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Effect of compressibility of synthetic fibers as conditioning materials on dewatering of activated sludge

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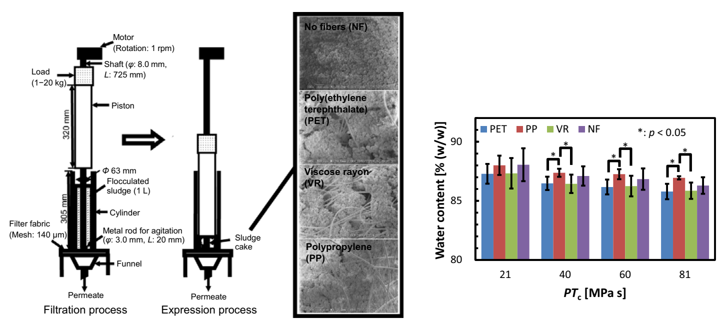
HIGHLIGHTS

- We focused on synthetic fibers as physical conditioners in sludge dewatering.
- All synthetic fibers examined accelerated sludge consolidation rate on expression.
- Some synthetic fibers reduced sludge water contents after expression.
- These fibers appear to maintain the sludge porous structure during expression.
- Fiber compaction properties may be a factor in improving sludge dewaterability.

GRAPHICAL ABSTRACT



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ABSTRACT

Efficient solid–liquid phase separation of excess sludge from the mixed-liquor suspended solids in wastewater treatment is difficult to achieve without prior sludge conditioning. Several physical conditioners have been assessed as skeleton builders or filtering aids to reduce sludge compressibility; however, little is known about how the properties of the physical conditioner affect sludge compressibility and dewaterability. In this study, synthetic poly(ethylene terephthalate) (PET), polypropylene, and viscose rayon (VR) fibers were used as physical conditioners for activated sludge, and the effects of the fiber compressibility on the dewaterability of activated sludge collected from a laboratory-scale reactor were assessed. Based on expression experiments using a laboratory-scale apparatus, it was found that: (1) the rate of consolidation of sludge cakes increased after incorporation of synthetic fibers, particularly at the primary stage. (2) The porosity of the sludge cake was maintained only with fibers that required high pressures for compaction (i.e., PET and VR); thus, high dewaterability of the cakes was achieved with these fibers. It is proposed that the compressibility of the physical conditioner may be one of the more important factors for improving sludge dewaterability.

1. Introduction

Excess sludge is generated as a byproduct of wastewater treatment using activated sludge processes. Activated sludge generally contains more than 98% water by mass [1]; therefore, dewatering is a key step to facilitate sludge transport and handling, and to minimize the space or energy required for drying or incineration

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Nomenclature

Abbreviations

MLSS	mixed-liquor suspended solids
PET	poly(ethylene terephthalate)
PP	polypropylene
SEM	scanning electron microscopy
VR	viscose rayon

Symbols

a_1	Cooper–Eaton model constant (–)
a_2	Cooper–Eaton model constant (–)
k_1	Cooper–Eaton model constant (kPa)
k_2	Cooper–Eaton model constant (kPa)
L	thickness of the consolidated cake at T_c (mm)
L_1	initial thickness (mm)
L_∞	final cake thickness, when $T_c = \infty$ (mm)
P	applied pressure (kPa)
p	p-value (–)
T_c	expression time (s)
U_c	consolidation ratio (–)
V^*	fractional volume compaction (–)
V_0	initial volume of synthetic fiber (mm^3)
V	volume of synthetic fiber at each loading step (mm^3)
V_∞	volume of synthetic fiber after final loading at 212 kPa (mm^3)
W_{dc}	dried cake weight (kg)
W_f	weight of fiber mixed in the sludge (kg)
W_{wc}	total cake weight after consolidation (kg)
X	water content (% (w/w))

of the excess sludge [2]. Dewatering is conventionally performed by using mechanical techniques based on centrifugation or filtration, and the application of pressure to force water molecules from the sludge. Various dewatering processes, including centrifugation, vacuum filtration, and the use of belt presses, filter presses, rotary presses, and screw presses have been developed [3], although it is still difficult to achieve efficient solid–liquid phase separation. This difficulty is related to the high organic content and presence of colloidal materials in the sludge, the compressible nature of sludge solids, and the high affinity of extracellular polymeric substances for trapped water molecules [3].

