On the role of gypsum ($CaSO_4 \cdot 2H_2O$) in conditioning and dewatering of a water treatment sludge

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Abstract

Problems concerning the management and utilization of sludge derived from water treatment processes are still not fully solved. A common approach is direct discharge to a landfill site. This study provides experimental data to demonstrate the effectiveness of a combination of gypsum ($CaSO_4 \cdot 2H_2O$) and an organic polymer in alum sludge conditioning and dewatering. Experimental results demonstrated that the filterability of dually conditioned alum sludge was significantly improved by the addition of gypsum at a 1:1 ratio (WT/WT) to original sludge solids. Dewatering tests showed that a further decrease of almost seven percentage of sludge cake equilibrium moisture content was achieved by the involvement of gypsum compared to the situation of single polymer conditioning. The importance of this study lies in the possible application of dewatered alum sludge to land use or as a filter medium in constructed wetland for wastewater treatment, providing a positive solution to the problem of alum sludge disposal.

Keywords: Alum sludge, conditioning, dewatering, gypsum, polymer, settling, skeleton builder.

1. Introduction

Waterworks sludges are referred to alum sludges on the basis of the use of aluminium sulphate as the primary coagulant for flocculating the raw water. Although organic polymers have been used for alum sludge conditioning and dewatering for many years, it is known that polymer conditioning of sludge affects only the rate of water release but not the extent of dewatering and makes the sludge more compressible [1-3]. 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. Further to a previous study [3,4], in which the gypsum ($CaSO_4 \cdot 2H_2O$) was firstly introduced as a skeleton builder to be involved in an alum sludge conditioning and dewatering, this study presents more experimental data to demonstrate the use of gypsum in alum sludge treatment, especially in high sludge solids concentration. An alum sludge was conditioned with both a polymer and gypsum. Filterability of the conditioned sludge was evaluated in terms of net sludge solids yield (Y_N), which takes into account the increase of sludge solids concentration by gypsum addition. Y_N was defined as follows [3]:

$$Y_N = \varphi\left(\frac{2P_tC_t}{\mu t}\frac{1}{SRF}\right)^{1/2} \qquad (1)$$

Where, SRF is the specific resistance to filtration determined by Buchner test [5]. P_t, μ and t are in turn the total pressure drop in Buchner test, the dynamic viscosity of the filtrate and the filtration time. φ is a correction factor in the form of C_s/C_t, where C_s and C_t are, respectively, the original sludge solids concentration and the total (original solids + conditioner solids) solids concentration.

In this study, the dewatering behaviour of dually conditioned sludge was examined in great detail using a lab-scale air pressure plate apparatus; thereafter, the possible application and potential benefit of dewatered alum sludge are highlighted.

2. Materials and methods

An alum sludge with solids concentration of 9230 mg/l and pH of 6.9 was collected from the sludge holding tank of a waterworks treating a low-turbidity, coloured water with aluminium sulphate as primary coagulant. The sludge was conditioned using Magnafloc LT25 (*Allied Colloids UK Ltd., now Ciba Speciality Chemicals Ltd.*), this being an anionic organic polymer with molecular weight in the range $1.0\text{-}1.5\times10^7$ and charge density of 15-30 %. A 0.01 % stock solution was prepared using nanopure water and allowed to stand for 24 h prior to use. For the sludge examined in this study, the optimum dose of polymer is 20.0 mg/l (data not shown), which was evaluated by modified SRF [6]. Gypsum ($CaSO_4\cdot2H_2O$) (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.

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. Sludge filterability was evaluated by net sludge solids yields (Y_N) [3]. After conditioning, the sludge was then subjected to dewatering tests using an air pressure plate apparatus, as described in Zhao and Bache [7]. The air pressure plate apparatus is a porous ceramic plate located in a pressure chamber. Samples are placed on the porous ceramic plate and a positive air pressure is supplied via a compressor. Moisture is driven from the samples through the ceramic plate. Conditioned alum sludge samples were poured into standard plastic rings (1 cm in height and 5 cm in diameter), which were placed on the ceramic plate of the air pressure plate. The air pressure was maintained up to 10 bar (1 bar = 100 kPa). Dewatering extent was evaluated by cake moisture content (MC) which was measured initially at hourly intervals for the first 6 h and then at daily intervals up to a periods of 8 days by which time the equilibrium moisture content was attained. Experimental procedures are shown schematically in Fig. 1.

