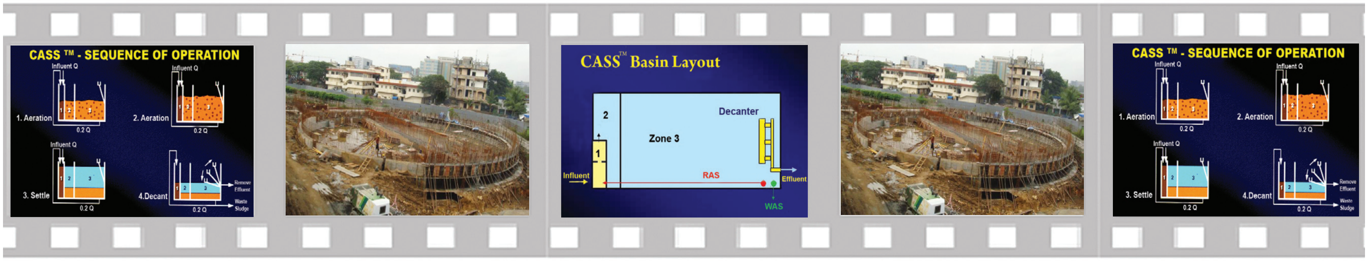
Biological Wastewater Treatment



This article briefly discusses the differences between aerobic and anaerobic biological treatment processes and subsequently focuses on select aerobic biological treatment processes/ technologies.

By Arun Mittal

Introduction

Biological treatment is an important and integral part of any wastewater treatment plant that treats wastewater from either municipality or industry having soluble organic impurities or a mix of the two types of wastewater sources. The obvious economic advantage, both in terms of capital investment and operating costs, of biological treatment over other treatment processes like chemical oxidation; thermal oxidation etc. has cemented its place in any integrated wastewater treatment plant.

Biological treatment using aerobic activated sludge process has been in practice for well over a century. Increasing pressure to meet more stringent discharge standards or not being allowed to discharge treated effluent has led to implementation of a variety of advanced biological treatment processes in recent years. The title of this article being very general, it is not possible by any means to cover all the biological treatment processes. It is recommended that interested readers, for deeper reading and understanding, refer to well-known reference books e.g. Wastewater Engineering by Metcalf & Eddy etc. This article briefly discusses the differences between aerobic and anaerobic biological treatment processes and subsequently focuses on select aerobic biological treatment processes/technologies.

Aerobic & Anaerobic

Before we go in to the discussions of various aerobic biological treatment processes, it is important to briefly discuss the terms aerobic and anaerobic. Aerobic, as the title suggests, means in the presence of air (oxygen); while anaerobic means in the absence of air (oxygen). These two terms are directly related to the type of bacteria or microorganisms that are involved in the degradation of organic impurities in a given wastewater and the operating conditions of the bioreactor. Therefore, aerobic treatment processes take place in the presence of air and utilize those microorganisms (also called aerobes), which use molecular/free oxygen to assimilate organic impurities i.e. convert them in to carbon dioxide, water and biomass. The anaerobic treatment processes, on other hand take place in the absence of air (and thus molecular/free oxygen) by those microorganisms (also called anaerobes) which do not require air (molecular/free oxygen) to assimilate organic impurities. The final products of organic assimilation in anaerobic treatment are methane and carbon dioxide gas and biomass. The pictures in Fig. 1 and 2 depict simplified principles of the two processes.

Table I summarizes the major differences in these two types of processes. From the summary in Table 1, it can be concluded that it is not anaerobic or aerobic treatment, but a combination of the two types of the technologies that give an optimum configuration for those wastewater treatment applications where the organic impurities are at a relatively higher concentration.

Overview:

Aerobic Biological Treatment Technologies

There are multitudes of aerobic biological treatment processes and technologies in literature and practice; however, for the purpose of this article, following four biological treatment technologies are described. After description of each process and corresponding advantages/highlights, a qualitative comparison of these technologies is tabulated. This comparison is based on an actual wastewater treatment application for a refinery project, where the treatment requirement was meant for discharge of treated effluent to the sea.

