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Disintegration of Sewage Sludge for Improved Dewaterability

Thomas Elsäßer, Lucie Houdková*, Petr Bělohradský, Petr Stehlík

Brno University of Technology, Faculty of Mechanical Engineering, Institute of Process and Environmental Engineering, Technická 2, 616 69 Brno, Czech Republic
houdkova.lucie@fme.vutbr.cz

Currently, disintegration methods are applied to increase the biogas production in fermentation or in case of operational problems (floating and bulking sludge). In order to increase biogas production, waste activated sludge is disintegrated. Here, mainly mechanical disintegration methods e.g. ball mill, ultrasound and lysate-thickening centrifuge are used.
Turovskiy (2006) states, that disintegration of stabilized sludge before dewatering influences the dewaterability of sludge by. Here, during disintegration the sludge flakes are disrupted and bound water becomes available for gravitational means of dewatering. The increase in total solids concentration in dewatered sludge goes along with the reduction of water contained in dewatered sludge. This reduces the total amount of sludge for disposal and increases the possibilities of sludge utilization in waste to energy as less water needs to be evaporated by drying or during incineration.
The contribution is devoted to the design of a sewage sludge disintegration unit with the capacity of 10.8 t/d of a liquid sludge (refers to a wastewater treatment plant capacity of 10,000 population equivalents). Used material properties and insights have been gained in experimental work. Based on measured data, a pressure vessel was proposed. Further, stress analysis, considerations concerning the vessel heating and an economical evaluation of the process was elaborated. In the evaluation, a payback period of approx. 15 y is determined, which emerges from the savings in sludge disposal.

1. Materials used for Experiments

The impact of thermo and thermo-chemical treatment of sludge on its dewaterability was assessed in laboratory measurements. The disintegration unit used, is built as a double jacket vessel designed to operate under pressure or atmospheric conditions and can hold up to 2.7 L of sludge. The admissible pressure is 1 MPa at an operating temperature of 180 °C.

2. Influence of thermo-chemical disintegration on WWTP operation

In experiments, NaOH was used as an agent in thermo-chemical treatment. The treatment conditions were selected 110 °C for 30 min at 0.5 MPa. Based on indicative measurements, the NaOH amount was adjusted to 100 g/kg of sludge solids and the polymer flocculant Ciba ZETAG 8185 was used in dewatering experiments. The flocculant dosage for untreated samples amounted to 6 g/kg sludge solids. For disintegrated samples, a higher flocculent dosage was selected (8 g/kg sludge solids).

2.1 Attainable total solid concentration under operational conditions

The experimentally determined total solid concentration using a beaker centrifuge is considerably lower in comparison with total solids (TS) concentration attained in operational-scale using a dewatering

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centrifuge or filter press. Transferring experimentally determined results to operational-scale was subject to research summarized by the Bavarian State Office for Water (2001). The lab-scale dewatering conditions for this work were chosen 1000×g for 5 min. For these conditions, the dependency of operational results on experimental results is given by Equation 1, which was published by the German Association for Water, Wastewater and Waste (2008).

$$TS_{op-scale} = 2.35 \cdot TS_{lab-scale} + 1.49 \quad (1)$$

where $TS_{op\text{-}scale}$ *= total solid concentration attained under operational conditions [%]*
$TS_{lab\text{-}scale}$ *= total solid concentration attained under laboratory conditions [%]*

2.2 Sludge dewaterability and centrate composition

The total solid concentration of digested liquid sludge used in experiments amounted to 3.1 %. The results of total solids after dewatering in lab-scale, and in operational-scale are given in Table 1. The dewatering tests, conducted at 1000×g over a period of 5 min, suggest an increase by seven percentage points in operational-scale. This corresponds to a reduction of 25 % for the disposal of dewatered sludge.

