# MEMBRANE BIOREACTORs

## Week 1st: Introduction

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# CEV4362 MEMBRANE BIOREACTORS

# 2018-2019 Spring Semester

**Time and Room:** Wednesday 11:00 - 11:50 FZ-82

12:00 - 12:50 FZ-82

**Instructor:** Prof.Dr.Özer ÇINAR, C Bloc 1-010 Environmental Engineering Department

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# Course Objective

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**The objective of this course is:**

Aim of the course is to teach students theory and application of membrane bioreactor and to establish a comprehensive knowledge on Membrane Bioreactors

# Syllabus

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| Week | Date | Subject |
|---|---|---|
| 1 | 13 Feb 2019 | Introduction |
| 2 | 20 Feb 2019 | Membranes, Modules, and Cassettes – **QUIZ (75-86)** |
| 3 | 27 Feb 2019 | Membranes, Modules, and Cassettes – **QUIZ (86 – 122)** |
| 4 | 6 March 2019 | Membranes, Modules, and Cassettes – **QUIZ (122 – 143)** |
| 5 | 13 March 2019 | Membrane Fouling – **QUIZ (147-170)** |
| 6 | 20 March 2019 | Membrane Fouling – **QUIZ (171-197)** |
| 7 | 27 March 2019 | Membrane Fouling – **QUIZ (197-222)** |
| 8 | 3 April 2019 | MBR Operation – **QUIZ (231-250)** |
| 9 | **8/12 April 2019** | **(Mid-Term Exam)** |
| 10 | 17 April 2019 | MBR Operation – **QUIZ (250-283)** |
| 11 | 24 April 2019 | Design of MBR – **QUIZ (306-327)** |
| 12 | 1 May 2019 | **LABOR HOLIDAY** |
| 13 | 8 May 2019 | Design of MBR – **QUIZ (327-340)** |
| 14 | 15 May 2019 | Case Studies – **QUIZ (398-415)** |

# Course Grading



- **1 Midterm exam (30%)**
- **12 Quizes (30%)**
- **1 final exam (40%)**

# Recommended Reading Materials

- Hee-Deung Park, In-Soung Chang, Kwang-Jin Lee, "Principles of Membrane Bioreactors for Wastewater Treatment", CRC Press, 2015

# Principle of Membrane Bioreactor (1/2)

**Membrane Bioreactor (MBR)** is a technology used to treat wastewater that combines a bioreactor and membrane separation.

**A bioreactor** is a tank of any activated sludge process in which wastewater is treated by the activity of microorganisms.

**In an MBR process,** instead of separating treated water and microorganisms (i.e., activated sludge) by gravity, porous membranes with 0.05–0.1 μm pore diameters are used to separate treated water and microorganisms (Figure 1.1a). The pore diameters are small enough to reject activated sludge flocs, free-living bacteria, and even large-size viruses or particles.

**Most important limitation factor is fouling.** It arising from activated sludge, suspended solids, organics, and inorganics during the filtration process (Figure 1.1b)

