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Materials and membrane technologies for water and energy sustainability

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ABSTRACT

Water and energy have always been crucial for the world's social and economic growth. Their supply and use must be sustainable. This review discusses opportunities for membrane technologies in water and energy sustainability by analyzing their potential applications and current status; providing emerging technologies and scrutinizing research and development challenges for membrane materials in this field.

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1. Introduction

Water and energy are fundamental resources used for economic, social and cultural development. These resources have been long presupposed as abundant. With the increase of population and the developments brought by the industrial revolution, their demand increased and scarcity is now an undeniable result.

Fig. 1 illustrates the total global stock of water for human use [1]. From the global water reserve, only 2.5% is fresh water and the rest is saline. From the 2.5% the largest part is frozen in polar regions and 30% are also in remote aquifers of difficult access. As a result only 0.007% of the total global water is directly accessible for use. Unfortunately part of this water is polluted by industrial plants, mining, oil or gas exploration, fertilizer and pesticide residue used in agriculture. In addition, the uneven distribution of water over the globe causes even more severe water scarcity in some regions. Desalination and water reclamation are of paramount importance in water security, where desalination happens to be one of the main life supports in many arid regions.

The current global energy problem originates not only from limited fossil energy supplies, but also its environmental impacts for its entire energy lifecycle, from mining and processing to emissions, waste disposal and recycling. The indicators of energy sustainability include its price, environmental impacts and greenhouse gas emissions, availability of renewable energy sources, land requirements, water consumption and social impacts [2]. One solution to achieve energy sustainability is to develop sustainable technologies to gradually replace non-renewable fossil fuels. These include energy conversion from renewable and/or natural resources (e.g. biomass, wind, solar and water) into usable energy (e.g. electricity) and energy storage systems for long-term or remote usage.

Membrane technologies play a significant role in water and energy sustainability. Some of them are already applied in industries at scale. Examples include desalination by reverse osmosis (RO), wastewater treatment by membrane reactors (MBR), lithium–ion batteries and membrane-based fuel cells. Besides addressing water and energy scarcity, membrane technologies meet sustainability criteria in terms of environmental impacts, land usage, ease of use, flexibility and adaptability. On the other hand, they still need to be improved in terms of cost and affordability, energy consumption and expertise. To achieve these improvements, advances in membrane materials are needed. This article aims to analyze opportunities for membrane technologies and the revolution and advancement of membrane materials to tackle water and energy sustainability. This review may provide membrane researchers with greater clarity in membrane criteria targets, provide industrial end-users with emerging membrane technologies and reinforce the engagement between research and application aspects.

2. Membrane technology in water sustainability

2.1. Desalination

Desalination plays an important role in water sustainability for many countries around the world, particularly in the Middle East. For instance the water supply for domestic and industrial use in Qatar and Kuwait is 100% provided by desalination [3]. Desaldata [4] reported that 63.7% of the total capacity of global desalted water is produced by membrane processes, validating the importance of membrane technologies in this application. Regarding water sources for desalination, seawater contributes for 58.9%, brackish groundwater 21.2%, surface water and wastewater for the remaining of 19.9% [4]. Application of membrane desalination to produce drinking water from seawater has been comprehensively reviewed [5–15]. Therefore, in this review, we focus on desalination for other applications. Examples are desalination of produced water, desalted water for agriculture, desalination in mining, and removal/recovery of heavy metals and rare earth elements (REEs) from saline wastewater.

2.1.1. Produced water

Produced water is the largest waste generated in oil and gas industries. The global amount of wastewater co-produced in oil and gas exploration is about 210 million barrels/day, three times higher than the produced oil [16]. Its production increases in an attempt to exhaustedly recover oil from matured fields with significant environmental consequences. Produced water management is one of the most challenging issues facing the oil and gas industries and protecting human health and the environment. Treatment of produced water for reuse and recycling is an effective option for its handling, which has the potential to be a harmless and valuable product rather than a waste for disposal.

Produced water is difficult to treat because of its complicated physicochemical composition, which may change over the lifetime and well-to-well. Produced water consists of dissolved and suspended organics and solids. Membrane technology plays an increasingly important role in produced water treatment to remove all above components. Depending on the reuse purpose of produced water, the quality of reused water may vary and the applied membrane techniques may be different. External reuse applications, other than for reinjection, require much higher water quality. Microfiltration (MF) and ultrafiltration (UF) standalone processes or their hybrid integration have been efficiently used to separate suspended particles, macromolecules and oil as a pretreatment step while the combination of ultra-low-pressure nanofiltration (NF) and reverse osmosis (RO) has been applied to treat produced water for higher water quality standards which are potable and for irrigation [17–29]. However, in this review, we focus more on

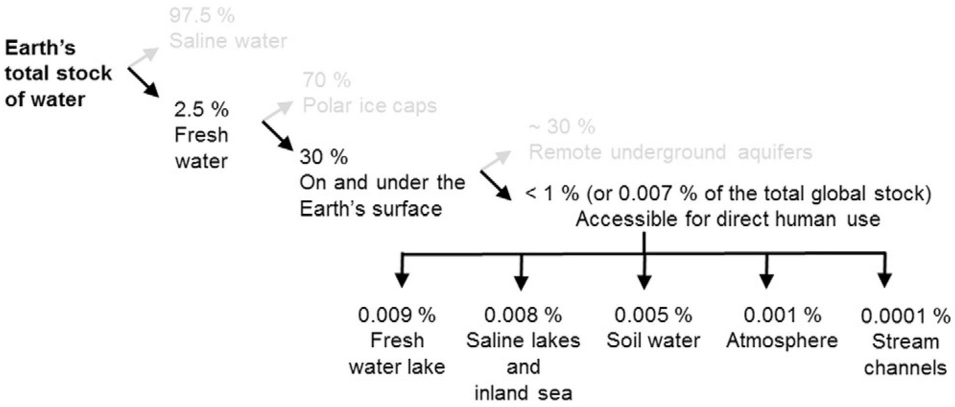

Fig. 1. The total global stock of fresh water for human use.