Table 1: Total solid concentration of thermo-chemically treated sludge

	TS in lab-scale [%] *Average of three samplings*	TS in operational scale [%] *Proposed by Equation 1*
Untreated sludge cake	8.3	21.0
Treated sludge cake	11.3	28.1

The amount of total solids in centrate ranged between 1540 mg/kg in untreated, and 9850 mg/kg in treated sample. For treated samples, the chemical oxygen demand (COD) was in the range of 9000 mg/L. The COD in the untreated sludge amounted to 1500 mg/L, which corresponds to real operational data given from Pospěch (2007). Sludge disintegration has minor influence on the ammonium concentrations in centrate. The concentrations determined in experiments amount to 1062 mg/L in treated, and 1031 mg/L in untreated centrate.

Table 2: Centrate properties of thermo-chemically treated sludge

	Untreated sludge	Treated sludge
COD_{Cr} [mg/L]	1500	8700
Undissolved solids [mg/L]	330	3720
Total solids [mg/kg]	1540	9850
pH [-]	8.0	9.2
NH_4 [mg/L]	1031	1062
NO_3 [mg/L]	< 0.20	1.58
NO_2 [mg/L]	0.13	1.09
Total nitrogen [mg/L]	844	1319

2.3 Additional load on the WWTP

Dewatering of disintegrated sludge causes a higher pollution in centrate. Treatment of this water is accomplished in the biological treatment stage of the wastewater treatment plant. The additional oxygen demand depends on the concentration of carbonaceous organic pollutants and the nitrogenous compounds (NH_4^+ and NO_3^-) in the centrate. The oxygen consumption is calculated from the pollutants' reductions (S_0-S) given in Table 3, where the outflow concentrations (S) of the biological treatment stage were selected according to operational data by Pospěch (2007) and the biological oxygen demand (BOD_5) is determined from the measured COD, where the BOD_5/COD ratio was 0.5.

Table 3: Pollution reduction (S_0-S) used in the calculation of oxygen requirement

	Untreated centrate	Treated centrate
BOD_5 [mg/L]	745	4345
N-NH_4^+ [mg/L]	796	821
N-NO_3^- [mg/L]	-11.2	-10.8
N-NO_2^- [mg/L]	-0.5	-0.2

The total oxygen consumption amounts to 1.72 g/L for untreated, and 4.57 g/L for treated centrate (see Table 4).
The consumption of electricity for the supply of air into the aeration tanks is influenced by the aeration efficiency (AE), which is defined as the ratio of the oxygen amount and the input power of the aerator and includes losses by transmission and frequency converter. The AE used in this work amounts 1.23 kg O_2/kWh and was evaluated for an existing WWTP with a capacity higher than 1,000,000 PE. The calculated values are given in Table 4.

Table 4: Oxygen consumption of centrate in the aeration process

	Untreated centrate	Treated centrate
Total oxygen consumption [g/L]	1.72	4.57
Electricity consumption [Wh/m³]	1406	3715

3. Disintegration process for enhanced dewatering

In order to improve dewatering, disintegration is integrated between digestion and dewatering unit as shown in Figure 1.

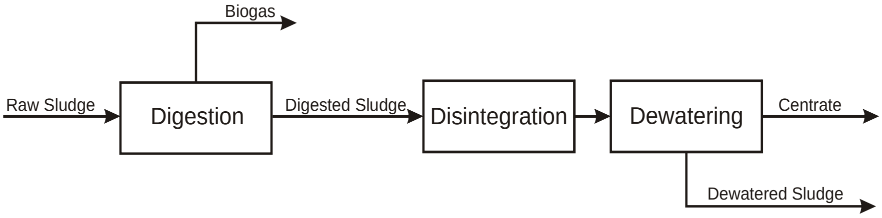

Figure 1: Flow diagram of sludge management for enhanced dewatering

The considered process of thermo-chemical disintegration is rated for a liquid sludge amount of 10.8 t/d containing 4 % of solids. The resulting amount of total solids (432 kg/d) refers to a WWTP capacity of 10,000 PE.
The disintegration process, as shown in Figure 2, is operated continuously and consists of the disintegration unit and a heat exchanger which recovers heat from the hot sludge, and thus raises the temperature of cold sludge from 10 to 50 °C. Further increase in temperature is accomplished in the disintegration unit. Prior to leaving the system, disintegrated sludge is re-cooled in the heat recovery.
For operational use of thermo-chemical disintegration, liquid agent is used to ease its handling. The considered specific dosage of NaOH 50 % into the sludge corresponds to the concentrations used in conducted experiments and amounts to 0.2 kg/kg TS. The temperature level for disintegration is selected according to conducted experiments.

