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MODIFIED CLUSTER SYSTEM APPROACH TO WASTEWATER TREATMENT BY USING MEMBRANE BIO REACTOR– A REVIEW

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ABSTRACT

The rapid growth of the population, the technological and industrial boom has brought enormous problems and degradation of the environment. Effective collection and treatment of urban wastewater is a critical problem in a developing country like India. This paper presents a review of decentralized approaches to waste water treatment and management using "Membrane bio-reactor". Make wastewater treatment facilities people centric and an approach towards "waste to resource. Cluster system seems good approach to waste water treatment in terms of sanitation and environmental protection. Need of modification in traditional decentralized system is required, where effluent quality of a septic tank is improved by the use of advance treatment approach like membrane bio-reactor. Advantages of the same are easier for management in term of operation, maintenance and effluent quality. However, centralized system not only require large land area but also high in operation and maintenance cost. Decentralized wastewater systems (DEWATS) allow flexibility in wastewater management and different parts of the system may be combined into "treatment trains," or a series of processes to meet treatment goals, overcome site conditions, and to address environmental protection requirements.

KEYWORDS: Decentralized wastewater treatment system; Cluster system; Membrane Bio-Reactor;

INTRODUCTION

Present scenario of wastewater treatment facilities in developing countries like Africa and Asia is very poor, where demand of fresh water is increasing rapidly in semi urban or urban areas of country for domestic and industrial purpose. The expected population growth between 2000 and 2025 will concentrate in urban areas, where by 2025 about 80% of the population will be living in developing countries in Africa, Asia and Latin America. Fulfillment of water demand by limited fresh water is not a smart decision and requires working on waste to resource approach. Especially in the urban areas, the disposing of domestic wastewater discharges directly into the nearby surface water bodies**. (Diana Paola BERNAL et al., 2012)** Lack of reliable and affordable wastewater treatment facilities in semi urban or urban areas cause pollution in surface water bodies which is also fresh water source for the locality at the downstream.

In this paper, we present a literature review of wastewater treatment in membrane bioreactors with a special focus on cluster system for municipal wastewater treatment. Decentralized sewerage system is defined as the collection, treatment, disposal/reuse of sewage from individual homes, clusters of homes, isolated communities or institutional facilities, as well as from portions of existing communities at or near the point of wastewater generation.(**CPHEEO Manual., 2012**) Cluster system is a type of decentralized system where a common sewage treatment facility is provided for a community or for number of homes.

Membrane bioreactors (MBRs) have been actively employed for municipal and industrial wastewater treatments. They have proven quite effective in removing organic and inorganic pollutants as well as biological entities from wastewater. Advantages of the MBR include good control of biological activity, high quality effluent without pathogens, smaller plant size and enable higher organic loading rates. There have been numerous successful pilot-scale studies reported with some full-scale models in operation in France, the United States, and Japan. (**NazimCicek, et al., 2002).**

CENTRALIZED VS DECENTRALIZED WASTEWATER TREATMENT SYSTEMS

Centralized treatment system is also called off-site system. A centralized wastewater treatment system is a treatment system where all sewage flows to one treatment plant. This type of system was used to treat wastewater for large residential area as a city. The centralized treatment had been applied very successfully in industrialized countries. It has been installed in developed industrial countries long time ago **(Willderer and Schereff, 2000)**.

Centralized system not only requires more money for operation, maintenance, and collection wastewater from generation point to treatment place, but also needs very good infrastructure support for its operation such as pipeline system, pump stations and electricity system. In the developing and lower income countries, it is very difficult to build this system because of inadequate funds and they have to save financial investment for other things. Centralized systems follow a "linear model" of energy intensive water Use and discharge. Under this system, wastewater is transported through the Sewers, treated, and discharge into a water body. Some of the Problems associated with this model were the high cost of building and maintaining infrastructure, bypassing of sewage systems during storms resulting in direct discharge of sewage into the water bodies, and groundwater contamination due to sewer crack leaks (**Elmer, et al, 2007**).

