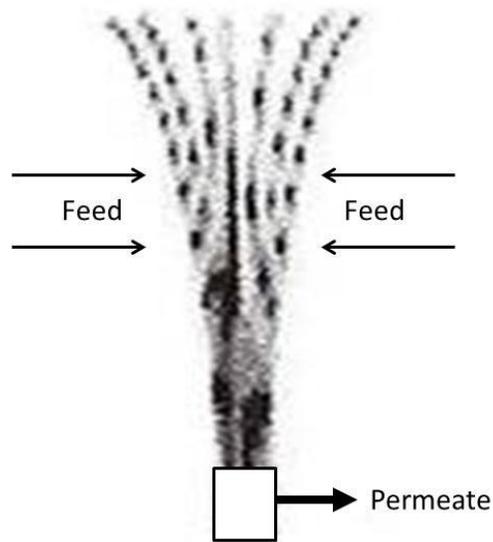
It contains one or several bundles of fibers in a 'U' configuration, and potted together at the bottom of the module. This arrangement is only possible with small diameter and deformable fibers.



U-Shaped Bundle

One-sided potted and freely movable

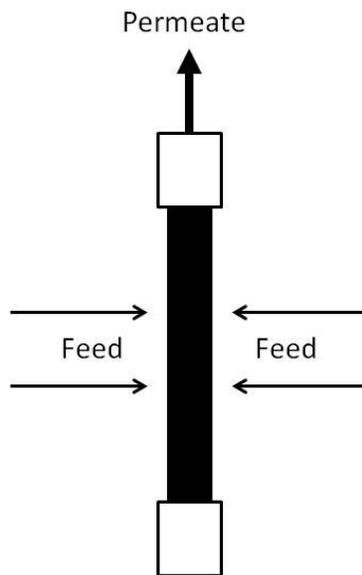
Each fiber is closed at the top and the bundle potted at the bottom. Fibers are free to move independently at the top and are fixed at the bottom.



One-sided potted and freely movable fibers

Rigid fiber bundle

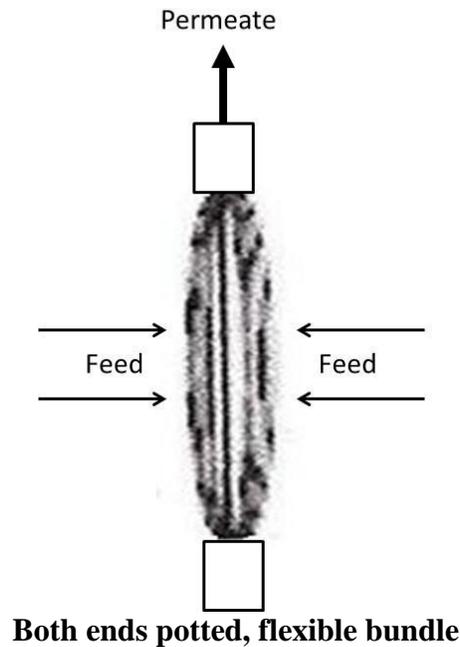
Fibers are potted together on both ends in a rigid configuration. This configuration does not allow fiber movement.



Rigid Fiber Bundle

Both ends potted, flexible bundle

These bundles have the same configuration as the previous one, but the fibers are not rigid. In this case, fibers are more free to move in between the two fixation points.



Tubular Elements

Manufactured from ceramic, carbon, stainless steel, or a number of thermoplastics, these tubes have inside diameters ranging from ¼ inch up to approximately 1 inch (6 to 25 mm). The membrane is typically coated on the inside of the tube and the feed solution flows under pressure through the interior (lumen) from one end to the other, with the permeate passing through the wall and collected outside of the tube. Tubular elements are illustrated below.

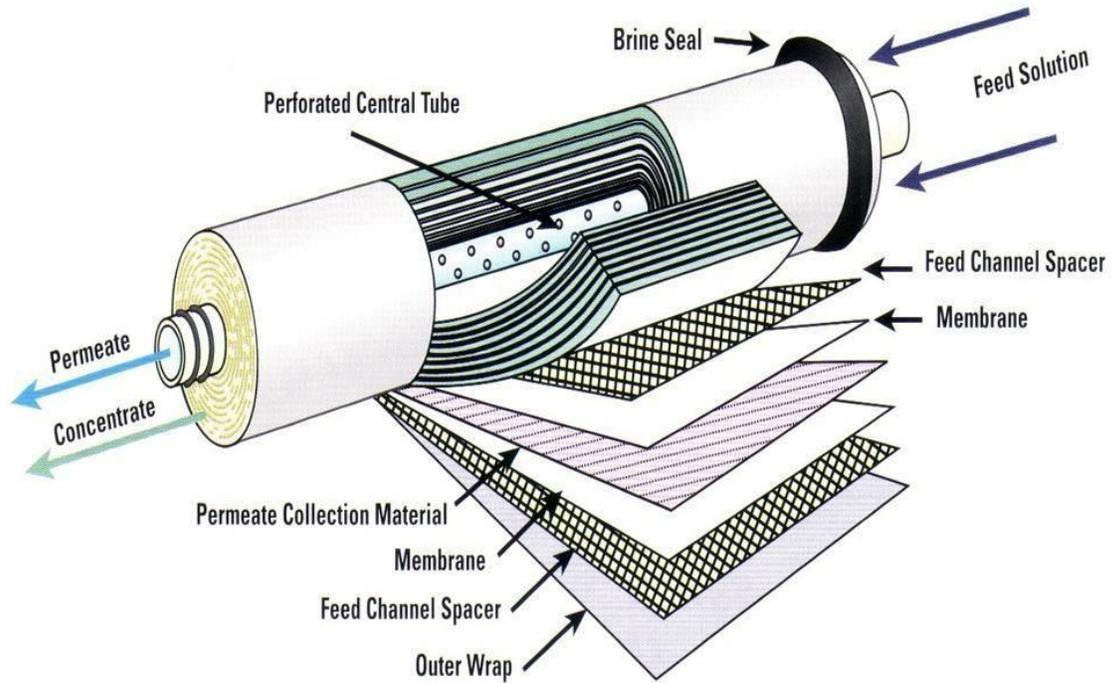


Tubular Membrane Element

This configuration is almost exclusively used only in external systems, as described below.

Spiral Elements

Spiral membranes can be immersed in the treatment tank, but have been only rarely used to date.



Courtesy of: John Peichel – GE Water & Processes Technologies

Spiral Wound Element

Membrane Materials

Typical MF and UF membrane polymer materials are listed in the table below.