Fig.1 [here]

3. Results

The response of sludge filterability to gypsum addition is illustrated in Fig. 2. Here, the dose of gypsum is expressed as the percentage of original alum sludge solids concentration. Fig. 2 indicates that the sludge filterability increased as gypsum was added, but decreased slightly with further gypsum addition. For the sludge examined, the addition of gypsum equivalent to 100% DS (dry solids of original sludge) gave the highest sludge filterability, correlating to the optimum polymer dose of 20.0 mg/l gauged by modified SRF [6].

Fig.2 [here]

Fig. 3 shows a profile of sludge dewatering behaviour at a polymer dose of 20.0 mg/l with gypsum addition in 100% 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, which was an indication of dewatering extent for dewatering apparatus in practice. Smaller cake moisture value implied higher solid content in the cake and lower volume of dewatered sludge for final handling. Fig. 3 also suggests that the dewatering behaviour can be significantly affected by applied pressure and dewatering time; the effects of these two parameters have been reported in detail in Zhao and Bache [7].

Fig. 3 [here]

To identify the effect of gypsum addition on sludge cake equilibrium moisture content, dewatering tests were carried out using the air pressure plate apparatus and the cake MC was measured until a constant MC, i.e. equilibrium MC, was obtained. This normally occurred after 8 days dewatering of applied pressure. The results are given in Fig. 4 which demonstrates that the addition of gypsum resulted in an obvious lower cake MC during dewatering process and eventually led to a further decrease of about 7 percent of the cake equilibrium MC, compared with the equilibrium MC obtained without the gypsum.

Fig. 4 [here]

Fig. 5 illustrates the settling behaviour of raw sludge, polymer conditioned sludge and polymer plus gypsum conditioned sludge. It is noted that the settling tests were performed in a series of 100 ml measuring cylinders. Although the scale of test is small, the 100 ml measuring cylinder is a useful tool for identifying sludge settling behaviour, from which an *ad hoc* test method was developed for evaluating optimum polymer dosage during alum sludge conditioning [8]. It can be seen from Fig. 5 that the sludge conditioned with both polymer and gypsum displays the best settling behaviour.

Fig. 5 [here]

4. Discussion

4.1 The role of gypsum in conditioning and dewatering

The data presented in this study demonstrate that gypsum ($CaSO_4 \cdot 2H_2O$) can be used as a physical conditioner in combination with a polymer for conditioning an alum sludge. Sludge filterability was improved with the addition of gypsum. At the dose of 100% DS the maximum value of Y_N was obtained (Fig. 2), indicating the minimum in the resistance to filtration [3]. The study on Y_N was followed by a group of experiments using an air pressure plate aimed to assess the overall influence of gypsum on the dewatering behaviour (Fig. 3 & 4). Experimental data showed that use of the gypsum enhanced the dewatering extent by further decreasing equilibrium MC by about 7 percent (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 to build up a more rigid lattice structure; such a structure can retain solid particles and allow the water to be transmitted during dewatering. This view has been supported by the direct measurement 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) and by the investigation of interactions among polymer, gypsum and sludge particles [3,4].

Sludge conditioning aims to improve predominately dewaterability and to obtain as high as possible sludge solids during dewatering. To achieve this objective, either chemical conditioners or physical conditioners can be used. It is well known that chemical conditioners improve sludge filterability by flocculating small gel-like sludge particles into large aggregates with less affinity for water. Physical conditioners are often inorganic admixtures, which are generally inert materials as part of the waste stream from industry. Although chemical conditioning using organic polymers has been a dominating method for decades, in recent years, physical conditioners emerged as an effective alternative for sludge conditioning. From 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 [9-15]. A number of researcher have demonstrated that physical conditioners can be served as skeleton builders as they can form a special floc structure; such structures remains porous under high pressure during mechanical dewatering. However, few studies focused on the combinative use of chemical and physical conditioners. Comparing with other studies in the literature, the attractive feature of this study is the use of not more than 100 % DS physical conditioner (gypsum). In contrast, an amount up to 500 % DS incinerator ash was reported by Smith et al. [16] in wastewater sludge dewatering; there is serious concerns that such a large amount of physical conditioners addition may make the sludge become minor constituent in the final dewatered sludge. The major benefit of gypsum's addition lies in its interaction with polymer, and it is such interaction that makes the sludge form a more compact structure, thereby reducing its compressibility during dewatering process as reported in previous studies [3,4].