A. Conventional Activated Sludge Process (ASP) System:

This is the most common and oldest biotreatment process used to treat municipal and industrial wastewater. Typically wastewater after primary treatment i.e. suspended impurities removal is treated in an activated sludge process based biological treatment system comprising aeration tank followed by secondary clarifier. The aeration tank is a completely mixed or a plug flow (in some cases) bioreactor where specific concentration of biomass (measured as mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS)) is maintained along with sufficient dissolved oxygen (DO) concentration (typically 2 mg/l) to effect biodegradation of soluble organic impurities measured as biochemical oxygen demand (BOD5) or chemical oxygen demand (COD).

The aeration tank is provided with fine bubble diffused aeration pipework at the bottom to transfer required oxygen to the biomass and also ensure completely mixed reactor. Roots type air blower is used to supply air to the diffuser pipework. In several older installations, mechanical surface aerators have been used to meet the aeration requirement. The aerated mixed liquor from the aeration tank overflows by gravity to the secondary clarifier unit to separate out the biomass and allow clarified, treated water to the downstream filtration system for finer removal of suspended solids. The separated biomass is returned to the aeration tank by means of return activated sludge (RAS) pump. Excess biomass (produced during the biodegradation process) is wasted to the sludge handling and dewatering facility.

B. Cyclic Activated Sludge System (CASS™):

Cyclic Activated Sludge System (CASS™) as the name suggests is one of the most popular sequencing batch reactor (SBR) processes employed to treat municipal wastewater and wastewater from a variety of industries including refineries and petrochemical plants. Aquatech has an agreement with AECOM (erstwhile Earth Tech), UK, the licensor of this technology to supply CASS™ technology in India on exclusive basis to both municipal and industrial markets.

This technology offers several operational and performance advantages over the conventional activated sludge process. The CASS™ SBR process performs all the functions of a conventional activated sludge plant (biological removal of pollutants, solids/liquid separation and treated effluent removal) by using a single variable volume basin in an alternating mode of operation, thereby dispensing with the need for final clarifiers and high return activated sludge pumping capacity.

