

## Potential of Membrane Bioreactors' in Ethanol and Biogas Production a Review

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### Abstract

In the recent years because of the vast globalization and industrialization leading to an alarming rate of increase in the consumption of non-renewable (conventional) fuels and detrimental increase in the pollution levels, the focus has shifted to the biomass based fuels (biofuels) which with every passing day are becoming more and more important as a source of energy. Researchers are focusing on the design of cost effective and environment friendly process for the production of these fuels of which bioethanol is of much importance. MBR (Membrane Bioreactors) are of utmost choice for the researchers these days. Many types and classification of MBRs have been mentioned in the literature; each with specific design and performance characteristics suited for a particular application. Each type has its own strength and weaknesses. Though they have been found to be very cost effective but they have certain limitations also. Combining biological processes with membrane separation techniques in a membrane bioreactor (MBR) increases cell concentrations extensively in the bioreactor. Such a combination furthermore reduces product inhibition during the biological process, increases product concentration and productivity, and simplifies the separation of product and/or cells. The current review presents an account of the membrane separation technologies, and the research performed on MBRs, focusing on ethanol and biogas production. The advantages and potentials of the technology are elucidated.

**Keywords:** Membrane Bioreactor; Ethanol; Biogas; Filtration.

## 1. Introduction

In the last decade, the application of membrane technology for biological separation processes have flourished throughout the world because it overcomes several constraints associated with conventional techniques. A large number of companies like Merck-Millipore, Sartorius, Kubota and GE Healthcare are providing a wide range of membranes suited for different separation processes. At present the MBRs are widely used for water and wastewater treatment, for achieving a quality effluent which can be used for reused or recycled [Judd S, Judd C, 2011]. Although the membrane technology has a widespread application in the field of wastewater treatment though the treatment is limited mainly to the aerobic biological processes, because of the complexity of biological reactions, microorganisms used and feed type etc which have a profound effect on membrane fouling [1,2]. Also the presence of inhibitory substances, cost of heating during cooling in cold environments limit the usage of Ambers industrial applications both for ethanol/biogas production as well as wastewater treatment [3]. Though the concept of using MBRs for ethanol is quite new ie. It's in its blooming stage and hence needs to be investigated and used further on a large scale.

Bioreactors differ from conventional reactors in the fact that in a bioreactor the living organisms present operate under mild conditions of temperature and pressure and also the biocatalyst which is used in these reactors is highly specific in terms of its action and very small in quantity. Membrane Bioreactor (MBR) systems essentially consists of combination of pemselective membrane and specificity of biocatalysts in biological reactor systems. The major limiting factor in the commercialization of biotechnology and bioprocess engineering, is the downstream processing including the separation of products from the spent medium [4]. Downstream processes can be both costly as well as challenging because of the dilute product streams obtained during the biological processes, hence this step of product recovery needs to be integrated with other processes so as to cut down operational and capital cost as well as time and increase product yield [5]. During the production of ethanol or biogas, the membrane can either be used for separating cells from the medium, thereby increasing the biomass concentration in the bioreactor, to aid removal of the inhibitor, or to recover product *in situ* as in case of an external MBR system where the bioreactor and membrane modules are separate. Membrane separation techniques can also easily be coupled with continuous processes.[6] Continuous processes have several advantages over traditional batch operations, especially since they use smaller reactors or employ higher dilution rates, lowering capital as well as maintenance costs. The continuous process demands an overall low level of inhibitors in the culture medium and/or high cell concentrations,[7] which is accomplished with the MBR technology.

The aim of the present review was to introduce the MBR technology in ethanol and biogas processes, and to summarize the development of MBRs and various membranetechnologies for these biofuels, and their advantages and future potential.

## **2. Production of Ethanol and Biogas**

Due to an increase in the prices of conventional sources of energy like coal and petroleum the need and demand for the non-conventional environmental friendly fuels like ethanol and biogas arose and by optimizing their production we can reduce the load as well as world's dependence on fossil fuels. This act will not only help in reducing greenhouse effect and hence global warming but also will lead to a decrease in other occupational and environmental hazards of these conventional fuels. As both ethanol and biogas can be produced from renewable feedstocks, such as agricultural, municipal and forest residues, their production does not contribute to net emissions of carbon dioxide. The basic problem with ethanol and biogas production is the question of process economy and product yield which can be curbed by using MBRs which helps in achieving high cell densities and product separation.

