Journal of Industrial and Engineering Chemistry 21 (2015) 254–260

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Assessment of fouling behaviour in submerged microfiltration system coupled with flocculation

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ARTICLE INFO

Article history:
Received 7 October 2013
Accepted 18 February 2014
Available online 25 February 2014

Keywords:
Membrane filtration
Microfiltration
In-line coagulation
Fouling

ABSTRACT

Microfiltration coupled with flocculation has the potential to remove colloidal and dissolved matter and hence mitigate membrane fouling. This study investigates the effects of flocculation on the performance of submerged membrane microfiltration of kaolin suspension. The addition of the flocculent (ferric chloride: $FeCl_3$) demonstrated better control of colloidal membrane fouling. The experimental results showed that trans-membrane pressure (TMP) development at optimal flocculent concentration was significantly less than it was with an unflocculated feed. In the case of 30 L/m^2/h, TMP was reduced by 85% with optimum concentration of flocculent. A regression analysis conducted between cake resistance and particle deposition showed a low specific cake resistance with flocculent addition.

1. Introduction

Membrane fouling process is widely recognised as being responsible for flux decline and reducing the performance of the membrane filtration system. Therefore it has been considered as an impediment to the widespread adoption of microfiltration in water treatment industry. Past experiences and research indicate that the membrane fouling is associated with the presence of dissolved organic materials and small colloidal particles in wastewater. Matsumoto et al. [1] showed significant fouling due to colloids in crossflow microfiltration units. Similarly, Haberkamp et al. [2] observed that the most severe fouling was from colloidal and dissolved organic substances in biologically treated wastewater during ultrafiltration of tertiary wastewater treatment. Lee et al. [3] also observed colloids in the size range of 0.2–1.2 μm as being the most significant particle size range that caused fouling during microfiltration of secondary effluent. Previous research [4–6] have reported that the presence of smaller particles resulted in flux decline for poly-dispersed feeds during microfiltration.

In order to mitigate the membrane fouling and enhance the permeate flux (system performance), a number of different approaches have been pursued. These include (a) chemical, (b) hydrodynamic, and (c) physical approaches [7]. Chemical methods involve modification of the membrane surface chemistry to increase the repulsion between the membrane and particulate available in feed suspension. This increased repulsion causes less deposition and results in less membrane fouling. Hydrodynamic methods consist of the application of secondary flow to produce turbulence in the membrane module and/or the reactor tank such that deposited particles on the membrane surface are transported back to the tank. While chemical and hydrodynamic approaches focus on changes to the membrane properties and operating conditions of filtration system, respectively, and physical methods involve pretreatment of the feed solution. Pretreatment of biologically treated sewage effluent prior to its application to the membrane processes will reduce cell deposition and subsequent bio-growth due to dissolved organic matter [8]. Pretreatment also reduces the need for frequent chemical cleaning, which is a major factor impacting the membrane life. Pretreatment offers considerable potential for improving the efficiency of membrane processes. Different types of pretreatment methods are described in literature. Each method has its advantage and disadvantage. For instance, physico-chemical treatment produces a considerable amount of sludge but takes a shorter time while biological processes takes a longer time but has a lower operational cost. The prime benefits of the physico-chemical processes are simplicity of operation and low capital. Moreover, physico-chemical treatment such as flocculation can remove 80–90% of the total suspended matter, 40–70% of the BOD5, 30–60% of the COD, and 80–90% of the bacteria [9]. Similarly, adsorption can remove organics which are

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http://dx.doi.org/10.1016/j.jiec.2014.02.032
1226-086X/

not removed by conventional chemical and biological treatment methods. Al-Malack and Anderson [10] found the improved flux values during flocculation as a physico-chemical treatment process. This flux enhancement was attributed to the agglomeration of particles which could then be easily removed by shearing action. Moreover, Chapman et al. [11] reported that the floating medium flocculator (a static flocculator) with the addition of ferric chloride caused the removal of 45% of suspended solids, 97% of phosphorus and 45% of the organics from the biologically treated sewage effluent. Therefore, an appropriate physico-chemical treatment as a pretreatment will not only enhance the permeate flux but also improve the removal of dissolved organic matter (DOM). Flocculation is one of the physico-chemical methods that can improve the permeate flux microfiltration and remove particles and colloids. This study focuses on a coagulation and flocculation: a physico-chemical treatment method.

In flocculation process, external agents (chemical) are added to the feed suspension that facilitates the agglomeration of fine particles and colloids into larger particles so that they can be easily separated from the liquid. It helps to modify the supernatant characteristics by aggregation of the colloidal fraction. In-line flocculation refers to the dosing of coagulant into feed water with rapid mixing, allowing flocs to form but not to settle, and finally feeding the resulting water with flocs for microfiltration or ultrafiltration. In-line flocculation therefore, involves the use of flocculents without removal of coagulated solids prior to the filtration process.