Chemical conditioners such as flocculants and coagulants are often used to promote agglomeration of the colloids into larger flocs prior to mechanical dewatering. However, sludge dewatering is often hindered by blinding of the filtration media and the filter cake itself because of the highly compressible nature of the sludge solids, resulting in the requirement for long expression times and high pressures to achieve effective mechanical dewatering [4,5]. To reduce the sludge compressibility, highly porous inert minerals are often added as physical conditioners. These include fly ash [6–10], gypsum [11–13] and lime [7,14], or carbonaceous materials such as bagasse [8,12,15,16], coal [15,17], lignite [18], rice shells and rice bran [19], wood chips, and wheat dregs [8,20,21]. These physical conditioners act as skeleton builders or filtering aids by reducing sludge compressibility and improving the mechanical strength and permeability of the sludge solids during compression [3]. Carbon-based materials are particularly effective for improving the sludge dewaterability compared with minerals due to the higher porosity of the former. Carbon-based materials also offer other advantages such as lower ash contents and higher calorific values than mineral conditioners, both of which are important properties for final incineration of dewatered sludge [5].

The merits of physical conditioners (i.e., skeleton builders or filtering aids) for improving sludge compressibility and permeability during filtration and expression processes have been well documented, but few studies have examined how the compressibility or strength of the physical conditioners themselves influence the compressibility and dewaterability of activated sludge. In this study, we focus on the use of synthetic fibers as physical conditioners for improving sludge dewaterability. In Japan, two million tons of these synthetic fibers must be disposed annually, and only 10% is recycled [22]. Employing synthetic fibers aimed for disposal as physical conditioners for dewatering sludge can reduce the expense associated with the disposal of the fibers as well as of sludge. It has been reported that the dewaterability of sludges containing large amounts of long fibers is significantly improved [23] due to modification of the structural rigidity or compressibility of the filter cake by such fibers [3]. We, therefore, investigate the effects of various synthetic fibers as physical conditioners on the dewaterability of activated sludge samples collected from a laboratory-scale reactor, with emphasis on the effects of the fiber compressibility. The water content of the sludge and the rate of consolidation of the sludge cakes are evaluated using a laboratory-scale expression apparatus.

2. Materials and methods

2.1. Conditioning sludge samples

Activated sludge samples were collected from a 40 L laboratory-scale batch reactor that has been fed with glucose, peptone, and KH_2PO_4 for more than 10 years. Each sludge sample was adjusted to approximately 10 g L^{-1} of mixed-liquor suspended solids (MLSS) by decantation. Sludge (1L) was placed in a glass beaker and approximately 100 mL of the supernatant was removed by decantation. The sludge was stirred at 200 rpm in the presence of either poly(ethylene terephthalate) (PET), viscose rayon (VR), or polypropylene (PP) synthetic fibers. These fibers were added to a final content of 10% (w/w) of the dried sludge samples. The lengths and diameters of the fibers were adjusted to 5 mm and 20 μm, respectively. Agitation was continued for 90 s and 1 g L^{-1} of amphoteric dimethylaminoethyl acrylate polyelectrolyte solution (Ixe-1360, Ishigaki Maintenance, Tokyo, Japan) was added in three increments at 0, 30, and 60 s during agitation to adjust the final level to 1% (w/w) of the MLSS. Here, dimethylaminoethyl acrylate polyelectrolyte acts as a chemical conditioner that promotes agglomeration of the colloids into larger flocs (the polyelectrolyte was dissolved in milliQ water with agitation for 24 h and a 1 g L^{-1} stock solution was prepared).

2.2. Filtration and expression of conditioned sludge

The filtration and expression properties of the conditioned sludge were determined using the laboratory-scale apparatus shown in Fig. 1. Conditioned activated sludge (1 L) was poured into a cylinder (φ 63 mm), and then filtered gravitationally with gentle agitation (1 rpm) before continuous measurement of the mass of permeate obtained using a balance (FX-3000i, A&D Co., Ltd., Tokyo, Japan). The filtration experiments were performed six times for each conditioned sludge sample (i.e., mixed with PET, PP, or VR, and in the absence of fibers (NF)). When a permeate <0.1 mg per min was being generated, the thickness of the sludge cake in the cylinder was measured, and the sludge cake was then pressed with increasing loads (1, 3, 5, 10, 15, and 20 kg, i.e., 3.14, 9.44, 15.7, 31.5,