Nanotechnology Project I

Project Summary

The proposed project involves the preparation of nano-engineered Forward Osmosis (FO) blend membranes with enhanced performance for use in desalination applications. The overall **objective** of this project is to develop FO membranes with high water flux and salt rejection. This will be achieved by the preparation of a membrane support layer using carbon nanotube porous networks onto which the membrane selective layer will be formed using interfacial polymerization. The characterization of the morphology, porosity, hydrophobicity and mechanical strength of the produced membranes will be carried out. The water flux and salt rejection of the prepared membranes will be tested. The use of FO membranes is expected to require lower energy consumption for the desalination process, as well as an improved antifouling performance, thus leading to operational cost savings. The **expected outcome** of the project is a novel nano-engineered FO membrane that would have a positive **impact** on contributing to the reduction of the cost of water desalination.

Introduction

The use of water desalination technologies in Egypt is growing fast, one of which, is Reverse Osmosis (RO) membrane processes and has become more reliable and cost competitive [1]. Development in membrane science aims at reducing the total energy consumption, prolonging the membrane lifetime and thus reducing the cost of water production. The morphology of the membrane has a direct bearing on its performance (permeability and selectivity). In this respect, the use of nanocomposite membranes with for example carbon nanotubes (CNTs) as fillers, though still very novel, is receiving close attention from researchers in order to exploit the recently discovered super-fast liquid transport properties of CNTs. Although researchers have focused on RO membranes, Forward Osmosis (FO) is attracting increasing interest as a promising alternative to RO in membrane-based water desalination. This is mainly due to the lower energy requirements for the FO process. The emphasis of this current project will be to engineer the support layer to be highly porous by making use of CNT networks.

Problem Statement

Sustainable production of water is critical and lies on top of the national priorities of the nations affected by water shortages. Egypt is currently under the international water scarcity limit of 1000 m^3/capita/year, and its growing population has meant that the per capita share is expected to keep decreasing [1]. Desalination is an effective solution for water shortage problems in Egypt and the region. Membrane processes are steadily becoming more reliable and cost competitive as a desalination option [2]. Developments in membrane technology have led to a marked decrease in cost and operating pressures [3]. Membrane desalination plants are maturing and costs have gone down to as low as 0.5 US$ per m^3 for large desalination plants and up to 1 to 2.5 US$ per m^3 for small and mid-size plants [4]. Membrane-based desalination systems rely on the use of semi-permeable membranes with tailored pore sizes. Energy consumption accounts for a significant 40-45% of the cost of membrane-based desalination plants [5]. The Desalination Technology Road Map 2030 developed by the Center for Future Studies, Egyptian Cabinet Information and Decision Support Center (IDSC) [6], identified the energy requirement and membrane know-how as the main challenges for desalination technology development in Egypt. Reverse osmosis (RO) is the most commonly used membrane technology in water desalination. Unlike RO, Forward Osmosis (FO) is a spontaneous process and thus does not require an external pressure, a fact that makes it an energy-efficient solution for water desalination [7].

Background
CNTs have gained considerable attention as additives to membranes following molecular dynamics simulations which established super fast water flow inside them [8][9]. In published studies, for example, CNTs were added to polymer matrices including polysulfones (PSF), aromatic polyamides, chitosans, cellulose acetate and polyacrylonitrile (PAN) to form nanocomposites [10-12]. Despite these reports, CNT-blend membranes produced using an economical scalable method and capable of high water permeation rates and suitable retention, while exhibiting a high resistance to fouling and long durability have not been developed. The Co-I of this proposal has filed a patent application titled "Polymer-Carbon Nanotube Nanocomposite Porous Membranes" in which a process for fabricating membranes with dispersed CNTs is detailed [12].

Significance
Research and development efforts aimed at producing fresh water at a lower cost by exploiting the innovative field of nanotechnology and new materials will boost existing freshwater resources in Egypt. Reducing the energy consumption of the desalination system is thus critical. One way forward is to investigate the use of FO processes, which are known to require much less energy compared to RO. The proposed project will focus on developing a novel FO membrane with improved performance.

Project Description
The project entails the development of a novel CNT blend FO membrane to be used for desalination: **(1) The synthesis of membranes:** Pretreatment of CNTs will be conducted in order to enhance their compatibility with the polymer matrix. This will be followed by vacuum filtration for preparing CNT buckypapers to be used as a support layer on which the thin selective layer will be added by interfacial polymerization. *Expected outcome:* Polymer-CNT FO membranes with controlled thickness, morphology and porosity. **(2) FO membrane characterization and testing:** Membrane characterization is needed in order to associate membrane properties to synthesis methodology. Properties to be characterized include support and selective layer thicknesses, morphology, pore surface area, overall porosity and pore size distribution, Hydrophobicity, CNTs dispersion and orientation, and mechanical strength. All characterization techniques to be used are present at AUC. *Expected outcome:* Polymer-CNT FO membranes with specific morphology, porosity, water permeation and salt rejection.
The duration of the project is 12 months. The first 6 months will be primarily for the preparation of the membranes with the optimal performance. The following 4 months will be for the characterization and testing. Finalization of the thesis document will take 2 months.

The Advancement of Scientific Knowledge and Broader Impact
In spite of Egypt's experience in RO desalination systems starting in the late 1970's the lack of domestic membrane preparation know-how has meant that desalination still presents less than 1% of freshwater resources yearly [6]. The growth of desalination as a source of fresh water in Egypt faces two significant challenges, membrane costs, and energy requirements. The use of nanotechnology in membrane synthesis can lead to enhanced performance and reduced membrane preparation costs. It is therefore believed that the proposed project can contribute very positively to Egypt's strategic water shortage problem. Developing the membrane national industry will lead to an increase of the share of domestic components in desalination units, which in turn will lead to the wider adoption of the water desalination technology in Egypt.

Biographical Sketches

Amal Esawi is a professor of mechanical engineering specializing in advanced materials and manufacturing. She has a PhD in materials engineering from University of Cambridge. In 2009, Esawi received the Egyptian National Award in Engineering Sciences, as well as the AUC Excellence in Research Endeavors award. She is a chartered engineer registered with the engineering council in the UK and is the local representative of the UK's institution of mechanical engineers (IMechE). Her research interests are in the field of nanocomposites for structural applications, as well as membranes for filtration and desalination applications.

Leveraging Resources

The project is an extension of research conducted by the Co-I and her group in the field of membrane preparation and characterization. The Co-I has collaborated on various aspects of the work with colleagues at the European Membrane Institute in Montpellier, France as well as a collaborator at Deakin University in Australia. All techniques to be used in the project are available at AUC.

Deliverables

Deliverables include a master thesis deposited at the Digital Archive and Research (DAR) Repository of the American University in Cairo, publically accessible. In addition, the results of the research project will be disseminated through recognized venues in the field, such as international conferences and/or journals.

Professional Development and Mentoring Plan

The selected student will work as part of an active multidisciplinary research team with broad experience in different aspects of desalination technology. The student will be mentored, supported, and guided directly by the Co-I for their research work. They will also be encouraged and supported to participate in local and international venues in the membrane field in order to develop expertise and network with peers and professionals.

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