SEWAGE SLUDGE DISINTEGRATION USING OZONE - A METHOD OF ENHANCING THE ANAEROBIC STABILIZATION OF SEWAGE SLUDGE

AUTHORS NAME

Robert Vranitzky, Dr. Josef Lahnsteiner

VA TECH WABAG, R&D Process Engineering, Siemensstrasse 89, A-1211 Vienna, Austria

telephone: ++43/1/25 105-4635; fax: ++43/1/25 105 211; e-mail: Robert. Vranitzky@wabag.com

ABSTRACT

The anaerobic digestion process is a proven technique for effective sewage sludge treatment. However, during anaerobic treatment, as a rule only about 50% of the organic matter in sludge is readily susceptible to biodegradation into biogas, the other half of the organic material being more recalcitrant and degrading very slowly. The combination of anaerobic sludge digestion with disintegration using ozone is seen as one promising technical and economic method of enhancing the stabilization process.

Through the implementation of sludge ozonization, refractory organic structures are oxidized and converted into biodegradable low-molecular compounds. Hence, a substantially increased degree of sludge stabilization can be achieved. Basically, the disintegration process is accomplished by the application of ozone to break down cell walls. Thus, cell walls are fragmented and intracellular compounds are released. The product can be utilized as a substrate in the anaerobic biological process.

The following paper focuses on the investigation of (a) the overall disintegration efficiency of ozonization at different ozone doses; (b) the achievable degree of stabilization for disintegrated sludge as compared to partly digested sludge and raw sludge; and (c) process performance in continuous operation and the resulting reload to wastewater treatment derived from sludgewater recycling. Additionally, a cost calculation for a model wastewater treatment plant of 20,000 m³/d capacity was carried out to prove the economic feasibility of the process.

Initial ozonization experiments showed that only 0.06 g O_3 / g DS was necessary to destroy the biological activity of treated biomass. In order to investigate the achievable degree of stabilization, both specific digestion batch tests and continuous experiments were conducted. The basic experimental set-up for the continuous experiment consisted of: (a) a wastewater treatment unit; (b) a sludge treatment unit; and (c) an ozonization unit.

The tests conducted provide evidence of an increase in the average degradation rate of organic matter to 65%, as compared to 45% in the conventional system. At the same time, an increase of 30-40% in biogas production (70% methane and 30% carbon dioxide) was observed due to disintegrated addition dosage, thus proving that no inhibitory by-products are generated during ozonization.

The wastewater treatment efficiency was monitored and special attention was paid to the effects of sludgewater recharge to the wastewater treatment unit. Thus, the achieved removal rate of carbon and

nutrients was slightly decreased, but remained in line with the legal requirements. Hence, it can be assumed that the sludgewater recharge had no significant impact on nitrogen removal.

KEY WORDS

anaerobic digestion, disintegration, ozone, sludge stabilization

INTRODUCTION

The growing quantities of sludge generated in urban areas require innovative treatment processes that are capable of achieving significant cuts in mass and volume. Technologies that combine efficient sludge mass and volume reductions with the production of reusable sludge products at competitive costs represent the most desirable solutions. The inclusion of disintegration technology into the sludge treatment process leads to reduced sludge quantities and markedly improved sludge quality.

In earlier studies that were conducted by the authors various technologies for sludge disintegration were investigated, such as ozonization, vapour-pressure treatment, sub-critical wet oxidation and sludge hydrolysis. After intensive assessment of these processes, it was agreed to focus mainly on oxidative sludge treatment rather than thermal or mechanical processing. This is because only the oxidative process could render refractory COD biodegradable. Processes that include the addition of oxidizing chemicals, e.g., sulphuric acid, raising the salt concentrations in the effluent, were assessed to be less attractive than processes with no chemical addition. Hence, ozonization emerged as the most attractive innovative sludge disintegration technology.

SLUDGE DISINTEGRATION USING OZONE

DEFINITIONS OF DISINTEGRATION

− Disruption of the microbial cells in the sludge, thereby destroying the cell walls and releasing the cell content, e.g.: mechanical decomposition [1].
− Breaking up or disrupting the cell walls, so that substances protected by the former are released and dissolved [2].
− Opening up the cell walls of organisms, so that the substances contained in the cell are solubilised [3].

Disintegration should not be confused with degradation, which is simply the reduction of organic material. The term stabilization is mostly used as a synonym for degradation.

SCIENTIFIC BACKGROUND - OZONIZATION TECHNOLOGY

Molecular Ozone Reactivity

Ozone is an allotropic form of oxygen with the chemical formula: O_3. In high densities, ozone has a characteristic blue colour. Ozone is an unstable gas obtained by electrically exciting oxygen. This is achieved by applying a high voltage to generate an electrical field, under the influence of which oxygen undergoes partial dissociation into radicals.