Ethanol is currently produced from sugar and starch-rich materials, which are also used as food and feed. The current global debate on food vs. fuel renders these raw materials unsuitable for ethanol production. Now the attention has shifted to wastes and lignocellulosic residuals from a variety of sources like municipalities, agriculture, and forest industries are [8]. Lignocelluloses are usually very recalcitrant, and need pretreatment or complete hydrolysis into fermentable sugars before being utilized for production of, e.g. ethanol or biogas. During their degradation, several toxic compounds are formed, which could have a negative effect on fermentation process. Numerous studies have therefore been carried out, to find ways to overcome the toxicity of hydrolysates, e.g. by using high cell densities, [9] MBR, [10,11] or detoxification [12].

The conversion of organic material mainly waste to methane (biogas) is immensely complex, and consists of four major stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Methanogenesis is the most sensitive step since the methane forming bacteria have a slow growth rate and are highly sensitive to pH, inhibitors and other conditions. Hence it becomes very important that the bacterial cells do not wash out of the reactor, An MBRs have been found to be very successful in achieving higher retention times and avoiding cell washout [Vishvanathan et al 2012].

In order to have an economically viable large scale production of these fuels, optimization of each and every step is important. This can only be achieved by continued and advanced researches in this field.

## **3. Membrane Unit**

For the separation of the components of the bioreactor, the bioreactor is coupled with the membrane unit, the membrane can be organic, inorganic or polymeric in nature. The driving force for the separation of the components is concentration gradient, pressure / vacuum difference across the membrane [Carstensen et al, 2012]. Membrane acts as a barrier allowing the passage of some components over others, the selective nature of membrane is mostly determined by its pore size [Judd et al, 2011]. MBRs used for the production of ethanol and biogas mainly use a microfiltration and ultrafiltration membranes.

Two configurations of MBRs are used these days, in the first configuration the membrane and the bioreactor are separate referred as external cross-flow membrane where a pump forces the broth from the bioreactor across the membrane. In external module the liquid flows parallel to the membrane surface, this type of flow reduces membrane fouling [Chang et al, 1994] and increases the flux but a large amount of energy is required to maintain the continuous flow. When the membrane is operated at pressure lower than the atmospheric pressure or vacuum, a pump can be used to pull the permeate through the membrane. This configuration is referred to as submerged or immersed, since the membrane is in direct contact with the liquid. Less energy is required for running this configuration but problems of membrane fouling may arise at high cell concentrations.

In bioprocesses, membrane is used for different downstream and upstream applications. The interest in membranes for biotechnological operations arises from the need to get high productivity at lower cost. The main MBR configurations used include PF, hollow-fibre, spiral, and tubular geometries [Belfort et al, 1989]. All these modules have been tested on small scale but hollow fibre module is the most widely used as it provides a large surface area per packing density and hence high cell densities can be achieved [Park et al, 1985].

MBR operation depends on membrane flux and with the passage of time due to membrane fouling the permeate flux will get decreased whereas the transmembrane pressure (TMP) will increase. Value of TMP depends on the a critical value, if the value of flux across the membrane is lower than this critical value then the TMP can be kept constant and no fouling of the membrane takes place but if the value of flux increases above this value then TMP increases rapidly along with membrane fouling. Hence, by monitoring the TMP value with time the membrane module can be cleaned on time to avoid fouling. Also the presence of a large amount of solids and soluble compounds, as is the case during fermentation processes, tends to lower the value of the membrane flux with increasing time and cell growth [6]. Different techniques have been explored to overcome this problem, e.g. turbulent promoters, rotating filters, unsteady flows, intermittent jets, periodical inversion of flows, ultrasound, gas injection, anti-fouling membranes, and dynamic membranes. These methods lower the turbulence of the liquid near the membrane, hence destabilizing the cake layer formation. It has been found that UF membranes have lower fouling tendency compared to MF membrane which may be due to differences in pore size [Patel et al, 1987].