# Principle of Membrane Bioreactor (2/2)

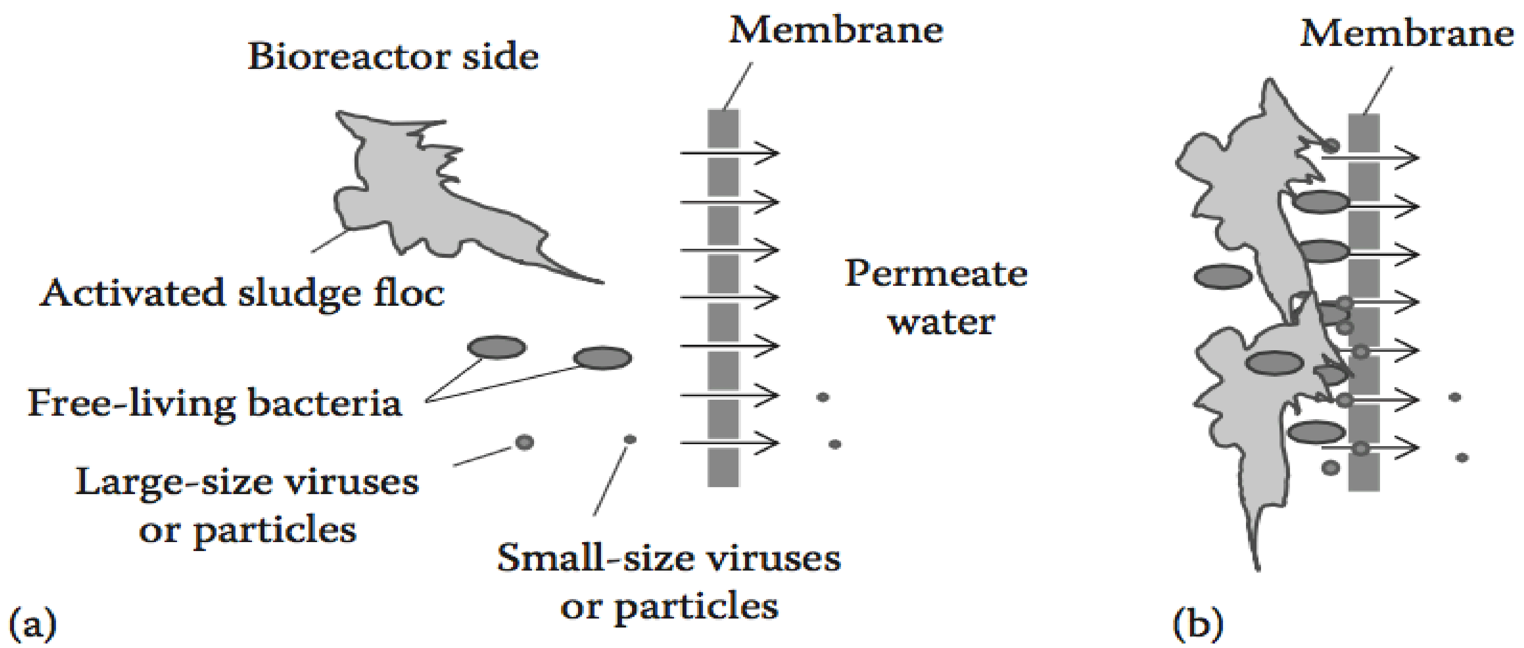


**Figure 1.1.** (a) Membran filtration in MBR, (b) Membran fouling in MBR

# Brief History of MBR Technology (1/3)

First MBR technology was developed by Smith et al. (1969). They obtained high-quality effluent without a sedimentation tank, they used ultrafiltration membranes. This MBR operational strategy called side-stream configuration (Figure 1.2).

The technology was first applied to very limited cases (e.g. industrial and leachate wastewaters), because of;

- High energy costs
- Membran fouling
- High membrane capital costs

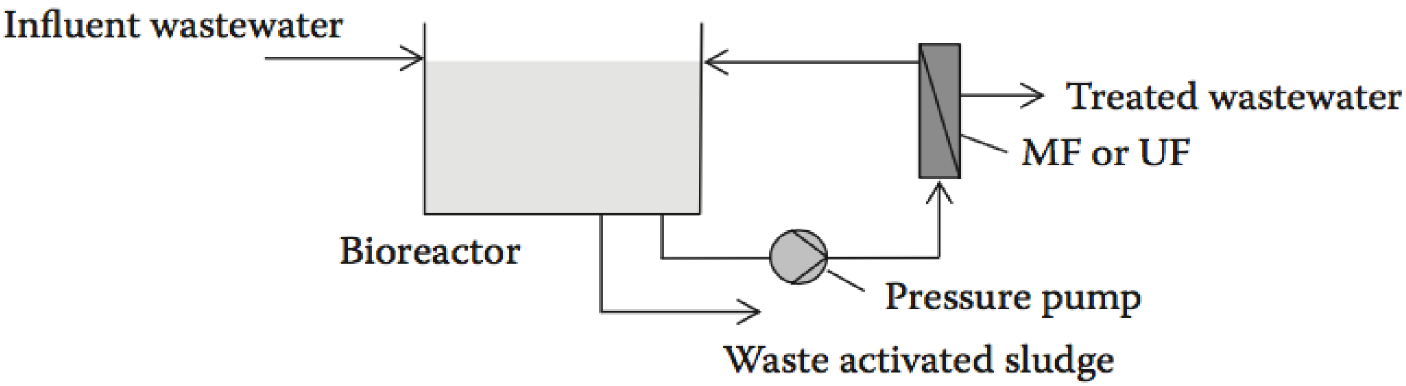


**Figure 1.2.** Side-stream MBR configuration

# Brief History of MBR Technology (2/3)

In 1989, Yamamoto et al. (1989) developed direct solid-liquid separation using 0.1 µm pore size polyethylene hollow fiber (HF) mebranes in an activated sludge bioreactor. Its used suction pump, instead of pressure pump (which was used in side-stream process). They immersed the membranes directly into the bioreactor and applied suction pressure to produce permeate (Figure 1.3).

