Enhancing the MTE dewatering of sewage sludge by conditioning with brown coal

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Abstract

Dewatering of sewage sludge is an important part of proper sludge management practice. It is becoming a more challenging issue for water industries as new regulations on sludge disposal are being imposed. In this paper, the application of mechanical thermal expression (MTE) to dewater sewage sludge and the conditioning of sludge by mixing with brown coal are investigated. Raw sludge, sludge flocculated with polyelectrolyte and flocculated sludge with further conditioning by mixing with brown coal are investigated at a range of processing conditions in an MTE cell. Dewatering performance is measured by determining the sludge water removal and specific cake resistance of the filter cake for various test conditions. Both flocculation of sludge with polyelectrolyte and mixing of sludge with brown coal improve the dewatering rate. However, the sludge which is flocculated prior to mixing with brown coal gives the best dewatering performance in a compression cell at room temperature. Increases in both the applied pressure and the amount of coal are found to have a positive effect on sludge dewaterability.

1. INTRODUCTION

The management of sewage sludge is becoming a more challenging issue for water industries as new regulations on sludge disposal are being imposed. The efficiency and effectiveness of meeting the disposal regulations and the economics of sludge management methods are dependent on the moisture content of the sludge. The conventional way of reducing the moisture by holding the sludge in an evaporation pond is unfavorable for countries where land is either expensive or not available or the climatic conditions are not suitable. Other dewatering technologies like centrifugation and mechanical pressing are also used but none of them are found to reduce the moisture content significantly. Eddy (1991) reported that conventional dewatering processes were unable to increase the solids content above 30 wt%. Since high levels of moisture are not desirable for processes like incineration and composting, there is a need to develop new dewatering technologies that can reduce the moisture content in sludge more economically and to a greater extent.

Sewage sludge is difficult to dewater because the properties of water in sludge are different to those in common colloidal suspensions and because the solid component of sewage sludge is mainly organic, made of microbial cells and organic macromolecules such as polysaccharides, proteins, nucleic acids, lipids and other polymeric compounds. The microbial cells hold a significant amount of water. Vesilind (1994) classified the water in sewage sludge into four different types: free water, interstitial water, vicinal water and water of hydration. The interstitial water, vicinal water and water of hydration are collectively known as bound water. The removal of bound water from the cell network requires severe conditions. To dewater the sludge to a greater extent, intracellular water and water trapped in the cell network (flocs) must be released, which requires disruption of cells. Erdincler and Vesilind (2003) examined methods like alkali treatment, heat treatment, NaCl treatment and the results showed that only a small amount of cell rupture can be achieved. Liu and Fang (2003) suggested that the microbial cells are embedded into highly hydrated gel like substances known as extracellular polymeric substances (EPS) which forms a protective layer for the cells against the harmful external environment. The EPS are the product of active secretion, cell surface material shedding, cell lysis and sorption from environment. They are charged 3D gel-like structures composed of proteins, carbohydrates, uronic acids, DNA and humous-like substances. The role of EPS on sludge dewatering is not fully understood, but it has been proposed that EPS is one of the causes of sludge dewatering difficulties.
Laboratory scale research has shown that MTE has the potential to dewater other materials such as bagasse and biosolids (Clayton et al. 2005). Therefore, there is a possibility of MTE as a new sewage sludge dewatering technology. In this paper, the application of mechanical thermal expression (MTE) to dewater sewage sludge and the conditioning of sludge by mixing with brown coal prior to compression at room temperature are investigated.

2. MATERIAL AND METHODS

Freshly generated sewage sludge samples were collected from the outflow of an aerobic digester at a municipal treatment plant in Australia. The samples have been stored in a laboratory cooling room maintained at below 4°C. The sludge has a solids content of 2 wt% and a pH of 7.23. A raw brown coal sample from the Loy Yang mine in Victoria has been provided by the CRC for Clean Power from Lignite. It has a moisture content of 60 wt%.

Sludge is thickened by flocculation before pressing in the MTE cell. Flocculation tests are carried out using polyelectrolyte (Zetag 7650). Using the jar test procedure, the optimum dose for flocculation is determined. For better dispersion of polyelectrolyte, raw sludge is diluted three times using distilled water before flocculation. Only the optimum poly electrolyte dose is used for MTE testing. The optimum dose of poly electrolyte and diluted sludge are mixed in a cylinder by inverting the cylinder ten times. The mixture is allowed to settle for five minutes. Settled floccs are separated by decanting the clear water. The water decanted is equal to the dilution water added, thus the resulting solids content (2 wt %) is not increased using the polyelectrolyte.

