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Membrane bioreactors for waste water treatment

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ABSTRACT

Membrane bioreactors can be defined as systems combining biodegradation of waste products with filtration. These are very effective in removing organic and inorganic contaminants as well as biological entities from wastewater. Main advantages of the MBR include good control of biological activity, high quality effluent free of bacteria and pathogens, smaller plant size, and higher organic load rates. This article aims to review all the principles and potential applications of the MBR technology.

Keywords: MBR, Fouling, mixing and hydrodynamics

INTRODUCTION

Membrane bioreactor is the combination of a membrane process like microfiltration or ultrafiltration with a suspended growth bioreactor, and is now widely used for municipal and industrial wastewater treatment with plant sizes up to 80,000 population equivalent (i.e. 48 million liters per day) [1]. It is possible to operate MBR processes at higher mixed liquor suspended solids (MLSS) concentrations compared to conventional settlement separation systems, thus reducing the reactor volume to achieve the same loading rate. Two MBR configurations exist: internal/submerged, where the membranes are immersed in and integral to the biological reactor; and external/side stream, where membranes are a separate unit process requiring an intermediate pumping step. Recent technical innovation and significant membrane cost reduction have enabled MBRs to become an established process option to treat wastewaters [1]. Membrane bioreactors can be used to reduce the footprint of an activated sludge sewage treatment system by removing some of the liquid component of the mixed liquor. This leaves a concentrated waste product that is then treated using the activated sludge process.

MEMBRANE FILTRATION

Filtration is defined as the separation of two or more components from a fluid stream. In conventional usage, it usually refers to the separation of solid or insoluble particles from a liquid stream. Membrane filtration extends this application further to include the separation of dissolved solids in liquid streams, and hence membrane processes in water treatment are commonly used to remove various materials ranging from salts to microorganisms. Membranes processes can be categorized in various, related categories, three of which are: their pore size, their molecular weight cut-off; or the pressure at which they operated. As the pore size gets smaller or the molecular weight cut-off decreases, the pressure applied to the membrane for separation of water from other material generally increases.

MBR CONFIGURATIONS

Internal/submerged

The filtration element is installed in either the main bioreactor vessel or in a separate tank. The membranes can be flat sheet or tubular or combination of both, and can incorporate an online backwash system which reduces membrane surface fouling by pumping membrane permeate back through the membrane. In systems where the membranes are in a separate tank to the bioreactor, individual trains of membranes can be isolated to undertake cleaning regimes incorporating membrane soaks, however the biomass must be continuously pumped back to the main reactor to limit MLSS concentration increase. Additional aeration is also required to provide air scour to reduce fouling. Where the membranes are installed in the main reactor, membrane modules are removed from the vessel and transferred to an offline cleaning tank [2].

External/side stream

The filtration elements are installed externally to the reactor, often in a plant room. The biomass is either pumped directly through a number of membrane modules in series and back to the bioreactor, or the biomass is pumped to a bank of modules, from which a second pump circulates the biomass through the modules in series. Cleaning and soaking of the membranes can be undertaken in place with use of an installed cleaning tank, pump and pipe work.

MAJOR CONSIDERATIONS IN MBR

Fouling and fouling control

The MBR filtration performance inevitably decreases with filtration time. This is due to the deposition of soluble and particulate materials onto and into the membrane, attributed to the interactions between activated sludge components and the membrane. This major drawback and process limitation has been under investigation since the early MBRs, and remains one of the most challenging issues facing further MBR development [3,4]. In recent reviews covering membrane applications to bioreactors, it has been shown that, as with other membrane separation processes, membrane fouling is the most serious problem affecting system performance. Fouling leads to a significant increase in hydraulic resistance, manifested as permeate flux decline or transmembrane pressure (TMP) increase when the process is operated under constant-TMP or constant-flux conditions respectively [5]. Membrane fouling results from interaction between the membrane material and the components of the activated sludge liquor, which include biological flocs formed by a large range of living or dead microorganisms along with soluble and colloidal compounds. The suspended biomass has no fixed composition and varies both with feed water composition and MBR operating conditions employed. Thus though many investigations of membrane fouling have been published, the diverse range of operating conditions and feed water matrices employed, the different analytical methods used and the limited information reported in most studies on the suspended biomass composition, has made it difficult to establish any generic behaviour pertaining to membrane fouling in MBRs specifically.