Decentralized wastewater treatment system is defined as the collection, treatment, and reuse of wastewater at or near the point of wastewater generation. This system had been utilized for many years using a number of different treatment technologies, most notably septic systems. It is a "close loop" system that treats wastewater onsite and provides treated water for some type of reuse, such as irrigation and toilet flushing. Depending on the technology, DEWATS could also provide the opportunity to reuse the nutrients of wastewater. In view of this, decentralized technologies covering a range of wastewater treatment technologies which could be an "*ideal*" solution to accommodate urban growth by providing location specific sewage treatment options that can outweigh most of the negative aspects associated with centralized systems **(Tjandraatmadja, *et al*., 2009).**

With the emerging suite of decentralized technologies, however, conventional technology such as septic tank can be combined with advanced decentralized wastewater treatment technologies to deliver treated sewage quality matching to Class A recycled water. The advanced suite of centralized treatment technologies include attached biological media (biological activated carbon & bio filters), adsorption processes using sand or clay materials, membrane technologies such as membrane bioreactor (MBR), microfiltration (MF), ultra filtration (UF) and reverse osmosis (RO) and tertiary disinfection treatments such as UV sterilization and chlorination. (**Meng Nan Chong *et al*., 2011)**

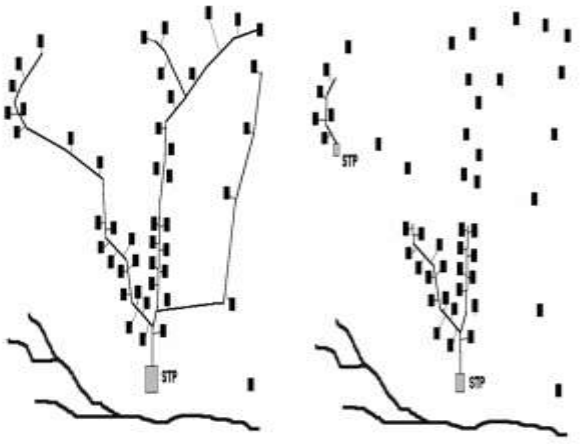


Fig. 1 shows comparison between centralized and decentralized system

NEED OF MODIFICATION

Decentralized system which was already in use from long time ago is septic tank which is used as treatment unit before discharge into nearby surface water and facultative lagoons and natural aeration tank which required large land area and required long time to achieve good effluent quality. By modification in the treatment process there is a chance to improve effluent quality with a low O &M cost and without any nuisance in surrounding environment. Advancement in wastewater treatment technology shows the requirement of tertiary treatment needed to remove suspended, colloidal and dissolved constituents remaining after conventional treatment. The need of advancement in cluster system is based on a consideration of one or more of the following factors which include the need to remove nutrients beyond what can be accomplished by conventional treatment processes so as to limit eutrophication of sensitive water bodies and to remove specific inorganic(eg. heavy metal and silica) and organic constituents for industrial and domestic reuse (eg. cooling water, process water, low pressure boiler make up water and high- pressure boiler water and flushing water in toilets, gardening etc.). (Metcalf**& Eddy, 2012**)

WHY CLUSTER SYSTEM?

Historically, wastewater collection and treatment systems were designed to handle wastewater flows generated within the urban core areas, typically at the lowest point that would drain by gravity near a point of discharge, typically a water body. It is fair to say that the early planners could not have anticipated the unprecedented growth that had occurred in most modern cities. As cities have continued to grow, many centralized wastewater management systems have become overloaded. Expansion of existing collection system components which would involve disruptions in the flow of traffic and other public activities is not viewed favorably by most municipal governments and the populous. As a consequence of growth and development and constructability issues, planners are now being forced to evaluate a number of alternatives for the future development of wastewater management facilities including the use of satellite and decentralized facilities, as discussed in this paper. If decentralized wastewater management facilities are to be used to reduce the demand for potable water, there should be opportunities to use the reclaimed water from these facilities**. (Petros Gikas, et al., 2009)**

MEMBRANE BIO-REACTOR PROCESS

A process that uses both biological stage and membrane modules has recently been developed for wastewater treatment: and known as the Membrane Bioreactor (MBR) process. The bioreactor and membrane module each have a specific function:

- Biological degradation of organic pollutants is carried out in the bioreactor by adapted biomass;
- Separation of biomass from the treated wastewater is performed by the membrane module.

