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MECHANICAL FREEZING OF ALUM SLUDGE

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ABSTRACT

This paper presents a new mechanical freezing concept for freezing alum or other hydroxide sludges as a conditioning step for dewatering. The basic concept is to freeze a thin layer of sludge on a continuously moving fabric belt. Sludge is attached to the belt by a vacuum drum belt filter which also removes one-half of the water and thus reduces the amount of sludge to be frozen. Filter leaf tests were conducted to determine the operational parameters and approximate production rates of this concept. These tests show that freezing alum sludge in thin layers will separate out the water as ice crystals and transform the solids into the same type of granular material produced in natural freezing beds. The average production rate of frozen sludge was 6.5 kg/hr.m^2 at -20°C. The belt area needed for a 10,000-m^3/day plant was estimated to be 48 m^2. This concept has been patented by the U.S. Patent Office.

KEYWORDS

Freeze conditioning; freeze separation; freeze crystallization; sludge freezing; sludge dewatering by freezing; freeze–thaw conditioning.

INTRODUCTION

Recently, sludge has become a major concern of the water treatment industry. The traditional practice of direct discharge into streams is becoming less acceptable because these sludges can contain trace contaminants. Discharge into lagoons is also of concern because of potential groundwater contamination and because lagoons eventually fill up and must be cleaned. Mechanical methods such as filter presses have been used with some success in dewatering these sludges, but they are difficult and expensive to operate.

Previous work by Martel (1988) and others has demonstrated that freeze–thaw can dramatically improve the dewatering characteristics of both water and wastewater treatment sludges. Alum sludge is especially transformed by this process. Freeze–thaw typically converts this sludge from a difficult-to-settle colloidal suspension to a mixture of settleable particles and clear supernatant. Upon removal of the supernatant and filtrate, the remaining particles resemble coffee grounds and do not re-dissolve.

In cold climates, freeze–thaw separation can be accomplished naturally in freezing beds. However, for obvious reasons, a freezing bed cannot be used in warm climates. Also, for large treatment plants, freezing beds would require a large piece of land which may not be available. For these situations, a mechanical method of freezing and thawing would be needed.

Several references can be found on attempts to build a mechanical freeze–thaw device. Doe *et al.* (1965)

proposed a process consisting of gravity thickening with slow picket stirring, storage and decanting for at least 16 hours, and freezing and thawing in a specially designed tank. However, the cost of this process was high because of the energy requirements and the capital, operation, and maintenance costs of the freezing tank (Benn and Doe, 1969).

Studies by Cheng *et al.* (1970) indicated that mechanical freezing can be made more economical by a film freezing technique. This technique was tried by the Sewerage Commission of the City of Milwaukee (1971), but the production rates were still not sufficient to compete with other mechanical processes for dewatering wastewater sludges.

Instead of freezing the sludge within a tank or on a surface, Randall *et al.* (1975) and Randall (1978) proposed freezing sludge by mixing it in direct contact with a refrigerant, such as butane. He claims that this method would result in better conditioning and better supernatant quality than solid freezing. Also, he concluded that the cost of this process would be more competitive with other dewatering processes because direct contact freezing is more energy efficient. However, this process has yet to receive widespread application.

Honda *et al.* (1981) successfully operated a pilot-scale freeze–thaw device for two years. This device was essentially a shell-tube heat exchanger that was separated into two compartments: a front part for freezing and a rear part for thawing. Sludge was forced into the tubes at the freezing end and thawed at the other end. Reportedly, this device proved to be reliable, but again, it has not been widely used.

One reason why none of these devices are in use today is the high cost of freezing and thawing. This is especially true of water treatment sludges, which are produced in great quantities and typically contain 99 percent water. Therefore, as much water as possible should be removed from these sludges before freezing. Also, the operation and maintenance of the device would be easier if it could operate in the continuous rather than the batch mode.

CONCEPT DEVELOPMENT

The proposed freeze-separator device basically combines a vacuum drum filter with a conveyor belt system. The drum filter is used to remove most of the water from the sludge and thus reduce the cost of freezing. The conveyor belt system is used to pick up and transport the sludge through the vacuum and freezing stages. A sketch of the proposed freeze-separator device is shown in Fig. 1.