Dewatering is also an issue with other materials such as brown coal or lignite, which can have moisture contents as high as 70% wet basis. Over several decades, there has been intensive research in the area of brown coal dewatering but none of the researched technologies have been successfully implemented at industry scale. Recently, the University of Dortmund Germany has developed a new dewatering technology known as mechanical thermal expression (MTE) to reduce the water content of brown coal prior to combustion (Bergins 2003). MTE is also being investigated by the CRC for Clean Power from Lignite to dewater Victorian brown coal (Clayton et al. 2005). In the MTE process a high temperature (up to 200°C) and a high pressure (up to 24 MPa) are applied simultaneously. Due to the combined effect of mechanical and thermal energy in the MTE process, rapid dewatering is achievable. Compared to other dewatering processes, MTE is highly cost effective and has a high moisture reduction capacity.
coupled with a personal computer. As a desired pressure is applied to the piston, it descends into the compression cell containing the sample, as shown in Figure 1. Both single pressure tests and stepped pressure tests are used to compress the sample. For single pressure tests, the compression is held at a desired pressure for a fixed amount of time. For stepped pressure tests, a desired pressure is held for a given time, after which the pressure is ramped up to the next pressure level. The pressures for step pressure tests are 0.75, 1.5, 3 and 6 MPa. Each pressure step is held constant for 10 minutes. Elevated temperature can also be used to enhance dewatering of sludge samples. For the high temperature tests, an electric band heater can be wrapped around the compression cell. However, in this paper only room temperature tests are presented. The computer records the sample height, applied pressure and elapsed time every two seconds. The change in height is the result of water removed from the sample. At the end of each test, both the water removed and solid cake is weighed. The moisture content of the cake is also determined by drying the cake to equilibrium weight in an oven maintained at 105°C.

Figure 1. Schematic of axial MTE cell

2.1. Theory: Cake Filtration and Specific Cake Resistance

In cake filtration, solids are deposited in the form of a cake on thin filter medium. At the beginning of the filtration when there is no cake formation, the whole pressure drop (driving force) available will act across the medium. In this case, the flow rate \( Q \) of filtrate can be determined by Darcy’s basic filtration equation (Tao et al., 2003).

\[
Q = \frac{dV}{dt} = \frac{A\Delta P}{\mu R}
\]  

(1)

Where, \( A \) is the area of filter medium, \( \Delta P \) is the driving force (pressure drop), \( R \) is the medium resistance, \( V \) is the filtrate volume, \( t \) is the filtration time and \( \mu \) is the filtrate viscosity. As the filtration progresses, solids are deposited on the medium and a thin layer of cake is formed which introduces an extra resistance to filtration called cake resistance and its magnitude, which is proportional to the amount of cake deposited increases as the filtration progresses. The flow rate of filtrate \( Q \) is now given by the following relationship:

\[
Q = \frac{dV}{dt} = \frac{A^2\Delta P}{\mu(RA + \alpha V)}
\]  

(2)

where, \( c \) is the concentration of solids in the suspension and \( \alpha \) is the specific cake resistance. By integrating and rearranging equation (2) gives the following equation.

\[
\frac{t}{V} = \frac{\alpha \mu c}{2A^2\Delta P} V + \frac{R\mu}{A\Delta P}
\]  

(3)

Equation (3) indicates that a graph of \( t/V \) vs \( V \) will give a straight line. This equation holds for constant pressure and for an incompressible cake. From the slope and intercept of the line, fundamental filtration parameters such as \( \alpha \) and \( R \) can be determined. For the cases where constant pressure can not be attained instantaneously, Svarovsky (2000) has proposed to integrate equation (2) starting from a point \((t_s, V_s)\) which correspond the time and filtrate volume at the beginning of the truly constant pressure period. After the integration the following equation is obtained which indicates the graph of \((t-t_s)/(V-V_s)\) vs \( V \) will be a straight line.

\[
\frac{(t-t_s)}{(V-V_s)} = \frac{\alpha \mu c}{2A^2\Delta P}(V + V_s) + \frac{R\mu}{A\Delta P}
\]  

(4)

If “a” is the slope and “b” is the intercept of the line then \( \alpha \) and \( R \) can be determined using the following equations.

\[
\alpha = \frac{2A^2\Delta Pa}{\mu c}
\]  

(5)

\[
R = \frac{A\Delta P(b-aV_s)}{\mu}
\]  

(6)

The specific cake resistance is further related to the cake permeability \( (K) \) by equation (7).
where \( \varepsilon \) is the equilibrium porosity of the cake and \( \rho_s \) is the solid density.

3. RESULTS AND DISCUSSION

The dewatering behaviour of raw sludge and the pre-conditioned sludge are compared in a series of step pressure MTE tests at room temperature. The starting sample height for all of the tests is kept at 110 mm with the exception of the sample with 30 g of brown coal. The sample heights versus time results are as shown in Figure 2. For the two tests involving raw (non-flocculated) sludge, the dewatering rate is the same, as the slopes of the two curves are identical, and therefore the addition of coal does not appear to be beneficial.

A large improvement on dewatering rate is seen when the raw sludge is flocculated with Zetag 7650 polyelectrolyte. The sample height reduction of about 50% (from 110 mm to 55 mm) is achieved in the first 8 minutes of the test, and the final sample height of the conditioned sludge at the end of the test (30 minutes) is 31 mm. The dewatering rate and extent is further improved when the flocculated sludge is mixed with brown coal.

