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Biodegradation of phenol from saline wastewater using forward osmotic hollow fiber membrane bioreactor coupled chemostat

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ABSTRACT

A chemostat was coupled with a forward osmotic hollow fiber membrane bioreactor (FOHFMB) for treatment of high strength saline phenolic wastewater using *Pseudomonas putida* ATCC 11,172. The microorganisms were protected from the inhibitory effects of phenol and sodium chloride through dilution of the feed wastewater. This resulted in high cell growth and biodegradation rates during transient operation and steady state was achieved within 20 h. Effluent from the chemostat was desalinated in the FOHFMB through forward osmosis (FO) using magnesium chloride as the draw solute (DS). Permeate flux during FO remained stable for over 70 h in the orientation with DS facing the porous side of the membranes (PRO mode of operation). Water used for dilution could be recovered using 0.8 M DS when the wastewater did not contain any sodium chloride, whereas, 1.5 M DS was required to recover water from the wastewater containing 0.6 M sodium chloride. Biomass attachment on the membranes during FO operation was visualized using SEM, which showed that FO membranes was susceptible to fouling propensity and biomass deposition on the membranes was directly associated with permeate flux. Nevertheless, biofouling of membranes was reversible and membrane performance was recovered by osmotic backwashing.

1. Introduction

Salts, especially sodium chloride, are important raw materials in chemical industries where they play an indispensable role in various manufacturing processes and other industrial operations. Some of the common industrial applications of salts are in deicing, paper manufacturing, food preservation, oil refining, tanning, water conditioning, agriculture, and synthesis of useful chemicals [1,2]. Consequently, the presence of salts in industrial wastewater is a common occurrence. In fact, it has been estimated that about 5% of industrial effluents generated throughout the world are either saline or hyper-saline [3].

Industrial saline wastewater is also usually rich in organic matter. Biological treatment of wastewater with high salinity is difficult due to the adverse effects of salts on microbial metabolism [4]. The problem is further aggravated when the wastewater contains toxic organic compounds as the microbial growth and metabolism are inhibited by high concentrations of salts, as well as the organic pollutants [5,6]. Although wastewater can be desalinated effectively using various techniques such as evaporation, flocculation, reverse osmosis (RO), forward osmosis (FO), or electrochemical methods [7], the salts thus recovered will have high organic content. In particular, salts polluted with toxic aromatics may not be suitable for reuse, whereas, disposal of the recovered salts may require further treatment. In order to treat saline wastewater laden with toxic organic content, the organic pollutants must be removed from the wastewater prior to desalination.

Traditional methods used to alleviate substrate inhibition, such as cell immobilization or two-phase biodegradation, are not very effective in protecting microorganisms in saline environment. Therefore, the preferred strategy while biodegrading organic pollutants in saline environment is the use of halophilic microorganisms [8]. However, very few halophiles have been isolated which are capable of metabolizing toxic aromatic compounds. Moreover, these halophiles very often exhibit low tolerance to the substrate, which can result in low cell growth and biodegradation rates [4]. Another approach to treat saline wastewater is by improving salt tolerance of biodegrading microorganisms such as *Pseudomonas putida* through adaptation. However, salt tolerance acquired through adaptation is temporary and it is quickly lost when the salinity of the medium is decreased [3,4]. A simple approach to mitigate inhibition arising from salts and organics is the dilution of the saline wastewater. However, dilution is not a preferred method because it requires large quantities of water,

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increases the process volume, and increases the treatment costs [9].

The drawbacks associated with dilution can be alleviated through the use of chemostat and FO technologies. Chemostat is an established technique used for continuous cultivation of microorganisms at constant volume; FO is based on the flow of water across a selectively permeable membrane under an osmotic pressure gradient and it has recently emerged as an energy efficient desalination technique [10]. Through integrating these two techniques, the strategy is to dilute the wastewater to enable biodegrading microorganisms to metabolize the pollutant in the chemostat; the organic pollutant free effluent from the chemostat is then desalinated through FO and water used for dilution is recovered and reused. The resulting chemostat coupled forward osmotic hollow fiber membrane bioreactor (FOHFMB) can mitigate the challenges associated with wastewater dilution, achieve high biodegradation rates and perform effective desalination [11,12]. Moreover, FO-based desalination using low or no hydraulic pressure can have the advantages of low energy requirement, better rejection of contaminants and a lower membrane fouling tendency [13].