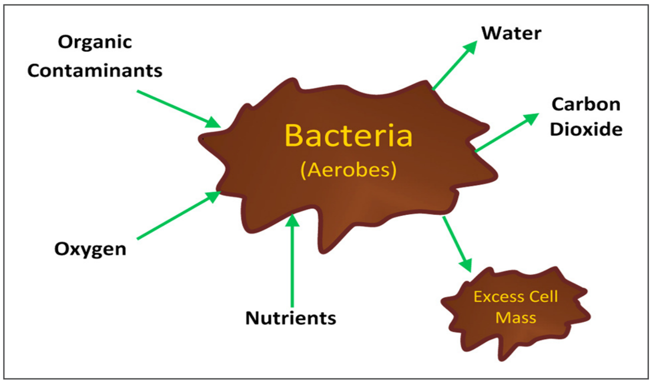


Figure 1: Aerobic Treatment Principle

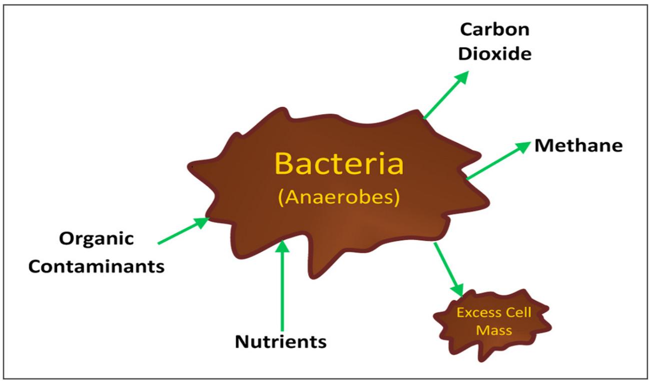


Figure 2: Anaerobic Treatment Principle

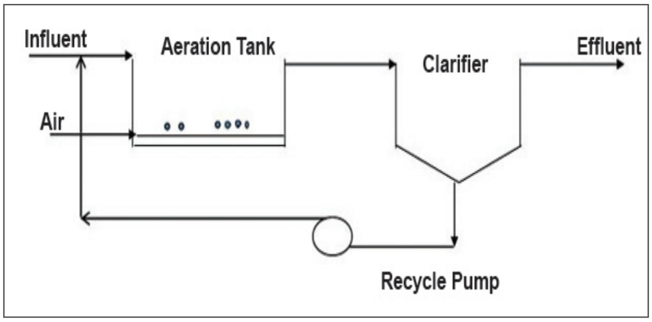


Figure 3: Conventional ASP System

The Cyclic Activated Sludge System (CASS™), incorporates a high level of process sophistication in a configuration which is cost and space effective and offers a methodology that has operational simplicity, flexibility and reliability that is not available in conventionally configured activated sludge systems. Its unique design provides an effective means for the control of filamentous sludge bulking, a common problem with conventional processes and other activated sludge systems.

The essential features of the CASS™ SBR technology are the plug-flow initial reaction conditions and complete-mix reactor basin. The reactor basin is divided by baffle walls into three sections (Zone 1: Selector, Zone 2: Secondary Aeration, Zone 3: Main Aeration). Sludge biomass is intermittently recycled from Zone 3 to the Zone 1 to remove the readily degradable soluble substrate and favor the growth of the floc-forming microorganisms. System design is such that the sludge return rate causes an approximate daily cycling of biomass in the main aeration zone through the selector zone. No special mixing equipment or formal anoxic mixing sequences are required to meet the effluent discharge objectives. The basin configuration and mode of operation enables combined nitrogen and phosphorous removal mechanisms to take place through a simple 'one-shot' control of the aeration.

CASS™ utilizes a simple repeated time-based sequence which incorporates:

- Fill – Aeration (for biological reactions)
- Fill – Settle (for solids-liquid separation)
- Decant (to remove treated effluent)

Advantages of CASS™:

The CASS™ SBR maximizes operational: simplicity, reliability and flexibility. Important reasons for choosing CASS™ SBR over conventional constant volume activated sludge aeration and clarifier process include:

- Operates under continuous reduced loading through simple cycle adjustment.
- Operates with feed-starve selectivity, So/Xo operation (control of limiting substrate to micro-organism ratio), and aeration intensity to prevent filamentous sludge bulking and ensures endogenous respiration (removal of all available substrate), nitrification and denitrification together with enhanced biological phosphorus removal.
- Simultaneous (co-current) nitrification and denitrification by variation of aeration intensity.
- Tolerates shock load caused by organic and hydraulic load variability. The system is easily configured and adjusted for short-term diurnal and long-term seasonal variations.