Microfiltration (MF) & Ultrafiltration (UF)

| Materials of Construction | Device Configuration | | | |
|---------------------------|----------------------|---------|---------------|--------------|
| | Hollow Fiber | Tubular | Plate & Frame | Spiral Wound |
| <u>Polymeric</u> | | | | |
| PS | X | X | X | X |
| PES | X | X | X | X |
| PAN | X | X | X | X |
| PE | — | X | — | — |
| PP | X | X | X | — |
| PVC | — | X | — | — |
| PVDF | X | X | — | — |
| PTFE | X | — | X | — |
| PVP | X | X | — | — |
| CA | X | — | — | — |
| <u>Non-Polymeric</u> | | | | |
| Coated 316LSS | — | X | — | — |
| α - Alumina | — | X | X | — |
| Titanium Dioxide | — | X | — | — |
| Silicon Dioxide | — | X | — | — |

PS = Polysulfone

PES = Polyethersulfone

PE = Polyethylene

PP = Polypropylene

PAN = Polyacrylonitrile

PVDF = Polyvinylidene Fluoride

PTFE = Polytetrafluoroethylene

CA = Cellulose Acetate

PVP = Polyvinylpyrrolidone

TF = Thin Film Composite

SYSTEM DESIGN

Introduction

The following table is a very general comparison of the most widely used MBR membrane configurations:

| Parameter | Membrane Element Configuration | | |
|---------------------------------------|--------------------------------|---------------|---------------|
| | Plate and Frame | Hollow Fiber | Tubular |
| Packing Density * | Moderate | High | Low |
| Fouling Resistance | Moderate | Moderate | High |
| Energy Requirement | Moderate | Low | High |
| Backwashable | No | Yes | Yes |
| Cleaning Ease | Moderate | Moderate | Easy |
| Net Flux Range (L/m ² /hr) | 15-25 | 20-30 | 70-200 |
| MLSS (mg/L) | 10,000-15,000 | 10,000-15,000 | 10,000-30,000 |

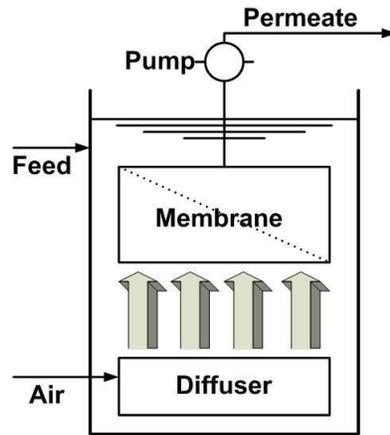
* Membrane area per total element volume

The most common biological treatment is aerobic and, typically, air is bubbled into the treatment tank to encourage bacterial growth. As noted earlier, the membrane elements are usually immersed vertically in the treatment tank and either the hydrostatic head of the solution or a vacuum pump provides the pressure to force the permeate through the membrane. In the aerobic process, air bubbles are also directed from below up across the surface of the membrane (air scouring) in an effort to reduce fouling.

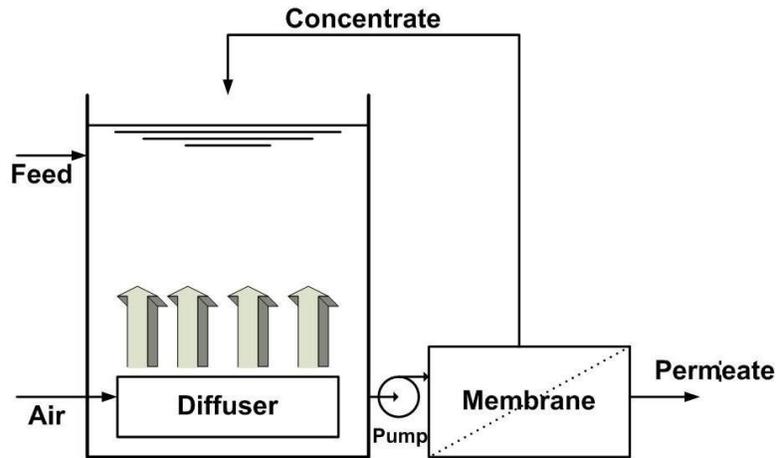
Another design involves pumping wastewater through the membrane system external to the treatment tank (sidestream design). The membrane configuration normally used for this is the tubular membrane element, in a “lumen feed” (inside-out) mode. To minimize fouling, the wastewater is usually fed into the membrane at a high velocity, resulting in relatively high energy consumption.

Yet another approach uses a separate tank for membrane processing downstream of the biological treatment tank. Additional designs and configurations are sure to appear as MBR technology becomes more widely used.

The following figures illustrate aerobic MBR applications for both “immersed” and “external” designs.



IMMERSED



EXTERNAL

The table below compares the immersed with the external system design for several important parameters. This comparison is very generalized, and the data may vary, based on the specific system design.

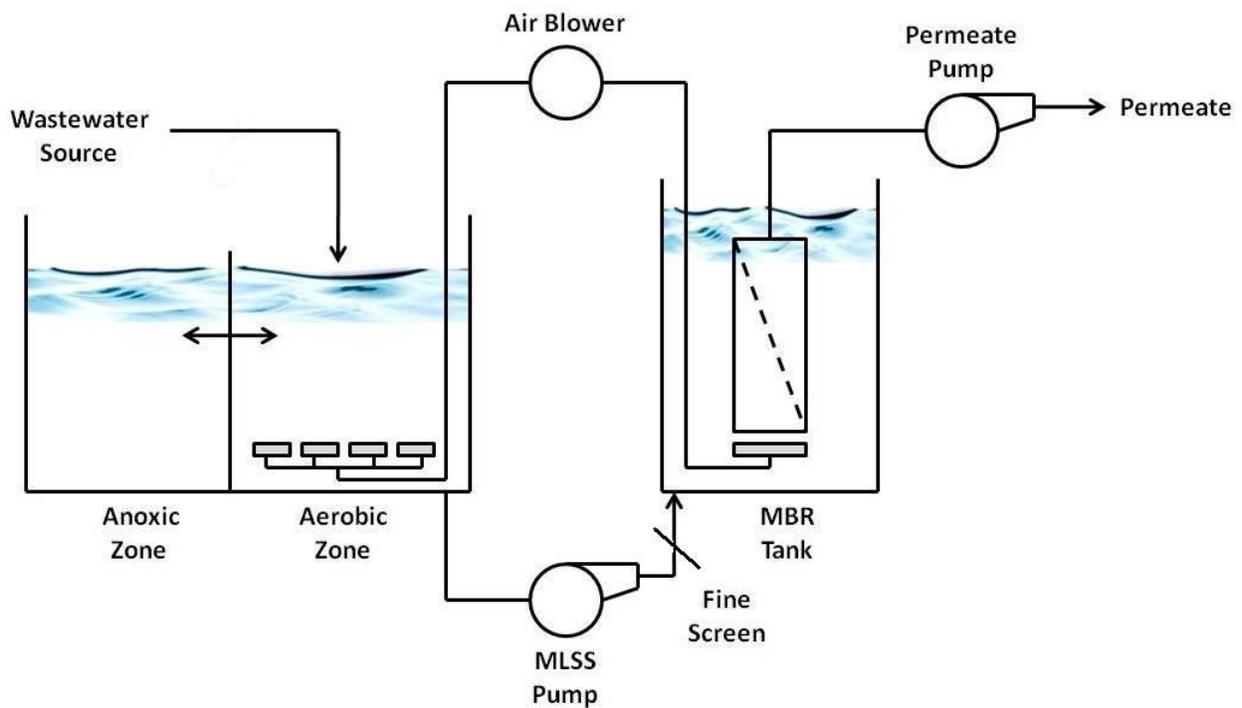
| Parameters | Immersed | External |
|----------------------|----------|----------|
| Aeration Cost | High | Low |
| Pumping Cost | Low | High |
| Membrane Flux | Low | High |
| Cleaning Frequency | Low | High |
| Total Operating Cost | Low | High |
| Total Capital Cost | High | Low |

System Components

A typical MBR System consists of the following main components:

- Fine screen
- Membrane cassettes containing elements
- Bioremediation tank(s)
- Permeate or feed pump
- Blowers with diffusers
- CIP (clean-in-place) system
- Backwashing/Backpulsing equipment

This system may be represented by the following schematic, illustrating the immersed MBR design in a separate treatment tank.