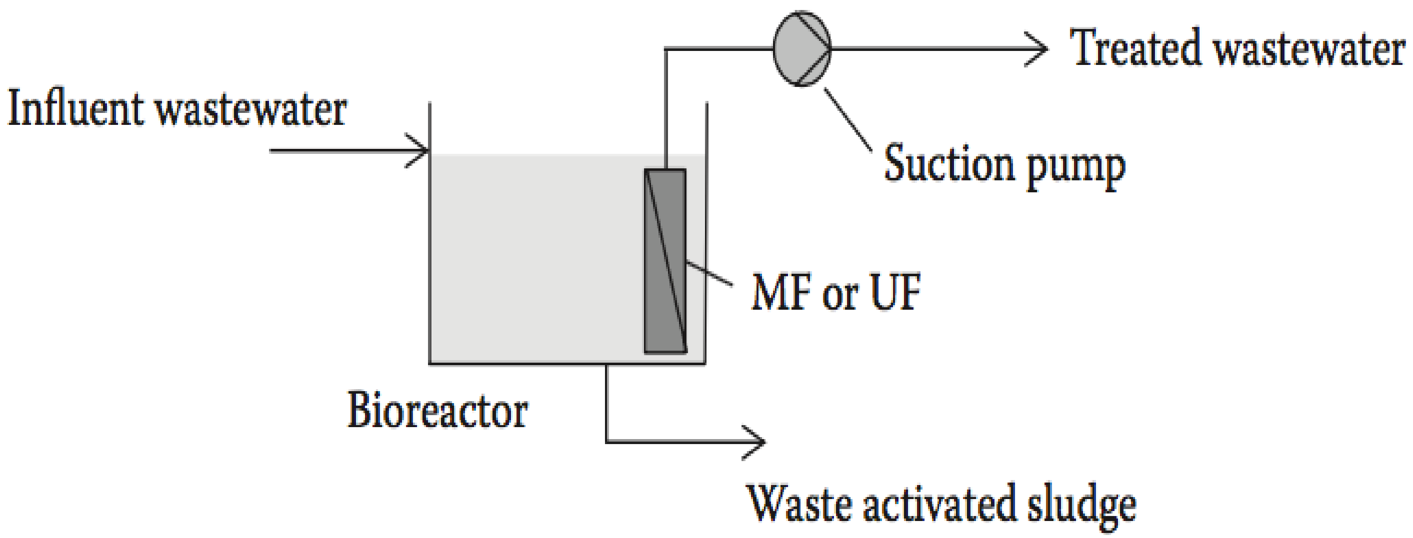


**Figure 1.3.** Submersed MBR configuration

# Brief History of MBR Technology (3/3)

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The appearance of competitive MBR providers (e.g., Zenon, Kubota, Mitsubishi Rayon, and US-Filter), as well as the accumulation of operational data via academic and field studies have accelerated the application of MBR technology since the mid-1990s.

MBR has especially gained popularity with the help of;

- dramatic membrane cost reductions (~1/10) over the last two decades.
- introduction of high-quality membranes
- construction of large-scale MBR plants
- wastewater reuse is necessary

# Comparison of CAS and MBR Processes (1/3)

**Conventional activated sludge (CAS)** processes (Figure 1.4) mainly consist of a bioreactor and a sedimentation tank or secondary clarifier (to separate treated water and microorganisms). Sedimentation tanks are not perfect in settling all of the activated sludge (Supernatant typically include 5mg/L suspended solid concentration even for properly working secondary clarifiers).

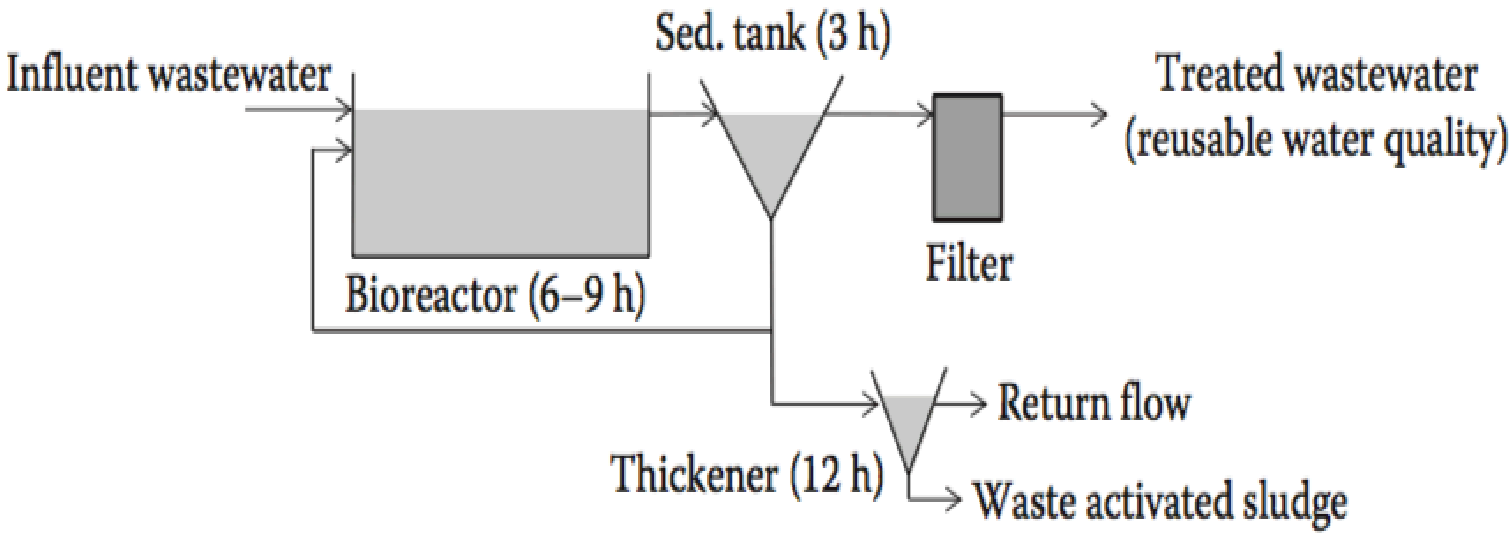


**Figure 1.4.** CAS process

# Comparison of CAS and MBR Processes (2/3)

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**Table 1.1.** Comparison of CAS and processes