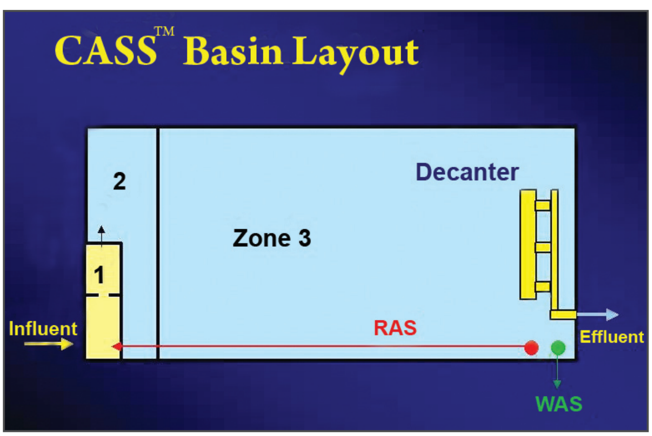


Figure 4: Typical Rectangular CASS™ SBR basin layout

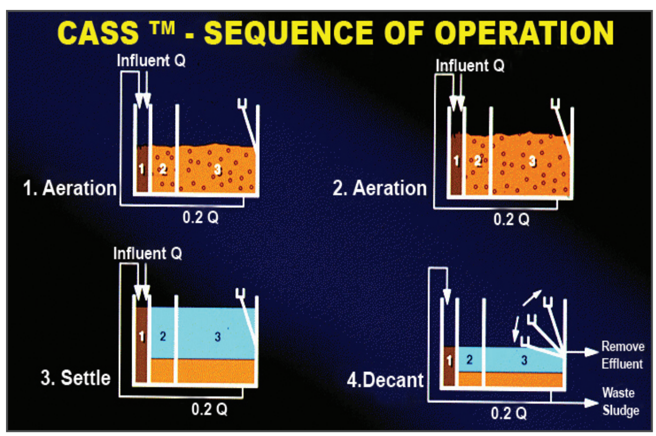


Figure 5: Typical Rectangular CASS™ SBR Sequence of Operation

- Elimination of secondary clarifier.
- Elimination of separate load equalization. The CASS™ SBR basin is in itself an equalization basin and a clarifier with a much lower solids flux, compared to conventional clarifier design.
- Inherent ability to remove nutrients without chemical addition, by controlling the oxygen demand and supply.
- Provision for energy optimization through nutrient removal mechanisms. The feed water carbonaceous BOD used in denitrification and enhanced biological phosphorus removal reduces overall oxygen demand and hence energy requirement.
- Capital and operating cost advantages.
- Minimum footprint and reduced land requirement.
- Provision for easy plant expansion through simple modular and common wall construction.

CASS™ incorporates a selector zone, which offers an operational flexibility that is not obtainable in other variable volume, and constant volume, activated sludge facilities. The selector enables a simple cost effective measure for reliable plant scale-up without encountering filamentous sludge bulking. The selector operates efficiently from plant start-up to design loading conditions. No adjustments to the return sludge flow rate are necessary. The incorporation of a suitably sized high rate plug-flow selector in front of the complete-mix unit combines the elements of the process which offer a stable and relatively uniform level of metabolic activity of the sludge in

Parameter	Aerobic Treatment	Aerobic Treatment
Process Principle	• Microbial reactions take place in the presence of molecular/ free oxygen • Reactions products are carbon dioxide, water and excess biomass	• Microbial reactions take place in the absence of molecular/ free oxygen • Reactions products are carbon dioxide, methane and excess biomass
Applications	Wastewater with low to medium organic impurities (COD < 1000 ppm) and for wastewater that are difficult to biodegrade e.g. municipal sewage, refinery wastewater etc.	Wastewater with medium to high organic impurities (COD > 1000 ppm) and easily biodegradable wastewater e.g. food and beverage wastewater rich in starch/sugar/ alcohol
Reaction Kinetic	Relatively fast	Relatively slow
Net Sludge Yield	Relatively high	Relatively low (generally one fifth to one tenth of aerobic treatment processes)
Post Treatment	Typically direct discharge or filtration/ disinfection	Invariably followed by aerobic treatment
Foot-Print	Relatively large	Relatively small and compact
Capital Investment	Relatively high	Relatively low with pay back
Example Technologies	Activated Sludge e.g. Extended Aeration, Oxidation Ditch, MBR, Fixed Film Processes e.g. Trickling Filter/Biotower, BAF, MBBR or Hybrid Processes e.g. IFAS	Continuously stirred tank reactor/digester, Upflow Anaerobic sludge Blanket (UASB), Ultra High Rate Fluidized Bed reactors e.g. EGSBTM, ICTM etc.

Table 1: Major Differences in Aerobic and Anaerobic Treatment

the complete-mix volume. Operation is therefore insensitive to influent flow and concentration variation.

CASS™ SBR designs have been available in the marketplace since 1980s. It is significant that the development of variable volume processes have incorporated the selector technology to enable scale-up in the 1990s to large multiple basin modules of around 50 MGD (200,000 m^3/d). Today, it is a well-established and proven technology for municipal and industrial wastewater treatment. The cost effectiveness of the facilities, their compactness and their simplicity of operation provide the consulting engineer or contractor with a very strong argument to make the available money for wastewater treatment spread a lot further.