OPERATING CONSIDERATIONS

Fouling

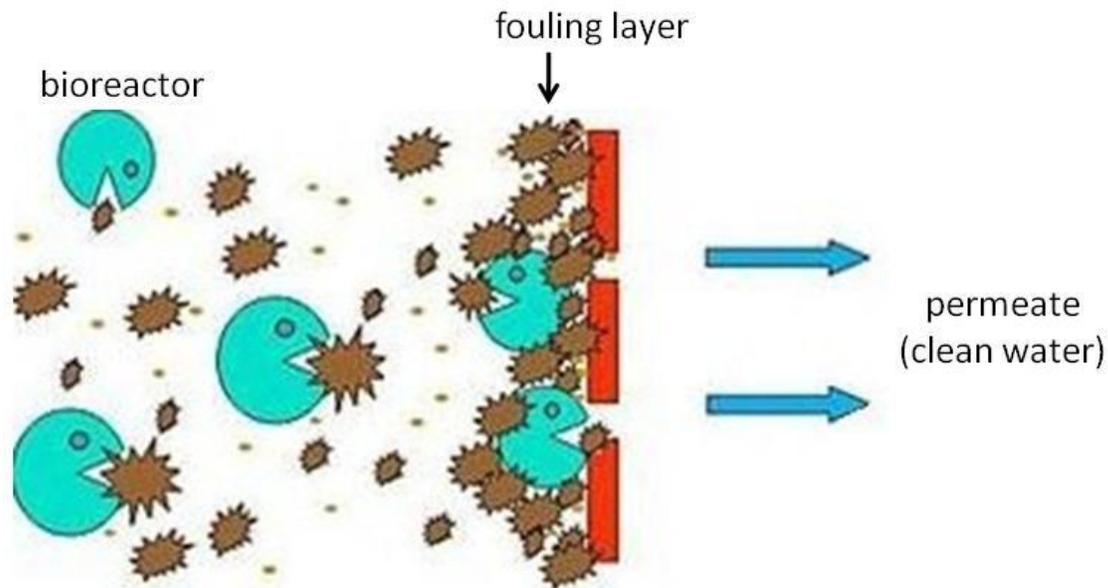


Illustration of Membrane Fouling

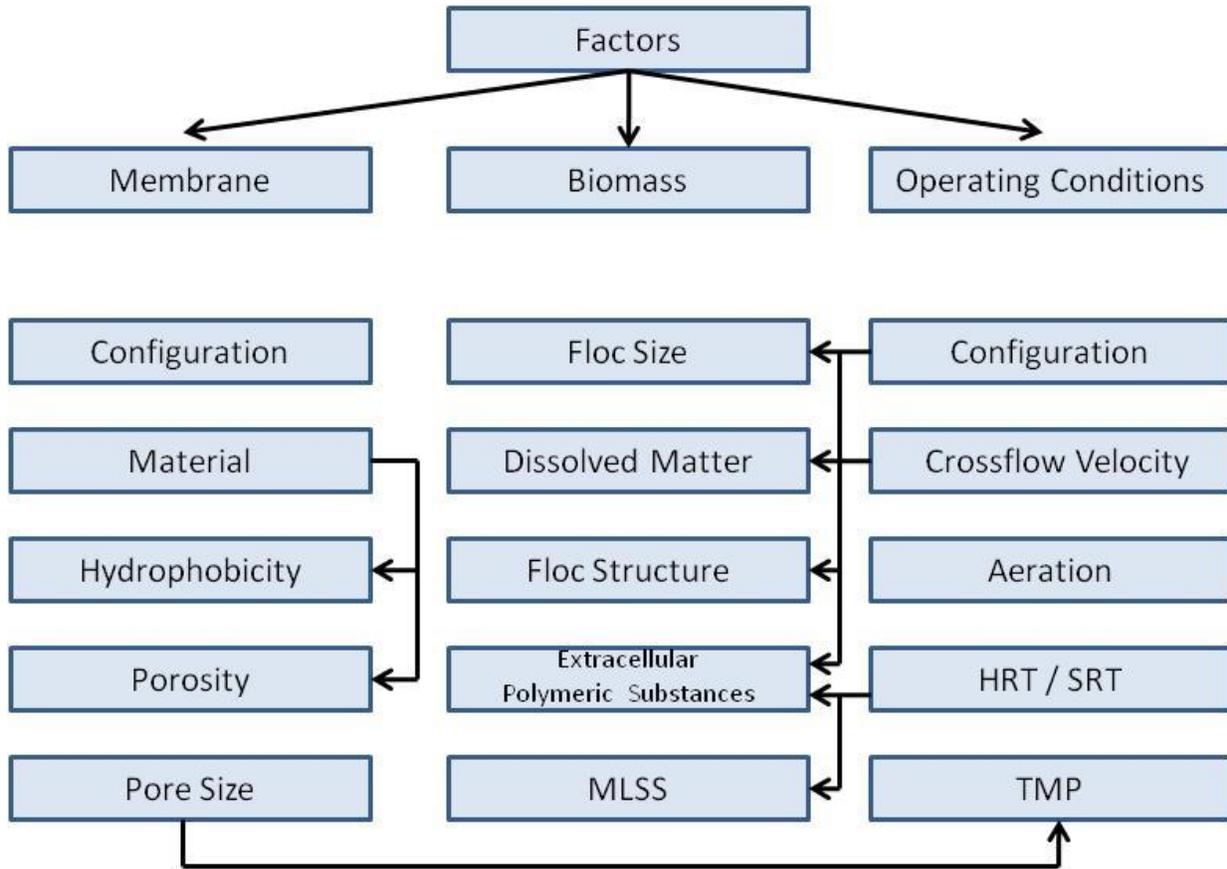
The performance of an MBR system inevitably decreases over time, resulting from the deposition of particulate materials from the activated sludge onto and into the membrane surface (fouling).

As with other membrane separation processes, fouling is the most significant problem affecting system performance. Fouling leads to an increase in hydraulic resistance, resulting in flux decline or transmembrane pressure (TMP) increase.

The suspended biomass has no fixed composition and varies both with feed water composition and MBR operating conditions. As a result, membrane fouling is extremely difficult to predict and prevent.

Frequent membrane cleaning or replacement is therefore required, increasing the operating costs significantly.

MBR performance can be influenced by interactions between the membrane system, the biological fluid and its composition, and the filtration operating parameters. This is illustrated below:



Factors influencing membrane fouling in MBR processes

In most municipal wastewater applications, non-biodegradable solids such as fibers, hair, plastics, rags and other trash, present potential fouling problems. Hair and fibers tend to bind with the biomass and create a reinforced plug that is usually removed by the 1 to 3 mm screens located in front of the membranes. Hair can present real problems with hollow fibers by winding around them, and, in some cases, breaking fibers.

