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Novel draw solution for forward osmosis based solar desalination

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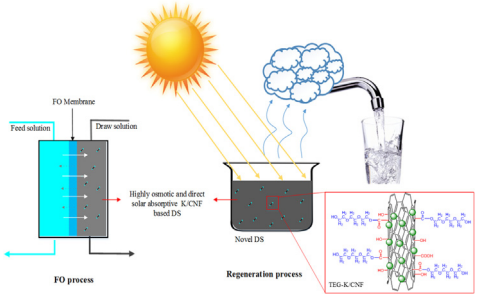
HIGHLIGHTS

- Osmotic pressure and temperature aspects are combined for the first time in novel FO solar desalination.
- The osmotic pressure is enhanced by 150% higher over the salt solution.
- Novel draw solution can be easily regenerated using solar energy.
- An enhancement of 105% in the photothermal efficiency is observed.
- The novel solar FO process is a potential candidate for solar desalination.

GRAPHICAL ABSTRACT



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ABSTRACT

Forward osmosis (FO) is an emerging technology for water desalination which requires no external force for its operation. The performance of FO for water desalination is dependent on draw solution (DS) that must provide high osmosis pressure, minimum reverse flux and efficient separation of water. This work proposes an innovative concept of energy efficient material as DS having two functions, i.e. high osmotic pressure and efficient absorption of solar energy for the regeneration phase. The potassium functionalised carbon nanofibers (K/CNF) which are highly solar absorptive, are engineered and suspended in triethylene glycol (TEG) aqueous solution with different concentrations to act as a novel DS. The TEG-K/CNF is fully characterised for morphological appearance and thermophysical characteristics before using in FO experiments. It is found that the osmotic pressure and water flux of the novel DS are directly dependent on the concentration of K/CNF and TEG. The draw solution is re-concentrated by evaporating the water aided by the highly solar absorptive K/CNF under simulated solar flux. The vapours are condensed and the quality of product water is found to be comparable with potable water standard. The novel concept proposed in this study has the potential to be used in arid areas where solar energy is abundant to fulfil the potable water needs.

1. Introduction

The availability of low-cost potable water has become a serious concern in the present ever-increasing world population scenario. Almost one-third of the world population is living in water stressed conditions and this figure is expected to increase to two-third in the next ten years [1]. Desalination of sea and brackish water and recycling of wastewater is being progressively practiced worldwide to augment the limited potable water supplies [2]. Easy, cost-effective and energy-efficient technologies are to be developed to cope with this ever

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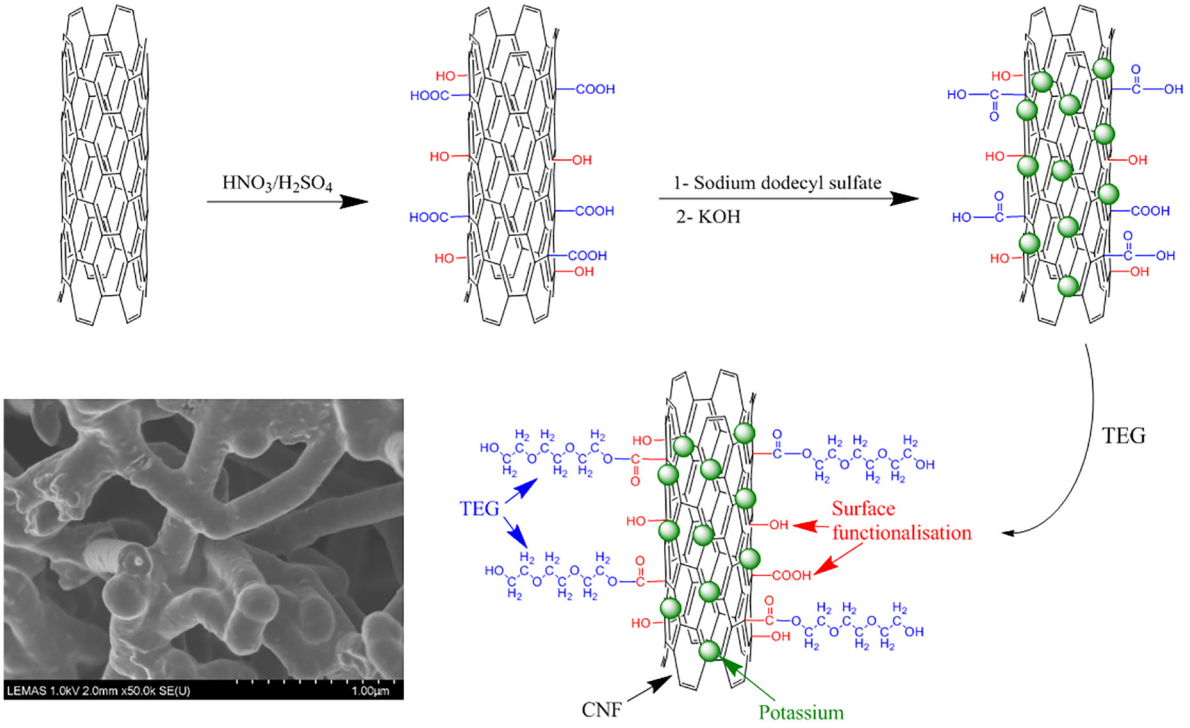