The membranes constitute a physical barrier for all suspended solids and therefore enable not only recycling of the activated sludge to the bioreactor **(B. Marrotet, al., 2004).** In addition, the process is more compact than a conventional activated sludge process (CAS), removing three individual processes of the conventional scheme and the feed wastewater only needs to be screened (1- 3 mm) just prior to removal of larger solids that could damage the membranes.Basically, primary sedimentation tank, final sedimentation tank and disinfection facility are not installed in this process. The reaction tanks comprise an anoxic tank and an aerobic tank, and the membrane modules are immersed in the aerobic tank. Pre-treated, screened influent enters the membrane bioreactor, where biodegradation takes place. The mixed liquor is withdrawn by water head difference or suction pump through membrane modules in a reaction tank, being filtered and separated into solid and liquid. Surfaces of the membrane are continuously washed down during operation by the mixed flow of air and liquid generated by air diffuser set at the bottom of the reaction tank. Permeate from the membranes constitutes the treated effluent. (**CPHEEO Manual., 2012**)

As already stated, MBRs represent an important technical option for wastewater treatment and reuse, being very compact and efficient systems for separation of suspended and colloidal matter and enabling high quality effluents to be achieved. A key advantage of the systems is complete biomass retention in the aerobic reactor, which decouples the sludge retention time (SRT) from the hydraulic retention time (HRT), allowing biomass concentrations to increase in the reaction basin, thus facilitating relatively smaller reactors or/and higher organic loading rates (ORL).

CONFIGURATION OF MBR

There are two main basic designs for MBR plants. The membranes can be submerged directly in the bioreactor, or submerged in multiple side tanks with a constant recirculation of wastewater. The design and selection of MBR process is dependent on a number of design considerations and it based on individual project (**Tchobanoglous, et al., 2003**).In which the membrane is directly submerged into bioreactor is known as immersed membrane system and in which where the membrane is externally fixed in a reactor is known as external membrane system. The optimal physical structure of the membrane material is based on a thin layer of material with a narrow range of pore size and a high surface porosity. This concept is extended to include the separation of dissolved solutes in liquid streams and the separation of gas mixtures for membrane filtration.

