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Hydrothermal treatment coupled with mechanical expression at increased temperature for excess sludge dewatering: Influence of operating conditions and the process energetics

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ABSTRACT

Dewatering is very important for excess sludge treatment and disposal. Hydrothermal treatment coupled with mechanical expression is a novel technology, in which a conventional pressure dewatering is combined with hydrothermal effect to realize an improved liquid/solids separation with low energy consumption. In this study, the process was performed by way of that the excess sludge was hydrothermally treated first and then the mechanical expression was employed immediately at increased temperature in two separate cells respectively. The results demonstrated that the mechanical expression employed at increased temperature showed a significant advantage than that at room temperature, given a further reduction of 19–47% of the moisture content. The dewatering process at room temperature was mostly depended on the effect of mechanical expression. Hydrothermal process, more importantly than mechanical effect at increased temperatures, seemed to govern the extent to which the dewatering process occurred. The dewatering began to show a positive effect when the temperature was exceeded the threshold temperature (between 120 and 150 °C). The residence time of 30 min promoted a substantial conversion in the sludge surface properties. After dewatering at temperatures of 180–210 °C, the moisture content decreased from 52 to 20% and the corresponding total water removal as filtrate was between 81 and 93%. It was observed that the moisture content of filter cake correlated with surface charge ($R_p = -0.93$, $p < 0.05$) and relative hydrophobicity ($R_p = -0.99$, $p < 0.05$). The calculated energy balance suggested that no additional external energy input is needed to support the dewatering process for excess sludge. The dewatering process needs an obviously lower energy input compared to thermal drying and electro-dewatering to produce a higher solids content cake.

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1. Introduction

Excess sludge, the residual generated during wastewater treatment using biochemistry processes, has posed a serious threat to the normal operation of wastewater treatment plant and the environment and human health (Yuan et al., 2011a). The high moisture content and biological activity of excess sludge limit its effective disposal, and make it expensive to transport. Sludge dewatering has proven to be an effective method to alleviate this problem. However, excess sludge containing high content of organic substances has normally less favorable dewatering properties (Saveyn et al., 2005). The established mechanical dewatering technologies, including centrifuges, belt presses and filter presses, have a limited dewaterability, generally attaining the highest value of 35% dry matter content even under conditioning (Raynaud et al., 2012). For thermal drying of excess sludge, a large amount of power consumption is indispensable and most of it is invested to remove the moisture by evaporation (Fytili and Zabaniotou, 2008). Therefore, the development of energy-efficient dewatering technologies to realize a higher solids content is urgent for the treatment and disposal of excess sludge.

The hydrothermal treatment, known as hydrothermal carbonization (HTC), has emerged as an appealing area of research in recycling of biomass (Román et al., 2012). The HTC process has been developed almost a century with the original aim of simulating the mechanisms of natural coalification in the laboratory (Titirici et al., 2007). It is a thermochemical conversion process that achieved in a suspension of biomass and water at temperatures around 180–250 °C for several hours, under autogenously saturated pressure. Many chemical reactions, such as hydrolysis, dehydration, decarboxylation, polymerization, and aromatization, might appear during the HTC process, thus resulting in significant conversion of characteristics of biomass (Funke and Ziegler, 2010). After HTC, the biomass is primarily converted into a solid product (carbonaceous matter); simultaneously, the by-products such as a large amount of process water and a little gas (particularly CO_2) are generated. The application of the HTC process to biomass shows an effective way to minimize the volume and reduce the capacity of moisture holding, meanwhile yielding an alternative fuel (Hu et al., 2008).

Following the nature of excess sludge, hydrothermal treatment may offer a pretreatment pathway for excess sludge to improve its dewaterability (Escala et al., 2013). Consequently, we investigated a combinational dewatering technology for excess sludge that the excess sludge was hydrothermally treated first and then the mechanical expression was employed immediately in two separate cells respectively, to remove the water from sludge as liquid at increased temperature. The most important feature of this process that provided a significant benefit is the separation of hydrothermal treatment and mechanical expression. The water bound in excess sludge is kept in liquid state in an independent sealed cell and its physical and chemical properties are significantly changed as temperature increases, facilitating the hydrothermal reactions quickly and sufficiently, and resulting in the sludge surface characteristics significantly changed (Mok et al., 1992). As a result, the process water can be removed easily even upon application of a mild mechanical pressure at high temperature. And most importantly, the mechanical expression performed at high temperature seems to be able to reach a higher water removal than that at cooling temperature by reason of the reduction of the viscosity of water.

So this work primarily focused on the investigation of hydrothermal treatment coupled with mechanical expression at increased temperature as an alternative to established dewatering technologies for excess sludge and sought to provide

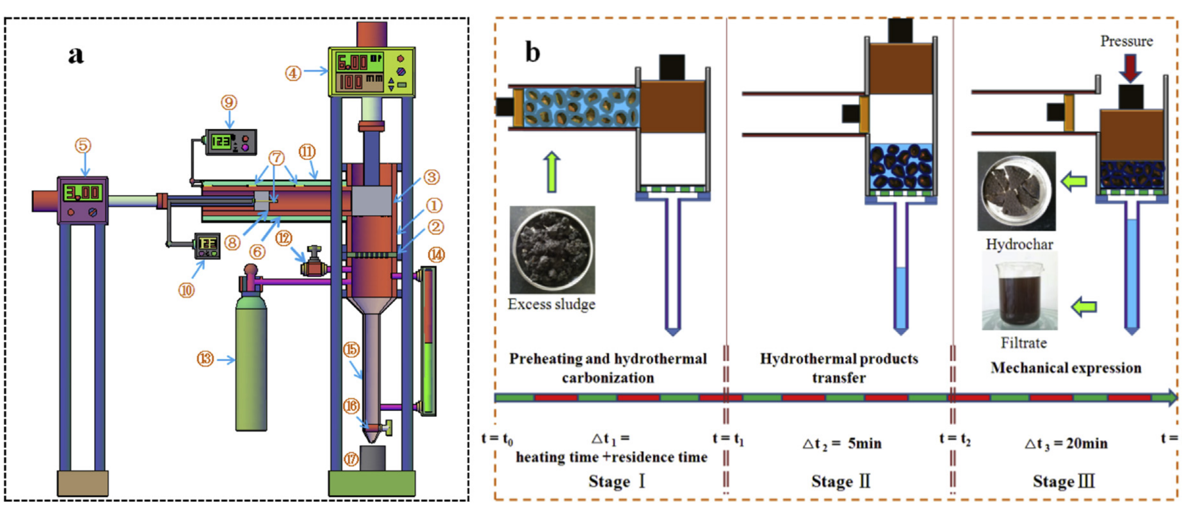

Fig. 1 – (a) The equipment of the dewatering by hydrothermal treatment coupled with mechanical expression. (1): Expression dewatering cell; (2): Stainless steel filter membrane and perforated plate; (3): Vertical piston; (4): Vertical presser; (5): Horizontal presser; (6): Stainless steel tubular reactor; (7): Temperature sensors; (8): Horizontal piston; (9): Programmable temperature controller; (10): Digital thermometer; (11): Electric heating jacket; (12): Pressure regulating valve; (13): N_2 cylinder; (14): Color level gauge; (15): Filtrate trap; (16): Drain valve; (17): Cooled filtrate collector. (b) Schematic representation of the different stages of the dewatering process.