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Influence of membrane material and corrugation and process conditions on emulsion microfiltration

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Abstract

An investigation of membrane materials for the cross-flow microfiltration of water-in-oil emulsions is reported. The membrane used were, PTFE, PVDF and nitrocellulose. The emulsion considered was water with kerosene using Span 80 as surfactant. The effects of operating conditions: cross-flow velocity, trans-membrane pressure, temperature and emulsion concentration is described and analysed in terms of a fouling index for filtration. An increase in trans-membrane pressure, temperature and flow rate of emulsion all result in an increase in membrane flux. Membrane flux falls initially with time under most conditions of operation, except at a temperature of 50 °C, where flux are stable. The use of corrugated membranes is shown to produce a large increase in flux rate in comparison to the use of flat membranes under the same conditions and cross-flow velocities.

Keywords: Membrane; Cross-flow filtration; Microfiltration; Emulsions; Corrugation; Fouling

1. Introduction

Separation of water from water-in-oil emulsions is of importance in several industries, e.g. organic solvent and vegetable oil, for the recovery of solvents and the purification of oil. The standard method [1] for the treatment of emulsions is chemical de-emulsification followed by gravity settling. This process requires the use of a variety of chemicals and the water phase from chemical treatment needs secondary purification. This will therefore entail additional energy requirements and hence higher cost. Several effective methods [1–3] have been recently developed for oil–water emulsion separation such as coalescence of dispersion in fibrous beds, chemically induced destability of w/o emulsion, and application of electric flotation to coalesce droplets. The development of membrane technologies has most recently embodied applications in the processing of emulsions.

Although there are numerous applications of cross-flow filtration only a few are related to the separation of water/oil emulsions. Anderson et al. [4] effectively separated oil from water emulsion. Their experimental results showed that cross-flow filtration is feasible for the concentration of oily waste by using ultrafiltration. Le Berre and Daufin [5] demonstrated separation of casein micelles from whey proteins through CFMF of skimmed milk with a ceramic membrane. There are several reports on separation of oil/solvent in water emulsions, for example [6–9].

Several studies have reported that cross-flow membrane microfiltration (CFMF) and ultrafiltration are effective processes in concentrating oil–water emulsions [9–15]. Lee et al. [16] used a ceramic membrane for the cross-flow microfiltration of soluble waste oil. This membrane was tested with soluble waste oil, which consisted of oil droplets whose mean diameter was 11 μm. The effects of the velocity and backflushing time on permeate flux were investigated. Limayem et al. [17] has considered the purification of nanoparticle suspensions by a concentration/diafiltration process. Ripperger and Altmann [18] have recently reviewed the state of the art in cross-flow microfiltration.

Many different approaches can be used to improve the flux in CFMF of emulsions. Turbulence promoters of various

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configurations have been studied [19]. However, flux enhancement is only achieved at the expense of significant increased frictional pressure drop. More recently, attention has been drawn towards using corrugated membranes as turbulence promoters [15]. It is proposed that corrugated membrane would promote turbulence preferentially near the wall region, causing less pressure drop in the flow channel along the membrane than will other techniques which promote turbulence in the entire feed stream. The use of corrugations of half-cylinder shape on membrane for hyperfiltration has already been reported [19,20]. There have been a number of studies on the influence of corrugated structures on mass transport behaviour [21,22].

This paper reports data for the cross-flow microfiltration of water-in-oil emulsions, using kerosene as the organic phase. The parameters which may affect the flux that are to be investigated include, membrane material, cross-flow velocity, temperature and differential pressure and corrugation of the membranes.

2. Experimental

2.1. Membranes

The membranes used in this work were:

- PTFE, Schleicher & Schuell (S&S), hydrophobic, 151 μm thickness, 0.2 μm pore size.
- PTFE, Gore-Tex®, hydrophobic, 185 μm thickness, 0.2 μm pore size.
- PVDF, Schleicher & Schuell (S&S), hydrophobic, 158 μm thickness, 0.2 μm pore size.
- PVDF, Pall, hydrophobic, 132 μm thickness, 0.2 μm pore size.
- Nitro-cellulose, Schleicher & Schuell (S&S), hydrophilic, 118 μm thickness, 0.2 μm pore size.