C. Integrated Fixed Film Activated Sludge (IFAS) System:

There are several industrial installations where two stage biological treatment comprising stone or plastic media trickling filter (also known as packed bed biotower) followed by activated sludge process based aeration tank, followed by secondary clarifier have been in operation.

Another modification of above configuration that has been implemented in newer industrial wastewater treatment systems is fluidized media bioreactor (also known as moving bed bioreactor (MBBR)) in lieu of biotower followed by activated sludge process. In some of the industries (e.g. refineries and petrochemical plants, where the existing wastewater treatment system was single stage conventional activated sludge process (based on aeration tank and clarifier unit), that underwent capacity expansion and/or faced stricter discharge regulations, the up-gradation of activated sludge process by addition of fluidized bio-media has been implemented to meet these requirements.This hybrid process of fluidized media and activated sludge process taking place in a single aeration tank is known as Integrated Fixed Film Activated Sludge (IFAS) process. The common advantages of all of the above described configurations are as follows:

- Fixed film media provides additional surface area for biofilm to grow on it and degrade the organic impurities that are resistant to biodegradation or may even be toxic to some extent.
- The overall efficiency of two stage biotreatment system is better than activated sludge process alone.
- Fixed film processes are more effective in nitrification of the wastewater than activated sludge process.
- The overall foot-print for a fixed film process based system is smaller than the activated sludge process system.
- Due to less sludge wastage, the sludge handling and dewatering facility is smaller compared to the activated sludge process.

Comparing IFAS with other configurations i.e. biotower followed by activated sludge or MBBR followed by activated sludge, following advantages for IFAS can be highlighted:

- It can be easily incorporated in the existing activated sludge system to meet additional processing capacity requirement and/or stricter discharge regulations without the need of additional concrete tanks.
- Foot-print of IFAS is smaller.
- Capital and operating cost for IFAS is lower.

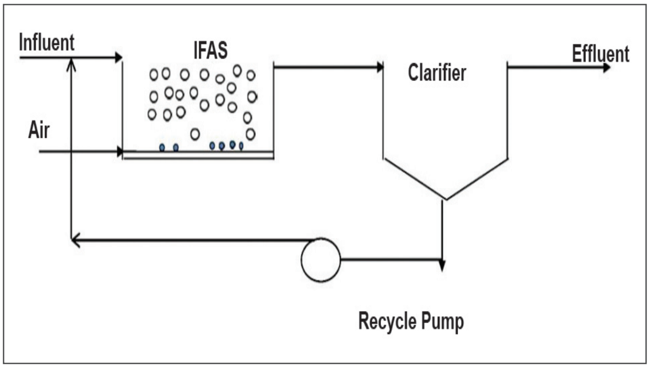


Figure 6: Integrated Fixed Film Activated System (IFAS)

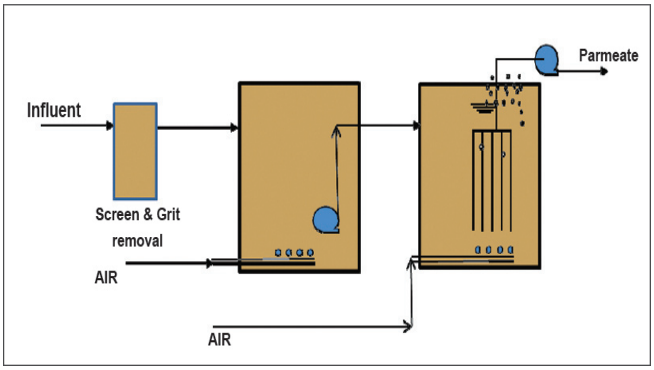


Figure 7: Submerged MBR System

D. Membrane Bioreactor (MBR):

Membrane Bioreactor (MBR) is the latest technology for biological degradation of soluble organic impurities. MBR technology has been in extensive usage for treatment of domestic sewage, but for industrial waste treatment applications, its use has been somewhat limited or selective. The MBR process is very similar to the conventional activated sludge process, in that both have mixed liquor solids in suspension in an aeration tank. The difference in the two processes lies in the method of separation of bio-solids. In the MBR process, the bio-solids are separated by means of a polymeric membrane based on microfiltration or ultrafiltration unit, as against the gravity settling process in the secondary clarifier in conventional activated sludge process. Therefore, the advantages of MBR system over conventional activated sludge system are obvious as listed below:

