International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Review of Modern Technologies in Biological Wastewater Treatment

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Abstract: ***The pollution of our water resources is mainly due to the discharge of untreated waste water. Hence the need of the hour is to have an efficient treatment for the waste water. The different stages of treatment are preliminary, primary, secondary, and tertiary or advanced treatment. In secondary treatment, biological treatment is more cost-effective than chemical treatment. Biological treatment of waste water reduces the concentration of pollutant through microbial action and removal of non-settleable organic colloidal solids. The conventional activated sludge process has some disadvantages like high operation cost, requirement of skilled supervision and requirement of more space for the treatment plant. There are various advances and improvements in the reactors to achieve variations in contact time and method of contact, which have resulted in the growth of suspended growth system, attached growth or fixed biofilm systems or combinations thereof. Biofilm processes are proved to be reliable for organic carbon and nutrients removal .In this study, a review of the various biological treatment technologies has been done. Both suspended as well as fixed film processes have been discussed. The various modern technologies include Moving Bed Biofilm Reactor (MBBR), Rotating Biological Contactor (RBC), Integrated Fixed Film Activated Sludge (IFAS), Membrane Bioreactor (MBR), Fluidized Bed Biofilm Reactor (FBBR) and Sequential Batch Reactor (SBR). The merits and demerits have also been ascertained. A comparison of these techniques will surely be helpful to choose the suitable technique.***

Keywords: Biological process, Biofilm, Activated Sludge Process, MBBR, RBC, IFAS, MBR, FBBR, SBR

1. Introduction

Populations require water for domestic and municipal usages; as an input in productive activities, agriculture, industry (including energy production) and services activities; and finally, in all usages, there is discharge of effluents (sanitation, removing industrial wastes etc.) (FAO, 1994). Demands from all these sectors are mounting and competing with one another. Freshwater is only a small fraction (2.5 percent) of the water present in our planet. Further, most of freshwater is in the form of permanent ice and snow, or of groundwater which, given its life cycle of several thousand years, must be regarded as unrenewable on a human time scale. In the end only 0.3 percent of freshwater is renewable(FAO, 1994). Finally, water resources are vulnerable, meaning that their flow patterns and chemical properties can easily be altered by human activities and natural factors in ways which negatively affect subsequent human usages. Thus increasingly rapid urbanization and industrial developments are major sources of environmental pollution (Mahajan, 1998).

India is the second most populous country in the world, with 1.3 billion people as on May, 2016, more than a sixth of world's population. Thus India is having a population of 17.5% of the world's population (en.wikipedia.org/wiki/Demographics_of India). The high density of population causes a server threat to our water bodies.

The pollutants in the domestic waste water arise from residential and commercial cleaning operations, laundry, food preparation, and body cleaning functions, and body excretions (Amir and Chottu, 2012). The composition of domestic water is relatively constant (Rana, 2013). Waste water is treated for removing the undesirable components both organic and inorganic matter which are soluble and insoluble. If these pollutants are discharged without any proper treatment, it can interfere with the natural self-cleaning mechanism of water bodies. The various constituents of waste water are potentially harmful to the environment and to human health (Rana, 2013). In the environment, the pollutants cause destruction for animal and plant life, and for aesthetic nuisance. Drinking water sources are often threatened by increasing concentration of pathogenic organisms and by many of the new toxic chemicals disposed of by industry, and agricultural wastes.

Waste water with high levels of organic matter, phosphorus and nitrogen cause several problems, such as eutrophication, oxygen consumption and toxicity, when discharged to the environment (Borkar et al., 2013). Thus, the treatment of these wastes is of paramount importance. Waste water treatment is generally divided in three or four main stages, which represent the degree to which the water is treated. These stages are preliminary treatment, primary treatment, secondary treatment, and tertiary or advanced treatment. Within these stages there are different steps and methods that can be employed to treat the water (Prescod, 1992).

Preliminary treatment is used to eliminate large, solid objects that are often present in waste water (Jillian and Isabella, 2012). In primary treatment, the majority of organic and inorganic material, as well as contaminants in the water, are removed. Secondary treatment of wastewater employs biological processes and the use of microorganisms to rid the water of any organic compounds that may still be present. This stage stimulates what actually happens in nature, when microorganisms break down organic wastes. The problems such as colour, odour, and taste are dealt in advanced wastewater treatment.

Biological processes are cost-effective and environmentally sound alternatives to the chemical treatment of nutrient containing waste water (Lawerence et al., 2010). Biological processes based upon suspended biomass (i.e activated sludge processes) are effective for the removal of organic carbon and nutrient in municipal waste water plants (Kermani et al., 2008). But there are some problems of sludge settleability and need of large reactors, and settling tanks, and biomass recycling (Pastorelli, et al., 1999).

2. Different Types of Biological Processes

The different types of modern biological treatment covered in this review are fixed film system namely rotating biological contactors, submerged fixed film systems namely biofilm upflow sludge blanket reactor, fluidized bed, moving bed biofilm reactor and membrane biofilm reactors and suspended film systems namely sequential batch reactor.

2.1 Attached Biofilm Process

Biofilm processes are proved to be reliable for organic carbon and nutrients removal without some of the problems of activated sludge processes (ϕdegaard, 1994). Biofilm treatment systems employ the use of bacteria, fungi, algae, and protozoa to remove organic and inorganic materials from the surrounding liquid.

In a fixed film system, microorganisms grow on rocks, sand, or plastic, to create a film (Jillian and Isabella, 2012). They grow on these surfaces by feeding off the organic matter and nutrients in the wastewater that flows over them. The three main fixed film systems that are commonly used are trickling filters, rotating biological contactors, and sand filters (Manci, 2009). A trickling filter consists of substrate (rocks of other material) on which cells can grow and over which the pre-treated sewage is sprayed (https://engineering.dartmouth.edu/~d30345d/courses/engs37/ActivatedSludge.pdf). The spraying action creates contact between BOD in sewage, oxygen in the air and cells on the substrate. Cells grow and degrade the sewage. Excess cells (slime) need to be periodically removed from the substrate. The main disadvantages are the high incidence clogging, need of regular operator's attention, and high maintenance cost.

2.2 Suspended Growth Process

Suspended film systems consist of suspending the microorganisms in the waste water(Jillian and Isabella,2012). While in the water, they absorb the organic waste and nutrients around them, which allows them to grow and reproduce to form micro-colonies. These micro-colonies settle as sludge, which is them removed and either reused in the process by being re-suspended, or treated in a sludge treatment process. Activate sludge extended aeration, and sequential batch reactor systems are some examples of suspended growth.