4.2 The potential application of this study

It could be argued that the gypsum is neither an inert material nor a waste from industry. Why is it selected? The selection of gypsum is derived from its common use in agriculture science as an amendment for ameliorating alkaline soils. More importantly, 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 because it is relatively inert, providing marginal, if any, benefits to soil fertility. It is noted that, 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 [17]. It is noted in the literature that some attentions have been paid to the assessment of alum sludge to land use [18,19]. In particular, according to the study reported by Geertsema et al. [17], 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.

Second, alum sludge dewatered with gypsum may be used as filter medium in constructed wetlands for wastewater treatment, particularly for the treatment of wastewaters rich in phosphorus. It has been recognised that constructed wetland is an effective and popular technique for wastewater treatment. Compared with conventional treatment systems, wetland systems have lower operating costs, and are more environmental friendly [20,21]. Alum sludge with gypsum is predominantly amorphous aluminium ions and is abundant with calcium ions. Both minerals have been shown to play an important role in the treatment of phosphorus-rich wastewater [22,23]. In addition, the use of dewatered alum sludge as filter medium in constructed wetlands will further reduce capital cost.

Overall, any attempt towards the development of a new approach to sludge disposal is encouraging. However, large scaled experimental study and further research in the application of dewatered alum sludge derived from this study is required.

5. Conclusions

- Gypsum ($CaSO_4 \cdot 2H_2O$) was used as a physical conditioner in combination with polymer for alum sludge conditioning. Solid-liquid separation in both settling (via gravity) and dewatering (via mechanical equipment) was improved due to the involvement of gypsum.
- Lab-scale experiments demonstrated that water release was significantly enhanced with the addition of gypsum at a dose of 100% DS (original sludge dry solids). More importantly, almost 7 percent further decrease of sludge cake equilibrium moisture content was observed in dewatering behaviour with the involvement of gypsum, 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 disposed 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 required.

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Figure captions:

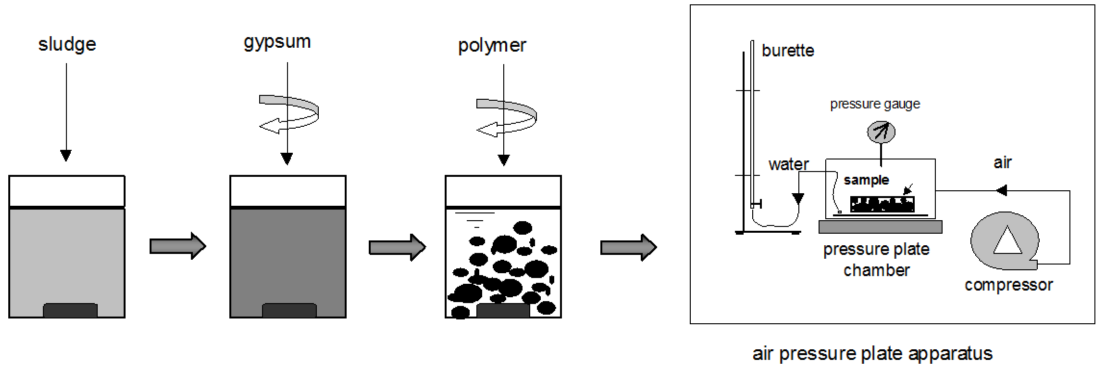
Fig. 1 Schematic diagram of experimental procedure

Fig. 2 filterability as a function of gypsum addition (% DS, referring original sludge dry solids) during conditioning at polymer dose of 20.0 mg/l (error bars denote SDs).

Fig. 3 Comparison of dewatering behaviour of alum sludge conditioned by polymer with gypsum (above) and without gypsum (bottom) additions (alum sludge solids concentration of 9230 mg/l, polymer dose of 20.0 mg/l, gypsum addition of 100% DS)

Fig. 4 Identification of dewatering behaviour with or without gypsum addition at applied pressure of 5.0 bar in air pressure plate (polymer dose of 20.0 mg/l, numeric values representing the cake equilibrium moisture content).

