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Energy demand in sludge dewatering

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Abstract

This work investigates the energy required to dewater a suspension, i.e., activated sludge dewatered by centrifugation or consolidation. Total energy input to the suspension from the dewatering device, bond strength between adjacent water and solid surface, and intra-cake friction loss were evaluated for original and flocculated sludges. In centrifugal dewatering, most energy input during the initial stage was consumed by overcoming process irreversibility other than intra-cake friction, and, thereby, had a low energy efficiency. To increase centrifuge speed or to flocculate the sludge at optimal flocculant dosage would yield a high-energy input. In the consolidation test, most energy input at the initial stage was consumed in breaking down the bond strength until the moisture content reduced to less than the critical content. During subsequent dewatering stages, friction loss became the dominant source of energy loss. Dewatering sludge with high-energy efficiency is beneficial to optimally operate a dewatering process.

Keywords: Energy; Efficiency; Bond strength; Friction loss; Centrifugation; Consolidation; Flocculation

1. Introduction

Energy consumption rate is an essential parameter determining the economy of dewatering a suspension by applying a solid–liquid separation (SLS) device. Professionals acquired knowledge by experience regarding energy cost for specific SLS processes. The minimum energy required to achieve a dewatering operation is both of academic and practical interest since the extent to which a given process deviates from an *ideal* dewatering operation can be estimated. To reduce the process irreversibility provides ways of maximizing energy efficiency (Bejan, 1996). Restated, if the ratio of real energy input to minimum energy requirement defined energy efficiency, then the process dewatering performance could be evaluated based on energy economy aspect.

Water with high water-to-solid bond strength can be referred to as sludge "bound water" (Vesilind, 1994). Various methods have been proposed for measuring bound water content (Heukelekian and Weisberg, 1956; Lee et al., 1975; Haschemeyer et al., 1977; Lewicki et al., 1978; Karr and Keinath, 1978; Katsiris and Kouzeli-Katsiri, 1987; Herwijn et al., 1992; Robinson and Knocke, 1992; Lee and Hsu, 1995). Kopp and Dichtl (2000, 2001a, b) proposed the correlation between the moisture distribution in sludge and the efficiency of sludge dewatering in full-scale plant. Chen et al. (1997, 1999) proposed a continuous scheme that considers the water–solid bond strength as a physically relevant classification index to assess the status of water in sludge. Driving "freed" water out of the suspension requires sufficient energy to overcome irreversible internal processes, such as cake and filter media fluid

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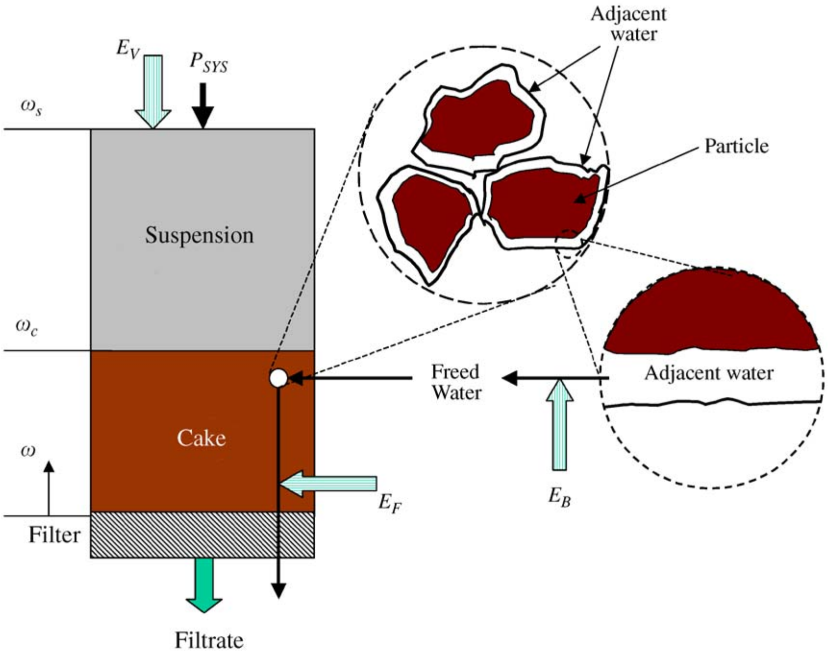

Fig. 1. The schematics of the moisture removal process. $E_V : p - V$ work done by the surroundings, E_B: energy needed to release the adjacent water from the bound surface; E_F: energy required to overcome the friction loss of water flow through the cake and the filter.

friction. Modified Darcy's law is typically used to describe this friction force (Lee and Wang, 2000). The sum of the bond strength and associated friction loss yielded the theoretically minimum amount of work needed to dewater a suspension, t.

Removing water from a suspension requires that (1) the bond strength between the adjacent water and the solid surface are broken down, without physically moving the water from its original position near the solid surface; and (2) that this water is moved from its original position in suspension to outside the system through the sludge cake and the filter medium. The energy needed to separate the adjacent water from the solid surface is denoted by E_B, and the energy required to force this water through the filter cake and filter medium is E_F. Therefore, the minimum energy requirement to dewater a sludge is $(E_B + E_F)$. If the energy consumed by the dewatering device (E_V) is higher than this minimum energy requirement, and the difference is $(E_V-(E_B + E_F))$, presented the irreversibility yielded by other process non-ideality. This work estimated the minimum energy needed to dewater a suspension, and used an activated sludge as the test example. Bond strength of water (E_B) was estimated by utilizing the method proposed by Chen et al. (1997). Then, pressure and volume work done on the suspension (E_V) and friction loss during the consolidated dewatering or centrifugal dewatering (E_F) were theoretically derived and evaluated based on experimental data. The removal process of moisture in suspension was schematically shown in Fig. 1. In this figure, ω is the solid volume coordinate per unit area of filter media, including cake, sediment, and supernatant, and where ω_s is the total solid volume above unit filter medium.

2. Energy demand in dewatering

2.1. Energy input

A mechanical dewatering device removes water from a suspension by supplying energy at a power level P. Consider that only some of the energy input is adopted during dewatering, characterized by an average efficiency of η_{ave}, then the input energy can be expressed as

$$E_V = \eta_{ave} \int_0^t P\, dt, \tag{1}$$

where E_V is total energy input received by sludge, and t is the dewatering time.

The mechanical work received by the sludge (solids and water that remain in the dewatering device) from the external environment is attributable to the change in volume of the sludge under shear owing to the removal of filtrate (Herwijn et al., 1992):

$$\begin{aligned} dE_V &= (p_{SYS} + dp_{SYS})(V + dV) - p_{SYS} V, \\ &= p_{SYS}\, dV + V\, dp_{SYS}, \end{aligned} \tag{2}$$