Fouling can also be attributed to too much air scouring as well as over feeding antifouling or flocculating chemicals.

Industrial applications, such as food processing, may introduce other types of foulants such as fats, oil and grease (FOG), which require pretreatment ahead of MBR system.

Many anti-fouling strategies can be applied to MBR applications, including:

- Relaxing, where filtration is stopped at regular time intervals for a couple of minutes before being resumed. Particles deposited on the membrane surface tend to release back into the tank, with the aid of continuous aeration applied during the resting period.
- Membrane backwashing, where permeate water is pumped backwards into the membrane, and flows through the pores to the feed channel, dislodging fouling materials.
- Backwashing may be automatic, in intervals such as 10 minutes of run time, one minute backwash, etc.
- Air backpulsing where pressurized air on the permeate side of the membrane is released as a pulse. This is directed through the permeate lines back through the membrane, as with backwashing.

Cleaning

Examples of chemical cleaning include:

- Chemically enhanced backwash (daily);
- Maintenance cleaning with higher chemical concentration (weekly);
- Intensive chemical cleaning (once or twice a year).

Intensive cleaning is carried out when filtration process cannot be sustained because of an elevated transmembrane pressure (TMP). Each MBR manufacturer has proprietary chemical recipes. Under normal conditions, the prevalent cleaning agents are NaOCl (sodium hypochlorite) and citric acid. It is common for MBR suppliers to adapt specific protocols for chemical cleanings (i.e. chemical concentrations and cleaning frequencies) for individual facilities.

Following is a representative list of cleaning chemicals utilized by some manufacturers.

| Agent | Chemical | Formula/Notation | Concentration |
|-----------|---|--|--------------------------|
| Detergent | Sodium hypochlorite | NaOCl | 200 ppm and 1900 ppm Ci- |
| Detergent | Hydrogen Peroxide (50%) | H ₂ O ₂ | 0.5% (w/w) |
| Detergent | KOH, NaOH, NTA-Na-Salts | — | 1% (w/w) |
| Enzymes | Ultrasil 67 + Ultrasil 69 (ECOLAB) | U67 + U69 | 0.5% (w/v) and 1% (w/v) |
| Acid | Hydrochloric acid | HCl | 0.056% (w/w) |
| Acid | Citric Acid | C ₆ H ₈ O ₇ | 1% (w/w) |
| Acid | HNO ₃ , H ₃ PO ₄ | — | 1% (w/w) |

Conditions: pH: 2-11

Temperature: 20°C (Elevated temperatures may improve cleaning)

Time: 2 hour soak

MYTHS & REALITIES

Following is a list generated from an excellent paper, “Ten Persistent Myths & the Realities of Membrane Bioreactor Technology for Municipal Applications,” by B. Lesjean, A. Taxi-Pain, D. Thaire, H. Moeslang and H. Buisson. This was presented at the IWA World Water Congress, Montreal, 19-24 Sept., 2010.

| Subject | Prevalent Perception | The Facts |
|------------------------------|---|--|
| MBR Market | The MBR market is an industrial duopoly. | The two pioneering companies Kubota and GE-Zenon are leaders but other commercial systems are available and increased competition is expected in coming years. |
| Filtration flux | The technology has become more competitive following increasing design and operation flux. | In the last decade, the design and operation filtration flux has increased only moderately. |
| Energy demand | Specific energy demand of an MBR system is <1 kWh/m ³ . | True only for larger plants operated under nominal design with optimized operation. |
| Competitiveness | The MBR technology will extensively replace conventional activated sludge plants. | Extensive switch unlikely unless further significant technological breakthroughs. |
| Decentralized systems | The MBR technology is a viable solution for decentralized sanitation. | With current commercial solutions, not cost-effective for most decentralized or semi-central applications. |
| Membrane impact on treatment | The membrane contributes to the treatment performance. | Direct contribution is insignificant except for the disinfection and turbidity removal. |
| Disinfection | UF membranes guarantee better disinfection performance than MF membranes. | Not true for bacteria: both MF and UF achieve 6 LRU (log removal unit). Minor superiority of UF membranes for virus removal (both achieve 4 LRU). |
| Trace organics | MBR plants are better for removing organic micropollutants. | Under similar operation conditions, MBR shows very similar performances to conventional activated sludge. |
| Sludge production | MBR produces less sludge than conventional activated sludge plants. | Wrong statement. MBR sludge yield is slightly higher due to complete retention by the membrane of particles and colloids. |
| Fouling indicator | Polysaccharides, proteins, Capillary Suction Time (CST), Time to Filter (TTF), etc., are relevant indicators of membrane fouling. | No recent studies could identify universal single indicators. |

CONCLUSIONS

MBR has become a practical process for treatment and recovery of wastewater in bioremediation applications. As more manufacturers enter the field and design and operational improvements are made, costs will come down. With the ongoing emphasis on water recovery and reuse, MBR technology provides a compact solution for direct wastewater reuse for virtually any bioremediation application.

DISINFECTION

Introduction

Once wastewater has been treated to reach a quality standard for reuse, it usually must be further treated to keep microorganism growth under control.

The industry has established three categories of microorganism inactivation (the microbiologists' term for microorganism destruction) based on the efficacy of the technology. These are imprecise, but nevertheless useful:

Sanitization – 70% inactivation

Disinfection – 95-99% inactivation

Sterilization – 99.99% inactivation

The most practical treatment in the industry (with rare exceptions) is disinfection.

Microorganisms

In general, the categories of water-borne microorganisms of concern are bacteria, viruses, protozoa, and to a limited extent, fungi and algae.

Following is a discussion of these microorganisms, with emphasis on those which are capable of causing disease in humans – pathogens.

The categories of microorganisms that make up the vast majority of waterborne pathogens are bacteria, protozoa and viruses. Approximately 300 have been identified to date, but that number will undoubtedly grow.

The following table lists a number of these:

Agents of Waterborne Disease

| Category | Pathogen | Category | Pathogen |
|-----------------|-----------------------------------|----------------|---------------------|
| Bacteria | <i>Vibrio cholerae</i> | Viruses | Norovirus |
| | <i>Salmonella</i> spp. | | Saprovirus |
| | <i>Shigella</i> spp. | | Poliovirus |
| | <i>Toxigenic Escherichia coli</i> | | Coxsackievirus |
| | <i>Campylobacter</i> spp. | | Echovirus |
| | <i>Yersinia enterocolitica</i> | | Paraechovirus |
| | <i>Plesiomonas shigelloides</i> | | Enteroviruses 69-91 |
| | <i>Legionella</i> | | Reovirus |
| | <i>Helicobacter pylori</i> | | Adenovirus |
| Protozoa | <i>Giardia lamblia</i> | | Hepatitis A |
| | <i>Cryptosporidium parvum</i> | | Hepatitis E |
| | <i>Entamoeba histolitica</i> | | Rotavirus |
| | <i>Cyclospora cayetanensis</i> | | Astrovirus |
| | <i>Isospora belli</i> | | Picobirnavirus |
| | Microsporidia | Coronavirus | |
| | <i>Ballantidium coli</i> | | |
| | <i>Toxoplasma gondii</i> | | |
| | <i>Naegleria fowleri</i> | | |

All human pathogenic bacteria are in a classification known as “heterotrophic (HPC),” meaning that they obtain their carbon from organic sources rather than carbon dioxide.

