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Cyclonic state micro-bubble flotation column in oil-in-water emulsion separation

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ABSTRACT

In order to improve the separation efficiency of oil-in-water emulsion, a novel cyclonic state micro-bubble flotation column was developed to enhance the separation efficiency. The flotation column comprises a column separator and a cyclonic separator provided on the bottom plate of the flotation apparatus. The process parameters, namely the feed volume flow rate, initial oil concentration, aeration rate, and oil droplet size on removal efficiency were investigated. The process efficiencies between the cyclonic state micro-bubble flotation column (FCSMC) and dissolved air flotation column (DAF) were compared. Results show that this FCSMC has higher oil removal efficiency and treated water with lower oil levels than the DAF, especially for the process of fine oil droplets (<10 μm). An oil removal efficiency of 92.19% was obtained with the treated wastewater effluent containing a final oil concentration of 37.10 mg/L using FCSMC (an oil removal efficiency of 76.65% with a final oil concentration of 110.92 mg/L using DAF) under conditions as following: a 18.75 min of residence time, a 475.05 mg/L of initial oil concentration, a 1.8 L/min of aeration rate and a 25.01 μm of mean oil droplet size in feed. The mean oil droplet size is 1.84 μm with 4.81% of the oil droplets above 5 μm in diameter in the treated effluent. It shows that the FCSMC is especially advantageous for the separation of fine oil droplets.

1. Introduction

Oily wastewater is a typical organic wastewater generated in large volumes during crude oil exploration and production in what is referred to produced water. These waters contain oil, organic, chemicals, salts and other components, which are dangerous to the environment and human health. Therefore it is necessary to treat these effluents for improving water quality and oil recovery. The most commonly used techniques for separation of the oily wastewater include gravity separation [1], filtration separation [2], flotation [3], membrane treatment [4], carbon adsorption [5], biochemistry [6], chemical separation [7] and flocculation separation [8]. The advantages and the limitations of various separation techniques have been discussed [9]. The selection and efficiency of these techniques are based on the critical diameter of oil droplets being treated [10].

Among these techniques, chemical separation have some drawbacks (e.g., residual chemical reagents, generated oil sludge, and increased operational costs), the use of some physical and physicochemical techniques have largely been explored owing to their high efficiency, simple operation, avoidance of chemical reagents and no secondary environmental pollution of effects. Flotation and cyclone appear to be two of the most attractive methods to removing emulsified oil from wastewater.

Flotation has been used for mineral (coal) processing using stable froths to selectively separate different minerals from each other in the early years. Currently the flotation has been practiced in other fields, such as oil–water separation, deinking of printed paper, recycling of organic compounds and removal of heavy metal. The common flotation devices for wastewater treatment include the conventional DAF cell [11,12], continuous nozzle flotation cell [13], microcel flotation column [14], jet flotation cell [15], modified jet flotation cell [16], FF-flocculation-flotation cell [17], multi-bubble flotation column [18], etc.

The cyclone has been used for the solid–liquid separation field to separate the dispersed phase from the continuous fluid initially. Because of higher efficiency, smaller volume, and lower cost, cyclones have been widely used in different fields such as

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liquid–liquid separation, gas–liquid separation and gas–solid–liquid separation. Many types of cyclones and their applications have been reported, such as air-sparged hydrocyclone [19], vane-type pipe hydrocyclone [20], cyclone column [21], air-injected de-oil hydrocyclone [22] and air bubbles enhanced hydrocyclone [7].

Since conventional flotation columns run based on the theory referred to as air bubble mineralization by reverse collision, the improvement of the separation efficiency generally requires increased residence time and column heights. Some hydrocyclones have also their drawback (e.g., complexity, low reliability and low separation efficiency) when the oil droplet diameter is less than 15 μm.

A normally structured hydrocyclone is not efficient for treating emulsified oil, while the flotation separation facility is not suitable for wider-range oil concentration in wastewater treatment. The existing literature does not mention explicitly or implicitly the combination of the column separator and the cyclonic separator for treating oily wastewater. In order to improve the efficiency of oil–water separation, a separation device namely cyclonic state micro-bubble flotation column, which combines the column separator and the cyclonic separator in what is called, is hereby proposed and developed in this work.