The effect of coal on sludge dewatering is further investigated by conducting a series of MTE tests on flocculated sludge (200 g) mixed with different amounts of brown coal, see Figure 3. The results show that there is a significant increase in water removal when the flocculated sludge is mixed with brown coal. The top most dashed curve in Figure 3 represents water removal from the sludge assuming that no water, originally present in the coal, is removed. The bottom curve represents the water removal from the sludge when 12% of coal water is assumed to be released. This value of 12% of the coal water is the amount of water removed when coal alone is pressed under identical conditions. When the coal is mixed with sludge, the coal water removal will lie somewhere between 0 and 12%. The solid line in Figure 3 is where the coal water removed is equal to the difference between the initial coal moisture and the final cake moisture content. The flocculated sludge conditioned with no coal shows approximately 75% water removal from the sludge. But it is increased to approximately 90% when 5 g of coal is added. The removal is further improved as the amount of coal added is increased. However, above 15 g of coal there is not a significant additional benefit in adding greater amounts of coal. According to Figure 3, 15 g of coal (moisture content ~60%) gives the optimum water removal from 200 g of flocculated sludge. The coal solids to sludge solids ratio in this case is approximately 3:2.

It is postulated that the enhanced sludge dewatering found after mixing with brown coal is due to the adsorption of components of the sludge on to the coal surfaces. Large and strong flocs are formed by the addition of brown coal which makes the flocs more porous resulting in higher water removal.

The effect of applied pressure on sludge dewatering is shown in Figure 4. It is found that the water removal from the sludge increases as the applied pressure increases. The flocculated sludge mixed with 6 g and 15 g coal is found to have a higher filtration rate during the first pressure step (0 to 0.75 MPa) than later steps. Therefore, most of the water (88 and 90% respectively) was removed during the first step. But in case of flocculated sludge mixed with 0 g and 4 g coal, water removal during later steps is also higher.
3.1. Determination of Specific Cake Resistance

The improvement of sludge water removal from the flocculated sludge by the addition of brown coal is further investigated by exploring the characteristic properties of the filter cake. One of those properties is the specific cake resistance. As explained in section 2.1, the specific cake resistance is estimated by obtaining the slope of the line \((\text{time/filtrate volume})\) vs \((\text{filtrate volume})\). Figure 5 shows one such plot of the constant pressure filtration experiment on 200g flocculated sludge mixed with 4g of brown coal and pressed at 0.75MPa. The slope 'a' is obtained from the linear regression of the experimental data which gave an \(R^2\) value of 0.99. The experimental data of flocculated sludge mixed with 6g and 15g of coal are also plotted in a similar way to obtain the slope of the straight lines for these cases.

The slope values are then used to determine the specific cake resistance of the filter cakes of the flocculated sludge mixed with various mounts of brown coal. The plot of the specific cake resistance of the filter cake against the mount of coal added is presented in Figure 6. It can be seen that with increasing amount of coal, the specific cake resistance of the filter cake decreases. Therefore the sludge water can be removed at a greater rate during the filtration. The effect of reduced specific cake resistance by the addition of coal is clearly reflected in sludge water removal plot shown in Figure 3, where more water is being removed at higher amount of coal addition.

The specific cake resistance for the flocculated sludge with no coal added is the highest \((9.53 \times 10^8 \text{ m/kg})\). To check whether the magnitude of the specific cake resistance are reasonable, they are compared with the specific cake resistance of the flocculated ultrafine coal filter cakes presented by Tao et al. (2003). The values of specific cake resistances found in this study are in a similar range to Tao et al. (2003) study where the lowest specific cake resistance was \(1.53 \times 10^9 \text{ m/kg}\).

Some assumptions are made during the specific cake resistance determination. It is assumed that there is no water removal from the coal particles at the lower pressure level (0.75MPa). The filter cake is made of two different solid types (sludge solid and coal solid) which may behave in different ways during cake formation. But it is assumed this behaviour is similar in this analysis. Also, during the filtrate volume determination the sample height is adjusted for the height attained by the coal added.

The equilibrium porosity of the cake is not known for this study because the sample is not pressed long enough to achieve the equilibrium height. Therefore, the permeability of the filter cake can
not be determined using the specific cake resistance and permeability relationship (equation 7). Future work will investigate permeability for a wide range of processing conditions.

4. CONCLUSION

It is found that the dewatering rate of raw sludge with no prior treatment is very low even at high pressures and long tests. Therefore, pre-treatment of raw sludge appears to be a crucial step for better sludge dewaterability. Flocculation of raw sludge improves the dewatering rate, but flocculation itself is not able to increase the solids content to a great extent. Mixing flocculated sludge with brown coal is found to increase the dewatering rate and increase the solids content significantly. Increasing the amount of coal reduces the specific cake resistance and hence increases the rate of water removal. Similarly, both final solids content and the percentage water removal are found to be dependent on the applied pressure. Increasing the applied pressure improves both the achievable solids content and the rate of water removal.

The investigation of the role of brown coal in the dewatering of sludge is ongoing with the aim to improve further the rate and extent of dewatering using MTE. Future work will also involve the use of refined filtration theories which will accommodate the limitations and assumption made in this study to obtain more accurate information of filter cake characteristics. Use of higher temperatures to increase the rate of dewatering and sterilization of the solids will also be investigated.

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6. REFERENCES


