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Enhanced sludge dewatering based on the application of high-power ultrasonic vibration

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ABSTRACT

Interest in producing heat and power using municipal wastewater sewage sludge as a fuel is increasing worldwide. Since its water content is initially high, sludge must be dewatered and further dried if it is to serve as an effective fuel for combustion. However, to maximize net energy production, the drying processes must use as little energy as possible.

The water content in sewage sludge comprises both unbound and bound water. Unbound water content is typically extracted using a number of mechanical dewatering techniques. In terms of total solids content (TS), dewatering processes can take sludge from an initial 3–5% to a more solid 25–45% TS with minimal energy expenditure. However, this level of dryness is not sufficient for effective combustion.

To produce an effective fuel, TS levels must be increased. Achieving high level of dryness involves removing any remaining unbound water and substantial bound water content as well. Heat is normally applied to accomplish this by changing the phase of the water from liquid to vapor. Although dewatering is energy-efficient, thermal drying is not. The energy used to thermally dry sludge can be two orders of magnitude greater than the energy used for dewatering. Therefore, to expend as little energy as possible to achieve the needed dryness, conventional dewatering processes clearly must be improved.

This paper describes work carried out to identify promising ways to efficiently enhance the dewatering and drying of sewage sludge. Available dewatering approaches were reviewed and experiments were carried out to examine the relative effects of temperature, atmospheric pressure, and high-power ultrasound. The high-power ultrasound approach seemed to be particularly effective. The mechanisms involved include atomization, microstructural effects, cavitation, and the sponge effect, which work to reduce both internal and external resistances. Applied in the right way, ultrasound could become a very effective way to enhance mechanical dewatering.

1. Introduction

In this paper, a new way of enhancing mechanical dewatering using High-power ultrasonic vibration is discussed and a plan to investigate it further is presented. The main objective of this research is to extract moisture from the sludge more efficiently at lower energy expenditure.

The main byproduct from a municipal wastewater treatment plant (WWTP) is sewage sludge. Based on 2005 data, sludge production was about 76,00,000 dry tonne per year in the United States and 83,31,000 in the European Union [1]. Estimates predict that sludge production for Europe will increase to 1,35,00,000 tonne/year by 2020 [2]. Normally, sludge is disposed of by dumping it into landfills and oceans, or by spreading it over farmland as fertilizer [3].

Sewage sludge transport and handling is expensive. According to estimates by the United States Environmental Protection Agency, the cost of sludge handling and disposal accounts for 40–60% of total WWTP operating budgets [4].

Increasingly strict legal requirements and higher transportation costs are making the dumping and spreading of sewage sludge even more of a problem [4]. Because, it contains high concentrations of micro-pollutants, heavy metals, and other hazardous substances, there is concern that sludge may contaminate the aquifer or affect food crops [5]. According to the requirements of the European Communities, “Sludge arising from waste water treatment shall be re-used whenever appropriate. Disposal routes shall minimize the adverse effects on the environment.” [6]. In addition, ocean dumping is currently being banned all over the globe [3].

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Classified as a renewable and environmentally friendly source of energy, sewage sludge can be used as a biofuel in a waste-to-energy facility to produce heat, steam, and/or electricity through combustion [2]. Burning sludge biofuel to produce energy at or near the WWTP will be more economical and more environmentally friendly than dumping or spreading. Moreover, because sludge disposal has recently been identified as polluting, turning it into a biofuel will solve a growing environmental problem.

At 3–5% TS, the sewage sludge coming from the primary and secondary settling tanks of a municipal WWTP is mostly water. This level of water content makes handling and transport prohibitively expensive. A portion of the 95–98% water content is interstitial (trapped in flocs or capillaries) or surface water (clinging to particle surfaces via adsorption and adhesion). The remaining portion of water content is bound (intracellular or chemically attached). Most of the unbound water can be removed with a mechanical dewatering system. Dewatering can bring sludge to a more solid 25–45% TS with minimal energy expenditure [7].

However, this level of dryness is not sufficient for effective combustion. Achieving this level of dryness involves removing any remaining unbound water as well as some of the bound water content. Heating the sludge to change the phase of the water content from liquid to vapor is the normal approach taken. However, thermal drying is not nearly as energy efficient as dewatering. The energy used to thermally dry sludge can be two orders of magnitude greater than the energy used for dewatering. Therefore, to expend as little energy as possible to achieve the necessary level of dryness, improving conventional dewatering processes should be a goal.

