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Review

Immersed membrane bioreactors: An overview with special emphasis on anaerobic bioprocesses

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ABSTRACT

Immersed membrane bioreactor (IMBR) has emerged as a novel potential technology which is considered globally as potent technology, primarily for wastewater treatment. It offers quality improvement in effluents treatment compared to other technological systems. It also offers potential benefits for the bioprocesses where product formation and separation is desired simultaneously in a compact container. This review gives insight for the wide range applications of IMBR focussing on anaerobiosis. It discusses the significance, advantages and drawbacks of IMBR against the conventional methods, highlighting the external membrane bioreactors. While the commercial significance of IMBR is obvious for industrial and municipal wastewater treatment, the current focus is shifting on other applications such as anaerobic bioprocesses. Though the IMBR technology is generally considered hand-in-hand as sustainable technology, the major bottleneck in its application at commercial scale for wastewater treatment seems its economic feasibility and compatibility. Among the technical issues, the membrane fouling is considered as a major problem for which several strategies have been developed to overcome the problem, though there is no complete or universal solution to this problem.

1. Introduction

Membrane technology has become a very dignified separation process due to its relatively low energy requirement with no additional chemical added. Membrane separation integrated with biological treatment lead to the development of membrane bioreactor (MBR) technology. It refers to a coupled process with these two elements rather than the sequential process. This review article is an attempt to highlight potential applications of IMBR other than wastewater treatment; however, wastewater treatment has been discussed as a major model application of the above technology. There are several documents on different issues of MBR related to wastewater treatment, membrane fouling, etc. available in the literature, but very few deal with other applications. It is considered in this document that anaerobiosis could be the most potential emerging application of this technology in coming years.

This technology finds immense potential for municipal and industrial wastewater treatment applications as it has a significant advantage that it generates a high grade effluent. It forms the basis of many industrial and wastewater treatment installations, where a high grade effluent is demanded. The number of the MBR installed worldwide has also increased due to reduction in membrane cost and increasing environmental stringent regulation. In Europe and North America it has been accepted as a preferred approach for wastewater treatment and reuse applications, particularly in environmentally sensitive regions or where water supply is limited. Wastewater treatment has been used as a model process initially to prove the significance of technology, but finds immense applications in various other processes where the products have inhibitory effects in the process and need to be removed for efficient performance. It can be applied for enzymatic reactions where product inhibition occur, since the membranes are able to remove continuously the product which in turn helps to avoid the inhibition and higher productivity can be achieved. For example, a thermostated membrane bioreactor has been applied for the hydrolysis of pectin by *Aspergillus niger* polygalacturonase to avoid product inhibition. In this process vacuum was used in the permeate side in order to increase the trans-membrane pressure, resulting in higher product removal rate (flux) and productivity (Kiss et al., 2009). High specificity membranes are now available which, for example, can separate butanol isoforms.

Mainly two configurations of MBR exist; internal/submerged/immersed where the membranes are immersed in the biological reactor or in separate reactor (IMBR) (Figs. 1a and b); and external/side stream (EMBR) (Fig. 2) where membrane is a separate unit process requiring an intermediate pumping step. The difference in these configurations is that the direction of flow is reverted and the achievable value of trans-membrane pressure (ΔP) is different. In

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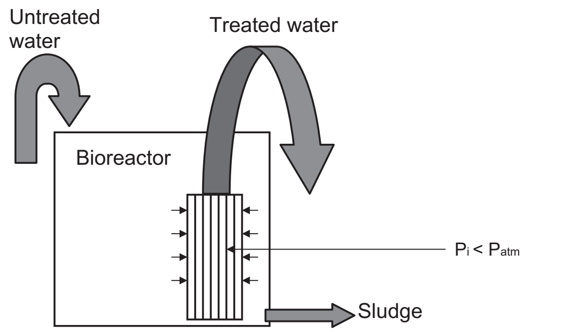

Fig. 1a. Internal immersed membrane bioreactor, Pi = pressure inside, Patm = atmospheric pressure.

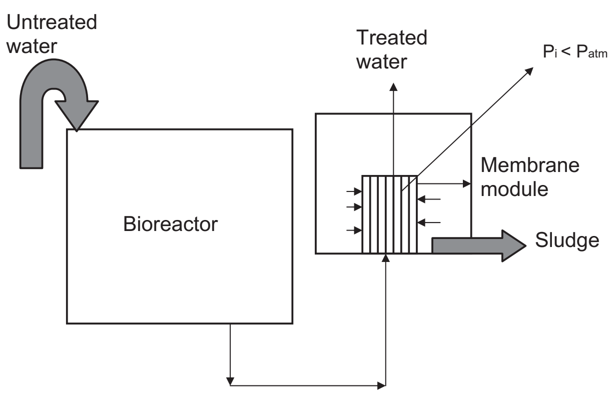

Fig. 1b. External immersed membrane bioreactor, Pi = pressure inside, Patm = atmospheric pressure.