| Parameter | CAS | MBR |
|---|---|---|
| Mixed liquor suspended solids, MLSS | Maximum 5,000 mg/L | No limitation 8,000-12,000 mg/L as optimal |
| Suspended Solid, SS | Typically 5mg/L | Almost no SS |
| Waste activated sludge, WAS | More | Less |
| Solid retention time, SRT | Typically 5-15 days | > 20 days |
| Quality of effluent | Adequate for discharge | Adequate for reuse |

# Comparison of CAS and MBR Processes (3/3)

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**Table 1.2.** Advantages and disadvantages of MBR over CAS

| | |
|---|---|
| *Advantages* | 1. Production of high-quality treated water that is reusable. In addition, removal of most of the pathogenic bacteria and some viruses are possible. |
| | 2. Low footprint due to the obviation of secondary sedimentation tank and smaller bioreactor size. |
| | 3. Reduced WAS production. |
| | 4. Fine control of SRT. |
| Disadvantages | 1. Greater operational and process complexity. |
| | 2. Higher capital and operational costs. |
| | 3. Greater foaming propensity. |

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# Operational Condition and Performance of MBR(1/1)

**Table 1.3.** Typical MBR Operational Conditions and Effluent Quality

| *Classification* | *Unit* | *Typical value* | *Range* |
|---|---|---|---|
| **Operational condition** | | | |
| COD loading | kg/m³·day | 1.5 | 1.0–3.2 |
| MLSS | mg/L | 10,000 | 5,000–20,000 |
| MLVSS | mg/L | 8,500 | 4,000–16,000 |
| F/M ratio | g COD/g MLSS·day | 0.15 | 0.05–0.4 |
| SRT | day | 20 | 5–30 |
| HRT | h | 6 | 4–9 |
| Flux | L/m²·h | 20 | 15–45 |
| Suction pressure | kPa | 10 | 4–35 |
| DO | mg/L | 2.0 | 0.5–1.0 |
| **Effluent quality** | | | |
| BOD | mg/L | 3 | <5 |
| COD | mg/L | 20 | <30 |
| $NH_3$ | mg N/L | 0.2 | <1 |
| TN | mg N/L | 8 | <10 |
| SS | mg/L | 0.1 | <0.2 |

# Membrane and Modules (1/5)

Membrane materials used for MBR processes can be categorized into polymeric and ceramic materials.

Diverse polymer materials including;

*polyethylene (PE)

*polytetrafluoroethylene (PTFE)

*Polyac-rylonitrile (PAN)

*polysulfone (PS)

***polyvinylidenedifluoride (PVDF)**

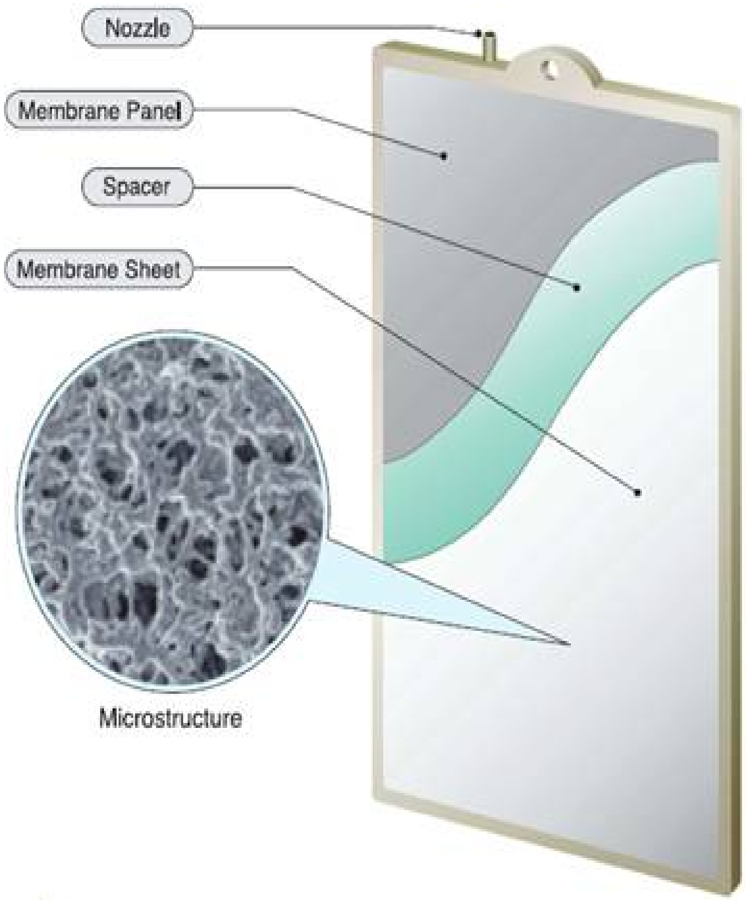
*polypropylene (PP)

*polyethersulfone (PES)

PVDF is the most popular material, because of the development of enhanced mechanical-structured PVDF membranes has made it possible to overcome the brittleness of membranes. The prolonged lifetime of PVDF membranes has led to widespread installations of MBR plants worldwide.