2.2. Emulsion characteristics

The method of Dean and Stark was used to determine the water content of the emulsion. During this test the sample is heated under reflux with an organic liquid (toluene) which is immiscible with water. The water and toluene are boiled off and reflux from the condenser is collected in a graduated vessel below the condenser. The water separates below the toluene and its volume may be measured directly. Water content greater than 2000 ppm can be detected with this method.

The dynamic viscosity of the emulsion was determined using an Oswald viscometer. The kinematic viscosity of the emulsion and oil solution in various compositions was determined by a Redwood Viscometer. The correlation between viscosity and temperature were also determined by the Redwood viscometer by varying the temperature of water in the jacket.

The emulsion density was measured using a Westphal Balance, which has been widely applied for petroleum oil measurement, and is especially suitable for viscous fluids or two-phase liquid mixtures.

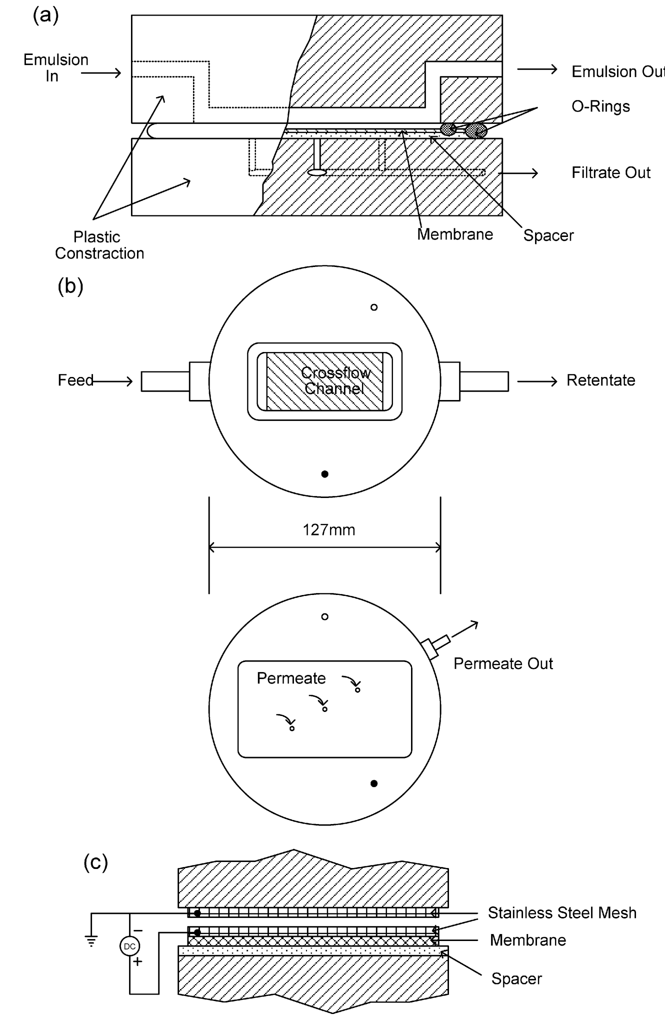

Fig. 1. Schematic diagram of membrane module unit: (a) side sectional view; (b) top and base sections of module; (c) module with electrode connected.

2.3. Emulsion formulation

The water-in-oil emulsions were prepared by adding kerosene, containing 3% (w/w) of surfactant (Sorbitane-monooleate) to a specified amount of distilled water to form a 30% water–kerosene mixture. The emulsion was generated by mixing for 15 min at a speed of 5500 rpm. This method allowed the production of stable emulsions, with an average water droplet size of 0.3 μm and 92% of the droplet population between limits of 0.12 and 2 μm, as measured by a laser light-scattering technique. Fig. 7a shows a typical droplet size distribution for the membrane separation system.

To form emulsions with various concentrations, the concentrated emulsion was dispersed into kerosene containing the same amount of surfactant.

2.4. The membrane module

The membrane module shown in Fig. 1, was composed of two pieces of machined circular polypropylene. The upper section contains a rectangular channel (25 mm × 66 mm) with a