Fig. 1 shows the relationship between sludge energy value and moisture content.

2. Mechanical dewatering description

Dewatering is the process of extracting water from a wet material or slurry by applying mechanical work. Water is removed without a change in its thermodynamic phase. Changing phase is energy intensive, and therefore expensive. Because it does not involve a change of phase, dewatering is relatively inexpensive from an energy consumption point of view.

2.1. Mechanical dewatering efficiency over thermal drying

Based on published energy consumption information for various available dewatering and drying systems, drying processes are on average about 300 times as expensive as dewatering processes. Dewatering costs approximately 0.02 €/tonne and drying costs 6.2 €/tonne for each 10% increase in TS. [8] In another research, drying was shown to be up to 500 times as expensive [9]. Dewatering is fast. It extracts more water in less time than drying.

Dewatering can routinely produce sludge cake with a TS content of up to 35% [10]. A few of the more advanced dewatering systems advertise dewatering to 45% TS content [11]. Some of the most common dewatering systems are as follows.

A *Centrifuge (Decanter)* offers high productivity and relies on large centrifugal forces of 2000–4000 G. Centrifugal dewatering uses the large centrifugal force to improve process time and efficiency [12].

A *Vibrating Screen* is a common system used for dewatering in mining. It offers high capacity or throughput as well as low energy consumption. The vibration frequency in these machines is normally between 30 and 60 Hz [13].

A *Rotary Press* works at a low speed of rotation. It is a durable system with low maintenance expenses and energy consumption [11]. This dewatering system uses screen plates for solid-liquid separation. Fournier, one of the most well-known rotary press producers, claims its products can dewater sludge to 45% of TS [14].

A *Filter Press* is a batch system that uses from 60 to 80 discrete filter plates that are compressed to extract water. The filter cloths must be washed frequently to maintain the efficiency of water extraction.

A *Belt Filter Press* has two continuous filter cloths that are under constant tension. The filter cloths both apply pressure and convey the sludge. The belts must be washed at the end of each cycle.

A *Rotary Vacuum Filter* system applies vacuum through a rotating filter disk to extract water [12].

Several approaches to enhancing the dewatering process to raise the current state of the art above 45% TS have been considered. Four of the more intriguing approaches involve the application of high-power ultrasound combined with electro-kinetics and/or temperature and/or vacuum. Our research and performed experiments demonstrate that ultrasound can be particularly effective. Clever application of these techniques should be capable of enhancing dewatering to reach a 60% TS level of dryness.

2.2. Ultrasonic-assisted dewatering

Fig. 2 shows high-power ultrasound being applied on a rotary vacuum filter system to dewater TiO_2. The ultrasonic vibrating plate was almost in direct contact with the TiO_2 cake. Resulting

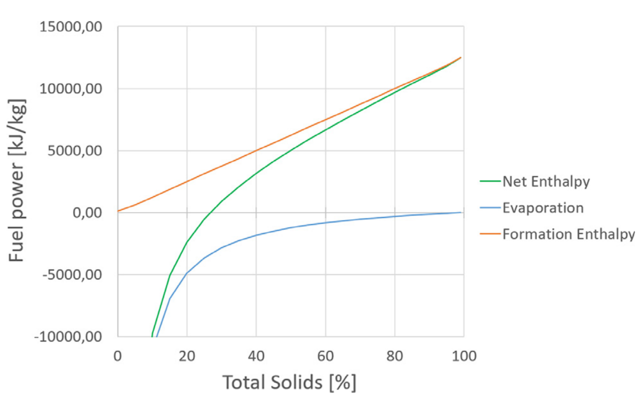

Fig. 1. Sludge energy value and moisture content; sludge has more power as a fuel at the higher total solids content. Formation enthalpy is the energy content of the sludge. For completely dry sludge, it is 12.480 kJ. Evaporation is the amount of energy that is needed to evaporate the water in the sludge. The net enthalpy is the sum of formation enthalpy and evaporation.

Fig. 2. Implementation of high-power ultrasound on a rotary vacuum filter dewatering system [16].