# Membrane and Modules (2/5)

Membranes are fabricated into flat sheet (FS), hollow fiber (HF), and multi-tube (MT) configurations.



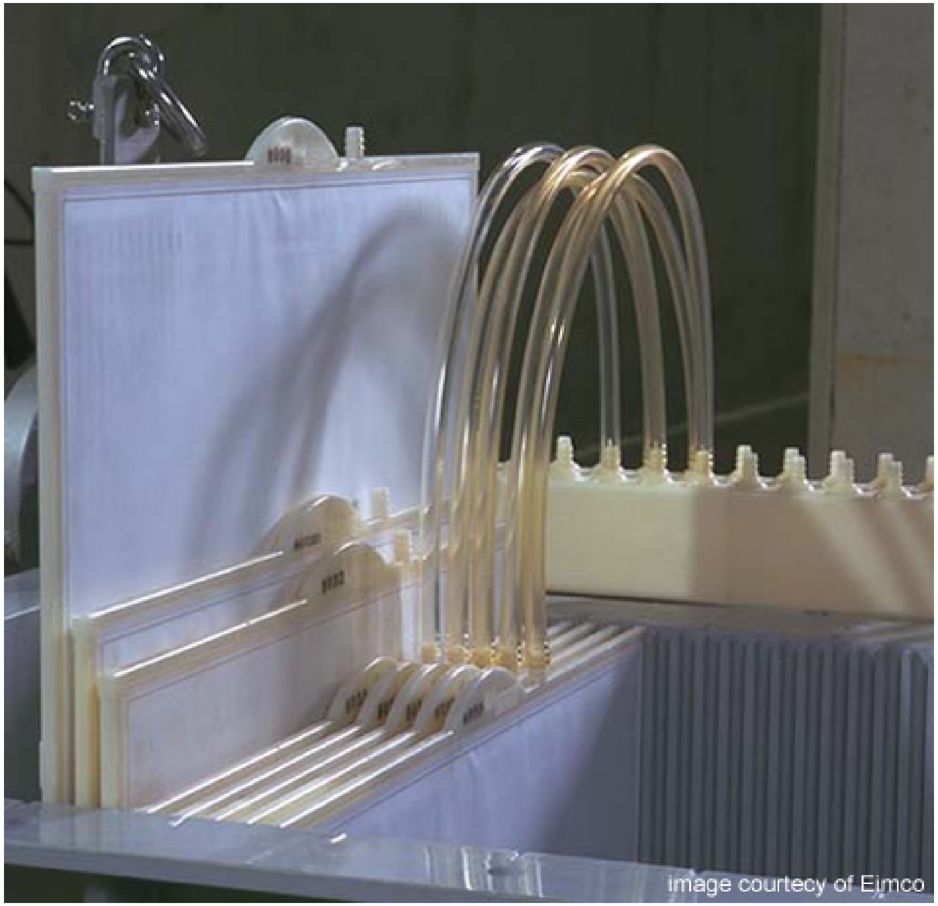




**Figure 1.5.** Flat sheet configuration

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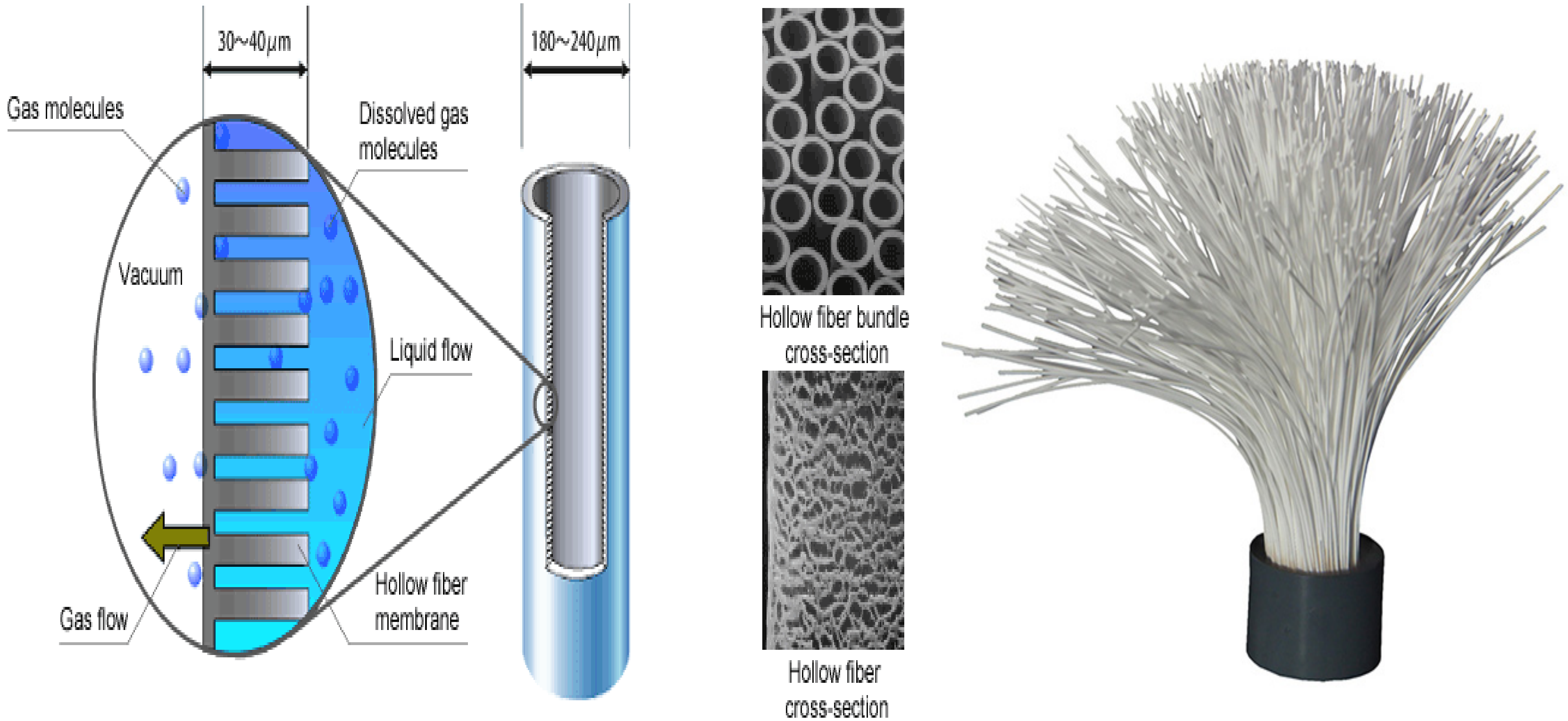


