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Investigation of high-intensity magnetic hydrogels in the application of membrane physical cleaning

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ABSTRACT

A newly synthesized magnetic hydrogel was applied to physical cleaning of low pressure microfiltration (hollow fiber) membranes. MC(50%)-90-3 h was chosen from several kinds of high-intensity magnetic hydrogels for its superior performance. According to the properties of the hydrogels, membrane filtration and cleaning tests was conducted under a orthogonal experiment with different factors and levels. An optimal combination of factors and levels was got as particle size of 5 mm, aeration intensity of 1 L/min and volume percent of 10%. The comparison of traditional aeration cleaning, backwashing and the hydrogels cleaning showed the superiority of the hydrogels with the TMP recovery of 93.07%. The results of shear stress detection showed that the outlet of membrane module received the lowest shear stress in corresponding with the most serious fouling. Therefore, a new cleaning method containing enhanced cleaning in position was created to make the intensive cleaning to the position with severe fouling. The recovery of TMP reached up to 96.62% after cleaning of the new method which indicated that reversible fouling can almost be removed completely. This good cleaning effect was hoped to provide support for further membrane physical cleaning.

1. Introduction

The increasingly serious water fouling and growing demand for potable water have urged us to explore new advanced water treatment technologies that can provide a safe water supply in a more energy efficient, environmentally sustainable way [1,2]. Recent years membrane modules have gained more popularity in wastewater treatment due to the high specific filtering area, low-cost, application flexibility, and easy installability [3,4]. Nevertheless, they usually suffer the limitation of membrane fouling, leading to the increase of TMP (transfer membrane pressure) and the decrease of water productivity during the pressure-driven membrane filtration which limits their wide industrial application [5,6].

To mitigate membrane fouling many strategies have been implemented such as membrane cleaning [7,8], module optimization [9,10] and developing antifouling membranes [11,12]. Physical cleaning was identified as one of the effective method which has been widely used for low pressure microfiltration membrane (e.g. hollow fiber membrane) in practical engineering [13,14]. Wang et al. [15] established a backwashing model and combined membrane backwashing with membrane module optimization to satisfy the needs of practical applications. Not only can the most suitable length of the fiber be designed on this basis, but also can the most suitable flow (pressure) for the fixed length of the membrane module be provided. Gonzalez-Avila et al. [16] proposed a new method to remove the particles deposited on the membrane surface by applying two different ultrasound frequencies in tandem. First a high ultrasound frequency, 220 kHz, is used to create microscopic bubbles that are immediately after excited with a lower ultrasound frequency, 28 kHz. A larger number of bubbles created on the surface of the membrane prior to the application of a lower frequency which induces cavitation. These low frequency driven cavitation bubbles acts as scrubbers that perform the effective cleaning of the membrane. These strategies all contribute to the understanding of membrane physical cleaning. Nevertheless, there are still some problems that need prompt solution. However, the main effect of physical cleaning for the surface cake layer was hydraulic cleaning which can not satisfy the requirements of long-term operation. Therefore, a more moderate physical cleaning methods is appropriate which can cut down the frequency of chemical cleaning and keep a long-term operation. Guo et al. [17] investigated the performance of three different sizes of sponge associated with continuous aerated SMBR. A laboratory-scale single stage sponge-SMBR (SSMBR) showed high performance for removing dissolved organic matter (>96%) and

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PO_4-P (>98.8), while coarse sponges could achieve more than 99% removal of NH_4-N. Meanwhile, when three-size sponges were mixed at a ratio of 1:1:1 the SSMBR system has proved its generic merit of less membrane fouling. Though the main object of this study is foulant removal, but the idea of cut down membrane fouling by sponges attracted our mind. Considering the mechanical damage to membrane, solubility in water solution and retrievability, the hydrogels were thought to be used in membrane physical cleaning. Hydrogels with characteristic properties such as desired functionality, reversibility, steriliz ability and biocompatibility meet both material and biological requirements to treat or replace tissues and organs, or the function of living tissues, as well as to interact with the biological system [18–20]. And there are still no previous studies using hydrogels for membrane physical cleaning, so this work is a research with novelty.

The aim of this work is to present an ingenious method of physical cleaning with the newly synthesized magnetic hydrogels. Optimum combination of operating factors (aeration intensity, particle size and volume percent) was also obtained by orthogonal experiment. The comparison of traditional aeration cleaning, backwashing and magnetic hydrogels cleaning was discussed. After shear stress detection, a new application of magnetism containing enhanced cleaning in position and magnetic hydrogels recycling was applied to make the intensive cleaning.

