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Role of two different pretreatment methods in osmotic power (salinity gradient energy) generation

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ABSTRACT

Pressure retarded osmosis is a membrane based technology that produces osmotic power as a sustainable energy by using salt and fresh waters. Pretreatment reduces membrane fouling as the main challenge in Pressure Retarded Osmosis (PRO). In this research, ultrafiltration and a sand filter were used for removing total organic carbon (TOC), turbidity, and hardness. In trials, efficiency and required power of the two methods were compared. Highest removal efficiency of turbidity occurred at 3.72 NTU and was 100% and 68.6% for ultrafiltration and the multimedia sand filter, respectively. Maximum TOC removal in ultrafiltration multimedia sand filter was 41% and 1.5% at 6.62 mg/L TOC initial concentration respectively. In all experiments, it was indicated that ultrafiltration had better removal efficiency and consequently more potential for osmotic power generation process improvement.

1. Introduction

Using renewable energies is a well-known way for reducing the amount of greenhouse gases in the world [1–4]. Osmotic power or salinity gradient energy as a renewable source of energy has attracted a lot of attention recently [5–9]. This energy is generated by mixing fresh and salt water [8,10]. The difference in the chemical potential of the fresh water and the draw solution causes a driving force that transfers water from the fresh side to the draw side. This gradient can be discovered in an estuary where fresh water from streams or rivers meets salt water from an ocean, gulf or salt lake [7]. The worldwide potential for producing the power from mixing of sea and river water is more than 2 TW [6]. Pressure Retarded Osmosis (PRO) is a membrane based technology that is used for production of the electric power based on salinity gradient energy [11,12]. The main obstacle of osmotic power is the availability of a membrane with a low fouling effect. Although much research has been done on PRO, the membrane fouling has not been studied very well yet. Usually river water, and brackish water are used as feed waters in the PRO processes. These waters generally contain high amounts of colloidal particles, organic and inorganic materials that cause critical fouling effects on the performance of the system by reducing the permeate flux and power density. Therefore, it is important to control and diminish the membrane fouling in PRO process [13]. Recently, there has been some progress for developing the membrane materials in order to reduce the fouling in PRO membranes. Although, these membranes have demonstrated favorable results at lab scale, there are still some challenges in terms of durability and upscaling of these new membranes [14]. Pre-treatment is a parameter which can control the membrane fouling [15–19]. As it was mentioned, fouling is a main challenge in membrane processes and imposes high cost to the system in terms of energy consumption. One way to decrease fouling and cost is using an appropriate pretreatment method. As little research has been done to study the effect of pretreatments on the membrane fouling in PRO processes [18], it is important to investigate various pretreatment methods in order to understand their role on the decrease of the PRO membrane fouling and the improvement of osmotic power generation. In this research, the physico-chemical characteristics of the river water including silt density index (SDI) were investigated. By using SDI as an empirical parameter, the fouling potential of a feed water stream can be determined [20].

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Ultrafiltration and a multimedia sand filter were used as two different pretreatment methods for reducing the amount of TOC, turbidity and hardness from raw water, which are very effective in PRO membrane fouling and consequently improving the osmotic power generation.

2. Materials and methods

2.1. Water sampling

In all experiments, fresh water was taken from the Saint-Maurice River, Quebec, at the entrance of pressure channels in hydropower central Shawinigan 2. The river water was transported to Hydro-Québec Research Institute located at Shawinigan, Quebec, Canada by a 2 m^3 polypropylene tank which was mounted on a trailer (Magnum Water Trailer – MWT500) rented from Hewitt Company.

2.2. Water quality

In order to investigate the fresh water characteristics, the amount of parameters such as color, iron, manganese, nitrate, total organic carbon (TOC), phosphor, silica, sulfate, suspended solids, alkalinity, hardness, pH, salinity, conductivity, resistivity, turbidity, dissolved solids, tannin and lignin, sodium, calcium, magnesium, potassium and SDI were determined in raw fresh water. The quality of fresh water was monitored during the winter and spring of 2014. The temperature of Saint-Maurice River was recorded by MDDELCC (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques) [21] and can be found in the appendix.