The electrical field increases the kinetic energy of free or dislodged electrons and causes them to enter into successive collisions, thus exciting the oxygen and producing dissociation. Ozone molecules form as the result of successive transitions.

An ozone-producing environment contains a huge amount of energy, which means that a number of transient forms are liable to occur: ions, atoms, free radicals, or energized molecules. Chemically speaking, these transient forms are highly reactive, which means that there is an increased tendency to form new stable products, which would be difficult, or even impossible, to produce using other types of excitation.

Ozone Generation

On an industrial scale, ozone is produced by passing air or oxygen between two electrodes bearing an AC potential. To ensure an even discharge and avoid arcing, one of the electrodes (or possibly both) is covered by a dielectric of even thickness, thus forming an equipotential layer. The potential difference applied between the electrodes will depend on the nature and thickness of the dielectric used, on the width of the discharge gap, and on the operating voltage, which is usually between 6,000 - 18,000 V.

In physical terms, the ozone-producing environment, or plasma, is characterized by the electron temperature (Te) and the electron concentration (Ne). Ozone-producing plasmas are generally induced by electrical corona discharge and contain electrons with average energy of between 1 and 14 eV and an electron concentration of between 10^8 and 10^{12} electrons per cm^3. Such plasmas are also termed cold plasmas, with the ratio between electron temperature (Te) and molecule temperature (Tg) ranging between 20 and 300.
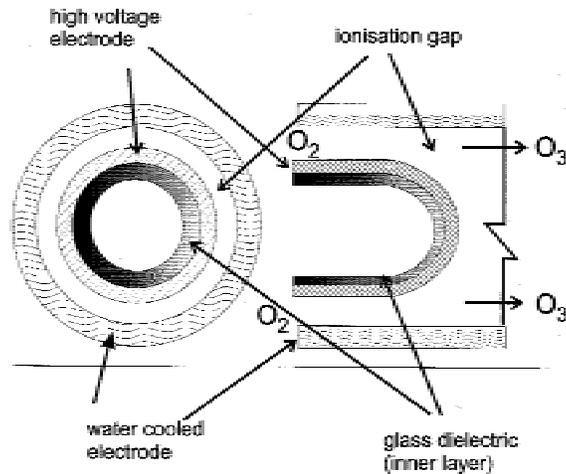
Figure 1: Principle of electrical corona discharge reaction [4]

For a given potential difference, the efficiency of the ozone generator will mainly depend on the geometrical shape of its component parts and on the temperature and pressure of the cold plasma.

For a given type of reactor, ozone production will mainly depend on the power input and the rate of the feed gas. The efficiency of the reactor can then be calculated from data on the power input. Typically, ozone concentrations in the feed gas are as follows: (a) 10-40 $g \cdot Nm^{-3}$ in air; and (b) 10-140 $g \cdot Nm^{-3}$ in oxygen. Provided the incoming air or oxygen is thoroughly dried, modern ozone generators are capable of producing between 70 and 450 grams of ozone per square meter of dielectric and per hour at the above concentrations.

Under normal conditions, the useful specific energy required for the production of one kilogram of ozone is calculated as follows: e.g. for a concentration of 18 $g \cdot Nm^{-3}$ using atmospheric air as oxygen source 13 to 18 $kWh \cdot kg^{-1}$ ozone are consumed. On the other hand, using oxygen, e.g., only 6 $kWh \cdot kg^{-1}$ ozone is consumed for a concentration of 70 $g \cdot Nm^{-3}$. A very substantial portion of this energy is given off as heat, which greatly increases the temperature of the plasma. The overall yield of the oxygen-ozone transformation is dependent on the temperature. Any increase in temperature is bound to decrease the overall yield. For this reason, the heat must be constantly drawn off in an effort to keep the plasma at a constant temperature. This means that the ozone generator requires an efficient cooling system, which is generally provided by water circulation. For the cooling, the additional energy requirement of roughly 4 $kWh \cdot kg^{-1}$ ozone has to be taken into account.

Inactivation of Microorganisms by Ozonisation

It can be said that a bacterium is schematically composed of a cell wall surrounded by exo-polysaccharides, then a cytoplasmic membrane, and finally the cytoplasm containing the genetic information-carrying chromosome. The cell liquid offers a near neutral pH and a high concentration of bicarbonate ions. It is therefore probable that the radical action of ozone is inhibited inside the cell. On the other hand, the cytoplasmic membrane can provide a site for ozone reaction, due to numerous proteins among its constituents. If residual ozone crosses this membrane, the cytoplasm and the chromosome become preferred sites, since the nucleic acids are quickly degraded by ozone. This has been shown by several studies carried out on *Escherichia coli*. These considerations may be useful for a better understanding of ozone disintegration.