**Figure 1.6.** Hollow fiber configuration

# Membrane and Modules (4/5)

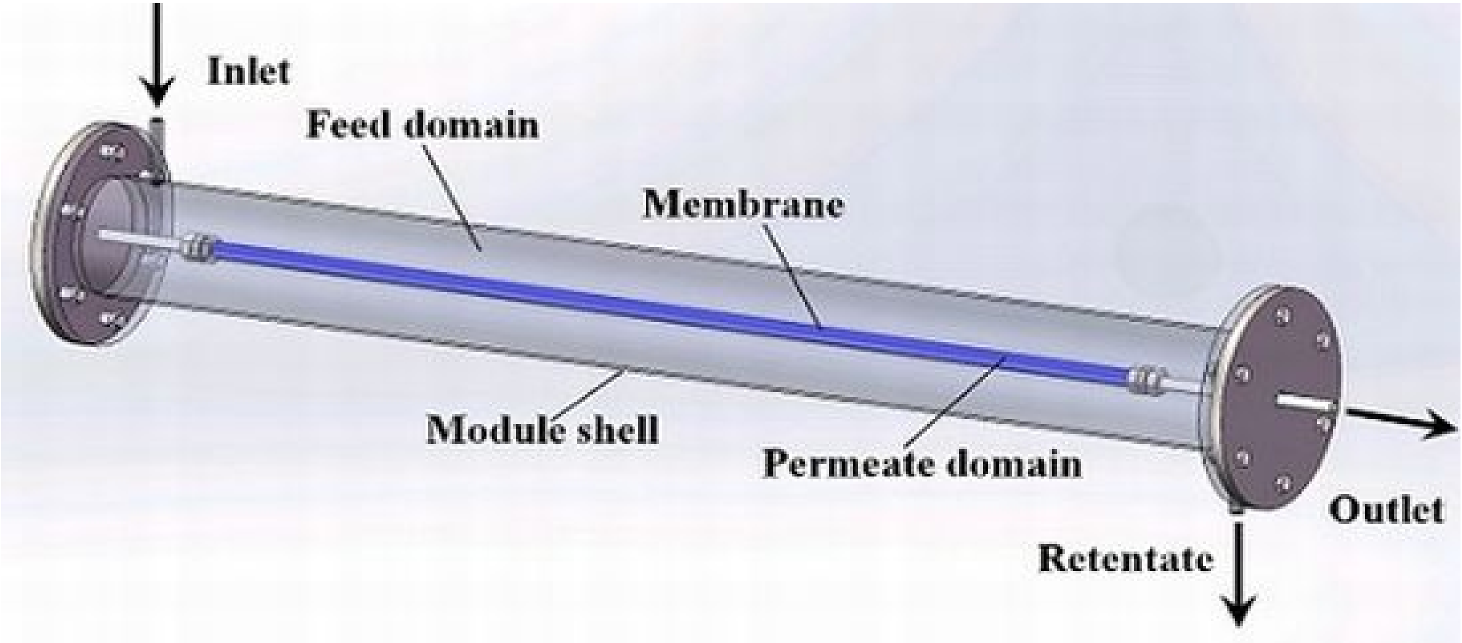


**Figure 1.7.** Multi tube configuration

FS and HF membranes are generally used for the submerged MBR configuration, while MT membranes are exclusively applied to the side-stream MBR configuration.