Conventional activated sludge systems are primarily composed of an aerated, conventional activated sludge systems are primarily composed of an aerated, suspended growth bioreactor, liquid-solids separation (eg. Secondary clarifier), and a recycle stream for return activated sludge (Hazen and Sawyer, 2011). A conventional activated sludge process consists of an aerated zone followed by a secondary clarifier from which the recycle activated sludge is recycled back to the reactor (http://dnr.wi.gov/regulations/opcert/documents/wwsgactsludgeintro.pdf). In the bioreactor, microorganisms remove soluble and particulate organic matter. Secondary clarification separates the mixed liquor suspended solids (MLSS) from the treated wastewater (Hazen and Sawyer, 2011). Bioreactors in plug flow conventional activated sludge systems are typically long and narrow. Nitrogen and phosphorus are essential components of cells. Therefore, some nutrient removal occurs naturally in any biological treatment system, the amount depending on the quantity of sludge produced and its nutrient content. Conventional biological treatment usually will remove approximately 20 to 30 percent of influent nitrogen and phosphorus for metabolic growth.

An increase in biological-nitrogen and/or phosphorus removal efficiency requires that theactivated sludge process be modified to enhance nutrient uptake biologically or to accomplish removal through other mechanisms (e.g. Chemical addition for phosphorus removal) (Hazen and Sawyer, 2011). Specifically, the control of internal recycles and the separation of reduction-oxidation zones in the activated sludge process is the widely accepted method to modify a conventional activated sludge process for advanced biological nitrogen and phosphorus removal. The advantages are already established and design well characterized, predictable performance, possibility for multiple treatment train configurations to achieve/enhanced nutrient removal. The disadvantages are large foot print than other treatment options, intensive equipment, sophisticated operation, equalization recommended for process stability, and lighter, fluffier sludge flocs that may require slightly larger clarifiers.

3. Modern Biological Treatment Techniques

3.1 Moving Bed Biofilm Reactor (MBBR)

Moving Bed Biofilm Reactors (MBBRs) are classified within a group of processes called mobile bed biofilm reactors (Hazen and Sawyer, 2011). MBBRs use low density media kept in motion using aeration or mechanical mixers. The media in MBBRs are made of polyethylene and are shaped like small cylinders with a cross piece on the inside, similar to the plastic media carriers used in IFAS system.

MBBR process was invented in 1989 by Hallvardϕdegaard and coworkers of Norwegian University of Science and Technology. It was first commercialized by Kaldnes in early 1990s in Europe. The first installation of MBBR in North America in 2002 in Minnesota by Hydroxyl systems. The influence of carrier size and shape on the performance of moving bed biofilm process related to highly loaded plants working was analyzed. It was concluded that the organic surface area loading rate is the main component for the removal of organic matter using MBBR (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor_For_Sewage_Treatment_Background).

Wang et al., 2006 carried out a laboratory scale test using biofilm carriers and a filling ratio of 50%. Kermani et al., 2008 evaluated MBBR and found that it could be used as an ultimate and efficient option for the total nutrient removal from municipal wastewater.

There were studies on a moving bed biofilm bioreactor with biodegradable polymers serving as biofilm carriers and also on the performance of MBBR for the removal of organics and nitrogen from wastewater with a low C/N ratio using the two different materials as carrier (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor_For_Sewage_Treatment_Background). Cao and Zhao, 2012 made a comparison of ASP (Activated Sludge Process) and MBBR at different operating conditions and the study revealed that there is similar efficiency of both process with regard to COD removal. An important advantage of MBBR is that less volume is required for treating the wastewater. The MBBR performance in terms of COD removal efficiency was higher than ASP (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor_For_Sewage_Treatment_Background). As per the study of Shrestha, 2013, the efficiency for the removal of dissolved organic carbon was found above 92% at all filling rates. The most common MBBR process is the Kaldnesprcess which was developed in Norway and for which several application guidelines and design criteria have been developed (Hazen and Sawyer, 2011).

3.1.1 Operation

MBBR meaning Moving Bed Biofilm Reactor combines the benefits of both activated sludge process and the fixed film process (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor_For_Sewage_Treatment_Background?auto=download). It is a continuous flow process which uses media/carriers which provide sites for the attachment of active bacteria in a suspended medium which can be used for waste water treatment. The media includes the small carrier elements which allow sites to retain active biomass within the bioreactor, thus eliminating the need to control mixed liquor suspended solids (MLSS) by recycling active sludge from secondary settlement tanks.

This process is based on biofilm principle using the polyethylene carrier elements (http://www.wateronline.com/doc/anoxkaldnes-mbbr-0001. The carrier elements (plastic carrier, PVA gel beads), which are less dense than water, provide sites for bacteria attachment in a suspended growth medium i.e a large protected surface for bacteria culture. The carrier elements thus allow a higher biomass concentration to be maintained in a reactor compared to a suspended growth process, such as activated sludge (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor _For_Sewage_Treatment_Background).

MBBR processes retain a large volume of biofilm within the biological waste water treatment process (www.academia.edu/5990470/Moving_Bed_Biofilm_Reactor_For_Sewage_Treatment_Background). As a result, degradation of biodegradable contaminants are sustained in highly compact tank sizes. Without the requirement to return sludge, the process provides increased protection against toxic shock, while automatically adjusting to load fluctuation.

The reactor in the MBBR process can be aerobic, anoxic, or anaerobic. The media is kept completely mixed by coarse bubble aeration (in aerobic zones) or mechanical mixers (in anoxic and anaerobic zones) (Hazen and Sawyer, 2011). Similar to IFAS systems with free-floating media, MBBRs require a screen or sieve to be installed at the effluent end of the reactor basin. It is important to keep the media constantly in motion to not clog the screens. The amount of media to install in an MBBR basin is dependent on a number of factors such as the original and hydraulic loading characteristics, temperature, and the degree of treatment required. . An MBBR may be filled up to 70 percent volume with media. Typical dissolved oxygen (DO) concentrations in MBBR systems for BOD removal are 2 to 3mg/l (http://www.murfreesborotn.gov/DocumentCenter/View/352). Higher DO concentrations have not been proven to be beneficial in practice. In terms of settleability, MBBR processes typically require chemicals to be added to improve the settling characteristics of the mixed liquor. This is because it has been shown in pilot studies that biofilm reactors with high organic loads produce solids with poor settling properties. Thus MBBR plants may use chemical polishing or operate at low organic loads to improve the settleability of sludge (http://www.murfreesborotn.gov/DocumentCenter/View/352).

The primary difference between MBBRs and IFAS (Integrated Fixed Film Activated Sludge systems) is that MBBRs do not incorporate return activated sludge. Both systems can be retrofitted in existing activated sludge basins (Hazen and Sawyer, 2011). These systems are primarily used for soluble organic matter removal as well as nitrification. MBBR effluent must undergo presedimentation treatment and must be followed by settling basins where the sloughed off biofilm is separated from the treated water. In general, moving media provide several advantages including the ability to control biofilm thickness, increase mass transfer efficiencies, reduce clogging, and provide high surface areas for biofilm development.

