Economic benefits of low pressure sludge homogenization for wastewater treatment plants

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Abstract: The increased production of sewage sludge and its subsequent environmental pollution has been a pressing problem in industrialized countries. Search for possible utilization of sludge or reduction of its disposal quantities has been going on since recent years. The EU has already set a target of about 12% of its total energy consumption from renewable sources by 2010. This unique move, which has the potential of creating about 500,000 to 900,000 jobs by 2010, has been welcome by different economic, social and political sectors of the union. Moreover, the set target would provide an annual fuel costs savings of ECU 3 billion from 2010, reduce fuel import by 17.4% and also reduce CO2 emissions by 402 million tons per year. The optimal combination of mechanical disruption of stabilized sludge at relatively low pressures using a special high-pressure homogenizer followed by anaerobic digestion in a novel laboratory anaerobic digester, was shown in previous publications. The laboratory results show more energy (i.e. methane gas) from concentrated and disrupted sludge than from untreated samples. The energy produced was higher than that invested during disruption and digestion processes (i.e. positive energy balance). About 23% sludge reduction was obtained. This new process was practically integrated in an existing wastewater treatment plant and the results confirmed those from the laboratory. The extra energy produced can be used for local electric supply, for heating the digestion tower while the sludge reduction provides new source of revenue for the plant operators. This paper is the first technically demonstrated work that shows positive energy balance and with high economic value for sludge and wastewater treatment plants. A reliable process was developed for significant digester improvement at technical scale. This improves the biological conversion process in the digester by means of patented external recirculation using a low-pressure-homogenizer for digester-sludge treatment. The demonstrations were made at two municipal wastewater treatment plants (MWWTP) for more than 7,000 hours. This unique process continuously supplies organic substrate for bioconversion and enlarges particulate surface by more than 100% to improve biodegradation significantly. Agglomerates are disrupted to release encapsulated water and substrate to further enhance reaction velocity. Organic conversion rate and biogas yield improves by 25% or more. Hence sludge disposal costs are reduced significantly. Basically this process has a payback period of 3 years with MWWTP cost reductions.

Keywords: concentration; digestion; disruption; disintegration; high-pressure homogeniser; sludge

INTRODUCTION

The application of high standard technologies improves wastewater treatment systems which results to rise in sludge production with increased contaminants. There is progressive annual sludge production increase (Leschber et al., 1998) which relatively low success in finding solutions to sewage sludge problems. Sewage sludge poses serious problems due to the high treatment costs and the risks to environment and animal and human lives. European regulations stipulate that from 2005, land-filled wastes should not contain more than 5% organic substance. Most conventionally stabilised sludge still contains about 50% gas production potential that could be exploited by disrupting the sludge cells with subsequent anaerobic digestion. Anaerobic digestion destroys micro-organisms and germs harmful to the environment, reduces unpleasant smells and organic content as well as improves the sludge de-watering properties.

Disintegration of sludge breaks the sludge conglomerates and liberates the cell contents such as light organic substances essential for anaerobic digestion. Most common cell disruption processes are carried out thermally, physically, chemically, biologically or their combinations. The mechanical disruption process, which is part of the physical process, is the mostly applied process while the biological process, such as the application of
enzymes, is rarely used in sludge treatment because of its intensive costs. Thermal processes have been successfully tested in large scales but the investment on exhaust gas treatment efficiency is relatively high. The chemical processes are normally not used here to avoid damage to the sludge compositions and valuable local bacteria needed for microbiological activities. The mechanical disruption process involves the action of externally applied stress or pressure on the cells. Cells are disrupted when the external pressure exceeds the cell internal pressure (Müller, 1998). Mechanical disruption of sludge has gained acceptance due to its various successful industrial scale applications. Tests have shown that the high-pressure homogeniser could be most efficient mechanical disintegration process considering the relatively low energy consumption.

In this work, the mechanical disintegration and anaerobic digestion of concentrated stabilised sludge was tested. Aim of this project was to modify existing high-pressure homogeniser (originally designed for homogenisation of dairies) for sewage sludge disintegration. The high-pressure homogeniser was applied due to its energy balance advantage and easy integration in any exiting wastewater treatment plant. This paper presents, for the first time, positive results from the application of high-pressure homogeniser in a wastewater treatment plant. The success was assessed based on sludge reduction, improved biogas (energy) production which led to positive energy balance and negligible effect on chemical oxygen demand (COD).