Operation of the device begins at the vacuum section, where sludge is partially dewatered by vacuum filtration before freezing. A rotating drum, immersed in a constantly replenished vat of sludge, filters water through an attached belt of cloth media. This filtrate is either returned to the head of the plant or used in the washing section. As the drum continues to rotate, a sludge cake builds up on the media until it emerges from the vat and enters the freezing section. The speed of the belt is controlled so that the cake is completely frozen by the time it reaches the end of the freezing section. When the belt exits the freezing section, the cake is separated from the media and discharged into a collection hopper. A heated roller may be needed to break the bond between the cake and the media. The frozen sludge cake is then thawed using the heat removed from the freezing section. Meltwater produced during this thawing operation is collected and mixed with the filtrate from the vacuum section. The remaining solids are then transported to a drying bed or other dewatering unit operation. Meanwhile the cloth media continues on through a washing section where any residual sludge particles are removed. The media then reenters the vat and the cycle is repeated.

As mentioned earlier, the main advantage of this design over other freezing devices is that much of the water is removed before freezing. Another advantage is that it is a continuous process. Both freezing and thawing can be conducted simultaneously. This freezing and thawing process can be designed so that the heat removed during freezing can be used for thawing. Therefore, the thawing process will not cost anything. Also, the sludge cake is frozen in thin sheets, which should require less time and energy than freezing in bulk. A patent for this device has been filed with the U.S. Patent Office.

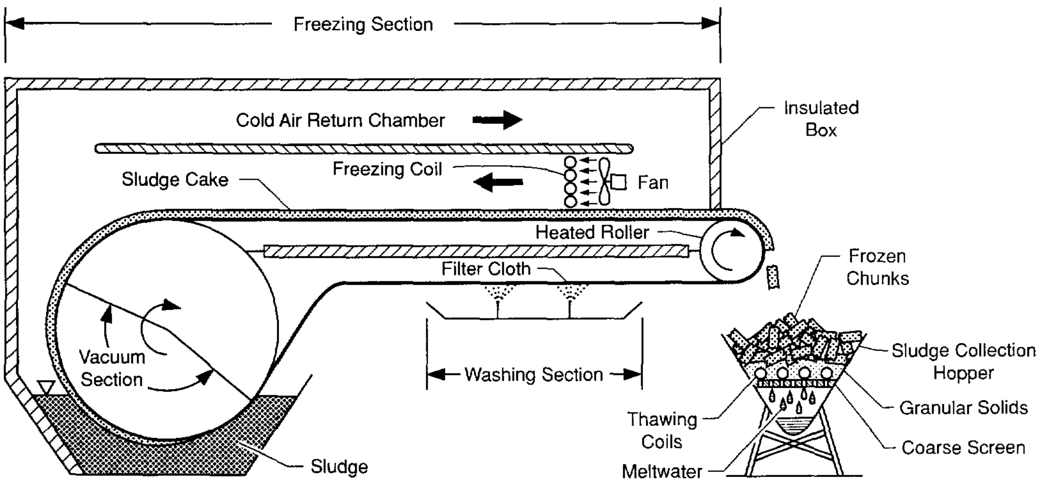

Fig. 1. Sketch of freeze-separator.

MATERIALS AND METHODS

A laboratory study was conducted to evaluate the feasibility of this device. Operation of the vacuum section of the freeze separator was simulated with a filter leaf test apparatus purchased from Komline Sanderson Engineering Corporation of Peapack, New Jersey. This apparatus resembles a funnel onto which a sample of the filter cloth is attached at the large end. The funnel is submerged in a container of sludge and a vacuum is applied at the other end. The filter leaf was originally developed to evaluate vacuum filter design criteria. A detailed description of the apparatus can be found in the company's instruction manual and in some textbooks.

The freezing section was simulated by placing the filter cloth and the attached sludge cake in a freezer at -20°C. This temperature was selected because it is easily attainable with conventional refrigeration equipment. One major difference between this freezing technique and that proposed in the freeze separator is the absence of a fan, which should increase the rate of freezing. Therefore, the freezing times obtained in the freezer should be conservative.