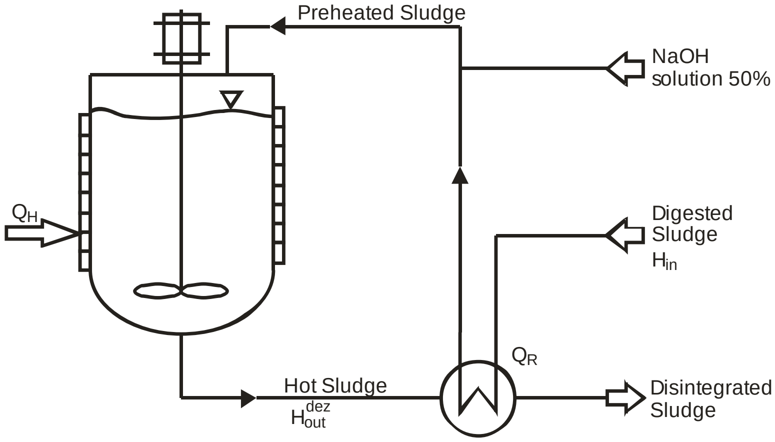

Figure 2: Flow diagram of disintegration process

3.1 Design of disintegration unit

In experiments a treatment temperature around 170 °C had been found unfavorable as it changes the properties of sludge. From this reason, the maximum temperature of heat transfer medium should be selected lower. For the designed disintegration unit, the maximum temperature of the heat transfer medium is selected 160 °C, which results in a minimum heating period of 80 minutes.

The disintegration is designed as a cylindrical, stirred pressure vessel suitable for thermal or thermo-chemical disintegration of sludge. It can hold a maximum volume of 2 m³ of sludge at an admissible pressure of 1.0 MPa. The required additional heat (Q_H) is transferred by heat transfer medium. This flows through heating ducts, welded on the cylindrical shell of the unit. Sludge enters the unit continuously at the top of the vessel, remains for a mean retention time of 4 h and leaves the tank at the bottom of the tank. The heat transfer inside the vessel is intensified by means of a stirrer.

3.2 Heat and mass balance

The flow rates after disintegration and conventional treatment is shown in Table 5. According to disintegration measurements, an increase in solid concentration in the dewatered sludge from 21.0 % to 28.0 % can be expected. The amount of dewatered sludge decreases by 25 % and the amount of centrate increases by 6 %.

Table 5: Mass streams in sludge handling process

		Conventional	Disintegration
inlet	Undissolved solids [kg/d]	10,800	
	Total sludge solids [kg/d]	432	
	NaOH solution 50 % [kg/d]	-	86.4
outlet	TS in dewatered sludge [%]	21.0	28.0
	Dewatered sludge [kg/d]	2057	1543
	Centrate [kg/d]	8743	9257

In terms of heat balance, the disintegration unit can be described as shown in Equation (2).

$$H_{out}^{dez} = Q_H + H_{in} + Q_R \qquad [J] \qquad (2)$$

where H_{in} *= enthalpy of digested sludge [J]*
Q_R *= recovered heat in heat exchanger [J]*
Q_H *= required additional heat supplied by heat transfer medium [J]*
H^{dez}_{out} *= enthalpy of hot sludge [J]*

The heat exchanger recovers a daily heat amount of 1.74 GJ from the hot sludge leaving the disintegration unit and reduces the amount of required heat to 2.66 GJ/d. Table 6 summarizes the heat streams and temperatures.

Table 6: Heat fluxes and temperatures in disintegration process

	Heat flux [MJ/d]	Stream temperature [°C]
Digested sludge H_{in}	440	10
Required additional heat Q_H	2658	-
Recovered heat in heat exchanger Q_R	1737	-
Hot sludge H^{dez}_{out}	4835	110
Preheated sludge	-	49.5
Disintegrated sludge	-	70.5

For sludge digestion, waste heat from the incineration of biogas can be supplied to the disintegration process. With respect to the amount of available waste heat from biogas utilization, the heat demand of the disintegration process (Q_H) is covered by internal sources or has to be acquired in the form of natural gas.