PROCESS DESCRIPTION

Basically, the disintegration process is accomplished by the application of physical or chemical methods to break down cell walls. Thus, cell walls are fragmented and intracellular compounds are released. The product can be utilized both as a substrate in aerobic and anaerobic biological processes.

As far as municipal sewage sludge treatment is concerned, a liquid-solid phase separation appears reasonable prior to the recycling of the disintegrated sludge. This can be accomplished in a standard thickening facility in combination with mixed primary sludge (PS) and surplus activated sludge (SAS).

The liquid phase contains dissolved organic compounds (such as amino acids, nucleic acids and fatty acids), which are released with the cytoplasm. It may be utilized as a carbon source to balance the additional carbon demand in the denitrification process during periods of high nitrogen loading rates. On the other hand, the solid phase contains cell fragments (so-called biosolids), which also represent a good substrate for biodegradation, as the refractory COD was converted into BOD. The recycling of disrupted and disintegrated biosolids to anaerobic digestion (AD) has a number of attractive aspects, which are described in the following section.

The AD of disintegrated biosolids enables advanced sludge stabilization due to the enhanced reduction of organic matter. Moreover, the residual sludge quantity can be slashed by another 30-40% (total sludge reduction up to 60%). The rate-limiting step in the AD-process is the initial hydrolysis phase. When sludge disintegration is employed, this reaction is accelerated. Hence, the sludge retention time in the AD reactor can be cut from the standard 15-20 days to below 15 days. As a consequence, the digester volume can be reduced, which leads to savings in investment and operating costs. The operating costs are influenced in two respects: (a) lower demand on reactor heating and (b) the conversion of refractory COD to BOD, providing higher biogas yields and hence increased electricity generation from biogas. Finally, due to the

destruction of filamentous flocs (responsible for water retention in the sludge) during disintegration, the dewatering properties of the residual sludge are improved.

Based on earlier findings [5], ozonization was adjudged the most promising. The background for this decision was formed by the following considerations.

In comparison with mechanical or thermal disintegration technologies, the oxidation processes have one main common advantage. Refractory COD (complex organic structures) is oxidized and converted to BOD (biodegradable low-molecular compounds, e.g. formic acid or acidic acid). Conversely, as opposed to other oxidation processes (such as wet-oxidation), ozonization does not demand an additional chemical dosage. As a result, effluent post-treatment is not required downstream of the process. The only by-product of the ozonization process is molecular oxygen, which can be positively reused for aerobic biological degradation processes.

EXPERIMENTAL SET-UP

Based on experiments that were conducted as part of the earlier studies, specific batch tests were carried out on a lab-scale to investigate the biodegradability of disintegrated sludge. Respirometric tests are usually conducted to investigate the biodegradability of different types of wastewater. In the case of disintegrated sludge, initial digestion batch tests had to be carried out under anaerobic conditions, since the cell fragments might be refractory for aerobic degradation but not for anaerobic digestion. The batch tests were conducted during the start-up phase of the continuous lab-scale experiment and the results obtained were utilized as additional information for the evaluation of analysis data.

INITIAL DIGESTION BATCH TESTS

The batch experiment was conducted in four parallel set-ups at a constant temperature of 35°C, using brown glass flasks to avoid light penetration, which would have caused harmful effects to the anaerobic biocenosis. A volume of two litres of different sludge samples (the detailed composition of all samples is contained in Table 1) were put into each flask and mixed with magnetic bar stirrers at an intermitting mode. On top, the reaction vessel was sealed and a 6-mm butyl tube was installed to deviate the produced biogas into a one-litre buffer flask. The buffer flask was filled with a solution of 0.1 mol/l hydrochloric acid which was necessary to prevent the carbon dioxide absorption of biogas into the liquid phase. The amount of biogas that streamed into the buffer flask, displaced the hydrochloric acid solution quantitatively into another collection flask. The volume of displaced solution corresponded with the volume of produced biogas. During the test-run it was necessary to refill the solution in the buffer flask. The running time of each experiment was 19 days of each test run.

Table 1 : Composition of sludge samples, (g per total volume of two litres)

Sludge Type	Sample			
	1	2	3	4
Primary Sludge [g]	-	-	8.4	7.8
Surplus Activated Sludge [g]	-	-	8.4	7.8
Digested Sludge [g]	66.0	49.3	50.6	31.1
Disintegrated Sludge [g]	-	16.4	-	15.6
Total [g]	66.0	65.7	67.4	62.3

Apart from the analysis (DS, VSS, COD, TN, TP) of unstabilized and stabilized sludge (after a 19-day test run), the daily gas production was measured and archived in the course of the batch experiments.