A typical test proceeded as follows. A sample of filter cloth (media) was attached to the filter leaf test apparatus. The filter leaf was immersed in a 7.6-liter container of alum sludge obtained from the Lebanon, New Hampshire, Water Treatment Plant. The vacuum was set at the desired pressure and maintained throughout the filtration period. Upon completion of the filtration period, the filter leaf was withdrawn from the container and the attached sludge layer was allowed to "form up" by maintaining the vacuum pressure for an additional 30 seconds. After removing the media and sludge layer from the filter leaf test apparatus, it was measured for layer thickness, and weighed to obtain the weight of wet cake. It then was laid in an aluminum pie plate and placed in the freezer. While the sludge layer was freezing, the volume and turbidity of the filtrate was measured. Every few minutes, the sludge layer was checked to see if it was frozen. When visual observations indicated that freezing was complete, the sludge layer was separated from the media by heating the underside of the media for a few seconds with a warm laboratory hot plate. The sludge layer then was allowed to thaw at room temperature. After thawing was complete, the meltwater was drained off and the remaining solids weighed to determine a drained solids content. The solids then were dried in an oven at

105°C for one hour to obtain the weight of dry solids. This completed a test. A total of 107 tests were conducted in this study.

RESULTS

Media Selection

The first series of tests were conducted to select the best filter cloths for this application. Eleven low-porosity filter cloths of various materials and weaves were selected for testing. Low-porosity cloths were selected because they can be expected to produce a higher quality filtrate. A relatively clear filtrate is desirable because the filtrate will be returned to the raw water intake for treatment. A turbidimeter was used to measure the quality of filtrate produced by each media. These tests were conducted at a vacuum pressure of 100 mm Hg and filtration times of two, five, and ten minutes.

A ranking of the media in order of lowest to highest average filtrate turbidity is shown in Table 1. The clearest filtrate was produced by Media 515, although Medias 201, 208, 210, 2015 and 2019 all had turbidities less than 30 NTU, which is a reasonably clear filtrate. In general, it seems that medias with low porosity produced the clearest filtrates. The type of material or the weave of the cloth did not seem to make a difference. Selection of the right media for this application may depend more on durability under freezing conditions than filtrate quality.

TABLE 1. Average Turbidity of Filtrate from Cloth Media

Media No.*	Material	Weave	Porosity $ft^3/min.$**	Average Filtrate Turbidity, TU
515	Nylon	Sateen	2-3	8.9
210	Dacron	Crowfoot	5-2	14.7
2019	Polypropylene	Twill	1-2	17.3
208	Dacron	Crowfoot	14	21.3
201	Dacron	Crowfoot 3x1	37	21.7
2015	Polypropylene	Twill 2x2	18	26.0
525	Nylon	Sateen	5	31.0
507	Nylon	Sateen	25	40.0
2038	Polypropylene	Twill	8	51.0
2016	Polypropylene	Twill	3	62.3
2025	Polypropylene	Twill 2x2	25	66.7

* According to Komline Sanderson Engineering Corporation, Peapack, New Jersey.
** 4.719474 $ft^3/min. = m^3/sec.$

Vacuum Pressure

The vacuum pressure must be high enough to significantly reduce the volume of sludge while retaining the sludge cake on the media. To determine the optimum vacuum pressure, eleven tests were conducted at 100, 200, 300, 400, and 500 mm Hg. Media 507 and 515 were selected for these tests. The solids content in the sludge was 1.14 percent and a 2.0-minute filtration time was used in each test.

The results of these tests indicate that increasing the vacuum pressure will not significantly increase the volume of filtrate. This can be seen in the plots of filtrate volume versus vacuum pressure shown in Figure 2. Therefore, a vacuum pressure of only 100 mm Hg appears to be adequate for this application. A lower vacuum pressure should also be less costly to provide.