Fig. 5 Settling behaviour of raw and conditioned sludge with or without gypsum addition in a 100 ml measuring cylinder (sludge solids concentration of 9230 mg/l, polymer dose of 20.0 mg/l, gypsum addition of 100 % DS).



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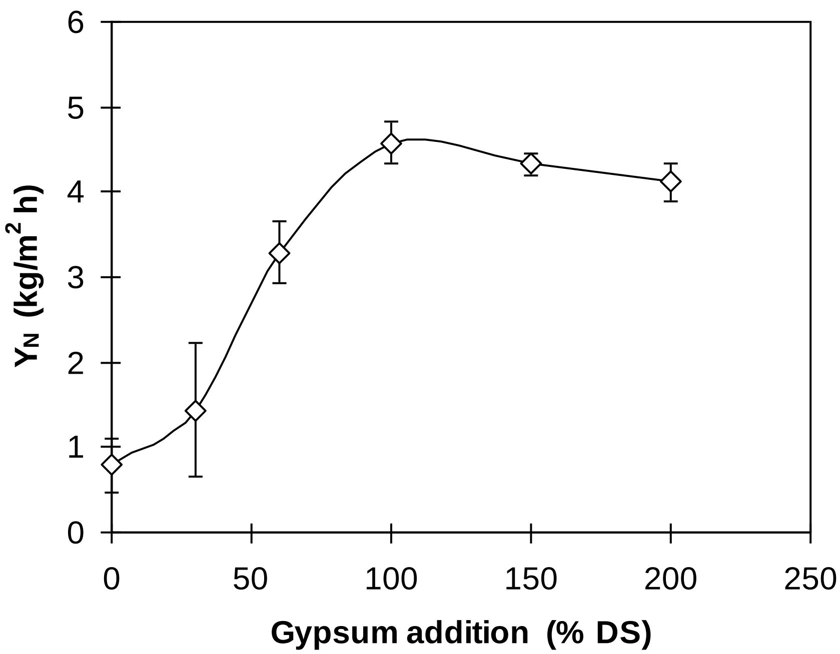

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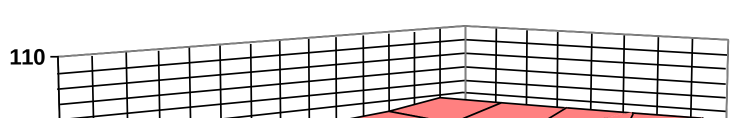