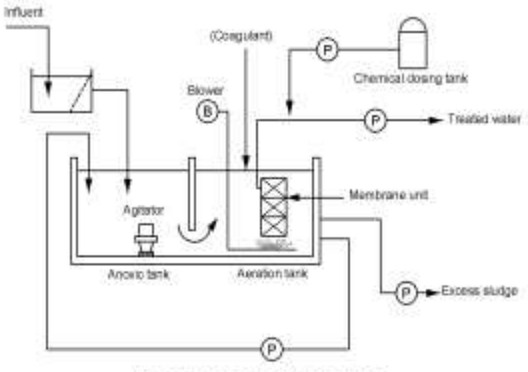
TABLE 1 COMPARISION OF SUBMERGED AND EXTERNAL MBR SYSTEMS

Sr. No.	Parameter	SUBMERGED MBR	EXTERNAL MBR	Sr. No.	Parameter	SUBMERGED MBR	EXTERNAL MBR
1	SUITABILITY	Low strength wastewater with good filterability	High strength wastewater with poor filterability	6	MEMBRANE AREA REQUIREMENT	More area is required	Less area is required
2	MEMBRANE FLUX	Lower membrane flux or lower permeate per unit area of membrane	Higher membrane flux or higher permeate per unit area of membrane	7	ECONOMICS	Generally less expensive at lower wastewater influent rate	Generally more expensive at lower wastewater influent rate
3	TRANSMEMBRANE PRESSURE (T.M.P.)	Lower TMP is required	Higher TMP is required	8	MEMBRANE BACKWASHING AND CLEANING	More frequent backwashing and cleaning required	Less frequent backwashing and cleaning required
4	POWER REQUIREMENT	Less power is required per m^3 of wastewater treated	More power is required per m^3 of wastewater treated	9	OPERATION	Less operational flexibility	More operational flexibility with control parameters like SRT, HRT,and MLVSS
5	SENSITIVITY	Less sensitive to variations in wastewater characteristics and flow fluctuations	More sensitive to variations in wastewater characteristics and flow fluctuations	10	EXTENSION OF WWTP CAPACITY	Difficult to extend	Easier to extend

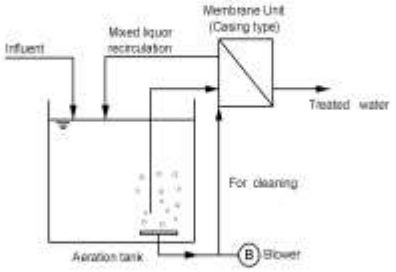
Source: water and wastewater treatment tech. –
C. Visvanathan

Membranes can be classified on the basis of

- The driving force used for the separation of impurities, such as pressure, temperature, concentration gradient, partial pressure, electrical potential etc
- The structure and chemical composition.
- The mechanism of separation.
- The construction geometry of the membrane. Microfiltration (MF) and ultra filtration (UF) are low pressure driven processes, where feed water is driven through a micro-porous synthetic membrane and divided into permeate, which passes through the membrane and the non-permeating species could be rejected. In wastewater treatment applications, these processes are more effective in removal of particles and microorganisms.



(a) Immersed membrane system



(b) External membrane system

Fig. 2 Configuration of membrane bioreactor system

Table 3 Membrane types and membrane characteristics used in submerged MBR systems. (B. Marrot et al., 2004)

Membrane geometry	**Membrane characteristics**	**Wastewater**
Hollow fibre	MF-polypropylene	Municipal and synthetic
Hollow fibre	MF(0.1µm) Mitsubishi	Municipal
Hollow fibre	Zenon (0.1µm)	Refinery
Hollow fibre	-MF polysulfone (0.2-0.4µm)	Municipal
Flat	MF polyethylene (0.4 µm)	Domestic
Hollow fibre	MF polyethyel ene (0.1 µm)	Municipal

Table 2: Membrane types and membrane characteristics used in external MBR systems. (B. Marrot et al., 2004)

Membrane geometry	**Membrane characteristics**	**Wastewater**
Tubular	Ceramic (0.2 µm)	Synthetic
Plate	UF (20 kDa)	Alcohol distillery
Tubular	Ceramic (0.2µm)	Food (ice cream)
	Zircon (0.05 µm)	
Tubular	Alumina (0.2 µm)	Municipal
	Zircon (0.05 µm)	
Tubular	Ceramic (0.1 µm) Kerasep	Municipal
Tubular	Ceramic (Al2O3-TiO2) (300 kDa) Kerasep	Municipal
		Synthetic
Tubular	Ceramic (ZrO2) (0.02 _m–300 kDa)	Municipal
Tubular	UF Zenon (75 kDa)	Sanitary and industrial
Tubular	UF (15 kDa)	Synthetic (fuel oil)