Achieving higher ethanol productivity is our aim, today centrifugation or filtration is the most preferred mode of separation of microbial cells at the industrial scale. However, other cell retention methods, such as cell immobilization, encapsulation, or cross-flow membranes, have also been utilized to maintain high biomass concentrations in the bioreactor. MBRs have been applied in several studies on cell recycling, with the purpose of gaining higher productivity. In addition to the external and internal MBR configurations MBR with cell recycle/retention [Cheryan et al, 1983] have been used to achieve high biomass concentration in the bioreactor, extractive

MBRs are used to remove inhibitors eg. Ethanol and pervaporation MBR to eliminate volatile inhibitory compounds from the fermentation broth [Lipnizki et al, 2000].

#### **4. Challenges of Ethanol/ Biogas as Fuel**

There are various social, economic, environmental and technical issues with biofuel production and use, which have been discussed in the popular media and scientific journals. These include: the effect of moderating oil prices, the "food vs. fuel" debate, poverty reduction potential, carbon emission levels, sustainable biofuel production, deforestation and soil erosion, loss of biodiversity, impact on water resources, drivability issues, water absorption, decreased life cycle of parts and engines . These are a few of the many challenges which scientists are facing before they can make ethanol as an economical and acceptable fuel for the common man of the world[Ziang et al,1991].

#### **5. Market Potential of Membrane Technology**

AnMBRs have been commercialized since 1970s firstly as external loops and then as immersed systems for wastewater treatment, desalination and water purification in countries like USA, Canada, Mexico, France, Germany etc. As of the current trend, about 4400 AnMBRs have been installed in over 200 countries by the major membrane manufactures like Kubota, Mitsubishi Rayon and Memcor. Membranes are usually made up of organic polymers, metallic and inorganic materials, e.g. ceramics. Although metallic and inorganic membranes have properties of high tolerance to corrosion, abrasion, oxidation, and better fouling recovery compared to organic polymers, polymeric membranes are more frequently used since they have lower cost. The choice of polymer, however, is often a compromise among the membrane properties which include hydrophilicity, ease of fabrication, cost, and robustness. Although, hydrophobic polymers have good properties including chemical resistance, biocompatibility, low swelling, among others, hydrophobic membranes were found to be more prone to fouling than hydrophilic membranes since most reactions between foulants and membranes are hydrophobic in nature. Therefore, most hydrophobic membranes are hydrophilized to obtain some desirable qualities. Generally, polyolefins, polyethersulfone (PES), and polyvinylidene difluoride (PVDF) are polymers are usually favoured.

#### **6. Future of MBRS**

Some of the advantages of MBR system are footprint efficiency, high quality effluent, high capacity, operation at low pressure(mild operating conditions), enhanced mass transport and reaction rate, saving in terms of labour and easy control. In spite of having a number of advantages the commercial application of MBRs is still limited, especially for ethanol production mainly due to membrane fouling. Membrane fouling not only increases the energy input but also the operating cost. Although anti-fouling measures such as biogas sparging, agitation and aeration, and membrane vibration are

used to reduce fouling rate in membrane operation, they cannot eliminate membrane fouling completely. Unrelenting efforts are being made by various researchers to find ways of keeping membrane fouling to the minimum to avoid frequent cleaning thereby lengthening membrane lifespan.

## 7. Conclusion

The bioeconomy, and in particular, biorefining and bioenergy production, have received considerable attention in recent years as a shift to renewable bioresources to produce similar energy and chemicals derived from fossil energy sources, represents a more sustainable path. Membrane technologies have been shown to play a key role in process intensification and products recovery and purification in biorefining and bioenergy production processes. Among the various separation technologies used, membrane technologies provide excellent fractionation and separation capabilities, diminished product inhibition, amplified product concentration, increased productivity low chemical consumption, and reduced energy requirements. Hence these techniques are being widely used for separation and purification of individual molecules from biomass especially for bioenergy and chemical production, such as bioethanol, biogas and acetic acid. The scientists are working tirelessly in this area and are trying to develop new membrane based integrated processes. As the famous comedian George Carlin quipped in his address on "On Losers" *if we run out of fuel, we run out of electricity, if we run out of electricity we run out of heat and water, if we run out of water we run out of food, if we run out of food, we all die*. Now, the biggest question in front of the scientific community was *Are we running out of water and food because of our quest for biofuels* and the learned community has answered this question with the ongoing and future researches on MBR which are often referred as Mini Biofuels Refinery ie. now we are moving towards a generation of miniaturization.

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