3.1.2 Advantages

(www.researchgate.net/publication/51488125_ Moving_Bed_Biofilm_Reactor_Technology_Process_Applications_Design_and_Performance)

1) It can meet similar treatment objectives as activated sludge systems for carbon oxidation, nitrification, and denitrification, but requires a smaller tank volume than clarifier-coupled activated sludge system.
2) They have the ability to increase biological reaction rates through accumulation of high concentration of active biomass.
3) They have high resistance to hydraulic and organic loading shock.
4) They can achieve high effluent quality in terms of nutrient removal, good disinfection capability.
5) Sludge production is less.

6) It is well suited for retrofit installation into existing municipal wastewater treatment plants.
7) Less mechanical equipments are required than Activated Sludge Process.
8) It has smaller footprint.
9) It can be retrofitted to activated sludge systems for increased capacity or higher quality of effluent.
10) The circulation of biomass is not necessary.
11) There is higher effluent quality in terms of BOD and suspended solids.

3.1.3 Disadvantages (Hazen and Sawyer, 2011)
1) There is increased power requirement for aeration and therefore increased operational costs.
2) The cost of media is high.
3) High oxygen concentration is to be maintained.
4) Increased level of pretreatment with fine screening.
5) The process is sensitive to sustained peak hour flow.
6) The replacement of media is required.

3.2 Rotating Biological Contactor (RBC)

Rotating Biological Contactors (RBCs) constitute a very unique and superior alternative for biodegradable matter and nitrogen removal (Cortex et al.,2008). The rotating biological contactor is an attached growth biological treatment used in removal of biodegradable matter present in wastewater. Microorganisms which break down wastewater are attached to media as part of a slime colony.The process is simpler to operate than activated sludge since recycling of effluent or sludge is not required (http://web.deu.edu.tr/atiksu/ana52/abdtre10.html). Special consideration is to be given to returning supernatant from the sludge.

The biological growth in an RBC secondary treatment process more closely resembles the zoological slime from a trickling filter than the mixed liquor from an activated sludge process, but there is one major difference (http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-501.pdf?ver=2013-09-04-070751-577).. While the trickling filter growth is layered with aerobic organisms living into the outer layers and anaerobic organisms living next to the media, the RBC growth is intentionally kept thin to discourage anaerobic organisms (Zickefoose, 1984).

RBC is a proved and prudent technology and are known widely used throughout the world particularly for addressing the need of small communities. Opatken and Bond (1991) treated leachate with high concentration of ammonia-nitrogen by nitrification process with a pilot scale RBC. Brower and Barford introduced different biological fixed film systems in their report. In 1978, a theoretical model for RBC systems was provided so that the process design criteria for a pilot-plant RBC process could be established and compared with the activated sludge process. They are now used widely throughout the world and although particularly well suited for treating waste water from small communities (Husham et al., 2012).

3.2.1 Operation

A rotating biological contactor is an attached growth biological process that consists of one or more basins in which large closely-spaced circular disks mounted on horizontal shafts rotate slowly through waste water (Husham et al., 2012). It contains a number of discs which are arranged along the shaft axis of the contractor (Ghavi and Kris, 2009). The disks, which are made of high density polystyrene or polyvinyl chloride (Husham et al., 2012). The wastewater is fed in the contactor at a certain flow rate (Ghavi and Kris, 2009). All the discs are partially submerged into the wastewater. When the discs are continuously rotated by a shaft, the lower portion of the discs submerged in the wastewater would then be turned to the upper atmosphere phase. Thus the microbial film on the disc that is initially in contact with the nutrients of the wastewater phase and the oxygen in the atmosphere would then perform its metabolism. Hence the organic compounds in the wastewater would serve as the nutrients for the microbes to digest and grow. By such periodical operation, the microbes would grow, and a certain thickness of the sludge film would be obtained. , The rotary movement also allows excess bacteria to be removed from the surfaces of disks and maintains a suspension of sloughed biological solids. A final clarifier is needed to remove sloughed solids (Husham et al., 2012).

RBCs are commonly used as secondary treatment process, but are also used in advanced wastewater treatment processes (Zickefoose, 1984). When temperatures are high enough and carbonaceous BOD is low enough, a shaft media identical to that used in secondary treatment will develop a biomass consisting of primarily nitrifying bacteria which will convert remaining ammonium-nitrogen to nitrate-nitrogen. If denitrification is required following nitrification, totally submerged RBC shafts in anoxic tanks are used to grow a denitrifying bacteria population. The denitrifiersconcvrt the nitrate to nitrogen gas which bubbles to the surface and escapes to the atmosphere.

3.2.2 Advantages (http://www.mecana.ch/en/products/scheibentauchkoerper-en)
1) It has open viewable biomass surface and hence there is no risk of clogging.
2) The entire disk surface can be used for design calculation without deduction.
3) There is simplicity of maintenance and operation. It has low operating and maintenance cost.
4) There is lower production of sludge than in the activated sludge process.
5) It can be combined with a clarifier for fast settling sludge.
6) There is lowest energy demand.
7) There is no sophisticated and expensive process engineering control required.
8) It has very low maintenance.
9) There are no flies or objectionable odours.
10) It has high surface area.
11) It has high activated sludge concentration.
12) The replacement of damaged rotating biological disks is possible.
13) Nitrification can be attained even at low temperatures.
14) It is a reliable, robust and durable technology.
15) The space requirement is low.

3.2.3 Disadvantages

1) There is limited control for the process.
2) There is limited experience and training.
3) There is complexity in the operation of RBC.
4) Proper recirculation is required in this process.

3.3 Integrated Fixed Film Activated Sludge (IFAS)

Integrated fixed film activated sludge is a relatively new technology that describes any suspended growth system that incorporates an attached growth media within the suspended growth reactor (http://www.sswm.info/content/fixed-film-activated-sludge). IFAS process is comprised of a fixed film media free moving or stationary combined with activated sludge (Abdel and Amr, 2012). The fixed film media allow attached biofilm growth within a suspended reactor, which increases the amount of biomass available (Hazen and Sawyer, 2011). Increase in biomass increases nutrient removal with minimal increase in basin size or foot print. By allowing the fixed film phase to retain biomass in the basin, the IFAS process can be operated at low solid retention time and still achieve nitrification.

The IFAS variation of the MBBR process gets its name from the integration of biofilm carrier technology within conventional activated sludge (http://www.headworksinternational.com/biological-wastewater-treatment/IFAS.aspx). This hybrid process enables activated sludge systems to achieve gains in volumetric productivity without increasing MLSS levels in the process. IFAS systems deliver improved performance while reducing the solids impact on clarification processes (http://www.sswm.info/content/fixed-film-activated-sludge). IFAS technology is the first process specifically designed for ideal operation in municipal wastewater treatment/activated sludge processes. The technology was initially developed by the Government of Canada through 1994-97 where multiple technologies were assessed for cost effective municipal waste water treatment upgrades(http://www.headworksinternational.com/biological-wastewater-treatment/IFAS.aspx).

An IFAS system can be located in the anoxic zone, aerobic zone, or both zones. Secondary clarification and tertiary filtration processes are still required with an IFAS system and are designed similar to conventional and advanced sludge systems. The IFAS configuration may vary by the type of activated sludge system and by the type of media used.