- Membrane filtration provides a positive barrier to suspended bio-solids that they cannot escape the system unlike gravity settling in activated sludge process, where the bio-solids continuously escape the system along with

Parameter	Conventional ASP	CASS™	IFAS	MBR
Treated Effluent Quality	Meets specified discharge standards with additional filtration step	Meets/ exceeds specified discharge standards without additional filtration step	Meets/ exceeds specified discharge standards with additional filtration step	Exceeds specified discharge standards without additional filtration step. Very good for recycle provided TDS level permits
Ability to adjust to variable hydraulic and pollutant loading	Average	Very good	Very good	Very good
Pretreatment Requirement	Suspended impurities e.g. oil & grease and TSS removal	Suspended impurities e.g. oil & grease and TSS removal	Suspended impurities e.g. oil & grease and TSS removal	Fine screening for suspended impurities like hair and almost complete oil & grease removal
Ability to cope with ingress of oil	Average	Good	Average	Poor & detrimental to membrane
Secondary Clarifier Requirement	Needed	Aeration Basin acts as clarifier	Needed	Clarifier is replaced by Membrane filtration
Complexity to operate & control	Simple, but not operator friendly	Operator friendly	Operator friendly	Requires skilled operators
Reliability & Proven-ness of Technology	Average	Very good	Very good	Limited references in industrial applications
Capital Cost	Low	Low	High	Very High
Operating Cost	Low	Low	High	Very High
Space Requirement	High	Low	Average	Low

Table 2: Comparison of Aerobic Biological Treatment Options

clarified effluent and sometimes a total loss of solids is also encountered due to process upsets causing sludge-bulking in the clarifier. As a result, the bio-solids concentration measured as MLSS/MLVSS can be maintained at 3 to 4 times in an MBR process (~ 10,000 mg/l) in comparison to the activated sludge process (~2500 mg/l).

- Due to the above aspect of MBR, aeration tank size in the MBR system can be one-third to one-fourth the size of the aeration tank in an activated sludge system. Further, instead of gravity settling based clarifier, a much more compact tank is needed to house the membrane cassettes in case of submerged MBR and skid mounted membrane modules in case of non-submerged, external MBR system.
- Thus, MBR system requires only 40-60% of the space required for activated sludge system, therefore significantly reducing the concrete work and overall foot-print.
- Due to membrane filtration (micro/ultrafiltration), the treated effluent quality in case of MBR system is far superior compared to conventional activated sludge, so the treated effluent can be directly reused as cooling tower make-up or for gardening etc. Typical treated water quality from MBR system is:
    - $BOD_5 < 5$ mg/L
    - Turbidity < 0.2 NTU

An external, non-submerged type MBR for industrial applications especially in refineries and petrochemical wastewater applications, is the Aqua-EMBR (Aquatech's Enhanced Membrane Bioreactor). Aqua-EMBR has been successfully piloted to treat wastewater from a petrochemical plant in middle-East. Aqua-EMBR filtrate was further processed through High Efficiency Reverse Osmosis (HERO™) process to recover 90% high quality permeate. The permeate quality was suitable for its recycle as feed to the demineralizer system. The advantages of Aqua-EMBR over submerged MBR systems include:

- Aqua-EMBR system (membrane modules) has no membrane tank, it can be built much quicker with less risks for contractors:
  - Installed as skid(s) on a flat concrete slab, no complex civil works required.
  - Civil works and skid assembly are independent and parallel activities.
  - Less risk for contractors because of delays in civil works due to weather conditions, environmental or other local uncertainties.
- The system offers an operator friendly working environment as opposed to obnoxious environment in case of submerged systems:
  - Operators don't see, smell or come in contact with the biosludge.
  - Operators do not work on top of open membrane tanks where the air could contain harmful aerosols.
  - In case of any maintenance issue, the membrane modules in Aqua-EMBR can be removed or replaced without any contact with the biosludge, whereas submerged membrane

