Involvement of gypsum ($CaSO_4 \cdot 2H_2O$) in water treatment sludge dewatering: a potential benefit in disposal and reuse

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Abstract
The research attempt to use gypsum ($CaSO_4 \cdot 2H_2O$) as a skeleton builder for sludge dewatering derived from the fact that polymer conditioning of sludge affected only the rate of water release but not the extent of dewatering. Involvement of gypsum as a physical conditioner associated with a polymer could improve sludge filterability. More significantly, gypsum serves as skeleton builder for the purpose of forming a permeable and rigid lattice structure that can remain porous under high positive pressure during the compression step after the cake growth of the filtration, thus keeping the size of the micro-passages through which water is expressed. Experiments using a high pressure call apparatus showed that a further decrease of two to seven percent of sludge cake equilibrium moisture content was achieved with corresponding to the sludge thickness for dewatering of 1 to 10 cm by the involvement of gypsum (with 60% addition of original sludge solids) compared to the situation of single polymer conditioning. The importance of the gypsum involvement in alum sludge dewatering is not only the enhancement of dewatering extent, but also the potential application in transforming dewatered alum sludge from 'waste' for landfill to useful 'fertilizer' or to be used as filter medium for 'waste to treat waste'.

Keywords: Alum sludge, constructed wetlands, dewatering, disposal, gypsum, skeleton builder

1. Introduction
Water treatment sludge refers to the by-product from the processing of drinking water in Water Treatment Works where aluminium sulphate is most widely used as the primary coagulant in Ireland. For this reason, water treatment sludge is commonly known as alum sludge. During alum sludge treatment, organic polymer is often used as chemical conditioner to improve sludge filterability by flocculating small gel-like sludge particles into large aggregates with less affinity for water. Ideally, the flocs are porous, permeable to water flow, and incompressible so that pore will not be blocked under pressure during filtration and dewatering. However, it is evident that polymer conditioning of sludge affects only the rate of water release but not the extent of dewatering and makes the sludge more compressible (Novak and O' Brien, 1975; Knocke et al, 1993; Zhao and Bache, 2001).

Keeping these in mind, it is reasonable to pursue that the target of conditioning should include both improvement of dewatering extent and diminution of cake compressibility. To achieve these objectives, an alternative approach may be the addition of skeleton

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builder or physical conditioners. As is known, physical conditioners are often inorganic admixtures, which are generally inert materials as part of the waste stream from industry. From the literature, fly ash, cement kiln dust, quicklime, hydrated lime, fine coal, bagasse, wood chips and wheat dregs have been reported to be used in sludge dewatering (Benitez et al, 1994; Zouboulis and Guitonas, 1995). Previous studies by Zhao and Bache (2001) and Zhao (2002) attempted to use gypsum ($CaSO_4{\cdot}2H_2O$) as a skeleton builder in association with polymer for water treatment sludge conditioning and dewatering have demonstrated that the use of gypsum could form a permeable and rigid lattice sludge structure that can remain porous under high positive pressure during the compression step after the cake growth of the filtration, thus keeping the size of the micro-passages through which water is expressed.

This paper presents an experimental study aimed to demonstrate the effectiveness of a water treatment sludge dewatering after a combined dually conditioning with gypsum and an organic polymer. This time a laboratory scale high pressure cell apparatus was used for dewatering tests. Thereafter, the possible application and potential benefit of dewatered alum sludge are highlighted. The importance of its potential application lies in transforming dewatered alum sludge from 'waste' for landfill to useful 'material' or to be used as 'waste to treat waste'.

2. Materials and methods

2.1 Experimental materials

An alum sludge used in present study was collected from sludge holding tank of a water treatment works treating a low-turbidity, coloured water with aluminium sulphate as primary coagulant. The sludge with solids concentration of 8,453 mg/l and pH of 6.7 was conditioned using polymer PW 85 (*from OCL Ltd, UK.*), this being an anionic organic polymer with molecular weight in the range 1.2×10^7 and charge density of 5 %. A 0.01 % stock solution was prepared using nanopure water and allowed to stand for 24 h prior to use. Gypsum ($C_aSO_4{\cdot}2H_2O$) (supplied by *Tioxide Europe Ltd*) with a density of 1,400 – 1,600 kg/m^3 and a particle size of 4 - 20 μm (measured using a Galai CIS – 100 particle size analyser) was used as skeleton builder in combination with polymer for sludge conditioning.