BIOLOGICAL PERFORMANCES/KINETICS

COD removal and sludge yield

Simply due to the high number of microorganism in MBRs, the pollutants uptake rate can be increased. This leads to better degradation in a given time span or to smaller required reactor volumes. In comparison to the conventional activated sludge process (ASP) which typically achieves 95 percent, COD removal can be increased to 96 to 99 percent in MBRs. COD and BOD_5 removal are found to increase with MLSS concentration. Above 15 g/L COD removal becomes almost independent of biomass concentration at >96 percent [6]. Arbitrary high MLSS concentrations are not employed, however, as oxygen transfer is impeded due to higher and non-Newtonian fluid viscosity. Kinetics may also differ due to easier substrate access. In ASP, flocs may reach several 100 μm in size. This means that the substrate can reach the active sites only by diffusion which causes an additional resistance and limits the overall reaction rate (diffusion controlled). Hydrodynamic stress in MBRs reduces floc size (to 3.5 μm in side stream MBRs) and thereby increases the apparent reaction rate. Like in the conventional ASP, sludge yield is decreased at higher SRT or biomass concentration. Little or no sludge is produced at sludge loading rates of 0.01 kg COD/(kg MLSS d)[7]. Because of the imposed biomass concentration limit, such low loading rates would result in enormous tank sizes or long HRTs in conventional ASP.

Nutrient removal

Nutrient removal is one of the main concerns in modern wastewater treatment especially in areas that are sensitive to eutrophication. Like in the conventional ASP, currently, the most widely applied technology for N-removal from municipal wastewater is nitrification combined with denitrification. Besides phosphorus precipitation, enhanced biological phosphorus removal (EBPR) can be implemented which requires an additional anaerobic process step.

Some characteristics of MBR technology render EBPR in combination with post-denitrification an attractive alternative that achieves very low nutrient effluent concentrations [8].

Mixing and hydrodynamics

Like in any other reactors, the hydrodynamics (or mixing) within an MBR plays an important role in determining the pollutant removal and fouling control within an MBR. It has a substantial effect on the energy usage and size requirements of an MBR, therefore the whole life cost of an MBR is high. The removal of pollutants is greatly influenced by the length of time fluid elements spend in the MBR (i.e. the residence time distribution or RTD). The residence time distribution is a description of the hydrodynamics/mixing in the system and is determined by the design of the MBR (e.g. MBR size, inlet/recycle flow rates, wall/baffle/mixer/aerator positioning, mixing energy input). An example of the effect of mixing is that a continuous stirred-tank reactor will not have as high pollutant conversion per unit volume of reactor as a plug flow reactor.

Many factors affect the hydrodynamics of wastewater processes and hence MBRs. These range from physical properties (e.g. mixture rheology and gas/liquid/solid density etc.) to the fluid boundary conditions (e.g. inlet/outlet/recycle flowrates, baffle/mixer position etc.). However, many factors are peculiar to MBRs, these cover the filtration tank design (e.g. membrane type, multiple outlets attributed to membranes, membrane packing density, membrane orientation etc.) and its operation (e.g. membrane relaxation, membrane back flush etc.).

Applications in Municipal Wastewater Treatment

MBR systems were initially used for municipal wastewater treatment, primarily in the area of water reuse and recycling. Compactness, production of reusable water, and trouble – free operation made the MBR an ideal process for recycling municipal wastewater in water and space limited environments. By the mid 1990s, the development of less expensive submerged membranes made MBRs a real alternative for high flow, large scale municipal wastewater applications. Over 1,500 MBRs are currently in operation around the world in Japan, Europe and North America [9].

CONCLUSIONS

The MBR concept is similar to conventional biological wastewater treatment except for the separation of the activated sludge and treated wastewater. In the MBR system this separation is done by membrane filtration whereas in the conventional system is done by secondary clarification. Also the process can be run in a nitrification/ denitrification mode to remove nitrogen compounds, and can be combined with the use of a coagulant for phosphorus removal. The MBR technology has great potential in wide ranging applications including municipal, industrial wastewater treatment and solid waste digestion.

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