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# Membrane and Modules (5/5)

All types of membranes are packaged into modules for application in MBR. Membrane modules have been developed to increase their packing density because of saving footprint.

Aeration are placed under membrane modules for aerated bioreactor and control membrane fouling. Optimum hole size, applied pressure, and air flow rates have been determined mostly experimentally.

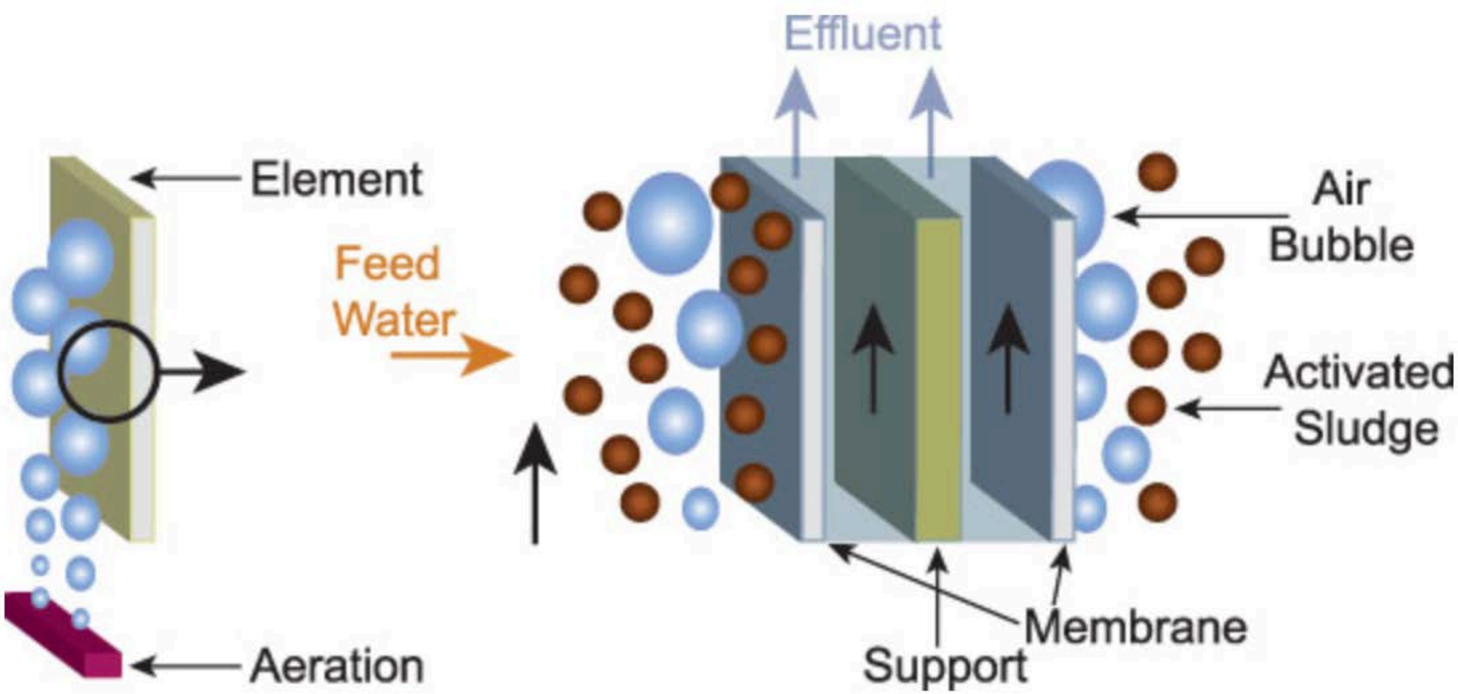


**Figure 1.8.** Aeration system of a MBR modules

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# Operation and Maintenance (1/3)

The important 2 issues Research and Development (R&D) of MBR are;

- the reduction of operation and maintenance (O&M) costs (mainly energy consumption)
- controlling membrane fouling

