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Fouling prevention, preparing for re-use and membrane recycling. Towards circular economy in RO desalination

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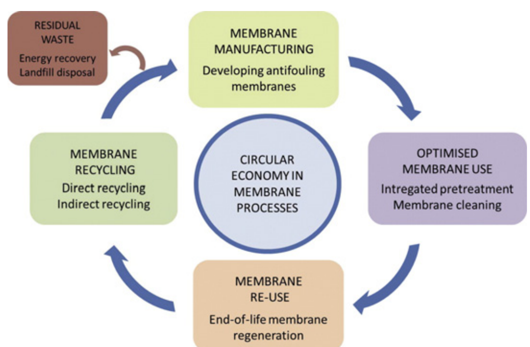
HIGHLIGHTS

- Circular economy can revolutionize membrane industry by designing recyclable modules.
- Antifouling membranes are based on higher hydrophilicity and less roughness.
- Pretreatment and cleaning are tailored processes in continuous research development.
- Near future discarded membrane management may include recycling and reuse.
- Sustainability assessment is necessary to decide other management alternatives.

GRAPHICAL ABSTRACT



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ABSTRACT

Reverse osmosis (RO) is the most employed technology for water desalination. Energy consumption and membrane fouling represent some of the major concerns in membrane technology because they increase the costs associated with treated water. Membrane lifespan is mainly correlated to the quality of the water and the operation condition and it is estimated that often membrane lifespan is 5 to 10 years. Remarkable advances have been made improving the reverse osmosis desalination by integrating pretreatment and cleaning processes. Attending to the membrane active layer, substantial research efforts have been conducted in preparing new antifouling RO membranes to i) enhance antifouling properties, ii) obtain high recovery flux and iii) have low energy requirements. However, scarce research has been detected in literature regarding end-of-life membrane management. This review summarizes the most representative research activities conducted to prevent membrane fouling. In addition, it highlights alternative routes to discarded end-of-life-membranes in order to prevent the uncontrolled disposal of fouled membranes in landfills. In this way, this review aims at summarizing research efforts found in literature in order to approach a more circular economy society, covering the whole life cycle of RO membranes: from the new development of antifouling membranes to the membrane waste management.

1. Introduction

Water is vital for human life, nature and economy. Around 97% of the total water mass on earth is salty water and 3% is fresh water. However, most of the fresh water on earth is captured as glaciers and ice caps.

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Therefore, readily available fresh water is a scarce and a valuable resource [1,2]. In addition, the increase in population, the water use in agriculture, industrial applications and water pollution has deteriorated the accessibility for safe and stable water supplies worldwide. Therefore, there is a need for alternative sources to obtain fresh water.

Desalination of sea and brackish water is broadly implemented in the industry to create fresh water. According to the International Desalination Association (IDA), in 2015, 18,426 desalination plants were installed in 150 countries with a global capacity of commissioned desalination plant of more than 86.8 million m^3 per day [3]. The seawater desalination capacity in Southern Europe represents around 10.6% of the global seawater desalination capacity [4]. Among the different technologies available, membrane technology such as reverse osmosis is very well established in the desalination industry and aromatic polyamide-based (PA) composite membranes currently are the most widely used membranes in RO desalination plants [5]. Energy consumption and membrane fouling represent some of the main concerns in membrane technology because they increase the associated financial cost for m^3 of treated water. Due to fouling, it is estimated that membrane lifespan is 5 to 10 years [6]. Hoek et al. [7] proposed a definition of RO membrane fouling comprising internal and external fouling. External fouling, also known as "surface fouling", is mainly affected by the quality of the water and the operation conditions. Some examples of process parameters to take into account are pH, temperature, chemical agents used as antiscalants or in cleaning steps, and either an effective pretreatment or not is used before the membrane system [8–10]. Internal fouling occurs due to a change in membrane structure due to physical compaction or chemical degradation, which alters solute and solvent transport through the membrane [7].