2. Process description

The cyclonic state micro-bubble flotation column (so called FCSMC column) was developed as shown in Fig. 1, which includes flotation column, cyclone separator and micro-bubble generation parts. The cyclone separator is a inner air-injected de-oil cyclone, which provides on the bottom of the column with a tangential inlet. The cyclone separator includes a cylindrical cyclonic shell and a horn shaped section fixed on the upper of the cyclonic shell, the inside of the horn shaped section forms a passage connecting the cyclone separator with the column separator.

The oily wastewater enters the column separator, flowing downward evenly within its whole section, and at the same time the bubbles rise from the bottom of the column separator and continuously collide with the oil droplets. The easy-to-separate oily droplets are effectively separated through the stage of column flotation, and formed bubble–droplets aggregates accumulate on the upper portion of the column separator to form a foam layer, which overflows into the foam collecting tank, from where the resulting concentrated product is discharged. The difficult-to-separate oily droplets from the cyclone separator will be sent to the cyclone separator for its further processing after pressurization, and in the jet pipe device undergo air suction, micro-bubble creation in intensely turbulent conditions. The oil droplets move towards the wall of the outer cylinder and are separated from the vertical flow under the action of centrifugal forces and collected on the bottom of the outer cylinder. Therefore, a circular processing of the difficult-to-separate wastewater is formed, that is, from the cyclonic separation to the jet pipe device then back to the cyclonic separation. The emulsification oil droplets are transported from cyclone separation zone to air flotation separation zone by the oil–gas complex which formed by the carry role of microbubbles, the oil–water separation has finished. The air flotation separation area has static separation effect of the "long and narrow" environment with "quiet" fluid dynamics.

The cyclonic state micro-bubble flotation column adopts an improved separation mechanism which is a combination of the cyclonic separation and the column flotation. The treatment is

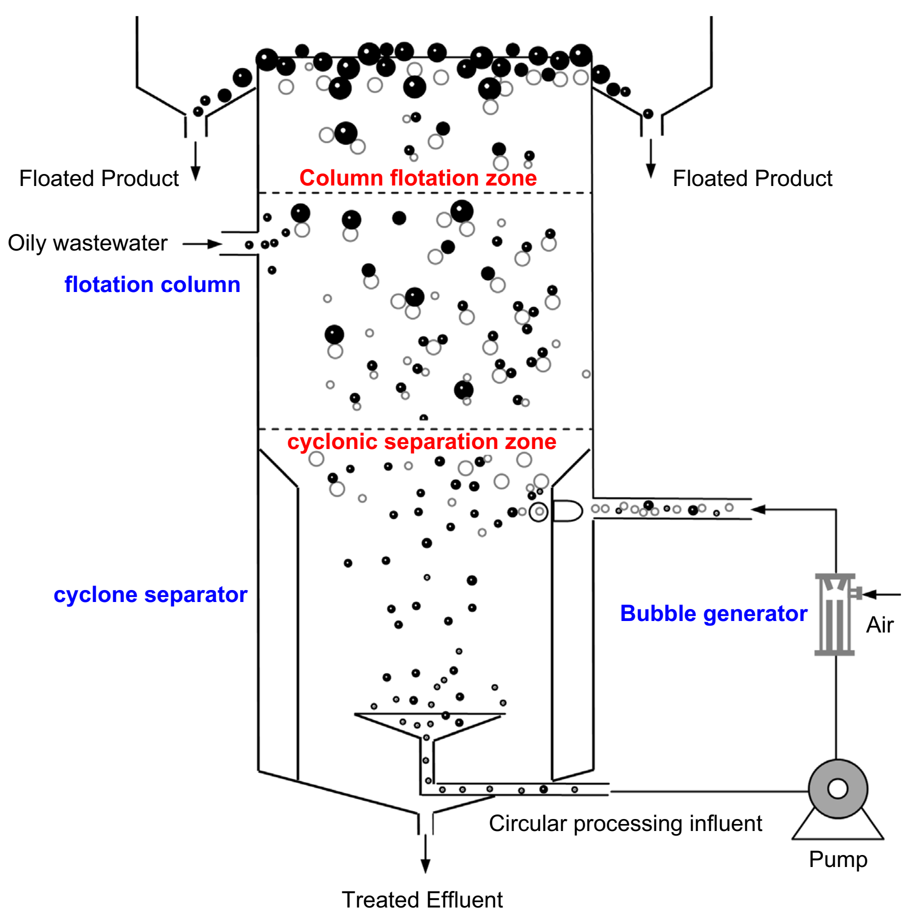

Fig. 1. Schematic of the cyclonic state micro-bubble flotation column.