APPLICABILITY OF MBR IN MUNICIPAL WASTEWATER TREATMENT

MBR treatment system is applicable to including municipal, industrial and water reclamation sectors. The use of MBR process for water reclamation can reduce the demand for potable quality water on local supplies, and pollution from waste discharges into local water bodies. (**Scott et al., 2003**). The filtration of municipal activated sludge is an ideal application for MBR treatment. Unlike the conventional system, the membrane bioreactor is characterized by a complete retention of the biomass inside the bioreactor because of the use of membrane separation, which controls and increases the sludge retention time (SRT) independently from the hydraulic retention time (HRT). High SRTs enable one to increase the sludge concentration and the applied organic load, thereby increasing the pollutant degradation. (**B. Marrot et al., 2004**). The use of MBR systems allows for higher sewage flow or improved treatment performance in a smaller space than a conventional biological system using activated sludge because there are no installations of secondary sedimentation tanks, sand filters and disinfection facilities. The high-quality effluent produced by MBRs makes it particularly suitable for reuse applications and for surface water discharge applications requiring extensive nutrient (nitrogen and phosphorus) removal. (**CPHEEO Manual, 2012**)

The specific sludge activity during organic matter decomposition and nitrification depends on the SRT. The SRT is a significant operational factor for the biological process (**Xia Huang et al., 2001**). The nitrifying activity of sludge is maximal at a SRT of 10 days, but the organic degradation rate decreases while the SRT increases. Huang et al. 2001 have compared variations in the SRT on the performances of a conventional bioreactor and a membrane bioreactor considering SRT. Chemical Oxygen Demand (COD) removal (70–80%) occurs in the conventional bioreactor a small reduction in COD consumption was observed in the bioreactor with short SRTs (5 to 10 days). In the MBR process, COD removal (90%) remains constant which was independent of SRT. (**B. Marrot et al., 2004**)

Case example- 4.54 MLD STP using MBR technology in the Games Village Complex, Delhi. (CPHEEO Manual., 2012)

In Delhi during commonwealth games MBR was used in STP of games village complex for an Average flow of 4.54 MLD, Peak Flow: 11.35 MLD, Lean Flow: 2.0 MLD

The schematic flow diagram of 4.54 MLD STP using MBR technology in the Games Village Complex is shown in Figure and the description of each process of this plant are shown in Table

Table: 4 Description of each process

Bar Screen	Fine Screen	Equalization/ Balancing Tank	Ultra-Fine	Anoxic Tank	Aeration Tank	Membrane Bio Reactor	Treated Water Holding Tank
1 Nos.	1 Nos.	1 Nos.	2 Nos.	2 Nos.	2 Nos.	4 Nos.	1 Nos.
Opening 20 mm	Opening 6 mm	2,900 m^3 (HRT 6 hrs.)	Opening 1 mm,	370 m^3 (Total) (HRT 1.9 hrs.)	830 m3 (Total) (HRT 6.5 hrs)	473 m^3 (Total)	2,244 m^3

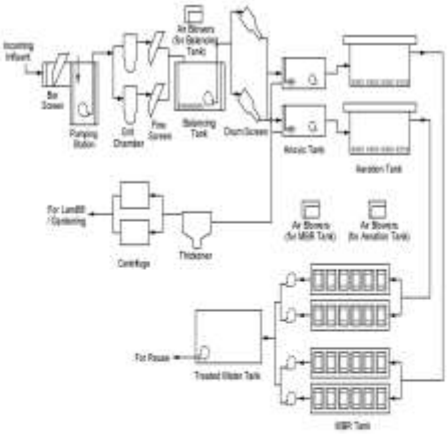


Fig. 3 The schematic flow diagram of 4.54 MLD STP using MBR technology, Delhi

Table: 5 Performance of plant- CPHEEO Manual., 2012

Parameter	**Unit**	**Influent**	**Effluent**
pH	**-**	**7.0-7.6**	**6.8-7.8**
Temperature	**^{o}c**	**18-38**	**-**
TSS	**mg/L**	**400**	**<1.0**
BOD_5	**mg/L**	**250**	**<2**
Total COD	**mg/L**	**750**	**-**
Total kjeldahl Nitrogen	**mg/L**	**40**	**<1.0**
Total NH_4^+-N	**mg/L**	**25**	**<0.5**
Total Alkalinity	**mg/L**	**305**	**-**
Total Coliform	**MPN/100ml.**	**-**	**2**

Why MBR IN CLUSTER SYSTEM?

