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Effects of wind intermittence and fluctuation on reverse osmosis desalination process and solution strategies

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HIGHLIGHTS

- Main risks for wind-RO are caused by the intermittent and fluctuating nature of wind.
- Negative effects of Wind's intermittence & fluctuation on RO unit were summarized.
- Solution strategies to alleviate above effects were reviewed in three classifications.
- Common features of wind-RO exemplars were concluded.

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ABSTRACT

With the significant increasing water demand and the fossil-fuel cost, the wind-powered desalination technique has become more and more attractive for coastal area. It has experienced fast development and brought amount of benefits into our daily life, industry and agriculture. The main risks for the further penetration of such autonomous and decentralized desalination systems are the intermittent and fluctuating nature of the wind power resource. They can potentially result in a series of problems, including negative effects on the membrane performance, the component service duration, and complexity of the plant configuration, operation and control. To avoid or alleviate these effects, the efforts about solution strategies have been developed and mainly divided into three categories. The first category is the energy storage trying to maintain a constant operation condition for the RO unit. The energy storage carriers include batteries, supercapacitors, hydrogen, flywheel, pumped water, compressed air, and their combinations. The second category is the hybrid energy system. In a hybrid energy system, wind energy combined with other forms of energy such as solar PV, diesel, gravitational potential energy is employed as the energy supply. The third category is adjusting operating conditions of RO process and matching the RO capacity with transient energy supply, to make the process be adaptable with the wind power variation. Based on above summaries and analyses, this paper is aiming to be helpful for the design, operation and application of wind powered RO hereafter.

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1. Introduction

Many countries have entered a period of water shortage due to the rapid increase of the worldwide population, global temperature increase, such as European countries, United States, India, Israel, Egypt, and China [1]. One in eight people (884 million people) worldwide lack access to drinking-water from improved water sources [2]. There is also a trend to develop the desalination to meet the water scarcity problem, especially in coastal regions and arid islands where are undergoing the rapid growth of water crisis and suffering from the lack of fossil fuels.

Desalination is considered as an effective mean to solve the serious water problems and has experienced an evolution more than 50 years [3,4]. Nowadays, the rising energy crisis and possible exhaustion of conventional fuels have motivated many countries to utilize renewable energy sources for desalination system taking place of fossil fuels. Since wind energy is one of the most frequently used renewable energy and reverse osmosis (RO) is reported as one of the desalination processes with the lowest energy consumption [5], wind-RO desalination process is favorable as the solution for fresh water supply of the coastal area, with the following benefits:

a. Wind energy is sufficient and convenient for rural area lack of electricity or off-grid.

Kalogirou argued that the electrical energy generated by world's wind energy could supply the present world electricity demand [6]. Nowadays, more and more countries have realized the advantages of wind energy, and devoted to wind energy exploration. It is reasonable to believe that with the continuous extension of the wind plant installations, Kalogirou's prediction will come true in the future.

For the coastal sites, islands and remote areas which own wind energy potential but have difficulties in connecting to grid systems, desalination plants coupled with wind energy are competitive for water purification, for they are more economical than transporting water to islands or using conventional fuels as power source [7].

b. Wind powered RO is more environmental friendly.

As the energy used for the seawater desalination, whether in the electrical or thermal form, is typically generated from conventional fossil resources, the release of air pollutants into the atmosphere becomes a main environmental and public health concern of desalination, chiefly greenhouse gases (CO_2), acid rain gases ($NOX;SO_2$) and fine particulate matter [8,9]. Energy requirements for different desalination processes and resulted greenhouse gas emissions are summarized in Table 1 [10] in which the carbon dioxide emissions are examined based on the assumption that 1 kW h electricity production produces 0.96 kg of CO_2 emissions [6,11–14]. It's obvious that among the mentioned desalination processes, the RO process has less negative effect on the environment.

Besides, even for the same RO process, the CO_2 emissions varies with different energy supply. Karagiannis and Freire predicted and compared the CO_2 emissions from a RO desalination unit with several energy supply based on Life Cycle Assessment (LCA) for desalination plants in the Greek islands area [15]. The results was summarized in Table 2, and showed that wind-RO was the most environmental friendly process, whether compared with conventional fuels or solar energy.

c. Cost of wind powered RO will continue to drop.

In certain locations, cost of wind power to drive desalination is becoming competitive with other energy costs in water supply. Wind systems cost about 5–9 cents/kW h onshore and 10–20 cents/kW h offshore [16]. However, these costs are planned to drop by 2020 to approximately 2–3 cents/kW h, which would come close to fossil fuel costs estimated at 2–4 cents/kW h for natural gas and 3–5 cents/kW h for coal [17].

Table 3 compares the costs of the water production of RO unit powered by different energies. Although the cost of wind energy is cheaper than PV, overall conventional powered RO plant is still considered to be the most cost-efficient, owning the cost advantage over wind energy. However, with growing scarcity and increasing price of the fossil fuels, the wind capacity will be enlarged and the utilizing technology will become more mature [2,18–20]. It is believed that the cost of wind-RO desalination will drop down in the near future and become more competitive.

Due to the aforementioned attractive benefits of wind-powered RO desalination, a variety of theoretical, simulating, experimental researches have been conducted in these years. By investigating the published English literatures, it is found that the major challenge for combination of RO process and wind energy is caused by the intermittence and fluctuation of wind power, which can bring numerous risks and difficulties to the operation and control of system.

In this article, the effects of wind intermittence and fluctuation on RO process are first summarized in Section 2. Then, the efforts about solution strategies are specifically reviewed based on the theoretical analysis proposed by Miranda, which classified the RO unit operation in two certain conditions: (1). systems which operate under approximately constant conditions, (2). and those that experience variable operational conditions [21]. To maintain the system running under nearly constant operating conditions when the wind output power varies, generally two kinds of means were adopted, i.e. energy storage and hybrid energy system, the research state of which will be illustrated in the Sections 3 and