2. Materials and methods

2.1. Materials

The pristine polyvinylidene fluoride (PVDF) hollow fiber micro-filtration (MF) membrane module (D = 0.05 m, L = 0.4 m) was provided by Tianjin Motimo Membrane Technology Co., Ltd. The dimensions of these membranes are presented as follows: Pore size, 0.22 μm; the outer/inner diameter, 1100/600 μm; length, 0.3 m. The pressure sensor was obtained from Shinaide sensor Co., Ltd. The peristaltic pump (BT100-2 J, Langer, China) was purchased from Baoding Lange constant flow pump Co., Ltd. Three-dimensional electromagnetic fluid speedometer (ACM3-RS, JFE Advantech Ao., Ltd., Japan) was imported to measure the shear stress. High-intensity magnetic hydrogels were synthesised independently.

2.2. Experimental setup

Fig. 1 represents the schematic diagram of the membrane filtration and cleaning system. The raw water in the water tank was sucked through using a peristaltic pump from outside to inside of the membrane module. The module was inserted in the reactor connected with a pressure sensor which could transmit the pressure data directly to the paperless recorder. The TMP variation was recorded every one minute by paperless recorder for the precise critical pressure [21]. When the filtration TMP increased to 50 kPa the membrane module need to be cleaned. As known in fact, cleaning duration in practical engineering usually sustained a very short period of time. So one minute is enough for the bench-scale testing. Apparent liquid velocity of membranes was measured for determining the shear stress. It can make sure the membrane surface position with inadequate cleaning. After that, the magnetic hydrogels were added into the membrane module through a piston. Then the aeration pump was opened for bubbles. Magnetic hydrogels were derived to rub with membrane surface. The foulant fell off by synergistic effect of bubbles and magnetic hydrogels. After cleaning the magnetic hydrogels were recycled with the cleaning waste water drained from the piston.

2.3. Preparation of high-intensity magnetic hydrogels

2.3.1. Materials

Acrylamide (AM), N-methylol acrylamide (NMA), 2-acrylamide-dimethyl propyl sulfonic acid (AMPS), N′-methylene bisacrylamide (MBA), Sorbitan monolaurate, Octylphenyl Polyoxyethylene Glycol Ether, Ammonium persulfate, Sodium bisulfite, Cyclohexane and Fe_3O_4 magnetic particle (MP) were purchased from Shanghai Chemical Reagents Company, China.

2.3.2. Principle of synthesis design

Considering the mechanical damage to membrane, solubility in water solution and retrievability, a new kind of hydrogels was thought to be used in membrane physical cleaning. The magnetic hydrogels (MH) was prepared by three continuous processes named preparation of reactive microgels containing hydroxymethyl, preparation of composite polymer microgels and preparation of magnetic (MC) hydrogels [22] (Fig. 2(a)). Microgel hydroxymethyl has high activity and easily reacts with acylamino.

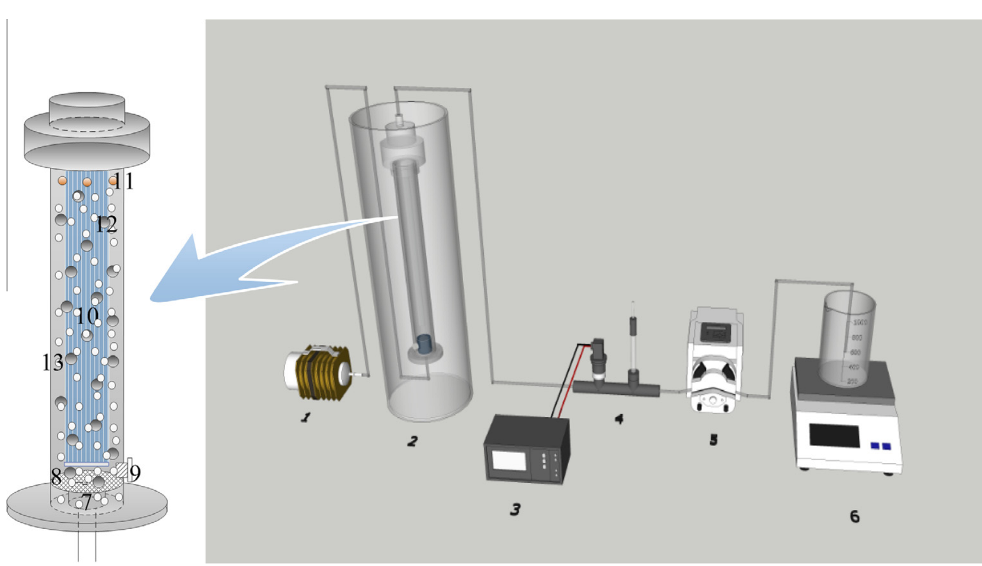

Fig. 1. Membrane filtration and cleaning system. 1: Aeration pump; 2: Membrane reactor; 3: Paperless recorder; 4: Pressure sensor; 5: Peristaltic pump; 6: Electronic balance 7: Aerator; 8: Filter screen; 9: Piston; 10: Membrane fibers; 11: Exhaust vent. 12: Magnetic hydrogels; 13: Bubbles.