SET-UP OF CONTINUOUS LAB-SCALE EXPERIMENT

A special lab-scale set-up was designed to conduct continuous disintegration experiments for the application of ozone to anaerobically digested sludge. This concept is considered as an extension to the conventional wastewater treatment system and includes (a) the conventional activated sludge process employing nitrification-denitrification; and (b) the anaerobic digestion sludge treatment process. The additional ozonization plant unit basically consists of (a) an ozone generator, and (b) a reaction tank. Ozone generation is based on corona discharges that are capable of transforming molecular oxygen into ozone. The tube type laboratory ozone generator (FISHER Ozone generator 500) has a maximum capacity of 2.5 g ozone per hour.
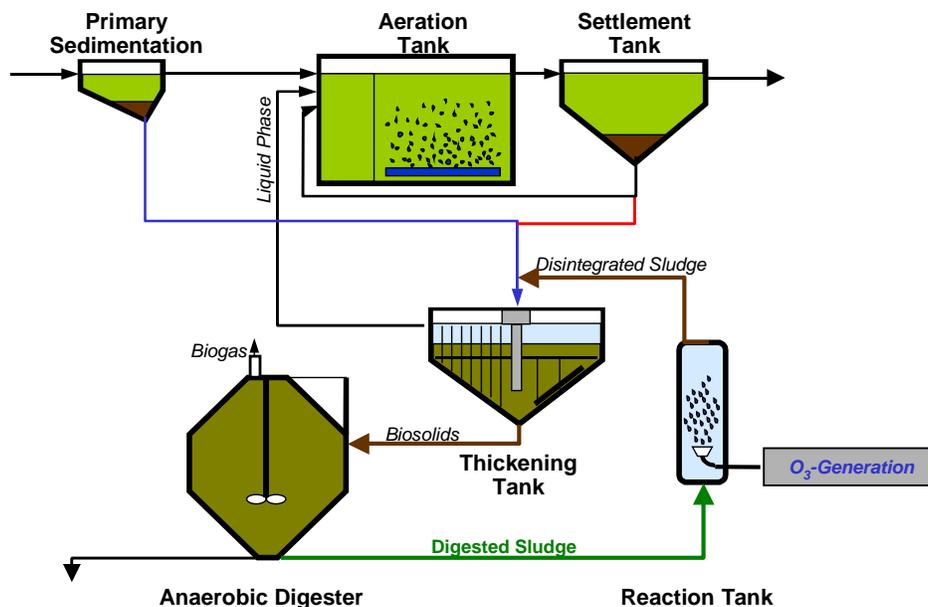

Figure 2: Schematic experimental set-up

A venturi type injection system was employed for the injection of ozone gas into the sludge suspension. With this injector type, high gas transfer rates with respect to specific power input are achieved due to high turbulence in the biosuspension (flow rate 1.5 $m \cdot s^{-1}$) caused by a progressing cavity pump (Netzsch, Nemo NM015). This generates microbubbles, which inhibit coalescence. The injection system is located in an external loop connected with the reaction tank, where the sludge suspension receiving the ozone is supplied in a closed circuit and enriched during several circulations.,

The tubing for the gas system is made of polytetrafluorethylene (PTFE) and the fittings are stainless steel (1.4571). The reaction tank is made of transparent PVC (volume 4 liters) and the connecting pipes of PVC-U. PTFE is recommended as a sealing material. Oxygen is used as a circulation gas and this is partially transformed into ozone when it passes through the ozone generator. Ozone measurement (Ozone Analyzer BMT 961) in the gaseous phase is carried out by direct UV-adsorption at a wavelength of 254 nm in accordance with the IOA (International Ozone Association) standard method 002/87 and without pressure compensation. Hence, ozone concentration, flow and pressure are measured in the inlet and outlet gas stream to recalculate the real ozone dose. In addition, the atmospheric pressure has to be taken into account. The final ozone dose (g O_3/h) is the difference between the corrected values from the inlet and outlet measured by the ozone analysers. In the outlet gas stream, additional safety and cooling devices are installed to prevent moisture entering the ozone analyser. At the bottom end of the system, a residual ozone destruction facility (containing activated carbon) is installed in order to trap non-reactive ozone before the off-gas is released to the environment.

RESULTS OF EXPERIMENTS

During sludge ozonization, cells are not completely decomposed but just partly damaged and thus inactivated. The remaining particles or disrupted cells are subsequently subjected to anaerobic biological decomposition. With the described row of experiments, the overall disintegration efficiency, expressed as g ozone necessary to disrupt one g DS, was investigated. The gained data proved that only 0.06 g O_3 / g DS were necessary to destroy the biological activity of treated biomass. At this specific ozone dose, no or only a minimal amount of the organic matter was completely oxidized into carbon dioxide. The release of COD from the damaged cells to the liquid phase corresponded well to the removal of suspended solids. But dissolved COD does not characterize the bioavailability of the treated sludge. BOD values of the total sludge exceeded the dissolved COD by far. The achieved findings showed that the inactivated biosolids represent a good substrate for biodegradation. The measured BOD values reached their maximum already after 30 minutes of ozonization and did not increase much more with ongoing treatment. On the other hand, after 120 minutes reaction time, a decrease of BOD in the sludge was observed, which could be due to the production of inhibitory substances during ozonization. Besides the biodegradability of the treated

anaerobic sludge, the issue of potentially inhibitory by-products during ozonization was investigated in more depth during initial digestion batch tests.