Interestingly, less than 4.5% of the average person’s HPC bacteria intake is derived from drinking water, as compared to food that is minimally processed after purchase, such as salad vegetables.

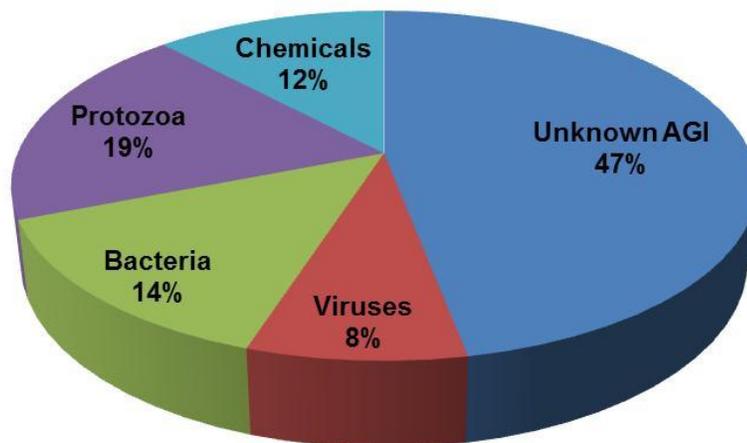
It is important to understand that the human body contains trillions of microbes that outnumber our own cells 10 to 1. A very few of these microorganisms are known as “opportunistic pathogens,” meaning that they only cause disease under certain conditions, such as if the immune system becomes compromised. Even fewer are outright pathogenic microorganisms.

The world has a growing number of immunocompromised individuals. This is the “sensitive subpopulation” and estimated to comprise 20-25% of the population. These individuals are more likely to be infected by waterborne pathogens and may suffer a higher death rate than normal healthy people. This includes the following:

- Elderly (>65 years)
- Very young (<5 years)
- Chronically ill (diabetes, dialysis patients, AIDS)
- Immunosuppressed (organ transplants, cancer treatment)
- Pregnant women

Of the 764 waterborne disease outbreaks in the U.S and documented by the CDC (Centers for Disease Control) between 1971 and 2020, 14% were caused by bacteria, 19% by protozoa and 8% by viruses, as illustrated below. Note that 12% were caused by chemical contamination and 47% could only be identified as “unknown acute gastrointestinal illness.”

U.S. Drinking Water Outbreaks (1971 - 2002)



Microorganism Categories

Bacteria – These are single-celled organisms enclosed within a cell wall, ranging in size from 0.1 to about 10 μ . Enteric bacteria, those capable of growing in the human stomach and intestines, include the following pathogens:

- Salmonella (typhoid, diarrhea)
- Shigella (diarrhea)
- Campylobacter (diarrhea, nervous system disorders)
- Vibrio Cholera (cholera, diarrhea)
- Escherichia coli (diarrhea, hemorrhagic colitis [certain strains])

Legionella bacteria can cause Legionnaire's Disease (Legionellosis), not by ingestion, but by inhalation of water droplets containing the microorganism. More on Legionella later.

Bacteria are a particularly troublesome microorganism because they can survive and propagate in virtually any environment, and are capable of forming biofilm colonies that can capture and release pathogens and chemicals. Biofilms will be discussed later.

Protozoa – These are single-celled animals that can live and multiply in the gastrointestinal tract of animals. They can range in size from 1 to 100 μ and produce an environmentally stable cyst (or oocyst) during their life cycle. The walls of the cyst protect the protozoa from most disinfectants used in conventional water treatment.

Cryptosporidium parvum and Giardia lamblia both cause diarrhea, and are the most prominent protozoa of concern in the U.S. They are both resistant to the chlorine concentrations used in municipal drinking water supplies, but can be inactivated by UV treatment.

Cyclospora caryentensis and Naegleria fowleri have also been linked to some outbreaks.

Viruses – These are intracellular parasites that require a host to replicate; however, they can survive for weeks or months in a water environment. They have the greatest infectivity of all pathogens, requiring the lowest number to cause infection.

Viruses range in size from 0.01 to 0.10 μ .

Those viruses of concern include:

- Enteroviruses (diarrhea, meningitis, myocarditis, fever, respiratory disease, nervous system disorders, birth defects)
- Hepatitis A (hepatitis, liver damage)
- Noroviruses (diarrhea)
- Astrovirus (diarrhea)
- Adenovirus (diarrhea, respiratory disease, eye infections, heart disease)
- Rotavirus (diarrhea)

We can never make our drinking water 100% free from waterborne pathogens 100% of the time. That said, there are a number of approaches possible to minimize these contaminants.

Disinfection Technologies

Disinfection is the process used to kill (inactivate) microorganisms. Most disinfectants are chemicals that are normally fed into the water treatment system at the treatment plant or used within a facility requiring more rigorous onsite microorganism reduction. The ideal disinfectant:

- Kills (or inactivates) microorganisms.
- Has no deleterious effect on materials of construction or components of the water treatment system.
- Is stable and retains its effectiveness during the disinfection process.
- Is easily removed from the entire water treatment system.
- Is easily monitored with a simple test kit.

The ideal disinfectant does not exist. Therefore, the selection of the optimum chemical and/or disinfection process used must be based on careful evaluation and testing for each specific application.

Chemical Processes

The following chemical disinfectants are used in water treatment systems:

Chlorine. Certainly, one of the greatest developments of humankind has been the addition of chlorine to water supplies. Judicious use of this chemical has virtually eliminated the traditional epidemics of waterborne diseases in the developed world (cholera, typhoid fever, etc.).

In the U.S., chlorination of municipal drinking water supplies has been the disinfectant of choice for well over 100 years. Chlorine, with its active ingredient, hypochlorous acid, is very effective in inactivating almost all waterborne pathogens, and provides an acceptable residual. But it does have limitations.

Chlorine has been under scrutiny because of its propensity to form THM carcinogens (trihalomethanes) upon reaction with naturally occurring organic materials such as fulvic and humic acids or with human-made organic contaminants in the water supply.

Bacteria concentrations can be reduced to low levels in the presence of 1 to 2 ppm of free available chlorine in the water supply; however, chlorine is relatively ineffective against acid-fast bacteria such as nontuberculous mycobacteria and cysts such as formed by *Cryptosporidium parvum* and *Giardia lamblia*. Also, viruses are more resistant to chlorine than bacteria.

Chlorine is normally pumped into the system as a solution of sodium hypochlorite (NaOCl), fed as tablets of calcium hypochlorite $\text{Ca}(\text{OCl}_2)$, or as a gas (Cl_2). Dissolved chlorine is readily removed by activated carbon acting as an oxidation/reduction catalyst, and can be monitored with simple test kits.

The pH of the water supply affects the efficacy of chlorine. Hypochlorous acid, formed at pHs below 7 is a stronger disinfectant than the chlorite ion compounds formed at higher pHs.

Care must be taken because excessive amounts of chlorine can cause corrosion as a result of its strong oxidation characteristics, and it can be difficult to handle.

