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Fertiliser drawn forward osmosis process: Pilot-scale desalination of mine impaired water for fertigation

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ABSTRACT

The pilot-scale fertiliser driven forward osmosis (FDFO) and nanofiltration (NF) system was operated in the field for about six months for the desalination of saline groundwater from the coal mining activities. Long-term operation of the FDFO-NF system indicates that simple hydraulic cleaning could effectively restore the water flux with minimal chemical cleaning frequency. No fouling/scaling issues were encountered with the NF post-treatment process. The study indicates that, FDFO-NF desalination system can produce water quality that meets fertigation standard. This study also however shows that, the diffusion of solutes (both feed and draw) through the cellulose triacetate (CTA) FO membrane could be one of the major issues. The FO feed brine failed to meet the effluent discharge standard for NH_4^+ and SO_4^{2+} (reverse diffusion) and their concentrations are expected to further increase at higher feed recovery rates. Low rejection of feed salts (Na^+, Cl^-) by FO membrane may result in their gradual build-up in the fertiliser draw solution (DS) in a closed FDFO-NF system eventually affecting the final water quality unless it is balanced by adequate bleeding from the system through NF and re-reverse diffusion towards the FO feed brine. Therefore, FO membrane with higher reverse flux selectivity than the CTA-FO membrane used in this study is necessary for the application of the FDFO desalination process.

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1. Background

Water stress is increasingly felt all over the world [1,2] and the impact of climate change is expected to further worsen the fresh water scarcity issues [3,4]. Effective water management strategies to alleviate this include supplementing existing water resources using impaired water such as through wastewater recycling and reuse, and desalination [5,6]. Nowadays, about 63% of the established desalination plant capacity around the world is based on using membrane technology, mainly using reverse osmosis (RO) process [7]. Despite significant progress in the technologies, desalination still remains a capital and energy intensive process making the technology affordable only to few privileged societies in the world [8]. Desalination has a high carbon footprint and also remains uneconomical for irrigation where a large amount of water is required. Irrigation alone constitutes about 70% of world's total water consumption [8,9] and water scarcity could have a devastating impact on agriculture production and food security as the limited fresh water resources are prioritised for other uses. Therefore, more cost-effective desalination technologies are needed to make irrigation affordable to meet the increasing food demand for the world's growing population and the world's increasing affluent society.

New and emerging technologies are being investigated, and forward osmosis (FO) process has emerged as one of the most promising candidates for low-pressure, low-energy and low-cost desalination [10–13]. FO is an innovative membrane-based process that uses concentration difference between the two solutions as the main driving force to separate water from the saline water sources instead of hydraulic pressure as in the RO process. However the energy consumption depends on the types of draw solute used and its end use applications. When a highly concentrated draw solution (DS) and a saline feed solution (FS) are separated by a special osmotic or FO membrane, the water moves from the lower concentrated FS towards the higher concentrated DS by natural osmosis due to osmotic pressure difference without the

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need of an external energy source. The DS finally becomes diluted but it cannot be used directly for potable purpose. Finding suitable draw solutes that can be easily separated from the diluted DS is therefore still a big challenge for potable water applications [10–12,14].

The concept of fertiliser driven FO (FDFO) desalination, in which saltwater is converted into nutrient rich water for irrigation using a fertiliser solution as DS and this FO process intends to avoid the issue of DS separation and recovery system [15–17]. Fertiliser is needed for the growth of crops/plants and the diluted fertiliser DS can thus be directly used for irrigation (referred to as fertigation) [15,16]. The diluted fertiliser concentration must meet the nutrition standards for direct fertigation and this has however been found challenging. The final fertiliser concentrations of the diluted DS are limited by the total dissolved solid (TDS) or osmotic pressure of the feed water based on the principle of osmotic equilibrium between the DS and the FS [18]. Some of the options to reduce fertiliser concentrations include direct dilution by mixing with the existing fresh water sources or other treated impaired water sources, using blended fertiliser DS to reduce the concentration of individual nutrients [19] and using nanofiltration (NF) as post-treatment process to remove the excess fertiliser concentrations [20]. Lately, pressure assisted osmosis (PAO) has also been investigated as an innovative and more practical way of reducing the fertiliser concentration without NF as a separate post-treatment process [21,22].

The FDFO process has so far mostly studied through lab-scale experiments except for a recent process optimisation study using 8040 FO membrane module [23,24]. This paper reports a six-month field study of the FDFO-NF process at a pilot-scale level for the desalination of saline water produced during coal mining activities at one of the coal mining sites in New South Wales, Australia.