Employing the ozone gas concentration of 2.4 g O_3/h, the reaction time could be reduced to below ten minutes, in order to achieve the required disintegration efficiency. Hence, as a result of several expert consultations, it was agreed to apply the following parameters during the subsequent continuous experiments. The reaction time of 15 minutes (0.13 g O_3 / g VSS) was chosen. However, this setting still bears a potential for further reduction.

INITIAL DIGESTION BATCH TESTS

In a special lab-scale set-up, the anaerobic digestion of disintegrated sludge was investigated. During the conducted experiment special attention was allotted to the achievable degree of stabilization and the significance of potentially inhibitory by-products after ozonization. Thus, the conventionally employed digestion time was extended from 15 to 34 days (a) without raw sludge dosage and (b) with raw sludge dosage (refer to Table 1).
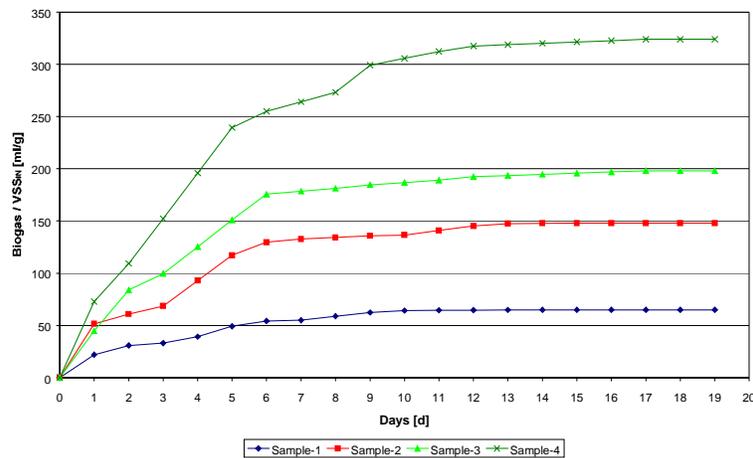

Figure 3: Biogas production of batch-tests, sample 1-4 (ml biogas / g VSS_{IN})

In the test run without raw sludge dosage it was shown, that the addition of one quarter disintegrated sludge improved the dry substance reduction by 116%, VSS were reduced by 150% and COD by 106% compared to the reference without disintegrated sludge. Due to the addition of disintegrated sludge, 1.7-2 times higher degree of stabilization was achieved compared to pure digested sludge The test run with raw sludge dosage proved that the ratio of DS elimination was between 1.9-2.5, for VSS between 1.6-1.9 and for COD 1.5-1.7. In general, it was observed that raw sludge is 1.5 to 2.5 times better biodegradable than disintegrated sludge. Bearing in mind that disintegrated sludge contains about 38% organic matter compared to 67% of organic matter in raw sludge, it can be stated that up to 80% organic matter of disintegrated sludge is transformed into biodegradable compounds.

Regarding the overall stabilization efficiency, the organic matter (VSS) in the residual sludge is reduced to 13% after enhanced stabilization (addition of disintegrated sludge), compared to 26% VSS after conventional stabilization.

At the applied ozone dosage, no inhibitory effect to the anaerobic biocenosis was observed. Besides the degradation data, the measurements of biogas production give evidence that no harmful side-products are formed during disintegration of partly stabilized anaerobic sludge. The gas production per g VSS was in line with calculated values according to the COD-removal (0.4-0.5 m³ biogas/kg COD removed). An increase of 56% biogas production due to disintegrated addition dosage was observed in the test-run without raw sludge dosage. On the other hand, the additional amount of biogas in the test-run with raw sludge dosage represented an increase of roughly 39%. A qualitative analysis of the gas composition revealed the following distribution: 70% methane and 30% carbon dioxide.

CONTINUOUS LAB-SCALE EXPERIMENT:

The experimental set-up for the continuous lab-scale experiment included: (a) a wastewater treatment unit; (b) a sludge treatment unit; and (c) an ozonization unit. The operation was divided into two phases of sixty days each. In Phase 1, sludge treatment was operated under conventional settings in order to serve as reference run for the subsequent Phase 2, where the ozonization experiment was conducted.