Chloramines. These compounds, produced by the reaction of ammonia with chlorine in water, are commonly used in U.S. municipal water supply systems because of the superior stability of chloramine compounds over chlorine. A further advantage is that chloramine compounds do not form trihalomethanes; however, chloramines do not possess as strong an oxidation capability as chlorine and thus have less ability to kill bacteria. Concentrations of these compounds in the range of 5 to 10 ppm in water are required.

Chlorine Dioxide. Chlorine dioxide exhibits stronger disinfecting characteristics than chloramines, but, as it is more expensive than chlorine, it is not widely used. Chlorine dioxide does not form trihalomethanes and exhibits rinsing, corrosion, and handling characteristics similar to those of chlorine. It has to be generated on site. Recommended concentrations are 2 to 5 ppm.

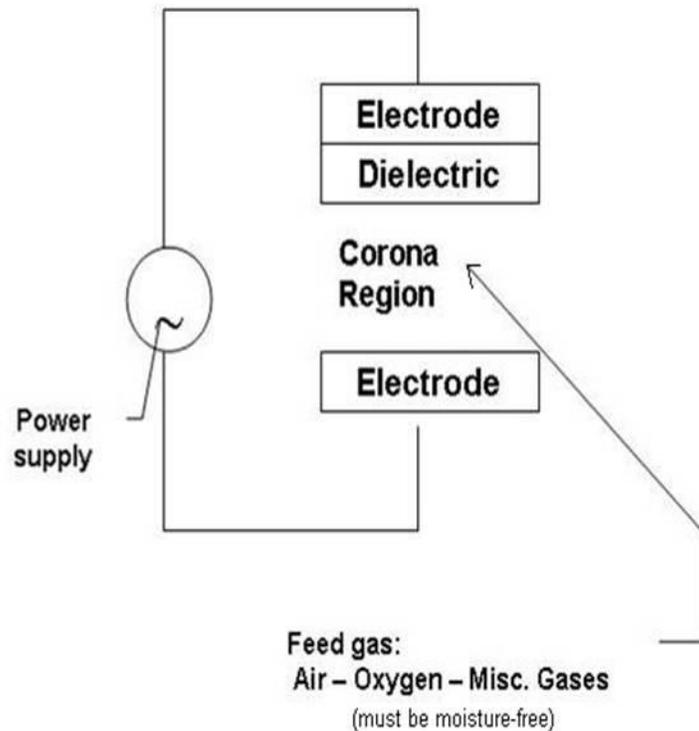
Iodine. This common relative of chlorine has been used for years for point-of-use treatment by campers and the military for onsite disinfection of drinking water of unknown quality. Unfortunately, certain gram-negative bacteria strains can become resistant to iodine. Much less reactive with dissolved organics than chlorine, it will not form trihalomethanes. The recommended concentration is 0.3 to 0.5 ppm.

The illustration below depicts a typical liquid feed system used to inject the disinfectant into a water line.



30 Gallon Stenner Pump System

Ozone. This powerful chemical, which consists of oxygen in a three-atom form (O_3), is used to disinfect some municipal water supply systems, particularly in Europe. It is a very effective disinfectant; however, it must be generated onsite and has a relatively short life (less than 30 minutes), thereby, leaving no residual. When used at the recommended concentration of 2 to 3 ppm, ozone will inactivate bacteria, viruses, spores, and cysts. It will also slowly breakdown biofilms and other organics. Both ultraviolet irradiation and activated carbon will remove excess ozone from water.



Corona Discharge Ozone Generation

Care must be taken in handling any of the above chemicals, and their effect on the materials of construction of the water treatment system must be evaluated.

CT Values

The U.S. EPA has established efficacy criteria for chemical disinfectants known as “CT value.” This is the concentration (C) multiplied by the exposure time (T) required to produce a certain level of inactivation, such as 99% (2 log), 99.9% (3 log), 99.99% (4 log), or higher. Different pathogens require different CT values to reach a specific level of inactivation; these data are affected by environmental conditions (temperature, pH, etc.) and generally must be determined empirically. The EPA documents, “Disinfection Profiling and Benchmarking Guidance Manual” (EPA 815-R-99-013) contains an extensive list of CT Values.

Ultraviolet Irradiation. Ultraviolet (UV) irradiation is a common method of disinfecting relatively small-scale water supplies. In this process, the water is exposed to ultraviolet radiation (with a wave length of approximately 254 nm) after it has been filtered. UV is also effective in inactivating *Cryptosporidium* oocysts. Only momentary exposure (at the appropriate dosage) is required to inactivate most microorganisms, but this condition may not be met if the lamps are dirty or if the microorganisms are shielded by particles in the water. Furthermore, there is some evidence that certain bacteria may merely be inhibited in growth, rather than killed by UV. Such bacteria, after a period of time, may recover and reproduce. If the bacteria recover in the presence of fluorescent light, the process is known as photoreactivation.

Because ultraviolet irradiation does not involve the addition of chemicals, it leaves no residual, and the only costs in this process are the investment in equipment, replacement of ultraviolet bulbs, electrical power consumption, and the occasional cleaning of the bulb enclosures. On the other hand, the dosage required for inactivation varies considerably with the specific organism.

The following table lists the UV dosage required to result in 99% (2 log) inactivation of several waterborne pathogens.

| Pathogen | UV Dosage MWs/cm² |
|-------------------------------------|---|
| Enteric bacteria | 3-8 |
| <i>Mycobacterium intracellulare</i> | 25 |
| <i>Cryptosporidium parvum</i> | 3-5 |
| <i>Giardia lamblia</i> | 40 |
| <i>Encephalitozoon intestinalis</i> | 5 |
| <i>Acanthamoeba</i> | 60 |
| Adenovirus | 109 |

Heat. Heating water to above 150°F (65°C), can be used to inactivate pathogens in a water supply system; the higher the temperature, the shorter the time required for inactivation.

This method is generally not practical for disinfecting an entire system because of:

- The difficulty of handling the water at such high temperature.
- Possible regulatory limits on water temperatures.
- The special materials required in construction of the system.
- Excessive consumption of energy.
- The difficulty in maintaining this temperature at the distal outlets (faucets, shower heads, etc.).

Physical Removal

In spite of their small size, most waterborne pathogens, particularly bacteria and protozoa, can be removed from water supplies with submicron filters.

Pneumonia caused by *Pseudomonas aeruginosa* and *Legionella* bacteria are a major cause of illness and death in hospitals and long-term care facilities in the U.S. As most patients in these facilities are immunocompromised, they are susceptible to infection, particularly through inhalation exposure from sink faucets, ice machines, shower heads, ventilators and nasogastric tube feeding devices. Below is a typical submicron filter cartridge. There are several suppliers of 0.2 μ filters designed for these applications.



POU Filter Cartridge

Biofilms

Probably the overriding issue affecting the growth, reproduction, release, and subsequent bacterial contamination inside a residence or other building is that of biofilms.

Bacteria like to attach themselves to surfaces, and many then produce biofilms, a matrix of organic material (glycocalyx) which forms protective layers over the bacteria. Biofilms also behave like sponges, capturing and holding other microorganisms, suspended and even dissolved solids, which may then be sloughed off and released into distribution systems. Biofilms protect the encased microorganisms from disinfectants and are very difficult to remove, often requiring scrubbing or other physical processes.