SDI was specified by using the standard method D4189 of American Society for Testing and Measuring (ASTM). Due to the different shape, size and nature of the particulate, the quality of particulate may not be measured absolutely [22]. In this method the rate of clogging (SDI_{15}(500 mL)) was calculated by passing a fixed volume of the water (500 mL) through a 0.45 μm membrane filter during a specific time (15 min) at a constant pressure of 30 psi (207 kPa) [23]. The direct method (Method 10129) for low range test (0.3–20 mg/LC) and the USEPA ManVer Buret titration method (Method 8226) for the range of 0–25,000 mg/L as $CaCO_3$ were used for TOC and hardness respectively [24]. For color, the iron and manganese platinum-cobalt standard method (method 8025), the USEPA FerroVer method (method 8008: 0.02–3 mg/L), and the 1-(2-Pyridylazo)-2- Naphthol PAN Method (method 8149) were used respectively. The used methods for nitrate, phosphorus, silica, sulfate, suspended solids, UV 254 and tannin and lignin were as follows respectively: the UV screening method (method 10049: 0.1–10 mg/L $NO_3\text{–}N$), the molybdovanadate method with acid persulfate digestion (method 10127: 1.0–100 mg/L PO_4^{-3}), the silicomolybdate method (method 8185: 1.0–100 mg/L), the USEPA sulfaVer 4 method (method 8051: 2.0–70 mg/L), the photometric method (method 8006: 5.0–750 mg/L), the direct reading method (method 10054), and the tyrosine method (method 8193: 0.1–9 mg/L).

These parameters were monitored during winter and spring seasons. Some of these parameters such as iron, manganese, TOC, phosphorus, silica, sodium, potassium, calcium, and magnesium were measured at CNETE (Centre National en Électrochimie et en Technologies Environnementales located at Shawinigan, Quebec, Canada) and the rest were measured at the Hydro-Québec Research Institute.

The amount of iron, manganese, phosphorus, silica, sodium, potassium, calcium, and magnesium were measured by optima 4300 DV ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer) from Perkin Elmer Inc. For TOC analysis, TOC-L (Laboratory Total Organic Carbon Analyzer) from Shimadzu Corporation was used. The amount of color, nitrate, sulfate, suspended solids, and tannin and lignin were measured by DR 6000™ UV VIS Spectrophotometer from the Hach Company. Alkalinity and hardness were measured by titration of sulfuric acid (0.02 N) and titration of Titraver EDTA (0.02 N) respectively. Salinity, pH, conductivity, resistivity, and dissolved solids were measured by a HQ440d Benchtop Dual Input Multi-Parameter Meter from Hach Company. Turbidity was measured by a Ratio Turbidimeter/XR 115/230 V from Hach Company. SDI was measured by using a Simple SDI: auto manufactured by SDI Solutions a division of Procam Controls Inc.

The results for the quality of raw water for SDI, TOC, hardness and turbidity will be introduced and discussed in the results and discussion section. The rest of results for water quality can be found in the appendix.

2.3. Chemicals

The prepared synthetic salt water was a combination of demineralized water, sodium chloride and calcium chloride. Calcium chloride was added in order to observe the effect of calcium ion on PRO membrane fouling. The used Na/Ca ratio was selected based on its ratio in sea water [25,26]. The mass ratio of Na/Ca was about 26. As the typical salinity of Saint Lawrence Estuary is 30 g/L [27], the used salt concentration was 30 g/L. Sodium chloride (NaCl-10 kg- S271-10) was used to prepare salt water in this study. This reagent salt was provided by Fisher Scientific Co. Calcium chloride dihydrate ($CaCl_2$ -3 kg-C79-3) was purchased from Fisher Scientific Co. as an additive to salt water. All experiments were done at Hydro-Québec Research Institute located at Shawinigan, Quebec, Canada.

2.4. Experimental design

2.4.1. Pretreatment

2.4.1.1. Multimedia sand filter. Fig. 1 shows the experimental setup for the sand filter at Hydro-Québec Research Institute. Materials and equipment that were used in the multimedia sand filter bench system are indicated in Table 1. Water from the fresh water reservoir was pumped to the multimedia sand filter and then filtered water was collected at the end of the sand filter column while impurities and suspended particles were rejected by the multimedia sand filter. The equation used to calculate the removal efficiency was (1):

$$\text{Removal Efficiency } (\%) = \left[1 - \left(\frac{C_P}{C_F}\right)\right] \times 100\% \tag{1}$$

where,

C_p: Permeate or Filtered Concentration, mg/L
C_F: Feed Concentration, mg/L

2.4.1.2. Ultrafiltration. Fig. 2 indicates the experimental setup for a dead end ultrafiltration system at Hydro-Québec Research Institute. Materials and equipment that were used in the ultrafiltration bench system are demonstrated in Table 2. The used membrane had an outside/in hollow fiber configuration with a molecular weight cut off (MWCO) of 400 kDa (Table 3) [28]. The used ultrafiltration membrane was selected based on the good removal results that have been achieved by Ødegaard et al. in their previous work [19,29,30]. As Fig. 2b shows, water was pumped from the fresh