Sludge Treatment

The anaerobic digestion process in the sludge treatment unit was significantly enhanced during Phase 2 as compared to the conventional operation in Phase 1. The resulting average degradation rate of organic matter was raised to 65% compared to 45% in the conventional system. The corresponding reduction of total solids increased from about 30% to 42% and the observed increase of mean biogas production rate was increased from between 150-290 l/d (0,35-0,4 m³/kg COD) to 250-570 l/d (0,4-0,45 m³/kg COD).
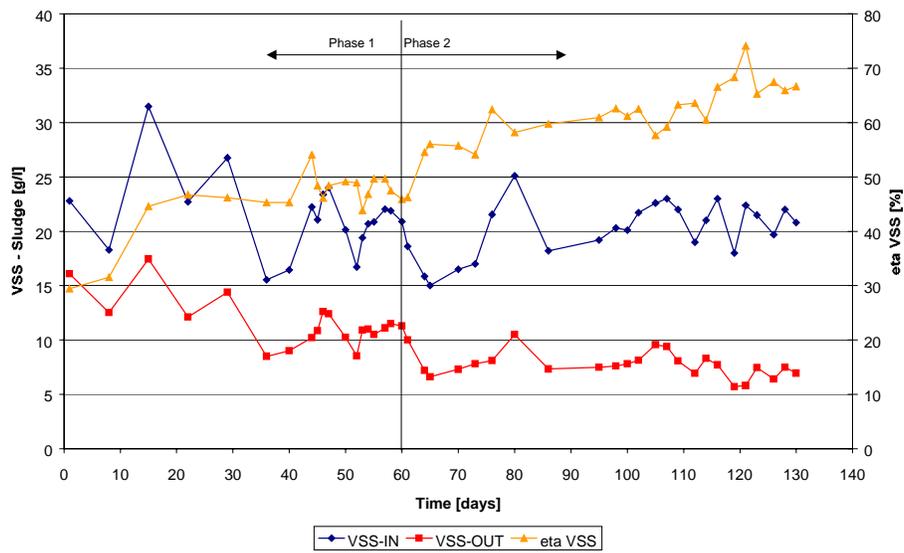
Figure 4: VSS concentration of thickened sludge prior to and residual sludge after anaerobic digestion in the course of the whole experiment
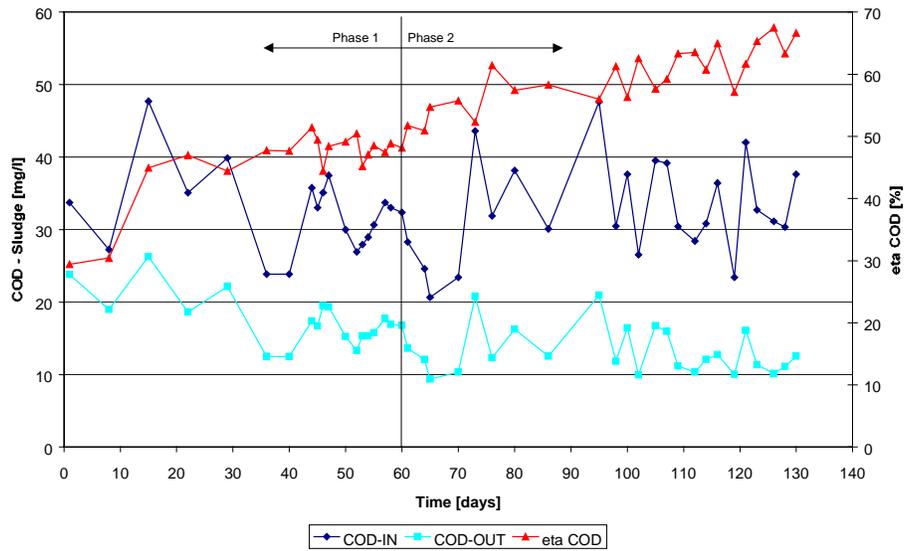

Figure 5: COD concentration of thickened sludge and residual sludge prior to and after anaerobic digestion in the course of the whole experiment
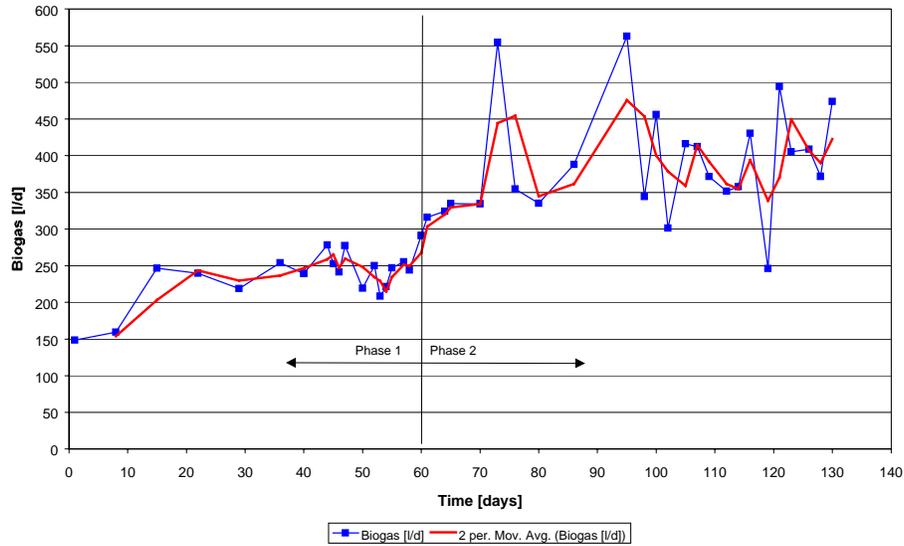
Figure 6: Course of biogas production during the whole experiment