It is estimated that 95% of the bacteria in drinking water systems are associated with biofilms attached to surfaces. Obviously, the surface characteristics of pipes, storage tanks and other components in contact with water influence the rate and extent of biofilm formation. Because PVC piping has a rougher interior surface than copper, it tends to accumulate biofilms more quickly. On the other hand, copper is more prone to corrosion by MIC (microbially influenced corrosion) than plastic materials.

Much remains to be understood regarding the nature of biofilms: the mechanisms of attachment and detachment, microorganism survival and reproduction, and the effect of outside factors (water chemistry, pH, temperature, etc.) on biofilm composition.

Recent studies have shown the ability of E.coli bacteria to propagate in drinking water biofilms under anaerobic (oxygen-free) environments, and proved that both pathogenic bacteria and viruses can survive in biofilms for weeks, even under conditions of high-shear turbulent flow.

Some estimates indicate that the concentrations of bacteria inside residences are 10 to 1,000,000 times greater than inside the supply lines to the residence. Others estimate that 95% of all bacteria in a facility are in biofilms.

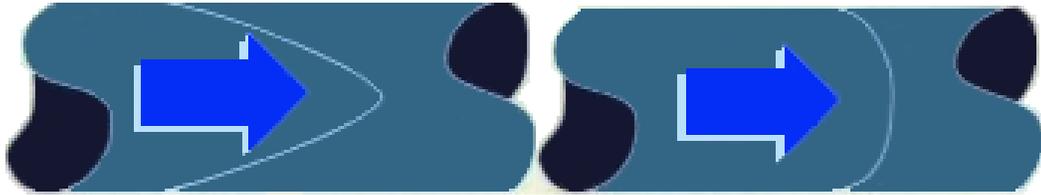
It is important to realize that pathogenic microorganisms may also enter the distribution system (downstream of the treatment step) by external contamination events such as ineffective treatment, cross connections, backflow, pipe breaks, negative pressure, or other failures. Once there, they survive and propagate, protected by biofilms.

Flow

Sound engineering design dictates that turbulent flow inside piping results in fewer surface effects, such as biofilm formation and hardness scaling.

The flow within a pipe can be assigned an engineering property known as a Reynolds Number. This is defined as a dimensionless number that provides a measurement of the ratio of inertial forces to viscous properties in a fluid. For water, turbulent flow is chaotic and has a Reynolds Number above 4,000. Laminar flow is characterized by smooth, constant fluid motion, with a Reynolds Number below 2,000. Between these two Reynolds Numbers, the region is known as transition flow.

The illustration below shows both laminar and turbulent flow within a pipe.



Laminar Flow

Turbulent Flow

The bottom line here is that the greater the turbulence inside a pipe, the thinner the layer of relatively stagnant water at the inside surface of the pipe resulting from the friction at the surface.

Legionnaires' Disease

Legionellosis (aka Legionnaires' Disease plus Pontiac Fever) deserves special mention here for a number of reasons:

Almost all microorganism related diseases are transmitted through drinking or eating; however, a notable exception are two respiratory infections caused by the inhalation of *Legionella* bacteria. Pontiac fever is a generally nonfatal form of the more dangerous Legionnaires' Disease.

- They are transmitted by inhalation only, and not through the gastrointestinal tract.
- Although considered “under recognized” and therefore under reported, it is estimated that as many as 18,000 cases per year are reported in the U.S., and this number is increasing.
- More than 10% of the cases prove fatal.

Legionella pneumophila bacteria are frequently found in potable water supplies. Some studies indicate that the bacteria are in 20 to 70% of building water supplies. Although present in potable water supplies, the bacteria are transmitted when the water is aspirated, such as from showers, faucets, ventilators, misters, cooling towers, decorative fountains, etc.

As an opportunistic pathogen, *Legionella* bacteria are of greatest concern in hospitals, acute-care and long-term care facilities, where patients are likely to be immunocompromised. In hospitals alone, Legionellosis accounts for 10-40% of pneumonia cases. It is also responsible for 2-15% of community-acquired pneumonia.

Controlling Legionella Bacteria

Just as these bacteria are unusual in their method of transmission and behavior inside a water system, the recommended treatment protocols are also a bit unusual.

Copper-Silver Ionization

The most effective Legionella bacteria inactivation technology to date is copper-silver ionization. This technology utilizes copper and silver electrodes and direct current to release ions of both metals into solution. For Legionella inactivation, a concentration in the water supply of 0.2 to 0.8 mg/L of copper and 0.01 to 0.08 mg/L of silver is required. This disinfection technology has been used in the U.S. since 1990, with outstanding results. It is being used in hospitals, long-term care facilities and in office and apartment buildings.

Copper-silver ionization systems are easily installed and maintained. Ingestion of these heavy metals is limited, because the treatment is typically only on the hot water recirculation loop. The efficacy of this treatment is not affected by temperature, but the water pH should be maintained below 8.5. Manufacturers of these systems must obtain EPA registration as a biocide. The system cost for a typical 250 bed hospital (hot water only) is estimated at \$40-50,000.

Chlorine Dioxide

This disinfectant has not been as thoroughly evaluated as copper-silver ionization. The available field data indicate that a minimum concentration at the hot water taps should be 0.25 mg/L. Chlorine dioxide must be generated onsite (as a gas), but has greater penetration into biofilms than chlorine. In addition, it does not produce the THM byproducts associated with chlorine. On the other hand, chlorine dioxide is relatively corrosive and expensive. Reactions with piping materials and other compounds in the water will degrade the chemical into chlorite and chlorate byproducts which are currently under investigation for health effects on their own. Chlorine dioxide systems also require EPA registration. The costs associated with chlorine dioxide generation, installation and maintenance are approximately similar to those of copper-silver ionization.

Chloramines

The trend for replacement of municipal chlorination with chloramines (chlorine injection followed by ammonia), appears to offer an advantage over straight chlorination with regard to controlling Legionnaires' disease. Preliminary data from locations where chloramination has replaced municipal chlorination show a significant decrease in Legionella bacteria. Chloramine compounds appear to effectively penetrate biofilms and are biocidal over a wider pH range than the other treatment technologies.

Hyperchlorination

The injection of high concentrations of chlorine (usually in the form of liquid sodium hypochlorite) into the water supply is considered the least effective means of inactivating Legionella bacteria. It has low biofilm penetrating capability, is corrosive to metals and produces hazardous THM compounds.

POU Filtration

As with the pathogen removal technologies discussed previously, submicron POU filtration is very effective in the removal of Legionella bacteria from faucet taps and shower heads. Because of the high cost of these devices, their use is usually limited to high-risk, low flow areas such as intensive care and transplantation units in hospitals.

UV Irradiation

As described earlier, this technology, utilizing UV irradiation at a wave length peaking at about 254 nm, has a long history of bacteria inactivation in many applications, including residential and industrial. UV leaves no residue, and suspended solids may shield the bacteria from the radiation. In addition, the ability of UV to penetrate biofilms has been called into question. On the other hand, UV irradiation is relatively inexpensive, and if installed with new plumbing (without established biofilms), it may be very effective, particularly if combined with one of the inactivation technologies described above.