3.3 Economical evaluation

The major part of sludge, produced in the Czech Republic is disposed of in agriculture and composting. As a result, the costs for disposal are relatively low and range from approximately 18 to 24 €/t. For the following economical evaluation, the costs are assumed 20 €/t.

Capital costs for the disintegration unit account for approximately 43,000 € and include a stirred pressure vessel, heat exchanger, burner for the heat transfer medium, dosage system for the chemical agent, project engineering and expenses for construction. The costs for the disintegration vessel and heat exchanger are determined based on the material costs of used steel. The material costs for the used agents remain unconsidered in this evaluation as the application allows to use a suitable chemical agent of low purity at low cost.

The produced centrate has an adverse influence on the cost-effectiveness of the process as it requires more oxygen for its cleaning in the aeration process (discussed in Section 2.3). The resulting increase in electricity consumption depends on the amount of produced centrate and amounts to 21.85 kWh/d for a TS increase from 21 to 28 % after dewatering. Additional electricity consumption is caused by the stirring of the disintegration unit and summarized in Table 7.

Table 7: Additional electricity consumption caused by disintegration

Vessel mixer [kWh/d]		3.1
Additional blower consumption	[kW/m³ of centrate]	2.3
Electricity costs [ct/kWh]		0.1

For TS concentrations determined in experiments, the payback period amounts to at least 15 y (in case the heat demand of the disintegration process is completely covered by waste heat) and probably exceeds the lifetime of the equipment. The payback period depends highly on the amount of acquired heat. For covering 5 % of the required heat by natural gas, the payback period is prolonged to 20 y. As shown in Figure 3, where the plumb line marks the TS concentration obtained from experiments for a increase in TS concentration from 21 to 28 %.

Due to the long payback period, the influence of increasing sludge disposal costs should be taken into account. During recent years, the fee for landfilling of sludge has risen by 5 %/y. Thus, the price adjustment for sludge disposal by the private sector can be expected to be in the same magnitude. For a 5 % p.a. increase in disposal costs, and TS increase from 21 to 28 %, the payback period will be reduced by 4 y and amounts to 11 y.

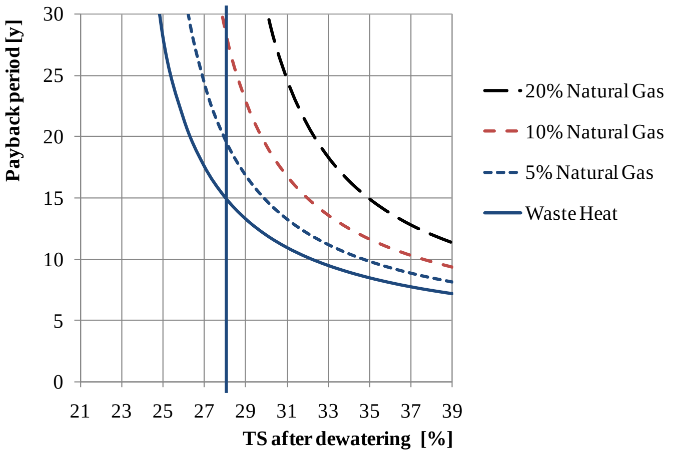

Figure 3: Payback period depending on attained TS and amount of acquired heat

4. Conclusion

Disintegration of digested sludge offers a convenient way of improving sludge dewaterability, and thus reducing its disposal costs. However, the costs (especially the costs for additional heating) strongly impair its economy and the payback over the lifetime of the equipment cannot be taken for granted.

The efforts undertaken for sludge disintegration should not only be seen as the reduction of waste for disposal, but also as an improvement of sludge quality. Thermo-chemical disintegration use similar process parameters as required for the sanitation of sewage sludges generated in the processing of animal by-products not intended for human consumption (e.g. from slaughterhouses). Here, the suggested disintegration process could provide a capable method to produce a harmless material fulfilling corresponding legal requirements. Moreover, the reduction of the water contained in dewatered sludge improves the possibilities of sludge utilization in incineration.

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