**METHODS**

Past experience in sludge mechanical disintegration using other techniques showed that the higher the sludge concentration, the better the disintegration efficiency and the more the biogas production. Fig. 1 below shows the integration of the new process in an existing wastewater treatment plant. Hence, part of the conventionally stabilised sewage sludge was concentrated from approximately 18 g/l to about 40 g/l using the decanter, which is basically a centrifuge. This concentrated sludge was passed through a maserator which is basically to cut the sludge into smaller particles to avoid blocking the homogeniser valve. Thereafter, the concentrated sludge was passed through the high-pressure homogeniser for disintegration with the help of a feed pump. Concentration of sludge brings the cells closer to each other thereby improving disruption at a single pass through the homogenising valve. The impact of homogenisation within the unit area of the valve is same at any set pressure. The higher the concentration at this set pressure, the higher the homogenisation efficiency (sludge exposure) and the less the specific energy input. Therefore, at any particular homogenisation pressure, the homogeniser homogenises more concentrated sludge than the nonconcentrated normal sludge.

**Obtained results (first phase)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>Sludge reduction</td>
<td>24 %</td>
</tr>
<tr>
<td>Extra energy production</td>
<td>25 %</td>
</tr>
<tr>
<td>Market potential</td>
<td>≈ 35 %</td>
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**Fig. 1:** Integration of sludge homogenisation in an existing wastewater treatment plant

Increased sludge concentration implies rise in static pressure within the homogeniser. Sludge concentration optimises the formation of the cavitation bubbles, which further intensifies the homogenisation effect.
The robust nature of this unique homogeniser has enabled its diversified industrial applications even in sewage sludge disintegration. The pressure of homogenisation is the most influential parameter when determining the performance of the high-pressure homogeniser. A modified homogeniser with flow rate of 2.7 m³/hr was used in this project at relatively low homogenisation pressure of 150 bar. It consists mainly of a multiple plunger pump and a homogenising valve fixed to the discharge. The function of this plunger pump is to compress the medium to the required energy level for the valve. It has the typical characteristic of non-pressure dependant of the throughput. The homogenising valve assembly is a combination of the adjustable valve, the stationary valve seat and the impacting ring which forms a defined outlet cross section thereby preventing damage to the valve casing by the flow. The energy consumption of the high-pressure homogeniser is linearly proportional to the input disruption pressure while the specific input energy is inversely proportional to the sludge concentration. Fig. 2 shows a simplified sectional diagram of a high-pressure homogeniser.

Fig. 2: Cross-section of high pressure homogeniser

The unhomogenised sewage sludge enters the valve area at high pressure and low velocity. As the sludge enters the adjustable, close clearance area between the valve and seat, there is a rapid increase in velocity (over fifty fold) with a corresponding decrease in pressure (static to atmospheric pressure). The intense energy release causes turbulence, localised pressure differences and liquid stress, which tear apart the particles and cells in the sludge. This process occurs at a distance less than 0.3 mm in few microseconds. The static pressure decreases until the vapour pressure of the liquid is reached resulting in steam or cavitational bubbles, which further increases the gas-liquid flow. Collision of these cavitation bubbles induces an energetic shear stress that disintegrates the sludge flocs and partly disrupts the cells (Pandolfe, 1993). The homogenised sludge impinges on the impact ring and exits at a pressure sufficient for movement to the next processing stage. Stress and abrasion increase with increased pressure and affect the homogenising valve unit. Hence, tungsten carbide or special ceramics are used for the valve parts.

The concentrated and homogenised sludge is pumped back into the anaerobic digester for subsequent digestion at mesophilic temperature of 36 – 38°C. Because the treated sludge is mixed with the activated and primary sludge from the plant before digestion, part of the treated sludge was digested in a standard laboratory anaerobic digester. The total solid content of the sludge and specific gas productions were measured before and after digestions. Results were compared with those from untreated sludge sample.

Experts in anaerobic digestion know how difficult it is to realize an efficient laboratory anaerobic digestion with total biogas recovery and recording with absolute digester seal (anaerobic) and adequate stirring. This led to another project for the development of such efficient anaerobic digestion unit which was used in this project to ensure same conditions as the waste water treatment plant and proper results.
RESULTS

The high-pressure homogenisation of stabilised sludge improved the anaerobic digestion process, improved biogas production, reduced sludge production, reduced investment and operational costs. Results obtained during the tests carried out at this particular wastewater treatment plant indicated about 23% less sludge production with more than 30% increased biogas production. The biogas (68 to 72% methane content) is good source of electrical energy and can also be used to heat the digester. The concentrated sludge produced the best results both in specific bio-gas production and sludge reduction. Concentration of sludge ensures reduction in digester capacity and sludge flow at the plant which further reduces the investment cost. Earlier work carried out at laboratory scale showed that concentrated sludge samples made best energy balances at homogenisation pressures between 100 and 200 bar (Onyeche et al., 1993). A combination of sludge concentration and low-pressure homogenisation led to the success of this unique project which is also a confirmation of the laboratory results. A calculated economic model indicates a payback period of less than two years.