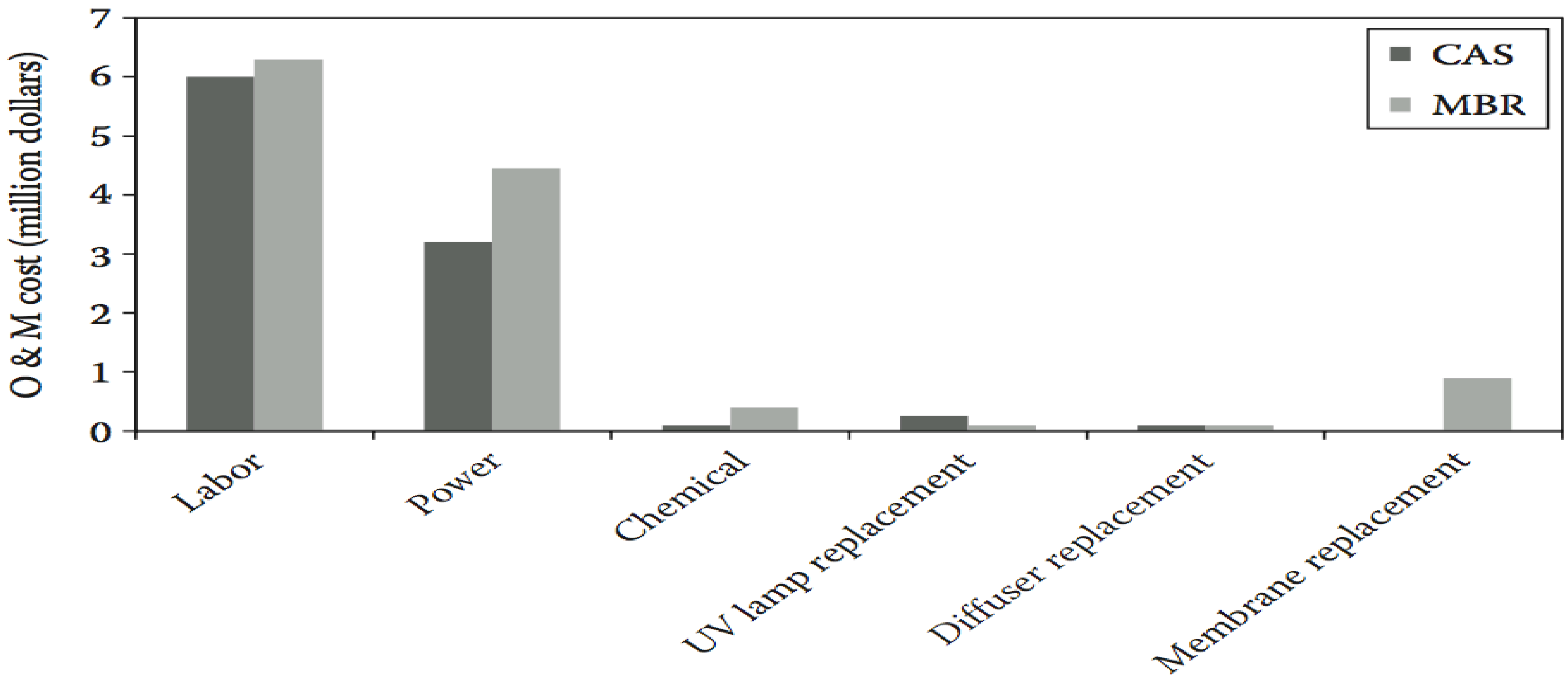


**Figure 1.9.** An estimation of the O&M cost differences between CAS and MBR plants treating municipal wastewater (Young et al., 2012).

# Operation and Maintenance (2/3)

To controlling of membrane fouling some strategies have been studied and developed academically and commercially:

- Coarse bubble aeration of membrane surface
  - Optimum airflow rate is important (high airflow rate cause energy consumption and deflocculation of activated sludge)
  - Some aeration strategies are developed (e.g. cyclically aeration)

- Moving bed carriers in MBR bioreactor

- Physical cleaning of membranes

- Chemical cleaning of membranes
  - Oxidizing chemicals (e.g. hypochlorite) are used for detach biosolids on membrane surface
  - Acids are used for detach inorganic solids on membrane surface

# Operation and Maintenance (3/3)

- Direct addition of chemicals or enzymes into a bioreactor
  - Coagulants (e.g., ferric chloride, polycationiic coagulants) are reduced soluble microbial products and extrapolymeric substances, which are known to cause membrane fouling, in MBR bioreactors.

- Quorum sensing
  - It is a bacterial communication system based on chemical signals known as autoinducers.
  - It is dependent on population density and involved in biofilm development in many bacteria.
  - Membrane fouling caused by biofilm formation and deposition to membrane surfaces by microorganisms could be directly reduced by adding enzymes that can degrade autoinducers or the microorganisms that can produce such enzymes.

# Prospect for Future R&D in MBR (1/1)



Ongoing and future trends in MBR Research and Development are;

- Energy consumption (Membrane fouling is closely related to energy consumption)

- Reuse of municipal and industrial wastewater (because of economical and environmental reasons)
  - Hybrid processes (e.g., MBR + reverse osmosis, MBR + advanced oxidation processes) are typical in wastewater reuse practices.

- MBR technology can be a core technology for producing energy and potable water.
  - Anaerobic digestion using anaerobic microorganisms is a way of generating biogas. (biogas can be use in the MBR system as aerator)

# Thank you…