3.3.1 Operation

IFAS technology appears in many forms, and a variety of media is available to choose from (http://www.headworksinternational.com/biological-wastewater-treatment/IFAS.aspx). The different types of media include networks of strings or rope that are suspended in the water, free floating sponges, and hard plastic media. Each of these media technologies has advantages and disadvantages. One difference is the biomass retention on a string system or free floating sponge and a hard plastic media.

By maintaining a low SRT (Sludge Retention Time), the process has also been credited with better settling sludge with lower SVI (Sludge Volume Index) compared with conventional activated sludge processes(Germain et al., 2005 and Hubbel and Krichten, 2004). This technology appears in many forms, and a variety of media is available to choose from. One difference is the biomass retention on a string system or free floating sponge and a hard plastic media (Johnson et al., 2004 and Kaldate et al., 2008).

Typical MLSS (Mixed Liquor Suspended Solids) concentrations range from 1000 to 3000 mg/l in IFAS systems, although concentrations as high as 5000mg/l have been used (Hazen and Sawyer, 2011). The sludge volume index (SVI) of an IFAS system is similar to an activated sludge system with biological nitrogen removal. An IFAS system is a maintenance intensive process. Free floating systems require additional component installation over the fixed film media type, which include screens to contain the media within the tanks, screen cleaning systems, and media circulation pumps. Air diffusers are also required to provide mixing and to keep the free-floating media from clogging downstream screens. Sponge type free floating media require recycle airlift pumps and media cleaning pumps while plastic carriers do not (Hazen and Sawyer, 2011). Additionally, free floating media are more susceptible to hydraulic problems due to media clogging the screen. Free-floating media must be pumped to another tank during maintenance and cleaning, and redistributed afterwards. Fixed media systems must be designed so that the media can be taken out or relocated during maintenance and cleaning. Odours are a significant concern when fixed film systems are dewatered as the media may quickly generated odours, Additionally, fixed media systems are generally more susceptible to supporting worm populations.

3.3.1 Advantages (www.headworksinternational.com/biological-wastewater-treatment/IFAS.aspx)

1) IFAS offers a cost-effective means of upgrading municipal wastewater facilities, minimal plant down time, optimization of existing equipment all result in cost savings.
2) IFAS technology has the unique capability to be expanded and upgraded to meet new demands, as populations grow, industrial activities increase or wastewater flows and concentrations change.
3) 3. IFAS achieves increased process stability under conditions of variable mixed liquor, solids retention, and organic loading rates.
4) Operators with experience in maintaining conventional activated sludge systems find the operation of IFAS processes highly intuitive.
5) By achieving a high density population of fixed film bacteria within the activated sludge process, MLSS levels are lower in relation to treatment productivity. Clarifier performance is optimized by reducing the solids loading generated from the secondary biological process.
6) It allows secondary treatment expansion without additional aeration basins.

7) Improved nitrification capacity, greater resistance to hydraulic washouts, and increased resistance to shock loads in IFAS technology.
8) It has improved solids settling and better SVI characteristics.
9) It has potential for simultaneous nitrification/denitrification.
10) It has small footprint.
11) It has improved sludge settling ie decrease in sludge volume index.
12) It is less sensitive to sustained peak flow and it is not susceptible to washouts.

3.3.2 Disadvantages

1) It is not a perfect fit for every plant.
2) It has performance based specifications
3) There is media migration or loss.
4) Media retention devices/sieves are required.
5) Increased oxygen supply is required.
6) There is accumulation of foam.
7) It is highly energy intensive and so operational cost is high.
8) There are only a few numbers of facilities operating with this technology.

3.4 Membrane Bioreactor (MBR)

MBR is technically similar to that of a traditional wastewater treatment plant, except for the separation of activated sludge and treated waste water (Abel, and Amr, 2012). In an MBR installation, this separation is not done by sedimentation in a secondary clarification tank, but by membrane filtration (Hazen and Sawyer, 2011). There is continuous development of membrane materials and membrane design and also on the knowledge of operational management.

The use of membrane bioreactors is becoming more popular since costs have decreased and more stringent effluent limits are being required (Hazen and Sawyer, 2011). Due to small footprint, this technology is a viable option in land constrained areas that are facing strict nutrient limits or capacity upgrades. Membranes replace secondary clarifiers and tertiary filters in a conventional treatment process (Hazen and Sawyer, 2011). Membranes must be preceded by a conventional activated sludge system, with or without advanced nutrient capabilities depending on the effluent disposal goals. The separation of reduction-oxidation zones and the use of internal recycles are still required to meet advanced nutrient removal goals.

3.4.1 Operation

MBR is a combination of conventional biological waste water treatment plant and membrane filtration (Abel, and Amr, 2012). MBR consists of activated sludge reactors, process air blowers, membrane reactors, membrane system, membrane blowers, return activated sludge pumps and waste activated sludge pumps. (Hazen and Sawyer, 2011). The purpose of activated sludge reactors is the same as in the conventional activated sludge process i.e. the use of microorganisms to remove soluble and particulate organic matter. Immediately downstream of the bioreactors are the membrane reactors. The membranes are submerged in mixed liquor. Either gravity or low head pumps are used to separate the permeate from the activated sludge solids. A separate set of blowers is required in the membrane reactors to maintain the proper thickness of sludge cake on the membrane surface. RAS (Return Activated Sludge) pumps are used to recirculate activated sludge back to the bioreactors to keep the solids in the membrane reactor within a target range and not overly concentrated. WAS (Waste Activated Sludge) pumps route waste sludge from the membrane reactors to solids handling facilities. Hollow fibers and flat sheets are the two most common membrane configurations in current use in MBRs. Hollow fiber membranes are long and narrow tubes grouped in bundles that are generally mounted vertically in frame and placed in a single module and it typically falls in the range of 0.04 to 0.1 micron. There are some hollow fiber membranes with pore sizes of 0.4 micron. Membrane flat sheets are flat sheets of membranes with pore sixes between 0.08-0.4 micrometers.

An advantage of MBR system is the ability to operate at high MLSS concentrations due to the effectiveness of membranes in solid-liquid separation (Hazen and Sawyer, 2011). Typical MLSS concentrations range from 8000 to 18000 mg/l in membrane reactors. At such high MLSS concentrations, the size of the bioreactor does not have to be as large as it does for conventional activated sludge. The ratio of bioreactor sizes for MBR systems to conventional treatment systems range from 0.5 to 0.67:1 for biological nutrient removal process.

3.4.1 Advantages (Hazen and Sawyer, 2011)

1) It is a smaller foot print treatment.
2) It has consistent, high quality effluent particularly for total suspended solids.
3) No final clarifier or filter is required.
4) It is resilient to fluctuations in solids loading.
5) It has high degree of automation.
6) No settling of sludge is required.
7) It has short reactor hydraulic retention times.
8) Membranes function as a positive barrier.