2.2 Experimental methods

Initially, gypsum was added to a 200 ml sludge sample with the dose expressed as the percentage of alum sludge solids concentration. After several seconds of rapid mixing to ensure dispersion, the polymer was added with dosage of 20.0 mg/l (excluding the gypsum in the sludge). Following polymer addition the sludge was subjected to 30 s of rapid mixing followed by 1 min slow mixing to promote flocculation. After conditioning, the sludge was then subjected to dewatering tests using a laboratory scale high pressure cell apparatus. Experimental procedures were described schematically in Fig. 1. The high pressure cell apparatus is an air pressure driven piston apparatus. As illustrated in Fig. 1, a positive pressure was applied to the sludge sample by an air pressure driven piston. Two Whatman 1# filter papers wetted with distilled water were placed at the base of the piston chamber of the high pressure cell to hold the sludge sample. Conditioned sludge samples were poured into the piston chamber up to depth of 1, 2, 3, 5, 7, and 10 cm, respectively, for dewatering test at applied pressure of 5 bar (1 bar = 10^5 N/m^2). During the test, the filtrate volumes and the filtration time were recorded. After the dewatering test (dewatering time being pre-set), moisture content (MC) of sludge cake was measured using standard method. In each test, the run was repeated in the same way to check the data reproducibility. The data showing below represent the mean values.

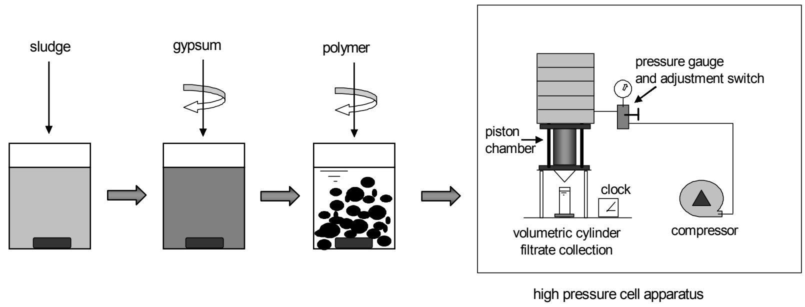

Fig. 1 Schematic illustration of experimental procedure

3. Results

Fig. 2 illustrates the volume of filtrate as a function of dewatering time when conditioned sludge was subjected to dewater using the high pressure call apparatus. On the basis of previous work reported in Zhao and Bache (2001), the present study focused on a gypsum dose of 60% dry solids (DS) of original alum sludge solids concentration, this having been demonstrated to produce a significant improvement of filterability in terms of net sludge solids yields, which take into consideration of the increase of sludge solids concentration by gypsum addition. Applied pressure for dewatering apparatus of 5 bar was also demonstrated as the suitable pressure for dewatering (Zhao and Bache, 2002). It was found from Fig. 2 that polymer dose of 20.0 mg/l resulted in a significant improvement of dewatering; further increase of polymer dose could hardly bring about the further change of dewatering behaviour. Thus, optimum polymer dose was set as 20.0 mg/l for the oncoming tests in this study.

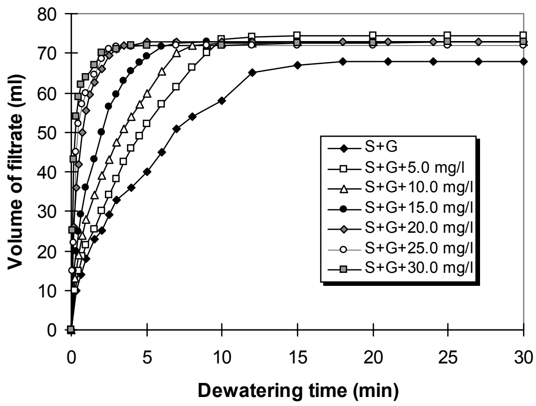

Fig. 2 Effect of polymer dosage on dewatering behaviour of 60% DS gypsum pre-added sludge (Conditioned sludge was poured into the piston chamber up to the depth of 2 cm. Applied pressure is 5.0 bar. In the legend, S refers to sludge, G represents gypsum and the values show the polymer dosage)

Fig. 3 provided an plots of sludge cake moisture content with dewatering time at the polymer dose of 20.0 mg/l with gypsum addition in 60% DS or without gypsum addition. Comparing the two plots shown in Fig.3, it is clear that the addition of gypsum improved sludge dewatering behaviour by further decreasing cake moisture content in the range from 16.9 to 4.1 percentages corresponding to the dewatering time of 1 h to 6 h, respectively. It is believed that cake moisture content is an indication of dewatering extent for dewatering apparatus in practice. Lower cake moisture value implied higher solid content in the cake and smaller volume of dewatered sludge for final handing.