Previous studies have shown that the use of flocculents to a feed suspension prior to microfiltration can enhance system performance leading to an improved permeate flux [12–14]. Fan et al. [15] suggested that this effect is due to the aggregation of colloidal and dissolved matter into particles that are too large to cause pore narrowing and pore plugging. Cho et al. [16] also indicated that the coagulation–microfiltration system has the potential to remove natural organic matter and reduce membrane fouling. They observed higher flux during microfiltration with longer flocculation times, due to the formation of loose and porous flocs and reduction of small colloidal particles. Most of the above studies have been with cross-flow and micro- and ultra-filtration.

This study investigates the fouling behaviour of kaolin clay suspension in submerged microfiltration coupled with in-line coagulation. The flocculent used in this study was ferric chloride ($FeCl_3$). The impact of flocculent addition was evaluated by examining the development in TMP and particle deposition at particular time of microfiltration.

2. Materials and methods

2.1. Materials

Flocculent: In this research, ferric chloride ($FeCl_3$) was used as flocculent. A laboratory grade reagent ferric chloride anhydrous was used.

Feed material: Small colloidal particles have been identified as the principal cause of membrane fouling. Therefore clay particles (often present in surface water) were selected as a model contaminant. The feed solution was prepared from commercially available kaolin clay (Sigma) which was dissolved in tap water to a concentration of 10 g/L. A high concentration of kaolin clay suspension was used to represent the mixed liquor suspended solids in submerged membrane bioreactor. The particle sizes distribution of kaolin clay based on the volume distribution of d[v,0.9], d[v,0.5] and d[v,0.1] were 3.91 μm, 2.10 μm and 1.61 μm, respectively (where d[v,0.9], d[v,0.5] and d[v,0.1] represent 90%, 50% and 10%, respectively, of volume distribution below the given value).

2.2. Experimental

Submerged membrane microfiltration coupled with flocculation was conducted to investigate the fouling behaviour of kaolin particles in a membrane reactor. Prior to these experiments, jar tests were carried out to determine the optimum dose of the flocculent. Six different jars with kaolin clay suspension of 1 L at a concentration of 10 g/L were used with different concentration of $FeCl_3$. The standard test involved 1 min rapid mixing at 100 rpm (revolutions per minute) and 20 min slow mixing at 25 rpm followed by quiescent settling. After 30 min of settling, the turbidity, suspended solids and pH were measured. Based on the turbidity, suspended solids and pH value, the optimum dose of $FeCl_3$ was determined as 150 mg/L (as $FeCl_3$) for a kaolin clay suspension of 10 g/L.

Flocculation experiments were then conducted in a submerged microfiltration system. A flat sheet membrane (A1 Company, Germany) with pore size 0.14 μm and effective area 0.2 m^2 was submerged into the reactor tank of full capacity 12 L. Ferric chloride (1% of $FeCl_3$ anhydrous) was used as a flocculent. Before the beginning of experiment, different doses of $FeCl_3$ were directly added to the process tank. Sufficient time (15–20 min) was allowed for flocculation in all experiments. A gentle mixing was provided with application of nominal air flow rate (1.0 m^3/h/$m^2_{\text{membrane area}}$). During flocculation, the kaolin particle agglomerated from micro-floc to visible flocs. The schematic diagram of the experimental set-up of flocculation–microfiltration test is shown in Fig. 1.

Microfiltration of flocculated suspension was performed at different permeate flux rates (30, 60 and 90 L/m^2/h). Flocculent was added to suspension only once at the start, prior to commencing experiment. The permeate flux was withdrawn through a peristaltic (suction) pump and returned back to the reactor tank to maintain the constant concentration. TMP was continuously monitored online and stored in a data logger which was later downloaded to a computer. Samples from the suspension tank were collected on an hourly interval for suspended solids measurement.

3. Determination of particle deposition

In this research, two methods were used to determine particle deposition on the membrane surface. Firstly, particle deposition was indirectly obtained from the feed concentration values at particular times by using turbidity method which was later used to determine particle deposited on the membrane surface. As

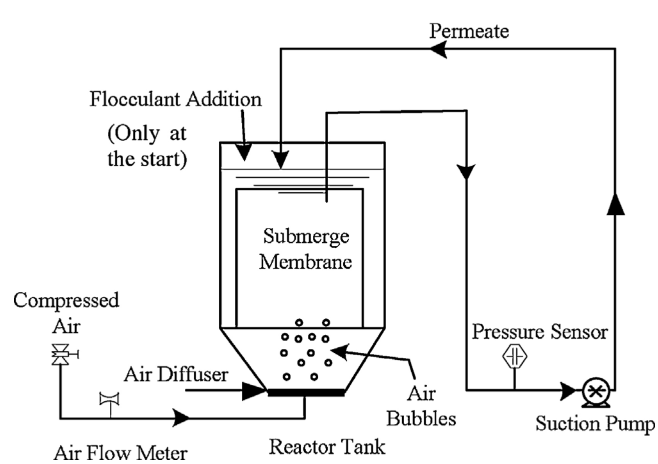

Fig. 1. Schematic diagram of experimental set-up of flocculation–microfiltration test.