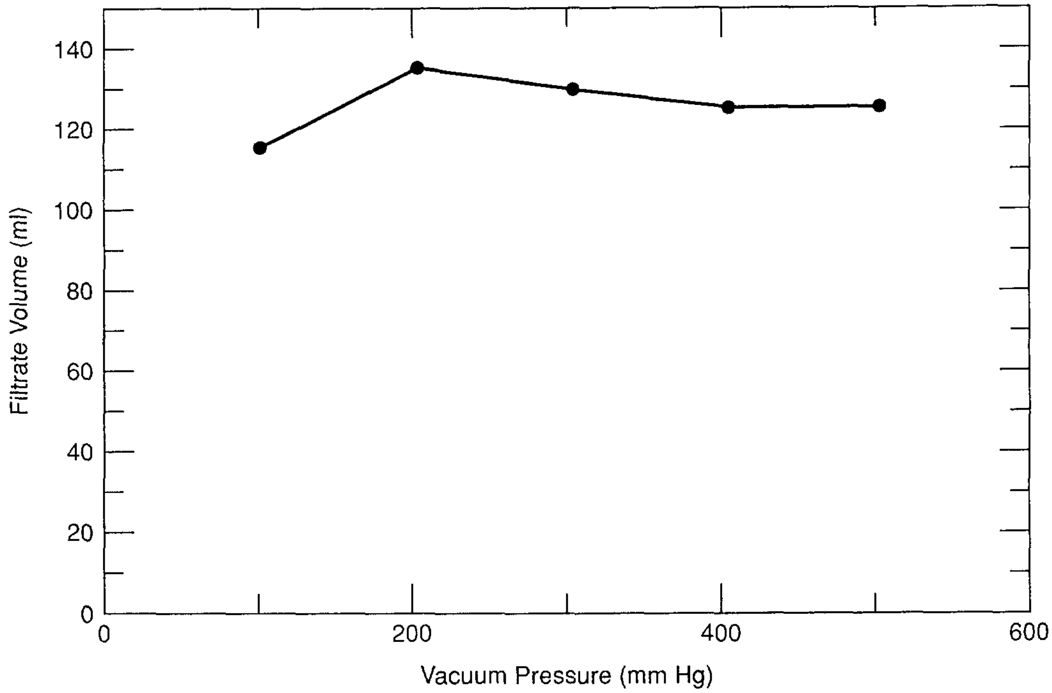

Fig. 2. Effect of vacuum pressure on filtrate volume from Media 507.

Filtration Time

The filtration time should be long enough to allow the accumulation of a sludge layer on the cloth media. A plot of filtration time versus the weight of wet cake produced by the previously selected medias is shown in Figure 3. Except for Medias 201 and 2015, the weight of solids attached to the filter cloth increased when the filtration time was increased from two to five minutes. Little or no increase was observed when the filtration time was increased from five to ten minutes. These data indicate that a filtration time of five minutes should be sufficient for accumulating the maximum sludge layer. These data also indicate that Medias 2019 and 2015 are better than the others because they accumulated the greatest amount of solids.

Based on the previous results, further tests were conducted with Media 2019 to determine its blinding characteristics when subjected to repeated use. These tests were conducted at a 100-mm vacuum pressure and a five-minute filtration time. The filter cloth was not washed between tests. As shown in Figure 4, a slight decrease in wet cake production was observed during the first four tests. No decrease was observed during the fifth test. These results indicate that wet cake production will stabilize after the first few cycles. Therefore, washing of the filter cloth between cycles may not be necessary. However, more testing must be done to verify this conclusion.

Freezing Rate

The time needed to freeze the sludge layer attached to the media varied considerably. One reason for this variation is the difference in layer thickness. Another is the visual method used to determine when the layer was frozen. However, a rough correlation between the weight of the sludge layer and the freezing time was obtained, as shown in Figure 5. These data were from all tests conducted with various filter cloths. From the slope of the line of best fit, the freezing rate for the filter leaf apparatus is approximately 1.0 g/min.

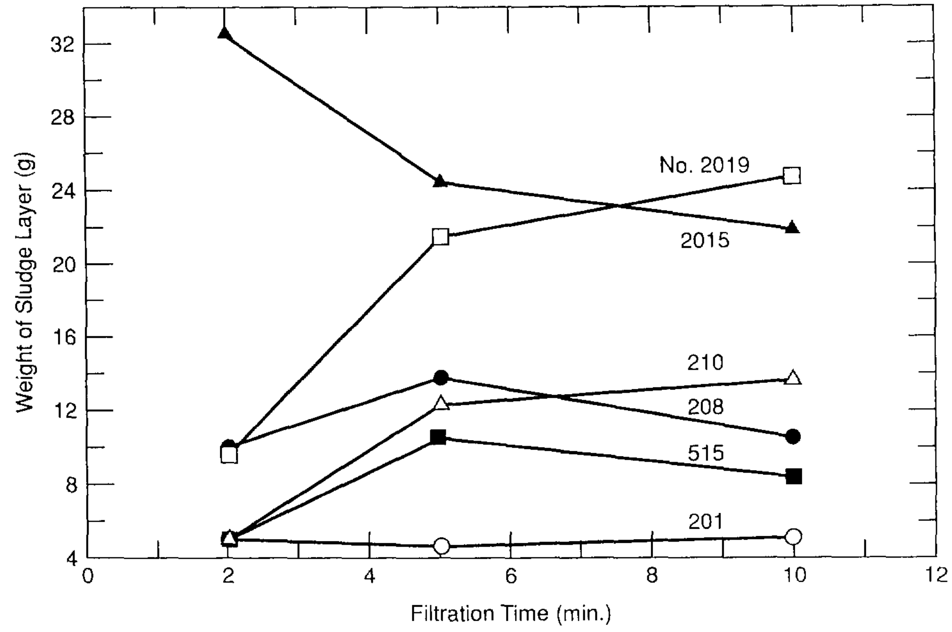

Fig. 3. Effect of filtration time on weight of sludge layer.