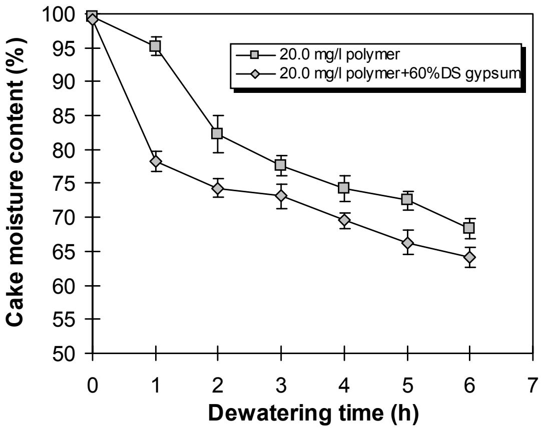

Fig. 3 Comparison of dewatering behaviour between polymer dosed and polymer plus gypsum dosed sludge (polymer dosage is 20.0 mg/l; gypsum is 60% DS. Sludge thickness in piston chamber is 2 cm. Applied pressure is 5.0 bar)

In order to identify the effect of gypsum addition on sludge cake equilibrium moisture content, groups of dewatering tests were designed and performed at the sludge thickness of 1, 2, 3, 5, 7, and 10 cm, respectively, in piston chamber of the high pressure call apparatus. At each sludge thickness, dewatering test was carried out continuously until 8 days at that time the constant moisture content, which was suggested as equilibrium moisture content, was reached. The results are given in Fig. 4. Fig. 4 demonstrates that, compared with the equilibrium moisture content obtained without the gypsum, the addition of gypsum resulted in an obvious lower cake moisture content during dewatering process and eventually led to a further decrease of 6.8 percent of the cake equilibrium moisture content at sludge thickness of 1cm and 2.3 percent of 10 cm of sludge thickness. In addition, Fig. 4 also indicates that the dewatering behaviour can be significantly affected by sludge thickness in dewatering apparatus; the effects of this factor has been investigated and reported in Zhao and Bache (2002).

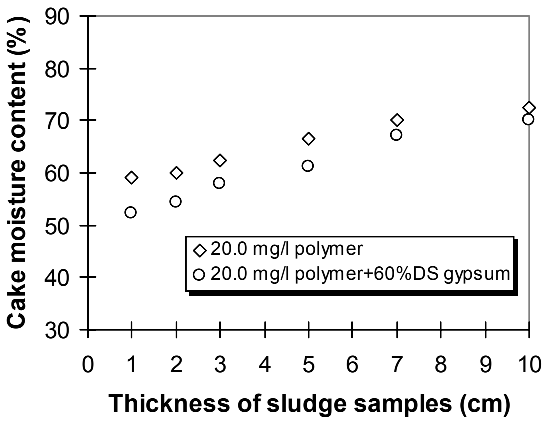

Fig. 4 Effects of thickness of sludge samples on cake equilibrium moisture content with and without gypsum addition (Applied pressure is 5.0 bar)

4. Discussion

4.1 Gypsum as a physical skeleton builder in alum sludge dewatering

Although gypsum is commonly known in agricultural science as an amendment for ameliorating alkaline soils, there is no report from the literature to discover its use to improve sludge dewaterability as a physical conditioner until the previous studies (Zhao and Bache, 2001; Zhao, 2002). The results presented in current study provide vital evidence that gypsum ($CaSO_4 \cdot 2H_2O$) can be used in combination with a polymer for conditioning an alum sludge. Sludge filterability was improved with the addition of gypsum. The involvement of the gypsum enhanced the dewatering extent by further decreasing equilibrium cake moisture content by 2 to about 7 percent depending on the thickness of sludge being dewatered (see Fig. 4). Therefore, it is reasonable to believe that gypsum functioned as the skeleton builder to help or enhance the interaction between polymer and sludge particles. This has been evidenced by direct measurement of polymer residual using size exclusion chromatography in previous study (Zhao and Bache, 2001). It is the enhanced interaction that makes the sludge form a more compact structure, thereby reducing its compressibility during dewatering process. Accordingly, the more rigid lattice structure can retain solid particles and allow the water to be transmitted via the micro-passages during dewatering. This view has been supported by the investigation of floc structure (evaluated in terms of fractal dimension, D_F, which is a quantitative measurement of how the original particles in the flocs occupy space) using image analysis system (Zhao, 2002) and has been described schematically by Lai and Liu (2004), as shown in Fig. 5.