In light of the employed process conditions (SRT 14 days in Phase 1 and SRT 9 days in Phase 2), which are considered extreme for anaerobic digestion, the gained degradation results were highly promising. Despite the lower degree of stabilization in the residual sludge that was achieved in the course of the conducted continuous experiment, the gained results succeeded to prove basically the trend of initial digestion batch tests. Upcoming research will have to determine the most suitable sludge retention time to achieve even higher degrees of stabilization with the innovative process combination. According to extensive expert consultations, a reasonable value for sludge retention time would be 12 days. Subsequent tests will form the basis to identify the optimum balance between technical and economical feasibility.

Sludgewater Monitoring

The results gathered during Phase 1 and 2 provide evidence of a certain shift in loading rates from sludgewater after dewatering to sludgewater after thickening. As far as the total reloading rate of both types of sludgewater is concerned, the following absolute reloading rates to wastewater treatment were observed during Phase 1; 86.0 g COD/d, 10.5 g NH_4-N/d and <0.1 g PO_4-P/d. These rates are 6.7% COD, 8.4% NH_4-N and 0.5% PO_4-P relative to the loading rate of incoming wastewater.

During Phase 2, the following total reloading rates were detected: 85.5 g COD/d, 15.2 g NH_4-N/d and <0.1 g PO_4-P/d, which represents a relative reloading rate of 6.6% COD, 12.1% NH_4-N and 0.6% PO_4-P.

Table 2 : Total reloading caused by sludgewater recharge to wastewater treatment, expressed as absolute values (g/d) and relative to the incoming wastewater load (%) in the course of the whole experiment

Source of Sludgewater	Absolute COD-reload	Relative COD-reload	Absolute NH_4-N-reload	Relative NH_4-N-reload	Absolute PO_4-P-reload	Relative PO_4-P-reload
	[g/d]	[%]	[g/d]	[%]	[g/d]	[%]
Phase 1	86.0	6.7	10.5	8.4	0.5	<0.1
Phase 2	85.5	6.6	15.2	12.1	0.6	<0.1

During sludge ozonization a certain quantity of biosolids is transformed into biodegradable substrate. Thus, refractory COD is oxidized with ozone and can be degraded during anaerobic digestion to a significantly greater extent than in the conventional system. With the results obtained, it was proved that most of the oxidized COD was removed by biological degradation and not merely resolved in the liquid phase. Despite the increase of COD removal in a range of between 15-20% (refer to Figure 5) during Phase 2, a slight decrease in COD load was observed in the total sludgewater reloading rate. Conversely, due to the reducing process conditions in the anaerobic digester, biologically bound nitrogen was resolved relative to the amount of degraded biosolids. Hence, an increase in the NH_4-N concentration of the liquid phase and subsequently in the sludgewater was observed. Finally, with regard to the PO_4-P concentration in the sludgewater, the measured values were in a range of between 0.6 and 3.2 mg/l. The related reload was mainly below 0.1% of the incoming wastewater load and can be considered as negligible. Therefore, no significant resolution of precipitated phosphorus was observed under anaerobic process conditions.

Wastewater Treatment

The wastewater treatment efficiency was monitored during Phase 1 of the experiment in order to characterize the system under conventionally applied conditions. In this period, the observed process performance was well in line with the relevant European legal standards and was utilized as reference for the subsequent ozonization experiment during Phase 2. In Phase 2, special attention was allotted to the effects of sludgewater recharge to the wastewater treatment unit. In fact, an increase of the mean COD-concentration in the effluent wastewater was observed. However, the effluent quality remained in accordance with the European legal standard and the overall COD removal rate was roughly 86%.