According to various literatures which were referred in this paper suggested a best process for decentralized system with a high quality effluent by the use of membrane bio-reactors. Conventional decentralized system require less energy to operate but have low efficiency of removing BOD_5, COD, TSS, TOS, and other content causing pollution in surface water and create nuisance to surrounding. In MBR less unit operations are required which is best suitable for cluster system where a less area and operations are required (**Metcalf& Eddy., 2012**).

It can reduce the amount of treatment chemicals and require less area for storage (footprint) i.e., 50 to 80% less space than conventional plants. The same also requires less labor requirement and can be automated easily. Membrane bioreactor (MBR) is an emerging technology for wastewater treatment that is capable of transforming various types of wastewater into high quality treated effluent, equal or exceeding almost every discharge requirement. Unlike conventional activated sludge process, MBR usually available in a small physical size, produces less activated sludge, and achieves higher biomass concentration for organic mineralization (**Gander et al., 2000**).

Membrane Bioreactors are able to provide the benefits of biological treatment with a physical barrier separation. Compared to conventional treatment processes, membranes are able to provide better quality effluent with a similar, automated treatment process (**Jain Jyoti., *et al 2013*).**

All these characteristics make MBR an attractive technology option for decentralized wastewater treatment. To date, there are only a few published studies that discuss the potential application of MBR for small-scale decentralized wastewater treatment (**Gander et al., 2000**).

Most of the current design knowledge and guidelines on MBR plants are applicable to large scale centralized WWTPs. Thus, there exists an imperative to close the knowledge gaps on design and implementation for small-scale MBR plants. (**Meng Nan Chong1., *et al 2011).***

This system is a holistic management approach that aims to develop a method to treat domestic wastewater and solid waste that would treat solid waste and reclaim wastewater effluent in a decentralized manner. The method includes an incorporation of the domestic wastewater and the liquid fraction of kitchen waste that contains the organic components, directing it in an aerobic membrane bioreactor (MBR) treatment module. **(Melissa Montalbo et al.)**

MERITS AND DEMERITS

Literature showed some merits and some demerits of MBR systems over conventional biological systems. The major claimed advantages include better effluent quality, smaller space requirements, and ease of automation. Specifically MBRs operate at higher volumetric loading rates which result in lower hydraulic retention times. The low retention times mean that less space is required compared to a conventional system. MBRs have often been operated with longer solids residence times (SRTs) which results in lower sludge production; but this is not a requirement, and more conventional SRTs have been used **(Crawford et al. 2000)**. Effluent contains low concentrations of bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD) and phosphorus. This facilitates high-level disinfection & effluents are readily discharged to surface streams or can be sold for reuse, such as irrigation. **(EPA REPORT., 2007)**. In membrane technology treatment system, high levels of mixed liquor suspended solids(MLSS) (7000-9000mg/l) level was observed in the aeration tank but the MLVSS was only about 50% of this value, clearly indicating 50:50 ratio of bacterial mass and other solids. The unit works more efficiently at high MLSS level than that at low MLSS. In the conventional Sewage treatment plants (CSTP) about 4660-5840 mg/l of MLSS was maintained in the aeration tank, which indicates well microbial mass whereas the MLVSS varied between 35% and 60% of MLSS. The DO in the aeration tank of was maintained very high (4.9 mg/l). This was due to the reason that extended aeration process was adopted and to maintain a high MLSS, high DO level was also required. In CSTP, generally DO maintained is 1-3 mg/l. Due to efficient oxidation, in the MBR, it was further seen that the treated effluent carried nitrate contents ranging 13-32 mg/l, which could be classified as well nitrified effluent. The increase in the Nitrate-Nitrogen and decrease of TKN (avg. 87%) and Ammonia cal-Nitrogen (avg. 85%) value in the final treated water indicated satisfactory oxidation level in both MBR unit and the CSTP. **(CPCB report, 2006)** The initial cost is more than that of the CSTP, whereas the operation and maintenance cost is less. The manpower required in this technology is less, as it is required only for supervision. So, in the long run, this technology will be economically viable as compared to the CSTP. The primary disadvantage of MBR systems is the typically higher capital and operating costs than conventional systems for the same through-put. O&M costs include membrane cleaning and fouling control and eventual membrane re-placement. Energy costs are also higher because of the need for air scouring to control bacterial growth on the membranes. In addition, the waste sludge from such a system might have a low settling rate, resulting in the need for chemicals to produce bio-solids acceptable for disposal (**Hermanowicz et al. 2006**). **Fleischer et al. 2005** had demonstrated that waste sludge from MBRs can be processed using standard technologies used for activated sludge processes.