Standards

A new standard, ANSI/ASHRAE 188-2015, “Legionellosis: Risk Management for Building Water Systems,” covers risk assessment protocols, and addresses:

- Human-occupied buildings
- Potable water supplies
- Cooling towers
- Evaporative condensers
- Whirlpool spas
- Decorative fountains
- Aerosol generating air coolers
- Humidifiers
- Washers

It emphasizes the development of risk management plans in the form of HACCP (Hazard Analysis Critical Control Point). It is expected to force institutions to look closely at the microbiological quality of their water systems.

Plumbing Design & Operation

As stated earlier, it is virtually impossible to prevent bacterial proliferation and biofilm growth in any water system. The preceding mitigation strategies are based on approaches to keep bacteria growth to a minimum. Additionally, piping materials of construction, plumbing design and system operation play critical roles in keeping microbial contamination under control.

For example, plumbing design engineers dictate that pipe flow to ensure turbulence be >3 m/sec, and that all regions of stagnant flow be eliminated.

With regard to pipe materials, in addition to the plastic or metal construction, interior surfaces should be selected with microorganism attachment and growth in mind. Tests on the attachment of Legionella bacteria on pipe walls showed three times higher concentration on crosslinked polyethylene and stainless steel than on copper pipe. This is not unexpected as copper is a heavy metal with antimicrobial properties. On the other hand, metal piping, such as copper, is more susceptible to corrosion than the plastics – no free lunches.

Following is a list of plumbing design considerations. As all designs contain many site-specific factors, it should only be used as a set of suggested guidelines.

- Piping material
- Pipe joining procedures
- Pipe size (to ensure turbulent flow at a given flow rate)
- Elimination of deadlegs or other areas of stagnant water
- Adequate backflow prevention (meets code)
- Hot water continuous recirculation
- Risk assessment plan (HACCP) in place
- Frequent water quality monitoring
- System-wide disinfection plans
- Adequate pressure within the system

GLOSSARY

Activated Sludge is produced by mixing primary effluent with bacteria-laden sludge in a process that is activated using aeration and agitation to promote biological treatment.

Advanced Waste Treatment is wastewater treatment beyond the secondary or biological stage of treatment. It includes the removal of nutrients such as phosphorous and nitrogen and a high percentage of suspended solids. It is also often called tertiary treatment.

Aerobic refers to life or processes that require the presence of oxygen.

Aeration is the process of exposing something to circulating air.

Anaerobic refers to life or processes that require the absence of oxygen.

Bacteria are single-celled microscopic organisms that grow in nearly every environment on Earth. In wastewater treatment, they can perform a variety of biological treatment processes, including biological oxidation, sludge digestion, nitrification, and denitrification.

Biochemical Oxygen Demand (BOD) is the measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD, the greater the degree of pollution.

Biosolids are the primary organic solid product of wastewater treatment processes and can be beneficially recycled or appropriately disposed of via landfilling or incineration.

Denitrification is the reduction of nitrate nitrogen to nitrogen gas.

Effluent is wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial outfall.

Influent is water, wastewater, or other liquid flowing into a reservoir, basin, treatment plant, or treatment process.

Infrastructure in the wastewater treatment industry refers to the expansive network of reservoirs, plants, and pipes above and below ground that provides, processes, and treats the water.

Land Application is the treatment or disposal of wastewater or wastewater solids by spreading them on land under controlled conditions.

Membrane Bioreactors combine activated sludge treatment and membrane filtration processes to separate liquids and solids.

Microconstituents are trace complex organic compounds, generally from industrial, medicinal, pharmaceutical, and personal care products, but may also be naturally occurring. They are sometimes called compounds of emerging concern (CECs) or endocrine disrupting compounds (EDCs).

Microorganisms are microscopic organisms, either plant or animal, invisible or barely visible to the naked eye; for example, bacteria, fungi, protozoa, and viruses.

GLOSSARY (cont'd)

National Pollution Discharge Elimination System (NPDES) is the permit process established under the U.S. Clean Water Act that requires municipal and industrial wastewater treatment facilities to obtain permits that specify the types and amounts of pollutants that may be discharged into water bodies.

Nitrification is the oxidation of ammonia nitrogen to nitrate nitrogen in wastewater by aerobic biological chemical reactions.

Nutrients are elements or compounds, such as nitrogen, phosphorous, and potassium, that are necessary for plant growth.

Operations and Maintenance (O&M) is the organized procedure for causing a piece of equipment or a treatment plant to perform its intended function and for keeping the equipment or plant in such a condition that it is able to continually and reliably perform its intended function.

Permit is a legal document issued by a government agency. In wastewater treatment, a discharge permit requires that the plant operator achieve specific water quality standards and discharge limits and also establishes monitoring and reporting requirements.

Preliminary Treatment is the initial treatment process within a treatment plant where large solids from the incoming influent are removed to enhance further treatment processes and prevent damage to equipment.

Primary Treatment is the stage in wastewater treatment where screens and sedimentation tanks are used to remove most material that floats and/or settles. Primary treatment results in the removal of a substantial amount of suspended matter but little or no dissolved matter.

Receiving Stream is a river, lake, ocean, or other watercourse into which wastewater or treated effluent is discharged.

Sanitary Sewer is a sewage system that carries only household, commercial and industrial wastewater.

Secondary Treatment is the stage in the wastewater treatment process where bacteria are used to digest organic matter in the wastewater. Sometimes the term is used interchangeably with biological wastewater treatment.

Sludge is solid matter that settles to the bottom of septic tanks or the material that results from wastewater treatment plant sedimentation.

Suspended Solids are insoluble materials that float on the surface of or are suspended in wastewater primarily due to their small size. They can also be called total suspended solids (TSS).

Ultraviolet Disinfection is the process of using ultraviolet light to inactivate disease-causing bacteria and viruses.

Wastewater is used water from a community or industry that contains dissolved or suspended matter.

ACRONYMS

| | | |
|---------------|---|--|
| BAF | ≡ | Biological Active Filters |
| Bio-P | ≡ | Biological Phosphorous Removal |
| COD | ≡ | Chemical Oxygen Demand |
| CSTR | ≡ | Continuously Stirred Tank Reactor |
| DO | ≡ | Dissolved Oxygen |
| F/M | ≡ | Food-to-Microorganism Ratio |
| FC | ≡ | Final Clarifier |
| HRT | ≡ | Hydraulic Retention Time |
| IFAS | ≡ | Integrated Fixed-film Activated Sludge |
| MBBR | ≡ | Moving Bed Biofilm Reactor |
| MBR | ≡ | Membrane Bioreactor |
| MLSS | ≡ | Mixed Liquor Suspended Solids |
| RAS | ≡ | Return Activated Sludge |
| RBC | ≡ | Rotating Biological Contactor |
| SALR | ≡ | Surface Area Loading Rate |
| SBR | ≡ | Sequencing Batch Reactor |
| SCOD | ≡ | Soluble COD |
| SLR | ≡ | Solids Loading Rate (clarifier) |
| VLR | ≡ | Volumetric Loading Rate |
| Autotrophic | ≡ | Nitrification |
| Heterotrophic | ≡ | BOD/Nitrification |