The integration of the homogeniser in a wastewater treatment plant required process adaptation and signal controls, repairs, maintenance and timing activities. Hence modification and integration of the existing homogeniser for sludge homogenisation at the treatment plant caused several operational interruptions due to blocking, signal failures, repairs and maintenance. However, information from the plant engineer indicated that during the period when the homogeniser operated longer without long interruptions, appreciable sludge volume reduction was realized as shown in figure 3 below. The sludge volume discharged to sludge dewatering unit was reduced by about 30% within a period of four months. This could lead to enormous savings in sludge disposal costs. Such reduction may provide annual savings in millions of Euro in large treatment plants especially in big cities of the world. Moreover, this less sludge is pumped to the dewatering unit resulting to corresponding reduction in operational costs and time of the dewatering unit.

Figure 3. Sludge reduction at the wastewater treatment plant

Moreover, there was concern about the possible rise in COD values due to the returned sludge water from sludge concentration. The separated sludge water was returned to the plant wastewater inlet. An efficient concentration unit does not permit much COD in the separated sludge water. In this particular plant, the COD increase was negligible and no significant negative effect during the tests was observed. The COD values of the effluent water from the treatment plant were generally reduced as shown in figure 4 below which compares the average COD values in 2000 (without the tests) and 2001 (with tests). Minimum interruption of the homogeniser resulted to about 30% COD reduction compared to the values acquired same period in previous year. Best results were obtained between May and October which covers the summer period.
Figure 4. COD values with and without the new treatment process

The energy balance of the entire process was considered to verify the difference between the total input and output energy of the system and the result is shown in figure 4 below. Volume of produced gas varies according to the sludge composition, method of sample preparation, type and intensity of homogenisation and efficiency of anaerobic digestion. Energies consumed were those by the decanter, high-pressure homogeniser, pumps and other accessories while the energy value of the methane gas produced during anaerobic digestion was considered as the produced energy. The green zone is the energy from biogas only while the orange and light green zones are the over all consumed and produced energies. Apart from the negative energy balance observed between first and third weeks, there was a positive energy balance in the rest weeks due to minimal operational interruptions. It should be noted here that the energy consumption of the decanter is relatively high. Nevertheless, there was an average energy production of 0.2 KWh/kg sludge. Operations during winter season increased the energy consumption due to the extra energy required for the heating of the lines and container, stirring and lights. Replacement of the decanter with a rotary sieve or any other low energy consuming concentrator would lead to better energy balance.

Figure 5. Energy balance using high-pressure homogeniser in sludge disruption
Laboratory analyses showed slight increases in heavy metals in homogenised and digested sludge but the values were below the limit for any effect. Microscopic study of sludge samples indicated drastic disintegration of sludge and probably appreciable disruption of the sludge cells.

CONCLUSION

This project provides the first adapted high-pressure homogeniser for sewage sludge homogenisation in a wastewater treatment plant. Adaptation of the homogeniser involved modification of the homogenising valve and the optimisation of the homogenisation process. The process control (automation) and the robust nature of the homogeniser were also improved for this purpose.

The homogeniser was successfully integrated in an existing treatment plant and the results confirm earlier laboratory results published by same author (Onyeche, 1999). Anaerobic digestion process was improved, more energy was produced and positive energy balance was obtained with negligible COD impact. Such new process provides extra energy for local consumption, provides savings in millions of Euro depending on condition, location and size of plant, reduces investment costs as well as operation time. All these economic and operational benefits make this process very lucrative with high global market potential depending on location and purpose of application.

However, there is need for continuous and uninterrupted operation of the homogeniser after installation of a rotary sieve for even better results. The entire sludge produced at the plant should be concentrated with the sieve, homogenised with the adapted homogeniser and anaerobic digested. Though blocking has been drastically reduced, there is still need for block-free operation. These and other factors have been considered for the next phase of this project and the results thereafter will be published when due.

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