This process does not need primary and final sedimentation tanks, and disinfection facilities; therefore, it requires smaller space than conventional biological systems (generally around 1/3 of ASP system). The effluent from MBRs is very transparent and fine containing almost no TSS. Organic matters (BOD) are well removed because of lower concentration of TSS compared with ASP process. Phosphorus also can be removed by adding coagulant in reaction tank. Oil and grease has to be totally removed otherwise membranes will be choked and unusable. It needed a flow equalization tank to regulate fluctuation of the influent and fine screens for pre-treatment to protect membranes. (CPHEEO Manual., 2012)

DESIGN/OPERATIONAL PARAMETERS OF MBR

Table: 6 Typical design parameters of MBR process-CPHEEO Manual-2012

COD Loading (kg/m3/ day)	F/M (kgCOD/ kgMLVSS/ day)	SRT (days)	MLSS (mg/L)	Flux (L/m2/day)	Applied Vacuum (kPa)	DO(mg/L)
1.2-3.2	0.1-0.4	5-20	5000-20000	600-1100	4-35	0.5-1.0

Table 7 EFFLUENT QUALITY COMPARISION OF ASP AND MBR (Cicek et al., 1999)

Parameters	Activated sludge	MBR
Sludge age (d)	20	30
COD removal (%)	94.5	99
Dissolved Organic Carbon removal (%)	92.7	97
TSS removal (%)	60.9	99.9
A-N removal	98.9	99.2
Total P removal (%)	88.5	96.6
Sludge production (kg VSS/COD.d)	0.22	0.27
Mean flocs size (µm)	20	3.5

CONCLUSIONS

This treatment process strongly depends on the biomass concentration which controls the mass transfer in the bioreactor and the level of membrane separation. Consequently, it is very important to be able to quantify and understand the factors limiting mass transfer. MBRs have been proven as efficient and versatile systems for wastewater treatment over a wide spectrum of operating conditions. The treatment performance of the MBR is better than in conventional activated sludge process. A high conversion of ammonium to nitrate (>95%) and constant COD removal efficiency (80-98%) was achieved, regardless of the in fluent fluctuations. Microbial analysis of permeate showed the absence of bacterial indicators of contamination and parasitical microorganisms. At the same time, the membrane presented over 98% efficiency in the elimination of viral indicators.The application of MBR technology is rapidly expanding, with new installation occurring every year. MBR tech. is highly suited for the reclamation of w/w due to the ability to produce drinking water quality effluent. The effluent produced can be reused within the industrial processes or discharged to surface water without degrading streams and water. The small foot print and ease of the MBR systems makes it ideal for cluster system approach where wastewater can be reused for industrial and irrigational purposes. In addition for urban areas where industrial and municipal waste both equally contributed in wastewater, cluster system seems to be a good approach by using MBR tech. is better than any other technology. It can be adapted to almost any industrial and municipal wastewater and thereby reducing demand on local supplies, and pollution in local water bodies.

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