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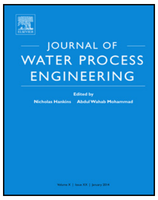

Dairy wastewater treatment using a novel low cost tubular ceramic membrane and membrane fouling mechanism using pore blocking models

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ABSTRACT

This study investigated the potential application of a novel low cost tubular ceramic membrane in treating wastewater generated by a local dairy industry. The low cost tubular membrane ($0.5) with 0.309 μm pore size, 53% porosity and 5.93×10^{-7} m^3/m^2s kPa water permeability was fabricated from natural clay materials by extrusion technique. The capability of the membrane for treating real dairy industry wastewater was tested in tangential mode of microfiltration operation at different applied pressure (207–414 kPa) and cross flow rate (5.55×10^{-7}–2.22×10^{-6} m^3/s). An increase in applied pressure and cross flow rate on the microfiltration process resulted in a decrease in percentage removal of chemical oxygen demand (COD). The novel membrane achieved a maximum reduction in COD up to 91% (135 mg/L) in the permeate stream with a flux of 2.59×10^{-6} m^3/m^2s, which is well within the permissible limit for wastewater discharge into the environment. These investigations affirmed the potential suitability of the membrane in dairy wastewater treatment to attain acceptable limit (<200 mg/L) of the permeate stream. Consequently, the membrane fouling mechanism was examined using conventional pore blocking models, viz. complete, standard, intermediate pore blocking and cake filtration model. The experimental results were well described by the cake filtration model. Additionally, the potential of the novel membrane was compared with other membranes reported in the literature for dairy wastewater treatment application.

1. Introduction

In recent years, water scarcity and disposal of wastewater, both domestic and industrial, are the two most serious problems all over the world. Most of the wastewater from chemical industries, in general, and food industries, in particular, must be treated prior to discharge [1]. Food processing wastewater is very distinct from other industrial activities, and among the food industries, dairy is considered the most important as it requires very large quantities of freshwater and generates large quantities of wastewater. This huge quantity of wastewater is produced due to the different unit operations, such as milk processing units, sanitization, cleaning and floor washing. Dairy industry generates 2.5 L (approx.) of wastewater for processing 1 L of milk and it contains a high lactose content, dissolved and suspended solids, fats and nutrients in the form of ammonia and phosphates [2]. Even though the dairy industry generally does not deal with hazardous or toxic pollutants, different kinds of contaminants at high levels constitute the dairy wastewater, which can harm the environment. In particular, dairy wastewater contains a high concentration of nutrients along with a very high chemical and biological oxygen demand (COD and BOD) content and total suspended solids (TSS). An appropriate index to specify the quantity of organics in water is the COD, and the existence of such organic matter in dairy wastewater leads to numerous issues and dramatically contaminates the environment. Ideally, the COD value should be reduced to 200 mg/L to meet the environmental discharge standards [1,3]. Owing to these concerns, the dairy wastewater needs to be treated prior to its discharge into the environment.

A variety of techniques has been established to treat wastewater generated from dairy industries. In general, biological and physicochemical treatment methods are utilized for treating dairy wastewater. However, several studies have found that the COD removal using physicochemical methods is poor and the cost of

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Table 1
Properties of low cost tubular ceramic membrane.

Properties	Membrane
Dimensions:	11.5 mm
Outer diameter	5.5 mm
Channel diameter	3 mm
Thickness	100 mm
Length	1.72×10^{-3} m^2
Unit surface	0.309 μm
Average pore size	53%
Porosity	5.93×10^{-7} m^3/m^2 s kPa
Water permeability	12 MPa
Mechanical strength	9%
Chemical stability:	0%
Acid – weight loss	0.5 $ (or 69 $/m^2)
Base – weight loss	
Membrane cost	

Table 2
Composition of the raw dairy wastewater.

