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A review of membrane technology for bioethanol production

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ABSTRACT

Bio-ethanol as a clean and renewable fuel has gained more attention; however greater energy inputs make a slow progress in industry. Membrane technology has potential in the bioethanol production process as a highly selective and energy-saving separation process. This review presented membrane technologies applied in three aspects: (i) microalgae harvesting, (ii) sugar concentration and detoxification, (iii) bioethanol recovery. The performance of different membrane processes was summarized and compared. The advantages and limitations of membrane technologies for these applications are discussed, and it was thought that the hybrid process has great potential in improving membrane efficiency.

Contents

1. Introduction

The increasing energy crisis and growing environmental concerns in recent years have driven the development of technologies to allow for the substitution of fossil fuels with renewable energy [1–4]. Several alternatives are currently being explored, including a range of carbon-free and renewable sources (photovoltaics, wind and nuclear power, hydrogen) in an attempt to replace natural gas, coal and oil in the electricity generation sector. However, there is no such equivalent in transportation, since fuel cells, electric/hybrids and natural gas-based cars are still a long way from becoming mainstream vehicles [5].

Bio-ethanol as a clean and renewable fuel has gained more attention. It can be produced from all kinds of renewable materials such as corn, sorghum, cellulose and algae biomass. On the basis of the raw material used for its production, bioethanol is divided into first-, second- and third-generation bioethanol [1]. The classification of bioethanol is shown in Fig. 1. Burning ethanol instead of gasoline reduces global warming emissions of 20% from corn ethanol and 85% from cellulosic ethanol while entirely eliminating the release of acid rain-causing sulfur dioxide [6]. Meanwhile, bio-ethanol can be added to gasoline for transportation which has been applied in several countries. In Brazil, more than 15% of cars can run on pure ethanol [7,8]. However, bio-ethanol production involves many processes such

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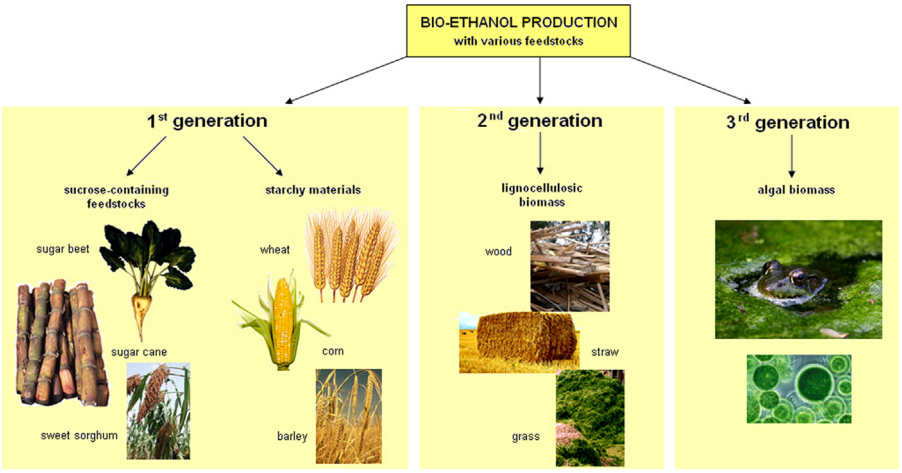

Fig. 1. Classification of bioethanol [17].

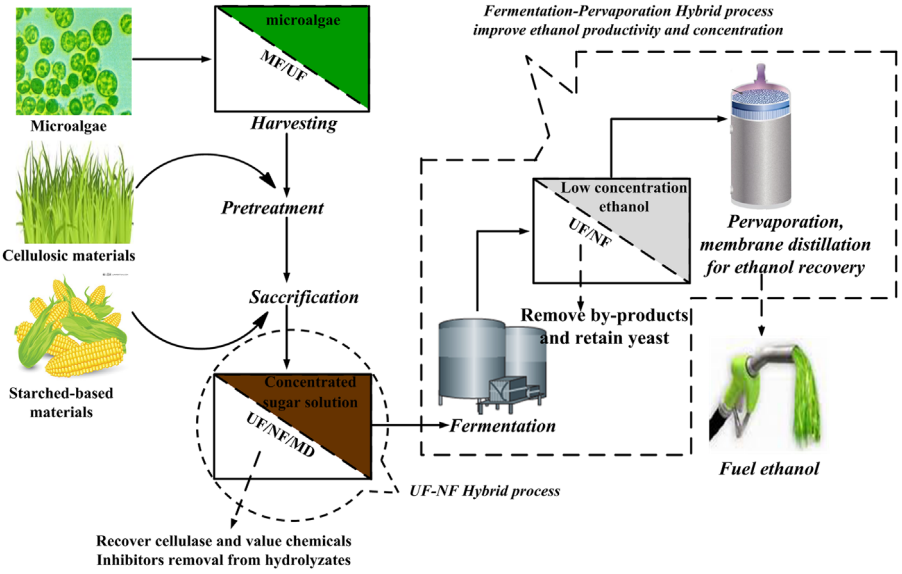

Fig. 2. Application of membrane processes for three generations of bioethanol production.

as pretreatment, fermentation, recovery and the refining process [9]. A total of 5.99 kJ of fossil energy is expended to produce 4.19 kJ of ethanol. The largest energy inputs in corn-ethanol production are for the steam and electricity used in the fermentation/distillation process [10]. Bioethanol will not be significant without improvements in this process and reduced energy requirements. Membrane separation technologies have gained more and more attention due to their reduced energy requirements, lower labor costs, lower floor space requirements and wide flexibility of operation [11]. This technology has applied in many processes of bioethanol production instead of the traditional process [12–16]. The aim of this article is to present a state-of-the-art review on the applications of membrane technologies for bioethanol production such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), membrane distillation (MD) and pervaporation (PV). We also discuss the problems confronted with every membrane process.

2. Membrane technology applied in bioethanol production

An overview of ethanol production with potential membrane applications is depicted in Fig. 2. The first potential membrane application is the harvesting of microalgae for third generation bioethanol synthesis. By the use of MF/UF, it is possible to recover microalgae. For second and third generation bioethanol, pretreatment is a necessary step to make the carbohydrates in the biomass accessible for conversion. The second potential membrane application is the purification and concentration of prehydrolyzates after pretreatment and before fermentation. MD, NF and RO can concentrate the sugar solution and remove inhibitors to fermentation. Regarding recovering the enzyme and other value-added production, an NF process has been considered, combined with UF. After fermentation, low concentration bioethanol is sent for pervaporation and pre-concentration. Fermentation and pervaporation have been integrated in order to perform continuous fermentation. During the hybrid process, UF and NF can be used to remove fermentation inhibitors and yeast. The section part will provide a detailed introduction for each membrane process.

3. Membrane technology for microalgae harvesting

Microalgae is getting more and more attention as a raw material for bioethanol production as it provides carbohydrates and proteins that can be used as carbon sources for fermentation. Meanwhile, microalgae cells have a very short harvesting cycle