Chemical Engineering Science 173 (2017) 335–345

Contents lists available at ScienceDirect

Chemical Engineering Science

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

Characterization and secondary sludge dewatering performance of a novel combined aluminum-ferrous-starch flocculant (CAFS)

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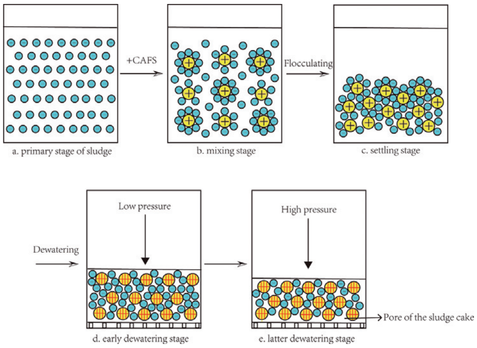
HIGHLIGHTS

- The novel flocculant has a superior sludge dewatering performance.
- The novel flocculant could break sludge colloids easily and release proteins.
- Cationic groups could promote the formation of large incompressible dense cakes.

GRAPHICAL ABSTRACT

The dehydration process is divided into two phases, the first phase destroys the stability of the sludge particle through breaking the hydration shell and gathers the dispersed particles (subfigure a, b, c); otherwise, the dispersed particle in small sizes will easily clog the pore of the sludge cake and increase the filtration resistance. The second phase requires a low compressibility sludge cake during the compression stage, which can keep the pore of the sludge cake unblocked so as to discharge water (subfigure d, e).



ARTICLE INFO

Article history:
Received 28 May 2017
Received in revised form 1 August 2017
Accepted 3 August 2017
Available online 4 August 2017

Keywords:
Sludge dewatering
Flocculant
Extracellular polymeric substance
Protein content
Cake structure

ABSTRACT

The sludge dewatering performance depends on the chemical and physical characteristics of sludge cakes. To investigate the relation between the sludge cake structural properties, the protein content in loosely bound extracellular polymeric substances (LB-EPS) and the dewatering performance of sludge, the sludge dewatering ability of a combined aluminum- ferrous- starch flocculant (CAFS) was evaluated for capillary suction time (CST), settling volume percentage (SV_{30}), specific resistance to filtration (SRF), time to filter (TTF), dryness and the LB-EPS protein content. The dewatering mechanism was also probed by investigation of the compressibilities, SEM images and structural properties of cakes. The results showed that CAFS could break sludge colloids easily and release more LB-EPS proteins. Cake microscopic structures and compressibility analyses indicated that the CAFS helped to form large incompressible dense cakes with discontinuous surfaces, containing a better adsorption capacity, which were closely related to the synergistic effect of cationic groups and starch mesh chains.

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http://dx.doi.org/10.1016/j.ces.2017.08.005
0009-2509/

1. Introduction

A large amount of sludge is produced in the process of wastewater treatment, and the sludge often contains over 90% water (Qi et al., 2011). To reduce energy consumption and the cost of subsequent processing, it is necessary to shrink the sludge volume by sludge dewatering. Starch-based flocculants have recently been applied to improve the dewaterability of the excess sludge by flocculating the sludge particles (Wang et al., 2013b; Ye et al., 2011; Lv et al., 2014), and the sludge dewatering performance was evaluated by specific resistance to filtration (SRF), time to filter (TTF), capillary suction time (CST), and sludge volume after 30 min of sedimentation (SV_{30}). Extracellular polymeric substances (EPS) are biopolymers that are believed to play an important role in sludge floc formation (Laspidou and Rittmann, 2002), biological flocculation sedimentation (Wang et al., 2013a; Szewczuk-Karpisz et al., 2014, 2016) and dewatering performance (Wilen et al., 2003). Because of its importance and complexity, the influence of EPS on the sludge dewaterability has been a topic of many investigations (Li and Yang, 2007; Wang et al., 2013b; Liao et al., 2001). In recent experimental studies, the loosely bound EPS (LB-EPS) content was found to be very closely related to the sludge flocculating behavior and dewaterability, while no correlation could be found between the tightly bound EPS (TB-EPS) content and the sludge characteristics (Li and Yang, 2007; Yang and Li, 2009). EPS analysis showed that between 60% and 80% of extracellular substances could be attributed to protein (Frolund et al., 1994; Bura et al., 1998); therefore, the determination of the protein content in the LB-EPS is very important for the evaluation of sludge dewatering performance. However, previous studies have not used LB-EPS protein content to study the dewatering mechanism of chemical conditioning sludge.