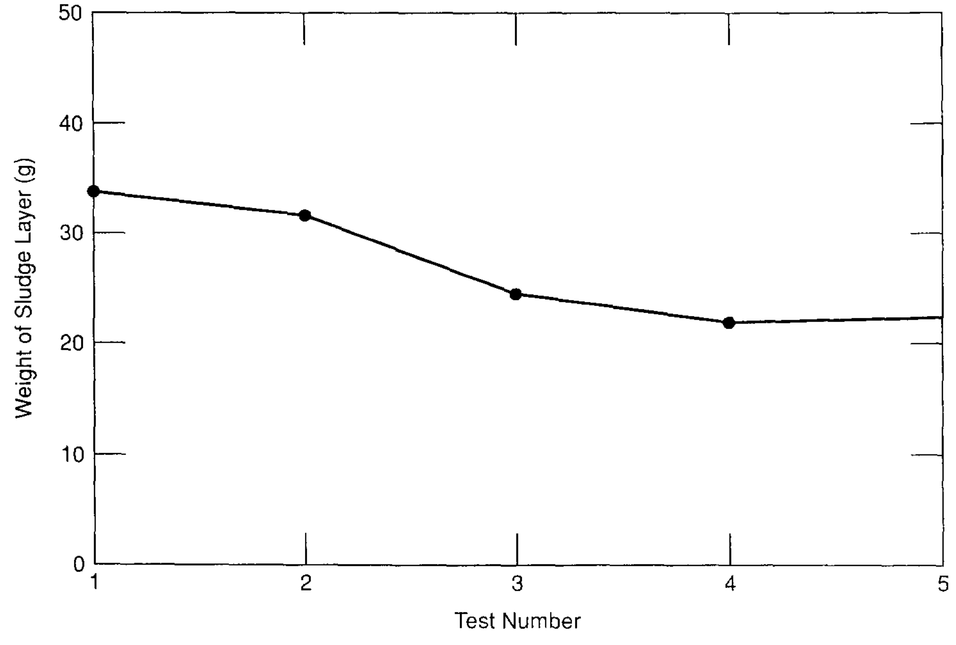

Fig. 4. Effect of repeated uses of Media 2019 on sludge layer production.