3.4.2 Disadvantages

1) It has higher capital cost and energy cost and there is cost of membrane replacement.
2) Maintenance requirement is higher.
3) One major drawback in MBR systems is membrane fouling. Fouling may be caused by scaling, biofouling, particle fouling or chemical fouling.
4) It has high degree of automation.
5) The performance is sensitive to pretreatment processes.
6) Some form of influent equalization is required.
7) High flow events can lead to increased membrane maintenance.
8) It has hydraulically limited capacity through membranes.

3.5 Fluidized Bed Biofilm Reactor (FBBR)

The Fluidized Bed Biofilm Reactor (FBBR) is a recent process innovation in wastewater treatment, which utilizes small, fluidized media for cell immobilization and retention (Shieh and Chun, 1989). Aerobic as well as anaerobic fluidized bed biofilm reactors (FBBRs) have received increasing attention for being an effective technology to treat water and waste water (Burghatel and Ingole, 2013). Its most important features are the fixation of microorganisms on the surface of small-sized particles, leading to high content of active microorganisms and large surface area available for reaction with the liquid; the high flow rate (low residence time) which can be achieved, leading to high degree of mixing transfer resistances) and to large reduction in size of the plant, and the removal of clogging (Traverso and Cecchi,1992).

Biological fluidized beds (BFB) originate from observations of denitrification made while using activated carbon to remove organic compounds from chemically treated sewage (Williams et al., 1986). Initially BFBs were developed for denitrification of fully nitrified sewage effluents and later developed for carbonaceous oxidation and nitrification of settled sewage. Patents for biological fluidized beds are vested in Ecolotorol Inc. of New York who have exclusively licensed Dorr-Oliver Inc. to exploit the use of the process under the trade names OXITRON and ANITRON. Dorr-Oliver have been involved in pilot scale research and built many demonstration and full scale plants in USA and Canada (Williams et al., 1986).

3.5.1 Operation

The basic concept of the process consists of passing wastewater up through a packed bed of particles at a velocity sufficient to impart motion to or fluidize the particles. As the flow of wastewater passes upward through the biological bed, very dense concentrations of organisms growing on the surface of the bed particles consume the biodegradable waste contaminants in the liquid (Burghatel and Ingole, 2013).

Fluidized beds combine the best features of activated sludge and trickling filtration into one process. Offering a fixed film and a large surface area, fluidized bed systems offer the stability and ease of operation of the trickling filter as well as the greater operating efficiency of the activated sludge process. Treatment is accomplished in significantly less space, time, and cost than conventional treatment.

3.5.2 Advantages

The advantages of FBBR are as follows (Burghatel and Ingole, 2013). :

1) As the media on which microorganisms grow is in fluidized state, the surface of the media available for the development of microorganisms is quite large which leads to high concentration of microorganisms and thus high flow rate can be achieved in FBBR.
2) Because of large concentration of microorganisms, FBBR bears high potential for the removal of various parameters such as BOD, COD, nitrogen etc.
3) Size of the FBBR plant is small as compared to other types of the reactors and hence the space requirement is less.
4) FBBR is capable of accepting shock loads.
5) Treatment by FBBR is economical where land cost is high.
6) If FBBR is operated properly, there is no need to provide secondary settling tank, which leads to a saving in the total cost of plant.
7) FBBR provides an extraordinary long SRT for microorganisms necessary to degrade the xenobiotic and toxic compounds.
8) The system operation is simple and reliable.

3.5.3 Disadvantages

1) Power is required for operation.
2) Inlet and outlet arrangement are to be properly designed.

3.6 Sequencing Batch Reactor (SBR)

Conventional SBRs were used all over the world in development of waste water treatment system (www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf). However, improvements in equipment and technology, especially in aeration devices and computer control systems, SBRs have become a viable choice over the conventional activated sludge system. They differ from activated sludge plants because they combine all of the treatment steps and processes into a single basin, or tank, whereas conventional facilities rely on multiple basins.

Conventional activated sludge process (ASP) is not designed to remove nitrogen(www.eolss.net/sample-chapters/c07/e6-144-11.pdf). Further due to its short detention time, the sludge produced is not well digested warranting an additional sludge digestion treatment. Since the 1970s, a modification of the conventional activated sludge process has made the emergence of the sequencing batch reactor (SBR) process. Conventional ASP systems are space oriented. Waste water flow moves from one tank in to the next on a continuous basin and virtually all tanks have a predetermined liquid volume. The SBR, on the other hand, is a time-oriented system, with flow, energy input, and tank volume varying according to some pre-determined, periodic operating strategy, falling under the broad category of an unsteady state activated sludge system(Irvine and Richter, 1976).

To achieve continuous flow with sequencing batch reactors, at least two reactors are required so that while one receives flow, the other is undergoing the treatment process reactor (Hazen and Sawyer, 2011). Three or more reactors may often be required for complete redundancy. In SBR system, sludge wasting usually occurs during the react phase. Additionally, return activated sludge is not required since the react and settling phases occur in the same basin. Pre-aeration and flow equalization basin is required for when the SBR is in the settle and/or draw phases.

3.6.1 Operation

As opposed to conventional activated sludge, sequencing batch reactors (SBRs) achieve both organic removal and settling in the same reactor (Hazen and Sawyer, 2011). Additionally, the wastewater is not continuously discharged into or withdrawn from the reactor. Instead, the wastewater flows into the bioreactor during a fill period. The biological reaction periods are then initiated, followed by the settling period. Clean effluent is then withdrawn from the rector and the biomass is left idle until the next cycle begins. These five steps may be described as the fill, react, settle, draw, and idle periods. Sequencing batch reactors may also be modified to achieve nutrient removal by providing aerobic, anaerobic, and anoxic conditions within the same tank. SBR systems do not have secondary clarifiers. Therefore, the footprint of an SBR system is generally smaller than that of a conventional system(www3.epa.gov/npdes/pubs/sbr_new.pdf).

The operation of an SBR is based on a fill-and-draw principle, which consists of five steps- fill, react, settle, decant, and idle. These steps can be altered for different operational applications(www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf). It is full during fill phase, the basin receives influent wastewater. The influent brings food to the microbes in the activated sludge, creating an environment for biochemical reactions to take place. Mixing and aeration can be varied during the fill phase to create the following three different scenarios:

Under a static fill scenario, there is no mixing or aeration while the influent wastewater is entering the tank. Static fill is used during the initial start-up phase of a facility, at places that do not need to nitrify or denitrify, and during low flow periods to save power(http://www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf). Because the mixers and aerators remain off, the scenario has energy-saving components. Under a Mixed fill scenario, mechanical mixers are active, but the aerators remain off. The mixing action produces a uniform blend of influenthttp:(www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf). Then, in the react phase, the basin is aerated, allowing oxidation and nitrification to occur. During the settling phase, aeration and mixing are suspended and the solids are allowed to settle. The treated wastewater is then discharged from the basin in the basin in the decant phase. In the final phase, the basin is idle as it waits for the start of the next cycle. During this time, part of the solids are removed from the basin and disposed of as waste sludge.