The sludge dewatering performance depends on the chemical and physical characteristics of sludge cakes (Thapa et al., 2009; Ning et al., 2013). Generally speaking, the dewatering process is divided into two phases, the first phase destroys the stability of the sludge particle and gathers the dispersed particles, and it requires a good flocculation efficiency; otherwise, the dispersed particle in small sizes will easily clog the pore of the sludge cake and increase the filtration resistance. The second phase requires a low compressibility sludge cake during the compression stage, or the sludge particles will deform easily and cause cake void closures, which further impedes dewatering (Zhao, 2003; Thapa et al., 2009). The compressibility and porosity are critical for sludge dewatering (Zhao and Bache, 2001), so it is significant for a novel flocculant to investigate the impact of the flocculated sludge structural properties on the sludge dewaterability.

In our preceding papers, we had discussed the preparation and simple flocculation efficiency of a novel combined aluminum-ferrous-starch flocculant (CAFS), but the characterization and its secondary sludge dewatering performance and dewatering mechanism are novel work remain to be done (Lin et al., 2012, 2015).

In this study, CAFS was prepared with starch, aluminum sulfate and ferrous sulfate, and its sludge dewatering ability was evaluated by the LB-EPS protein content and the five conventional evaluation indices (i.e., SRF, CST, TTF, SV_{30} and dryness). The dewatering mechanism was also probed by investigation of the compressibilities, SEM images, surface areas, pore volumes, and pore diameter of the sludge cakes. The aim of this work was: (1) to seek the correlation between the cake structural properties and the sludge dewaterability, (2) to correlate the LB-EPS protein content with the dewatering performance of sludge, and (3) to provide a green agenda for sludge dewatering.

2. Materials and methods

2.1. Reagents

Maize starch was purchased from Changchun Dacheng Maize Starch Co., Ltd., PR China (The moisture content, swelling power, solubility index of maize starch are 13.4%, 22.63 g g^{-1}, 10.5%, respectively). Aluminum sulfate, ferrous sulfate, sodium hydroxide and sulfuric acid were ordered from Guangzhou Chemical Reagent Factory, PR China. Ferric chloride and cationic polyacrylamide (CPAM, the molecular weight is about 8–12 million) were ordered from Tianjin Damao Chemical Reagent Factory, PR China. Polyaluminum chloride (PAC) was purchased from Nanning Chemical Industry Co., Ltd, PR China. Thereinto, maize starch, aluminum sulfate and ferrous sulfate were used for preparing CAFS, sodium hydroxide and sulfuric acid were used for pH adjustment, while ferric chloride, CPAM and PAC were used as alternate flocculants. All of these reagents were of analytical grade, and all solutions were prepared by deionized water.

The procedure used for the preparation of CAFS was described in the preceding paper (Lin et al., 2012), with its mesh starch chains grafted on polyaluminum and polyferrous. The synthetic pathway is shown in Scheme 1.

The bond strengths of Fe—O, Al—O and H—O are 390.40 ± 17.20 kJ/mol, 511.00 ± 3.00 kJ/mol and 429.99 ± 0.38 kJ/mol (David, 2004), respectively. There is not too big gap among them and the polyreaction and hydroxyl bridging reaction can proceed, thus aluminum and ferric graft on modified starch chains smoothly. The charge density of CAFS was measured by a Mütek PCD 03 particle charge detector, and derived a consequence of 4.15 meq/g. Measurement of molecular weight was performed on high performance liquid chromatograph (Waters1525) with refractive index detector (Water140) and Empower workstation, and derived consequences of 1480 g/mol of number-average molecular weight (M_n) and 1561 g/mol of weight-average molecular weight (M_w, $M_w/M_n = 1.05$).

2.2. Secondary sludge

The sewage sludge samples used in this study were obtained from the secondary settling tank of Lijiao Municipal Sewage Treatment Plant in Guangzhou City, Guangdong Province, China. The samples were transported to the laboratory within 30 min of sampling; next, the samples underwent gravity thickening, and then, the supernatant was removed. Subsequently, the samples were stored in a refrigerator at 4 °C for less than 2 days. Before conditioning, the sludge samples were kept in a water bath at 15 °C for 30 min and then shaken well for further using. The moisture content, SRF, CST, SV_{30}, TTF, dryness and pH value of secondary sludge samples were 95.0%, 98.3×10^{11} m/kg (under a vacuum pressure of 0.06 MPa), 120 s, 85.0%, 162 s, 15.25% and 6.75, respectively.

2.3. Determination of sludge dewaterability

In the beginning, the pH of 100 mL of waste sludge was adjusted by sodium hydroxide or sulfuric acid, and then put in a certain dosage of flocculant, followed by a rapid stir of 250 rpm for 1 min and a slow agitation at 50 rpm for 5 min.

At the terminate stirred period, the CST was determined by a TYPE304 M Capillary Suction Timer (Triton Electronics, UK), while the SV_{30} was measured according to the standard method (APHA, 1998). For zeta potential measurement, samples were centrifuged and the centrifugate was analyzed using a Nano-ZS90 Zeta Sizer