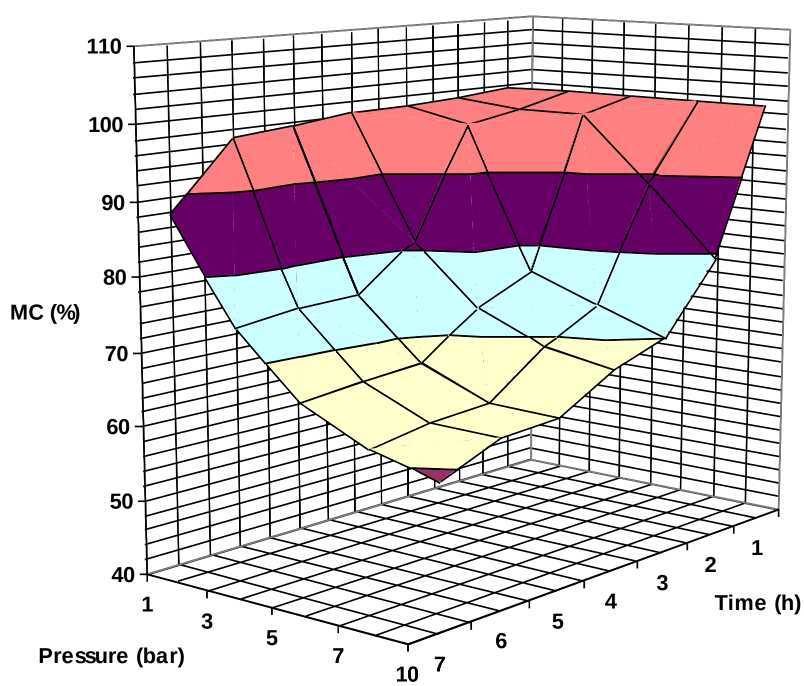

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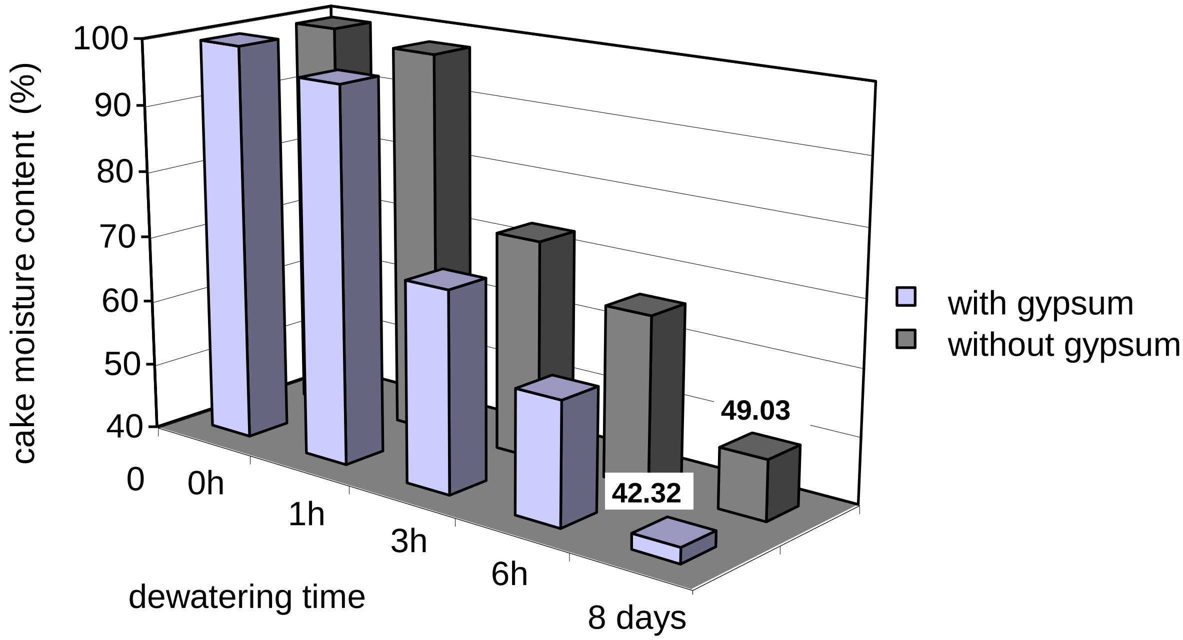

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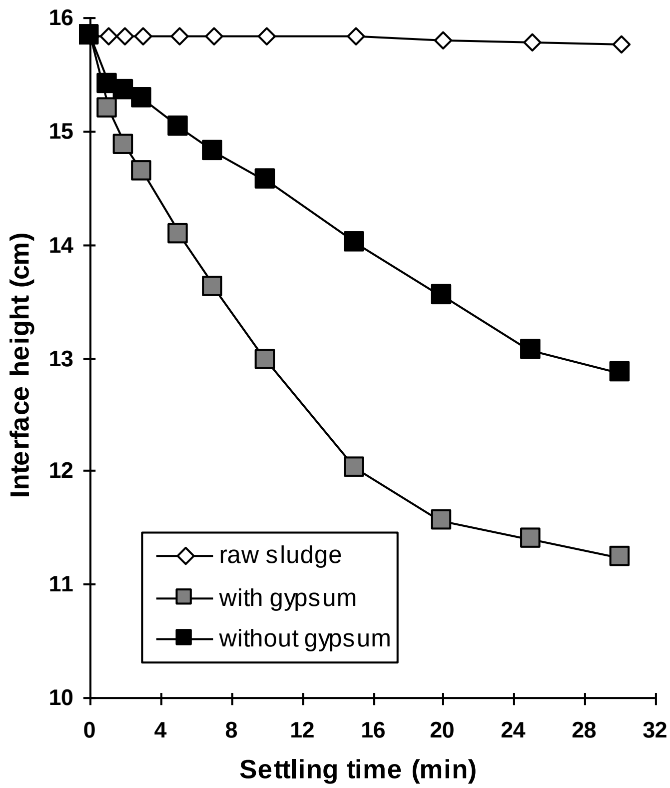

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