3.6.2 Advantages

(http://www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf)

1) SBR has the ability to adjust process timing via PLC in reactor for specific processes (such as aerobic, anaerobic, and anoxic).
2) High quality effluent can be achieved when operated properly.
3) It has smaller footprint than conventional activated sludge.
4) No secondary clarifiers and RAS pumping is required.

3.6.3 Disadvantages

1) There is discontinuous discharge and consequent negative effect on downstream processes.
2) There is relatively large reactor volumes.
3) The advanced nutrient removal is difficult.
4) There is discontinuous discharge and consequent negative effect on downstream processes.
5) Batch discharge may require post-equalization.
6) High peak flow may disrupt performance, therefore influent equalization should be considered in design.

4. Comparison of the Techniques

A comparison of these biological treatment techniques namely MBBR, RBC, IFAS, MBR, FBBR, and SBR was made. MBBR and FBBR are attached growth process with mobile media with biofilm whereas RBC is an attached growth process with one or more basins with circular disk mounted on horizontal shaft. IFAS is an attached growth media within the suspended growth reactor. SBR and MBR area suspended growth process, but membrane filtration is done in the case of MBR. In the case of MBBR, FBBR, and IFAS systems, additional components namely screen to contain the media within the tanks; screen cleaning systems, and media circulation pumps are required. Air diffusers are also required to provide mixing and to keep the free floating media from clogging downstream screens. Free floating media are more susceptible to hydraulic problems due to media clogging the screen. During maintenance, free floating media must be pumped to another tank during maintenance and cleaning. In RBC, fixed media can be taken out or relocated during maintenance and cleaning.

In MBBR, solids with poor settling properties are produced and hence chemicals are to be added to improve settling characteristics of the mixed liquor. Improved solid settling and better SVI characteristics can be observed in the case of IFAS.

In fixed film system namely MBBR, and RBC, the microrganisms are attached in fixed films attached to media. Hence they cannot be washed out with increased flows. Fixed film systems also have a greater mass of microorganisms, making them able to handle increased organic load. The microorganisms in a fixed film system are attached to a media, they cannot wash out with increased flows. The activated sludge process, on the other hand is more susceptible to performance deterioration due to hydraulic and organic load variations.

5. Conclusion

Biological treatment of waste water reduces the concentration of pollutant through microbial action and removal of non-settleable organic colloidal solids. The conventional activated sludge process has some disadvantages like high operation cost, requirement of skilled supervision and requirement of more space for the treatment plant. There are various advances and improvements in the reactors to achieve variations in contact time and method of contact, which have resulted in the growth of suspended growth system, attached growth or fixed biofilm systems or combinations thereof. Biofilm processes are proved to be reliable for organic carbon and nutrients removal .In this study, a review of the various biological treatment technologies has been done. Both suspended as well as fixed film processes have been discussed. The various modern technologies include Moving Bed Biofilm Reactor (MBBR), Rotating Biological Contactor (RBC), Integrated Fixed Film Activated Sludge (IFAS), Membrane Bioreactor (MBR), Fluidized Bed Biofilm Reactor (FBBR) and Sequential Batch Reactor (SBR). The merits and demerits have also been ascertained.

MBBR and FBBR are attached growth process with mobile media with biofilm whereas RBC is an attached growth process with one or more basins with circular disk mounted on horizontal shaft. IFAS is an attached growth media within the suspended growth reactor. SBR and MBR area suspended growth process, but membrane filtration is done in the case of MBR.

In the case of MBBR, FBBR, and IFAS systems, additional components namely screen to contain the media within the tanks; screen cleaning systems, and media circulation pumps are required. Air diffusers are also required to provide mixing and to keep the free floating media from clogging downstream screens. The cost of additional cost due to return sludge can be avoided in all cases except IFAS. There is risk of clogging in the case of MBBR and IFAS. The power requirement is low in the case of RBC and SBR.

From the above, it can be observed that every technique has its advantages and disadvantages. When we consider space requirement, less space is required for all the process except IFAS. When the cost of operation is considered, RBC and SBR are less costly. MBBR, IFAS, and FBBR are resistant to shock load. A comparison of these techniques will surely be helpful to choose the suitable technique.

6. Acknowledgements

The authors gratefully acknowledge Dr. Jaya, V., Head of Department of Civil Engineering and Prof. Sunil C. Behanan, Department of Civil Engineering, Government Engineering College, Barton hill, Thiruvananthapuram, for their valuable support

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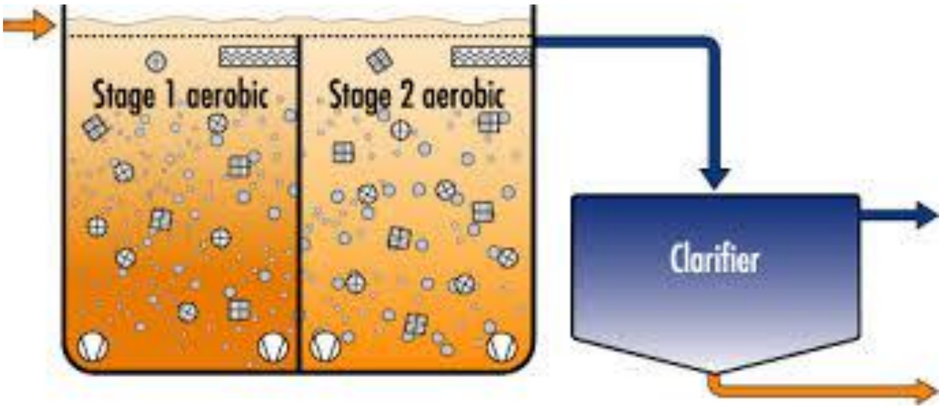

Figure 1: Moving Bed Bioreactor
(Source: lenntech.com/processes/mbbr.htm)

Figure 2: Polyethylene carrier element of MBBR
(Source: lenntech.com/processes/mbbr.htm)

Figure 3: Biofilm in polyethylene carrier element
(Source: lenntech.com/processes/mbbr.htm)

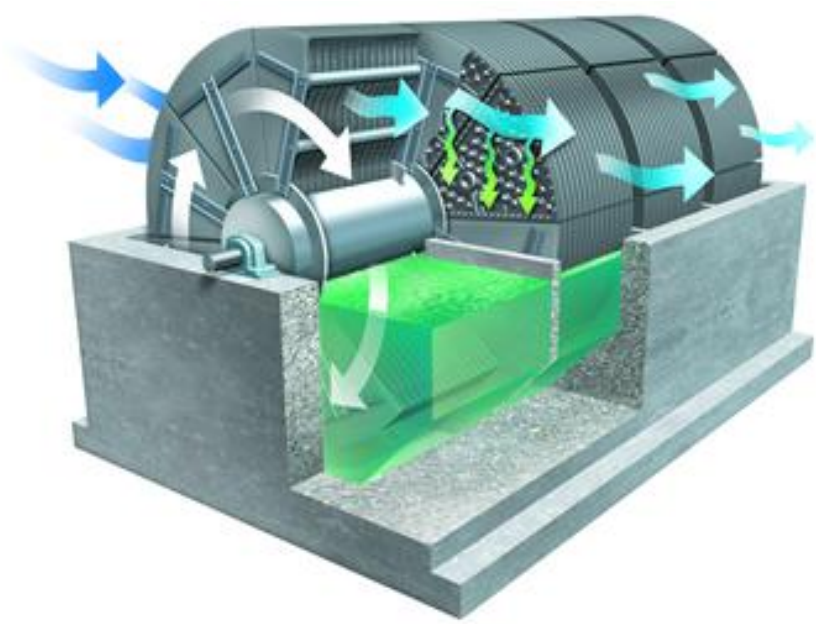

Figure 4: Rotating Biological Contactor
(Source: www.walker.process.com/prod_bio_RBC.htm)