2. Materials and methods

2.1. Location and source of saline water

The FDFO-NF pilot desalination system was operated at Newstan Colliery (Centennial Coal Pty. Ltd), State of New South Wales (NSW), Australia (Fig. 1). The saline water used for the pilot-scale FDFO-NF study was obtained directly from a newly built water treatment plant (WTP of 15 ML/day capacity), which treats mine impaired groundwater. The WTP process consists of a screen mesh, coagulation/flocculation process followed by a lamella

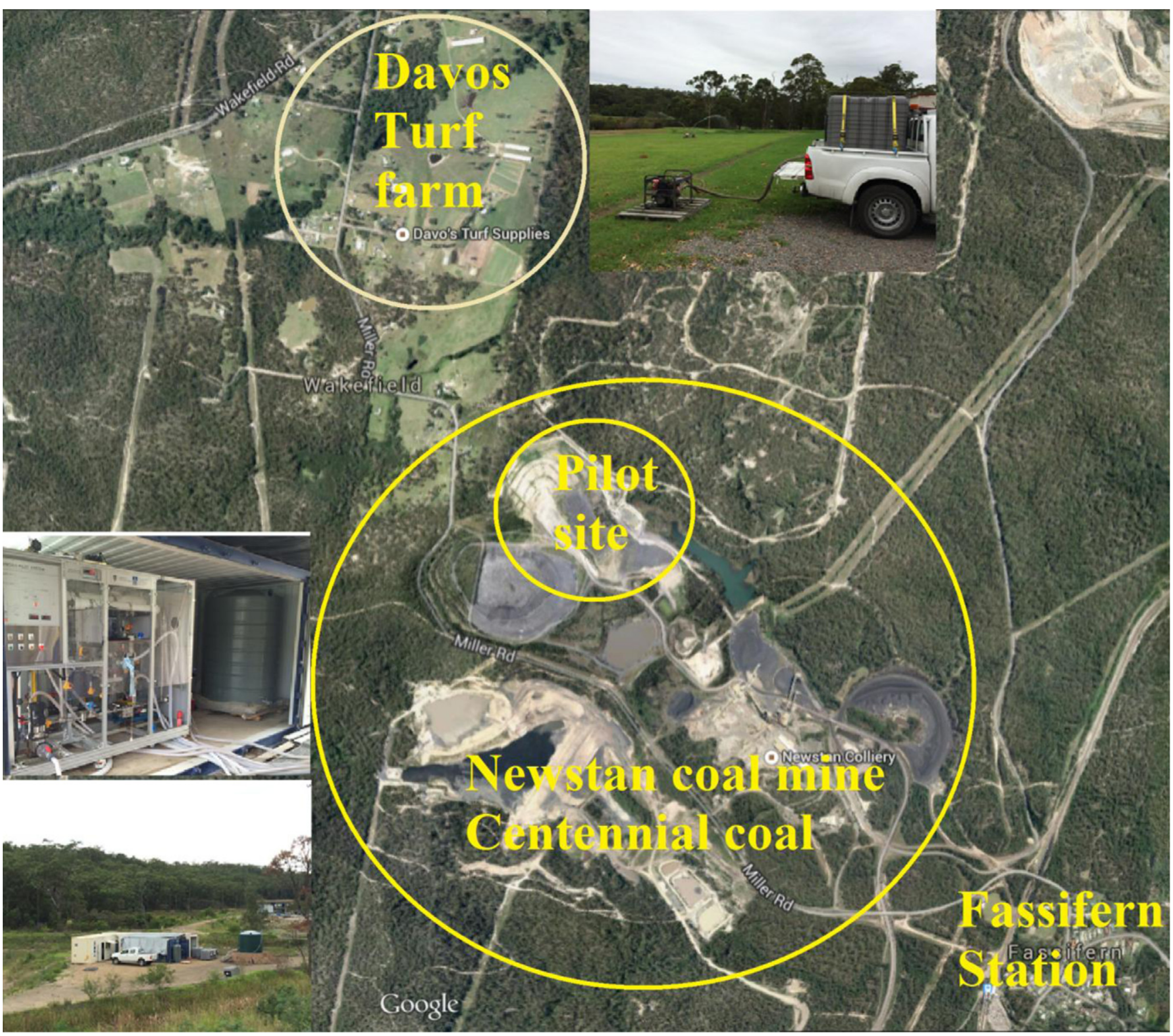

Fig. 1. Location of the pilot-scale FDFO-NF desalination testing site at the Centennial Coalmine site under the State of NSW, Australia.

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