Parameter	Value
Color	Dark grey
Smell	Pungent
pH	5.64
Total suspended content	976 mg/L
Total suspended solids	254 mg/L
Total dissolved solids	722 mg/L
Total fat content	294 mg/L
Total carbohydrate	366 mg/L
BOD	758 mg/L
COD	1462 mg/L
Total phosphate content	0.45 mg/L
Conductivity	853 mS/cm
TKN	24.5 mg/L

chemical coagulants is high [4]. Membrane technology has been applied for the reduction of organic materials present in wastewater. Various membrane separation processes (reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF)) can be employed for the treatment of dairy wastewater and reuse of the decontaminated water. Membrane technology is the most promising and alternative emerging process particularly for wastewater treatment applications. This process is more economical than that of the conventional techniques and can be operated with much less footprint; as it requires four times smaller area than conventional wastewater treatment plants [5]. Among the various membrane based treatment options for reducing the COD of effluent from dairy industry, microfiltration processes are more economical than the other (RO/NF/UF) processes in terms of achieving a high flux with a low energy input [6]. In membrane technology, ceramic membranes are suitable for different treatment/separation processes. It can be operated at high temperature and many ceramic membranes are highly stable even at above 1000 °C. In addition, ceramic membranes are highly resistant to corrosive chemicals even at high temperature due to an extensive variety of materials utilized for its preparation. While polymeric membranes cannot be applied under the various harsh operating conditions listed above owing to their restricted resistance. In general, most of the commercially available ceramic membranes are made up of alumina; however, from an industrial point of view, the alumina based ceramic membranes are not suitable because of its overhead expenses increased due to the cost of sintering and input raw materials [7,8]. Therefore, the preparation of low cost ceramic membranes with excellent material properties is still a major problem limiting its application for treating a large volume of wastewater. Tubular ceramic membranes are especially suitable in applications where the feed stream contains a relatively high proportion of large particles or where the membranes are exposed to extreme pH and temperature conditions. In general, the size of the feed flow channels in tubular ceramic membranes is larger than those in other membrane modules. This type of open channel geometry reduces the risk of the blockage of the feed channels and hence the requirement of costly pre-treatment before microfiltration [9]. However, literature on low cost tubular ceramic membranes for wastewater treatment application is very scarce. It is particularly important to further establish the potential of low cost ceramic membrane for large scale environment application.

In our previous study, we reported the fabrication of tubular shaped novel ceramic microfiltration membrane using locally available low cost raw materials with excellent characteristics for synthetic wastewater treatment application [10]. This study reports the application of the tubular membrane for the treatment of real wastewater generated by a local dairy industry. Due to the chemical complexity of the effluent, COD was used as an indicator to assess the performance of the membrane [12]. The various process conditions, mainly the effect of applied pressure (207–414 kPa) and cross flow velocity (5.55×10^{-7}–2.22×10^{-6} m^3/s) were investigated on the treatment process. Furthermore, the membrane fouling which inevitably occurs due to the adsorption of proteins in the pores as well as on surface of the membrane during the separation process was studied. Investigating the fouling mechanism facilitates prediction of the flux behaviour, thereby evaluation of the economic value of the process [13]. In this study, the empirical model used to predict the permeate flux declination, as described by Hermia [14] was employed to analyse the fouling mechanism associated with the microfiltration process. Besides, the performance of the membrane was compared with that of the other membranes reported in the literature for dairy wastewater treatment.

2. Experimental

2.1. Apparatus

Fig. 1 illustrates a schematic along with the real depiction (inset) of overall tangential microfiltration scheme followed in this work. The system consisted of a series of feed tank, metering pump for circulation of the feed solution, membrane module with tubular configuration, pressure indicator and flow meter to measure the cross flow rate along with flow control valves (3 numbers). The tubular ceramic membrane was incorporated into the module for tangential cross flow microfiltration. The membrane module comprises of one hollow and two bolt parts that were made of stainless steel. The membrane was fixed between the two bolt parts using O-ring washers, and two end ducts were joined with two hosepipes. The feed was pumped to the module from the feed tank and retentate employed with the recirculation arrangement. The permeate flow through the membrane was determined using an electronic weighing balance at open atmospheric condition. The operating pressure was adjusted manually using the flow control valves each located at by-pass (V_1), inlet (V_2) and retentate (V_3) flow paths (Fig. 1). Cross flow rate was adjusted with a flow control valve (V_3) at the retentate side flow path.

2.2. Membrane preparation

The methodology followed for the fabrication of tubular ceramic microfiltration membrane and its characterisation have been presented in our earlier published work [10,11]. The tubular membrane was fabricated using locally available low cost natural clays (kaolin, quartz, ball clay, pyrophyllite, feldspar and calcium carbonate) by extrusion technique. The clay mixtures were well mixed with Millipore water (ELIX-3) to create paste for extruding tubes. The paste was fed in the extrusion cylinder and extruded with the