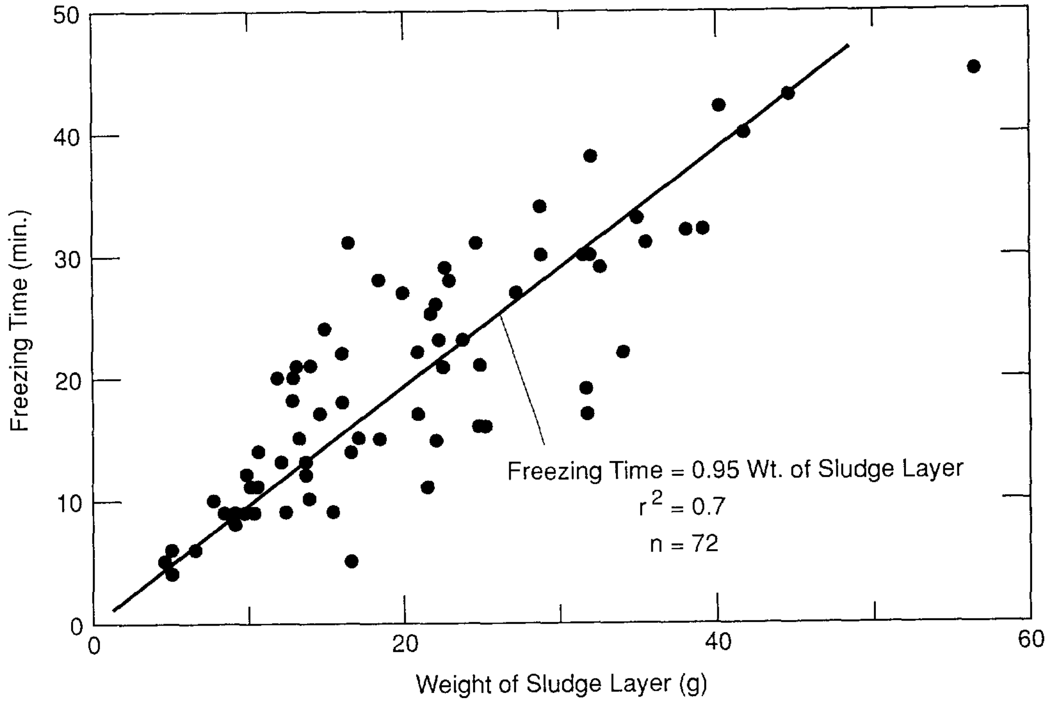

Fig. 5. Freezing time as a function of sludge layer weight.

Dewatering Efficiency

During nineteen tests with Medias 210 and 2019, the total solids content was measured before vacuum filtration, after vacuum filtration, and after freezing, thawing, and drainage. Before vacuum filtration, total solids content of the sludge ranged from 1.9 to 2.1 percent and averaged 2.0 percent. After vacuum filtration, the solids content in the sludge ranged from 3.5 to 6.0 percent and averaged 4.2 percent. This increase in total solids content indicates that approximately one-half of the water was removed from the sludge before freezing. After freezing, thawing, and drainage, the solids content ranged from 9.3 to 14.9 percent and averaged 11.8 percent. Since the original solids content of the sludge was 2.0 percent, an increase to 11.8 percent means that 83 percent of the water was removed by the process. Including the thickening step needed to increase the solids content from 1.0 to 2.0 percent, the overall reduction in water content was 91.5 percent.

DISCUSSION

Although the total solids content of the sludge after freezing, thawing, and drainage was low relative to other mechanical methods, further dewatering can be expected if it is applied to a drying bed or other mechanical device. Experience has shown that the drying rate of these solids is greatly accelerated because of the granular structure of the solids. No other conditioning method can make this transformation. Typically, the total solids content is 75 percent or greater after one day of drying.

The freeze-separator should not be difficult to design and manufacture because it is made up of several familiar components. For example, vacuum filtration has been used for several decades in dewatering wastewater sludges. Refrigeration on a belt moving in a horizontal configuration is often used in the food processing industry. Therefore, the capital cost of such a unit should be competitive with other mechanical dewatering devices.

The belt area required for a freeze separator can be calculated from the production rate and the volume of sludge produced by a water treatment plant. The production rate of a freeze separator is estimated to be 6.5 kg/h.m^2 based on a freezing rate of 1.0 g/min for a 0.0093-m^2 filter cloth area. Assuming a 10,000-m^3/day plant, the volume of sludge produced is usually less than 0.1 percent of the water processed (Sanks, 1978), or approximately 10 m^3/day. Thickening will reduce this volume by approximately one-half, leaving 5 m^3/day. This quantity will be further reduced by the vacuum filtration step in the freeze separator to approximately 2.5 m^3/day or 2,500 kg/day. If the unit operates for eight hours per day, the required surface area is 48 m^2 (2,500 kg/day/6.5 Kg/hm^2 x 8 h/day).

If the filter cloth is 2 m wide, the length of the cloth must be 24 m to provide the 48-m^2 surface area. A cloth this long will require a considerable amount of floor space if aligned horizontally. Potential methods for reducing the size of the unit include operating the unit continuously rather than just eight hours per day, changing the unit from a horizontal to a vertical configuration, and shortening the freezing time. The freezing time could be shortened by blowing refrigerated air over the sludge cake. A shorter freezing time would reduce the cycle time and thus increase the dry solids production rate. However, shortening the freezing time may cause a decrease in the particle size of the thawed solids so that drainability is reduced.

CONCLUSIONS

The results of this study indicate that this concept is capable of removing 91.5 percent of the water in alum sludges. The best filter cloth for this application appears to be a low-porosity polypropylene. Discharge of the frozen sludge cake from the cloth media was easy and clean. Washing requirements should be minimal. The product from the freeze separator will be a granular material that can be easily drained and dried. To my knowledge, no other process can produce this type of product. As a result of this study, I conclude that a pilot scale study should be conducted to further evaluate the freeze separator concept.

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