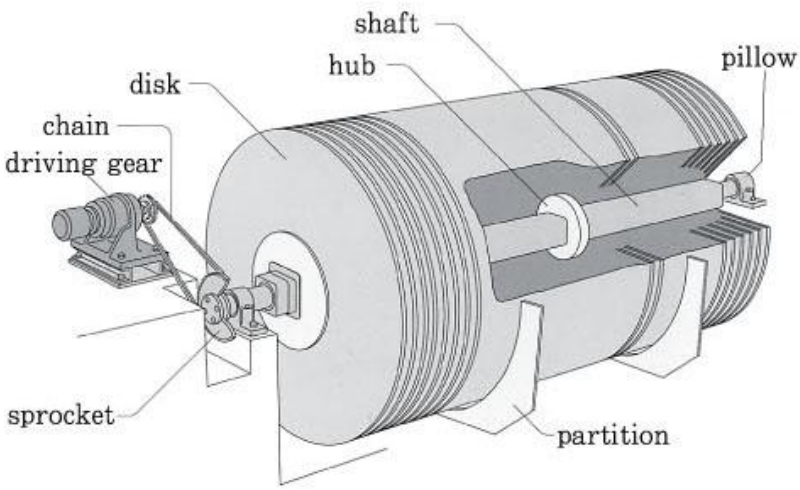

Figure 5: Parts of Rotating Biological Contactor
(Source: www.metal.ntua.gr/pkousi/e-learning/bioreactors/page_16.htm)

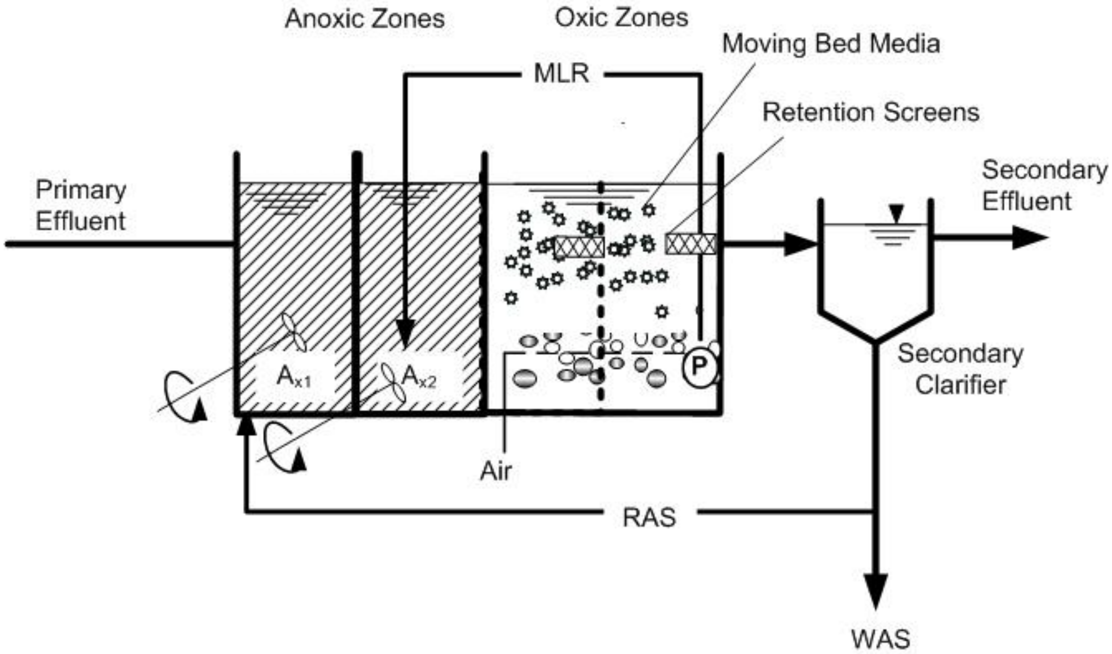

Figure 6: Integrated Fixed Film Activated Sludge (IFAS)
(www.fixedfilmforum.com/q-and-a-forum/integrated-biological-processes)

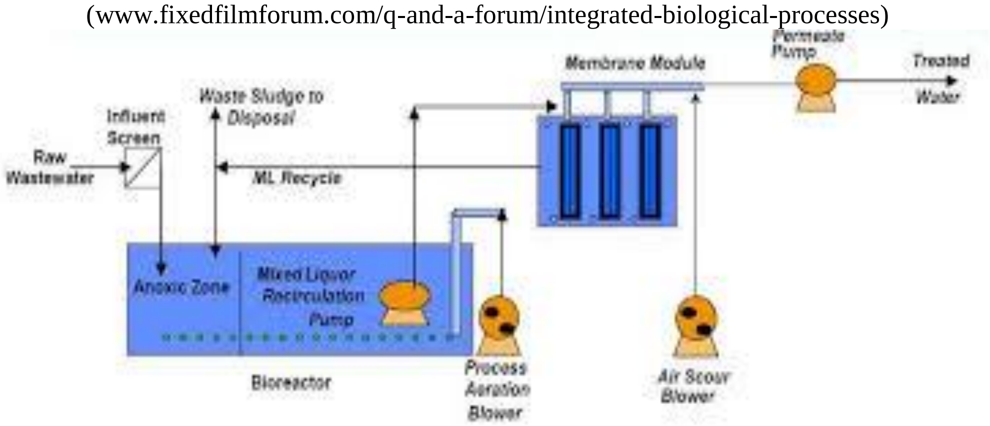

Figure 7: Membrane Bioreactor
(www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/semi-centralised-wastewater-treatments/m)