The current economy is based on a linear model, which assumes that resources are abundant and with the pattern of "take–make–consume and dispose". Industrial processes that use membrane technology are not an exception of the current economy model and membranes tend to be discarded when the flow rate/water quality is unrecoverable. In desalination, the annual membrane replacement percentage is around 10–20% [6,11]. This, together with the continuous growth of reverse osmosis technology, is creating a non-stop accumulation of end-of-life reverse osmosis membranes. Generally, end-of-life membranes are handled according to the laws of each country and unfortunately, membranes usually end up in landfills [12]. Landfill disposing is wasteful, environmentally damaging and costly. Furthermore, it is in direct conflict with EU goals to move towards a circular economy system and to achieve a cross continental recycling society. In this way, the main objective of the circular economy is to keep the value of the materials and energy used in products for as long as possible, minimizing waste and the use of resources. For this purpose, actions must be taken at all stages of the life cycle of the product, from the extraction of the raw materials, through material and product design until the waste management and recycling.

In membrane processes developments are continuously being achieved, both at industrial and scientific levels, to keep the membranes as long as possible within the value chain of their processes. Some examples of these actions are i) manufacturing novel membrane materials that show enhanced process performance, ii) applying more efficient integrated pretreatment and cleaning processes and iii) developing innovative membrane recycling. All these actions make the membrane industry to move towards a more circular economy. Under this framework, the objective of this review paper is to report a comprehensive overview of research efforts found in literature covering the whole life cycle of RO membranes: from the new development of antifouling membranes to the membrane waste management (Fig. 1).

2. Membrane design and manufacturing. Developments in antifouling membranes

Even though membrane physical damage and compression have a big impact on the membrane lifespan, fouling is one of the main reasons that reduce the lifespan of a membrane, causing membranes to become waste. In order to overcome the fouling drawback, in the last years, special research interest has grown in the scientific and industrial communities on the design and preparation of novel antifouling membranes [13].

In this review two main routes for preparing antifouling membranes are discussed: i) the preparation of tailor made new generation antifouling membranes and ii) surface modification of membranes (Fig. 2). Either one route or the other is chosen, the studies focused on the preparation of antifouling membranes generally aimed to enhance surface hydrophilicity as well as to reduce surface roughness (Table 1).

2.1. New generation antifouling membranes

Interfacial polymerization is still the dominant method to prepare the ultrathin barrier of the thin film composite membranes [14]. In

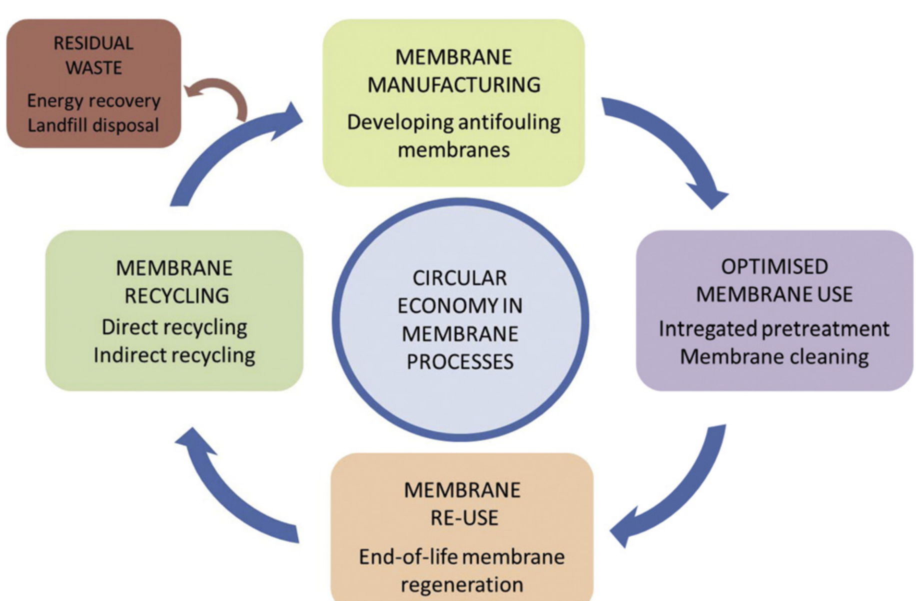

Fig. 1. Circular economy in desalination.