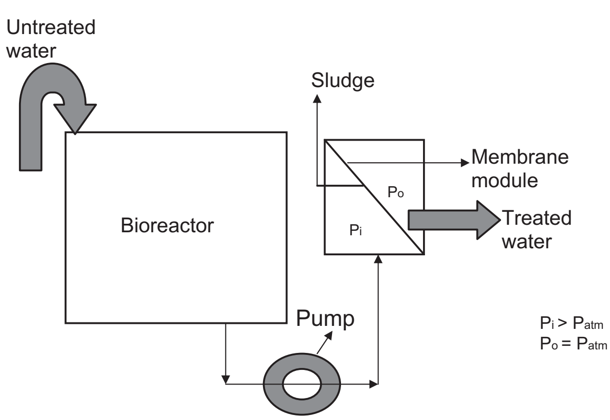

Fig. 2. Non-immersed/external membrane bioreactor, Pi = pressure inside, Po = pressure outside, Patm = atmospheric pressure.

EMBR, the liquid is pushed across the membrane while in IMBR, it is pumped. The trans-membrane pressure for EMBR can thus be higher than for IMBR thus decreasing the exchange area needed for a given permeate flow and increasing the energy requirement for the former. The MBR was commercialised in 1970s as a side-stream process, where membrane was located outside the main reactor (biological treatment) separately in a separation device, but the breakthrough in MBR arose in 1989 with the idea of Yamamoto and his co-workers to submerge or immerse the membrane in biological reactor, which gave rise to immersed membrane bioreactor (IMBR) (Benedek and Cote, 2006). IMBR technology offers several advantages over conventional approaches of wastewater treatment such as small footprint (compact process), high grade effluent, low energy input and the most importantly environmental sustainability (Pabby et al., 2008; Oron et al., 2008; Le-Clech et al., 2006; Yang et al., 2006). But, its widespread implementation and sustainability for viable wastewater treatment is limited due to its relatively higher cost (Judd and Judd, 2010) due to high energy requirement for aeration in particular (Verrecht et al., 2008), which is not required for conventional treatment and membrane cleaning management and replacement (Kennedy and Churchouse, 2005). In IMBR, aeration is considered as the major parameter for both the hydraulic and biological process performance as it maintains solids in suspended form, scours the membrane surface and also provides oxygen to the biomass for better biodegradability and cell synthesis, so energy requirement for aeration cannot be compromised.

Since IMBR technology is only 20 years old, so long term operational experience and membrane performance data is limited and if it is; rarely detailed report is available on installation for more years. Hence, it can be said as an emerging technology and extensive research is needed in all the areas including design of bioreactor, membrane material, type of module, strategies to prevent membrane fouling, potential applications, etc.

In this technology the cost of membrane and its maintenance also shares a major portion of the cost. Recent technical innovations and significant reduction in membrane cost have enabled immersed membrane bioreactor technology to be accepted as preferred process for any biological process including wastewater treatment, though further reduction in cost is required to be an economic efficient process.

2. Commercial status of membrane bioreactor

MBR global market is experiencing an accelerated growth which is expected to be sustained till next decade. It was in 1970s that it was commercialised as side stream process but the introduction of immersed system after two decades resulted in exponential growth of the technology (Judd, 2008). European membrane bioreactor market was estimated to be nearly 57$ million in 2004 and is expected to have sustainable growth in future too. UK/Ireland, France, Germany, Iberia, Benelux and Italy are the major players in European market for membrane bioreactors (Frost and Sullivan, 2003, 2005) (Fig. 3). United States and Canadian MBR market is also expected to have sustained growth in the next decade mainly due to revenue from membrane based water purification, desalination and wastewater treatment (Frost and Sullivan, 2004). It has been estimated that the market will double every 7 years (Judd 2008).

In North America, MBR market has been dominated by Zenon and according to review published in 2006 (Yang et al., 2006), 71% of the total installations of MBR in USA, Canada and Mexico is provided by Zenon. Memcor is a long established HF membrane filter supplier and represents a potential significant player in MBR market which is at par with Zenon on potable water treatment (Judd and Judd, 2010).

3. Evolution of Immersed membrane bioreactor

IMBR is a result of evolution of MBR where the membrane is immersed in the bioreactor instead of being outside as a separate unit. The idea of IMBR was conceived in late 1980s or early 1990s by independent team at Japan and Canada. Prof Yamamoto and Aya conducted laboratory experiments with fine hollow fibres immersed in an activated sludge reactor (Benedek and Côté, 2006). The concept was picked up by Japanese companies Kubota and Mitsubishi Rayon who continued the research and development