In this research, a chemostat-FOHFMB integrated bioreactor system was operated to demonstrate the suitability of the 'dilute–biodegrade–desalinate' approach in the biodegradation of high concentrations of phenol in saline wastewater. The effects of wastewater salinity, extent of dilution, FO membrane orientation, draw solute (DS), concentration, and DS flow rate on the performance of the chemostat-FOHFMB system were examined, and biomass attachment on the membranes was also characterized. Phenol was chosen as the model pollutant because of its toxic and recalcitrant nature. Besides, phenol and its derivatives are found in saline wastewater emanating from petroleum, textile, and leather industries [9].

2. Materials and methods

2.1. Microorganisms, culture conditions, and chemicals

P. putida ATCC 11,172 was used throughout this study. Stock cultures were maintained on nutrient agar (Oxoid, Hampshire, UK) slants at 4 °C. The microorganisms were grown in a chemically defined mineral medium supplemented with phenol in Erlenmeyer flasks on a shaking water bath (GFL 1092, Burgwedel, Germany) at 30 °C and 150 rpm. The composition of the mineral medium has been described elsewhere [14]. All media (except phenol), pipette tips, and Erlenmeyer flasks fitted with cotton plugs were autoclaved before use. Prior to inoculation, cells were induced in mineral medium containing 200 mg/L phenol as the sole carbon source. Activated cells in the late exponential growth phase were used as inoculum for all the experiments.

All the chemicals used in this research were of analytical grade. Phenol was dissolved in 0.02 M sodium hydroxide to prepare a stock solution of 10 g/L. Magnesium chloride was used as the DS in all the experiments, whereas sodium chloride was used to maintain wastewater salinity.

2.2. Chemostat-FOHFMB

2.2.1. FO membrane contactor

Cellulose acetate (CA) nano filtration hollow fiber membranes were used for FO. The inner surface of the membranes was porous, whereas, the dense outer surface of the membranes acted as the rejection layer. A detailed description of the membrane characteristics and its synthesis are given elsewhere [15]. A shell and tube membrane contactor with an inner diameter of 1.27 cm was fabricated by potting the CA hollow fiber membranes into a perfluoroalkoxy module using epoxy resins (Araldite, England). The membrane contactor contained 50 fibers with an effective length of 25 cm.

2.2.2. Experimental setup

Fig. 1 shows the schematic diagram of the experimental setup. The chemostat consisted of a 500 mL Erlenmeyer flask with a working volume of 250 mL. A dual channel peristaltic pump (L/S modular pump, Easy-Load II pump head, Masterflex, USA) was used to pump the feed wastewater in and out of the chemostat at a constant flow rate. Humidity saturated purified air was sparged into the chemostat at a rate of 2 gas volume per reactor volume per minute (VVM). The effluent from the chemostat was fed into one side of the FOHFMB, whereas, the DS was pumped into the other side of the membrane contactor using another peristaltic pump. Note that the RO unit required for DS recycle was not operated for these experiments.

2.2.3. Operation

The synthetic feed wastewater was prepared with 1000 mg/L phenol along with mineral salts required for cell growth. In the desalination experiments, 0.6 M sodium chloride was also added into the wastewater to increase its salinity. The wastewater was

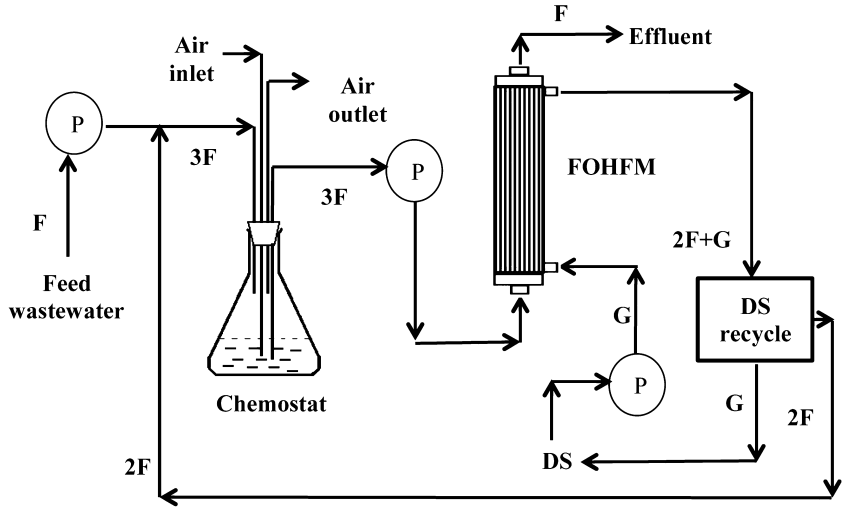

Fig. 1. Schematic diagram of the chemostat-FOHFMB.