Fig. 1. The schematic synthesis route of TEG-K/CNF novel draw solution.

worsening potable water issue. Using renewable energy sources, especially solar energy [3] in connection with water treatment technologies [4–6] is highly essential in the present scenario of energy and water crisis.

Forward osmosis (FO) has recently been recognised as one of the most promising low energy technologies in the field of water desalination which uses the osmotic pressure of the draw solution to permeate portable water from the feed side through a semi-permeable FO membrane [7,8]. Osmotically driven FO has numerous advantages over the pressure-driven reverse osmosis (RO) such as low energy intensity, less membrane fouling, reversibility of membrane fouling, minimum environmental impact of the salt concentrate, low reverse solute flux [9,10] and water recovery up to ~70% [11,12]. However, appropriate draw solutions (DS) for FO having high osmosis pressure, low revers flux of solute particles, easy regeneration and causing minimum membrane propensity are still to be developed to make FO a viable solution for potable water issues.

Various types of media have been experimented as FO draw solutions which can be broadly categorised as conventional DS including gas or volatile compounds [11,13], inorganic [14,15] and organic solutes [16,17]. Organic coated magnetic nanoparticles (MNPs) [2,18–21] have been used in FO draw solutions which can be regenerated using a strong electric or magnetic field followed by ultrafiltration process. Nanoparticles have the advantage of high surface area to volume ratio and larger size in comparison with ions and molecules of organic and inorganic draw solutions. Ge *et al.* [22] investigated poly (ethylene glycol) di-acid coated magnetic nanoparticle [(PEG-$(COOH)_2$)-MNPs] as draw solutions but they reported aggregation of nanoparticles and water flux reduction by 21% after several runs. Ling et al. [23] used various concentrations of MNPs with three types of surface functional groups and observed that water flux increased with the concentration in a non-linear manner. However, there was agglomeration issue and unsatisfactory recovery of small sized MNPs due to the increased thick layer of poly (acrylic acid) (PAA). In another study, Ling *et al.* [24] developed PAA and poly(N-isopropylacrylamide) (PNIPAM) coated MNPs with −COOH functional groups. Water flux of PAA-MNPs was higher than that of PAA-PNIPAM-MNPs in either case when feed water was DI water or synthetic brackish water.

Above mentioned a few studied have shown a number of problems arising from the use of MNPs as draw solutes in FO desalination. Though these investigations are the preliminary results, they are facing the problem of agglomeration, reduced water flux over time and recovery problem of the nanoparticles even after using high magnetic field and nano filtration. Hence there is a strong prospective to develop and explore efficient nanofluid based draw solutions using other nanomaterials. Moreover, the energy aspect in the above mentioned nanoparticle based draw solutions is primarily missing. In this work we report for the first time combining FO with solar energy for water desalination using a novel absorptive nanofluid.

Herein we investigate the dual functioned potassium doped carbon nanofibers (K/CNF) in tri-ethylene glycol (TEG) aqueous solution as a novel DS for producing potable water. The novel DS does not only have high osmotic pressure to develop a high water flux across the FO membrane, but also possesses a high solar absorption capability to separate product water and regenerate the draw solution. This is a unique work of its kind and utilises the solar energy for water desalination using osmotically driven forward osmosis process. Several surface treatments have been implemented to make the TEG-K/CNF composite osmotically active and a laboratory scale cross flow FO cell is used to evaluate the performance of these novel DS experimentally. The photothermal performance in water recovery phase of FO process is evaluated using simulated solar flux against various concentrations of TEG-K/CNF composite. The quality of water is examined through several water quality tests and compared with the international standards.

2. Materials and methods

2.1. Synthesis of TEG-K/CNF based draw solution

Surface functionalisation of carbon nanofiber (CNF) is an effective route where some crucial functional groups on the internal or external surface can increase the hydrophilicity. 5 g of CNF [graphitized (iron-free) compressed of conical platelets D = 100 nm, L = 20–200 μm,