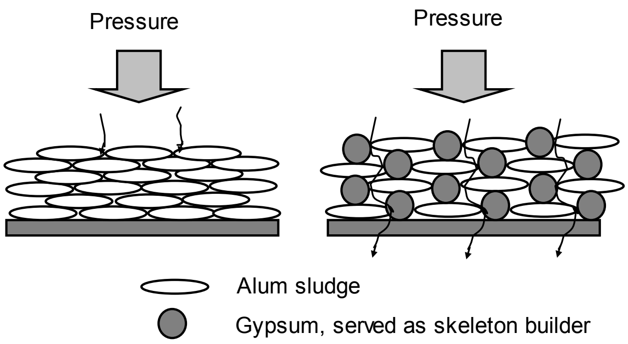

Fig. 5 Conceptual description of the role of gypsum as skeleton builder in sludge dewatering (Lai and Liu, 2004)

4.2 The potential application of this study

It is noted that gypsum is neither an inert material nor a waste from industry. Why is it selected as skeleton builder? The selection of gypsum derived from its common use as an amendment in agricultural science. Thus, the involvement of gypsum in alum sludge treatment could render the dewatered sludge some possible applications:

First, dewatered alum sludge with the involvement of gypsum makes land use a possibility. To date, efficient techniques for utilizing the dewatered sludge are still lacking, and the most economic way to dispose dewatered sludge is the application on land as a soil fertilizer. However, alum sludge is directly discharged or landfilled in Ireland because of high levels of aluminum and some heavy metal ions, which have been noted to be toxic to aquatic life, providing marginal, if any, benefits to soil fertility. However, land disposal of alum sludge has advantages; compared with sewage sludge, alum sludge is relatively clean with respect to heavy metals and organics, and poses lower environmental risks (Geertsema et al, 1994). It is noted in the literature that some attentions have been paid to the assessment of alum sludge to land use (Dempsey et al, 1990; Lucas et al, 1994). In particular, according to the study reported by Geertsema et al. (1994), there was no long-term adverse effect being observed when an alum sludge was applied to forest lands at a loading rate of at least 1.5 to 2.5 percent by dry weight. Therefore, it is fair to say that the involvement of gypsum in alum sludge will enhance its possible application to land, particularly for ameliorating alkaline soils.

Second, alum sludge dewatered with gypsum may be used as filter medium in constructed wetlands for wastewater treatment, particularly for phosphorus-rich wastewaters, such as agricultural wastewater. It has been recognised that constructed wetland is an effective and popular technique for wastewater treatment. Compared with the other technologies, e.g. activated sludge, tricking filter and biological reactors, constructed wetlands have the advantage of aesthetical appearance and lower energy consumption, and are more environmentally friendly (Verhoeven Jos and Meuleman Arthur, 1999; Kivaisi Amelia, 2001). The raw alum sludge contains flocs of humic matter and metal hydroxide in which the impurities removed from the natural water are entrapped, adsorbed or chemically bounded. More significantly, the dewatered alum sludge is predominantly composed of amorphous aluminium ions. Further more, the involvement of gypsum makes the dewatered alum sludge be abundant with calcium ion. Both amorphous aluminium and calcium ions have been evidenced to play an important role in the treatment of phosphorus-rich wastewater (Zumpe Heidi and Baskaran, 2002). Currently, in Centre for Water Resources Research (CWRR) of University College Dublin, a research project focused on the identification of the absorption capacity of phosphorus by dewatered alum sludge is performed. The results derived from this project can be used for further and extensive research toward the possible application of dewatered alum sludge in wastewater treatment engineering, thus transforming the dewatered alum sludge from a 'waste' into useful material. In addition, the use of dewatered alum sludge as filter medium in constructed wetlands will further reduce the capital cost of engineered wetlands.

5. Conclusions

Gypsum ($CaSO_4 \cdot 2H_2O$) was introduced as a physical conditioner in combination with polymer for alum sludge conditioning. Dewatering tests in a high pressure call apparatus have demonstrated that water release was significantly enhanced with the addition of gypsum, which served as a skeleton builder. Addition of gypsum by 60% DS (original alum sludge dry solids) can lead to a further decrease of about 7 percent of the cake equilibrium moisture content at sludge thickness of 1cm and 2 percent of 10 cm of sludge thickness, compared with the moisture content achieved with only polymer conditioning. The lower moisture content will benefit the final handling of dewatered sludge. The beneficial effect of gypsum lies in its role as a skeleton builder to help or enhance the interaction between polymer and sludge particles and to build up a more rigid lattice structure. Dewatered alum sludge could be used to land or alternatively as a filter medium in constructed wetlands for wastewater treatment. These possible applications provide a promising prospect for the disposal of alum sludge, but more research work is needed.

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