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A more effective method for fouling characterization in a full-scale reverse osmosis process

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Abstract

Membrane fouling is customarily indicated and measured by permeate decline at constant operating conditions. Although this method has been widely used for many years, it is inadequate for characterizing fouling development in modern full-scale RO processes. It has been demonstrated that in some full-scale RO processes with highly permeable membranes, the initial development of membrane fouling may not apparently affect the permeate flux. When the permeate flux is noticeably affected, the membrane is so severely fouled that restoration to its original permeability may become impossible. In this study, the permeate flux of a full-scale RO process and its controlling mechanisms are studied with numerical simulations. Particular attention is given to the relationship between permeate flux and the change of membrane resistance. Results show that the filtration coefficient (a collective parameter related to distribution of the membrane resistance) can be a better indicator or measurement of membrane fouling in a full-scale RO process. With this new fouling indicator, the development of membrane fouling in a full-scale RO process under any conditions can be accurately characterized. The advantages of the new characterization method include early and accurate indication of fouling development and quantitative assessment on the effectiveness of membrane cleaning.

Keywords: Fouling characterization; Reverse osmosis; Filtration coefficient; Mass transfer; Thermodynamic equilibrium

1. Introduction

Application of reverse osmosis (RO) processes for water and wastewater treatment has been growing rapidly in recent years and it has become one of the major technologies for producing potable water in many places in the world [1,2]. However, economic viability of RO water treatment plants is still very much affected by membrane fouling rate and effectiveness of fouling control [3]. Membrane fouling is widely recognized

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as the most critical problem in RO processes [2,4–6]. In the extreme cases, uncontrollable fouling can cause complete failure of the whole RO plant [7]. Even in cases where fouling can be effectively controlled, the cost associated with fouling mitigation and prevention, such as pretreatment and membrane cleaning, represents a substantial portion of the total cost of a RO process [8,9].

Membrane fouling is a phenomenon or process that the membrane resistance increases with time due to the accumulation of foulants on membrane surface and/or inside the membrane [2]. However, membrane fouling is customarily indicated or measured by flux decline with time in a RO process. In some research articles and books, membrane fouling is directly defined phenomenologically as "flux decline with time" [2,4,10]. It is commonly believed that under fixed operating conditions, an initial period of constant flux in a RO process indicates the absence of membrane fouling [10].

Observations of constant flux in the initial period of a full-scale RO process under low average permeate flux lead to the belief that low average permeate flux can reduce or prevent membrane fouling [11]. It is believed that fouling can be effectively prevented if a RO process is designed to have an average permeate flux below a "critical" value. However, this opinion cannot explain why membrane fouling starts to occur after the initial period when the permeate flux is kept unchanged. The explanation for the period of constant permeate flux in an initial period of operation is crucial for fouling characterization. It is imperative to clarify that the constant flux is truly because of "the absence of fouling" or simply due to the inability of permeate flux to reflect membrane fouling.

The above observations dictate that more research efforts are required to study membrane fouling in full-scale RO processes and its characterization methods. There is also a need to further delineate the controlling mechanisms on permeate flux in full-scale RO processes. If the operating conditions are kept unchanged and fouling is detected in an RO system after an initial period of constant flux, it is more reasonable to assume that fouling occurs right from the beginning of filtration operation. This hypothesis prompts the possibility that membrane fouling in the initial period of full-scale RO operation under certain conditions may not be directly reflected in the average permeate flux. And if this is true, there will be a need to develop a better fouling characterization method for full-scale RO processes.

In this paper, flux decline as an indicator for fouling in full-scale RO processes was first analyzed and assessed. Then permeate flux in a full-scale RO process under the increasing resistance (as a result of membrane fouling) was systematically investigated and discussed with numerical simulations. Based on the results, a new and more effective method for fouling characterization in full-scale RO processes was proposed. Finally, the advantages of the newly proposed characterization method were demonstrated through numerical simulations.

2. Flux decline as an indicator for membrane fouling

Membrane fouling in a RO process is commonly indicated and measured by using flux decline under constant operating conditions. The membrane is said to be fouled when there is a flux decline. This characterization method for membrane fouling is fundamentally based on the principle that water flux is inversely proportional to the overall membrane resistance. The overall membrane resistance includes the clean membrane resistance and the additional resistance due to membrane fouling. At a constant applied pressure and salt concentration, any increase in overall membrane resistance due to the accumulation of foulants on the membrane surface and/or inside the membrane will result in a flux decline.

This fouling characterization method has been used since 1960s when the application of RO process in water treatment was still in its infancy