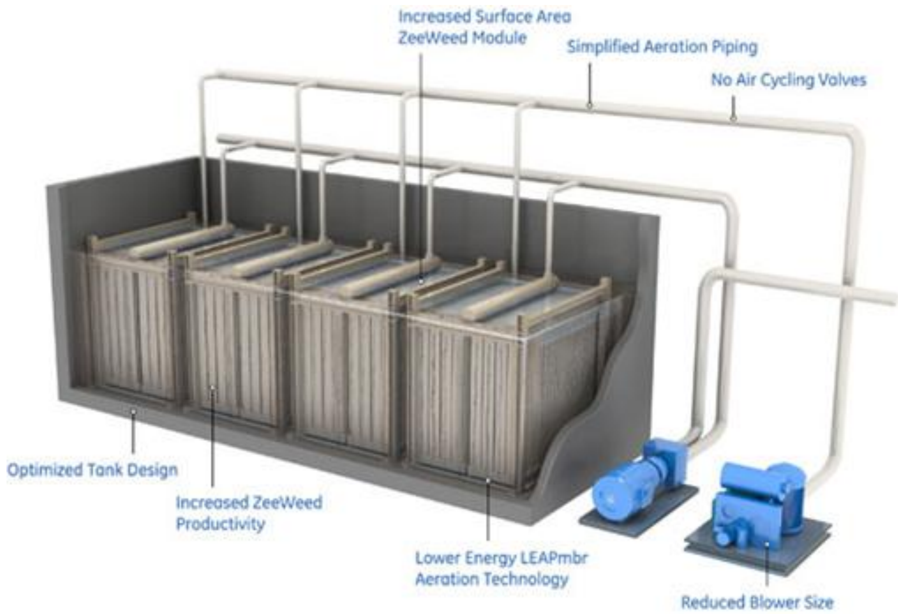

Figure 8: Membrane block
(ww.gewater.com/products/membrane-bioreactor-mbr.html)

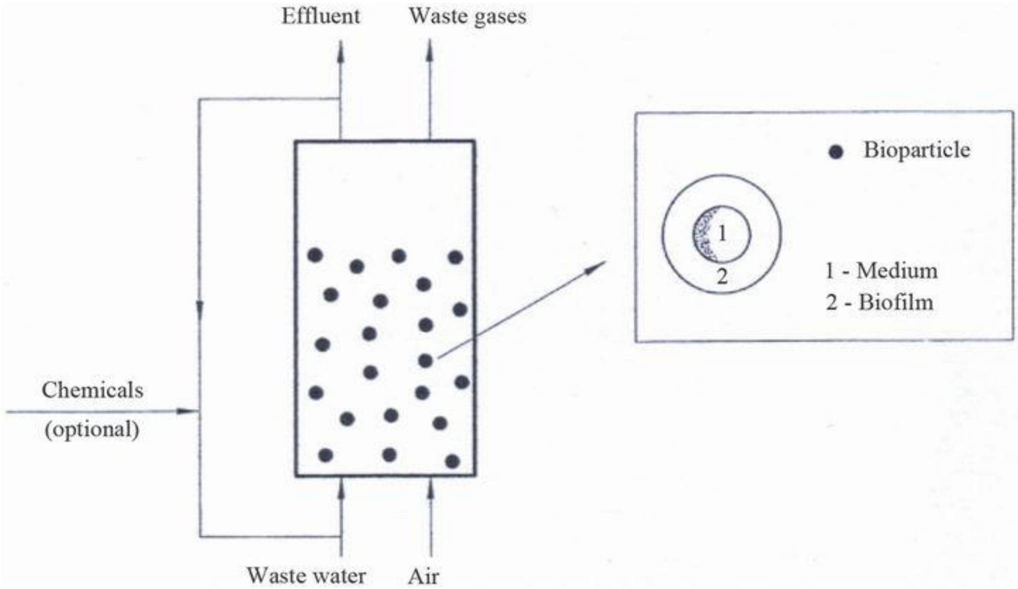

Figure 9: Fluidized Bed Biofilm Reactor (FBBR)
(http://file.scirp.org/Html/10-3700144_20837.htm)

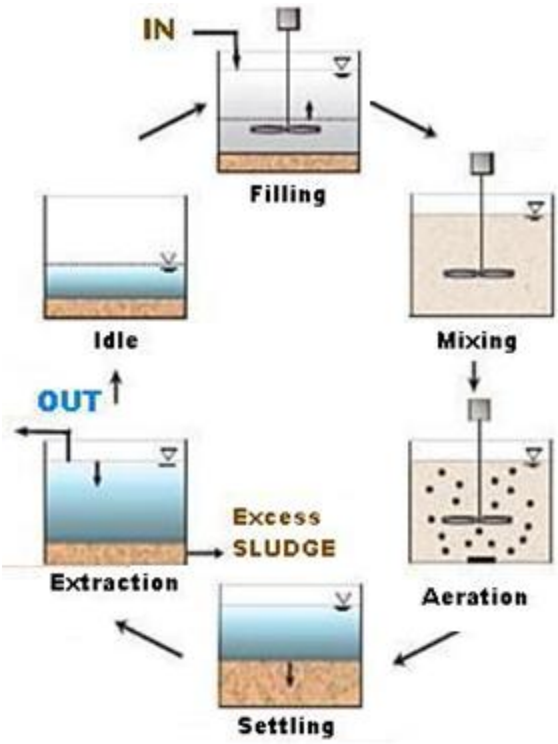

Figure 10: Sequencing Batch Process
[**Source:**www.emaze.com/@AQWIFWI/Final-Design-3-Pres.pptx]

Table 1: Comparison of different biological treatment techniques

No.	Item	MBBR	RBC	IFAS	MBR	FBBR	SBR
1.	Process	Attached growth process Mobile bed biofilm reactor	Attached growth process with circular disk on horizontal shaft	Attached growth media within the suspended growth reactor	Suspended growth process and membrane filtration	Mobile bed biofilm reactor	Suspended growth process
2.	Media	Low density media (polyethylene)	Circular disk mounted on horizontal shaft	String, rope, free floating sponge, hard plastic media	No media	Sand	No media
3.	Activated sludge	No return of activated sludge	No return of activated sludge	Return of activated sludge	No return of activated sludge	No return of activated sludge	No return of activated sludge
4.	Conversion of existing activated sludge process	Easily converted	Not easily converted	Easily converted	Not easily converted	Not easily converted	Not easily converted

5.	Post settling basin	Needed	Needed	Needed	No Membrane filtration.	Not needed	Biological reaction and settling in the same tank
6.	MLSS concentration			1000-3000mg/l	8000-18000mg/l		
7.	Chance of clogging	Clogging of screens due to free floating media	Open viewable biomass surface and no risk of clogging.	Clogging of screens due to free floating media	Membrane fouling. Fouling may be caused by scaling, and biofouling	-	No clogging
8.	Maintenance and cleaning	Free floating media must be pumped to another tank	Disk can be taken out or relocated.	Free floating media must be pumped to another tank	High maintenance	High maintenance	-
9.	Shock load	Resistant to shock load	-	Resistant to shock load		Accept shock load	Shock load disrupt performance
10.	Settling characteristic of sludge	Sludge has poor settling characteristics	Low production of sludge than ASP	Improved solid settling and better SVI characteristics	Membrane filtration and no settling	-	-
11.	Power requirement	High	Low	High	High	High	Low
12.	Operation cost	High	Low	High	High	High	Low
13.	Space requirement	Less	Less	Large	Less	Less	Less