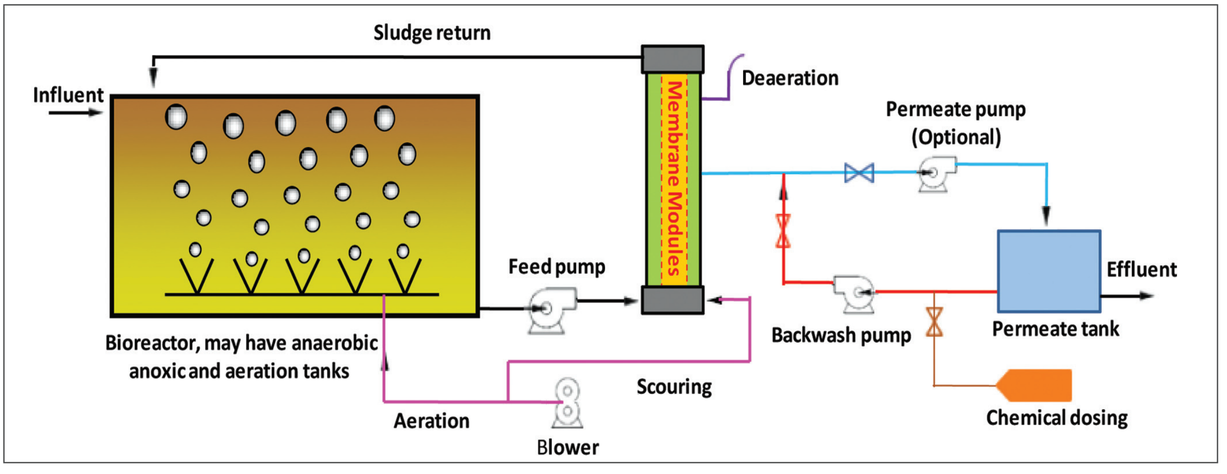


Figure 8: Aqua-EMBR System

Figure 9: CASS™ Plant under Construction at Mumbai International Airport, Mumbai

modules contaminated with sludge, have to be lifted out of tanks posing potential contact with the sludge.

- The flux is ~50% higher which equates to 50% less surface area of membrane needed per unit volume permeate production. This results in:
  - Lowest membrane cost per unit volume filtrate, resulting in lower capital and operating costs.
  - Smallest footprint (about 20% less).
  - Lowest maintenance costs (chemicals, man-hours etc.).
- Electrical power consumption is 10 to 15% lower compared to submerged systems due to the use of airlift pump effect.
- Aqua-EMBR has the tightest membrane pore size:
  - Pore size nominal / maximum: 30 nm / 50 nm
  - Turbidity of permeate: < 0.2 NTU
  - TSS levels: < 0.5 mg/l

Highest effluent quality is an important factor for re-use purposes and future regulations.

Comparison Of Aerobic Biological Treatment Options

A detailed technical evaluation of various options of biological treatment processes for a given wastewater from a refinery and the treated effluent quality requirements has been carried out. Based on this evaluation, Table 2 summarizes the pros and cons of each option.

Based on these comparisons, it can be inferred that CASSTM technology is superior to other aerobic biological treatment technologies in terms of overall life cycle cost and returns to the owner.

About The Author

Arun Mittal has over 25 years of experience in water and wastewater treatment plants design. Currently he is the Director of Wastewater Applications Engineering department at Aquatech. He has been with Aquatech in various positions for the last fourteen years and involved in process design and proposals preparation for water pretreatment, demineralization, wastewater treatment and recycle including zero liquid discharge systems for the Power, Fertilizer, Oil Refining and Petrochemical industries. He has a Bachelor's Degree in Chemical Engineering.