Regarding nitrogen removal, the following aspects had to be taken into account. In light of the applied internal sludge recirculation rate of 150% relative to the incoming wastewater flow and the observed increase of wastewater temperature, the denitrification efficiency was constantly improved from about 31% to 62%. The denitrification capacity of 62% does not comport to standard environmental requirements, but due to the lack of an additional internal recirculation between nitrification and denitrification the employed recirculation rate of 150% formed a systemic limit. Thus, the observed process performance was sufficient for meeting the project objectives and the achieved denitrification rate was in line with the theoretically

achievable results. Hence, it was assumed that sludgewater recharge had no significant impact on nitrogen removal.
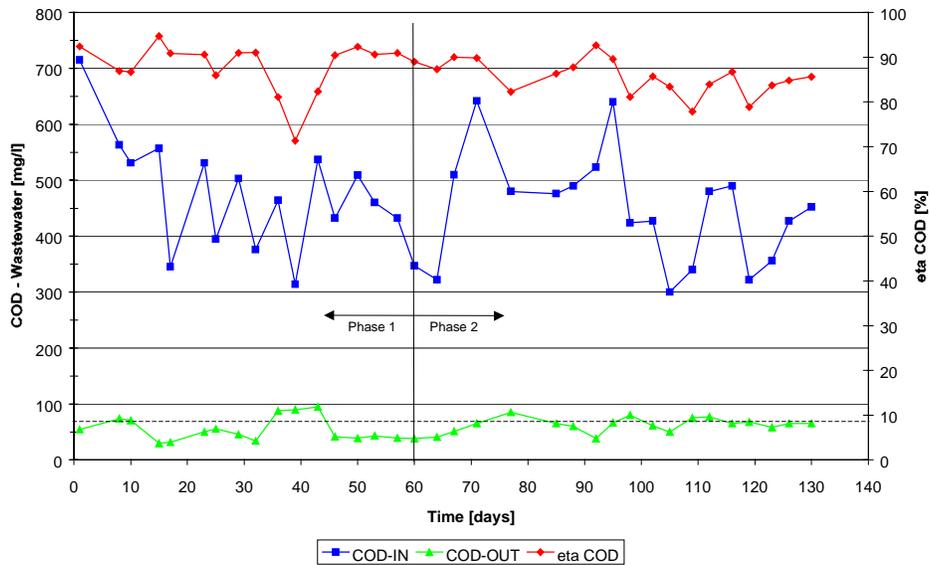

Figure 7: COD concentration of incoming- and effluent wastewater (mg/l) and degradation efficiency (%) in the course of the continuous experiment
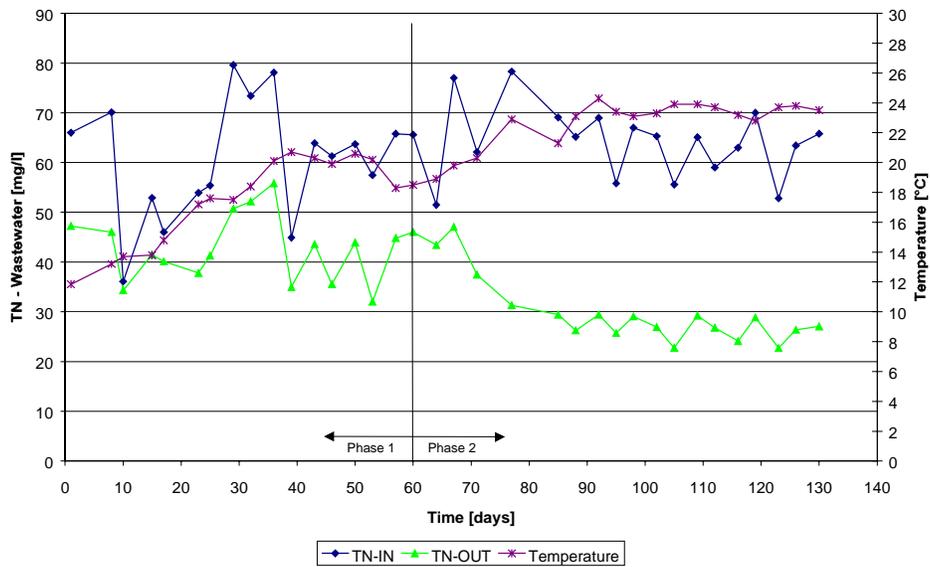

Figure 8: Total nitrogen (TN) concentration of incoming- and effluent wastewater (mg/l) and wastewater temperature (°C) in the course of the continuous experiment

ECONOMIC FEASIBILITY

In order to assess the economic feasibility of the described process a detailed cost calculation for a model wastewater treatment plant (WWTP) of 20,000 m³/d capacity was carried out using rather conservative assumptions. The projected costs for the innovative plant concept were based on an ozonization plant unit of 19.2 kg O_3/h capacity in addition to the conventional process. In the ozonization plant, partly stabilized digested sludge is disintegrated prior to its recycling to the anaerobic digestion tank. Thus the sludge retention time in the digestion tank can be reduced from the conventional SRT of 18 days to 12 days. Hence, the digester volume is designed to be roughly one-third smaller, which has a significant impact on the total investment costs. The savings derived from the digester volume reduction affect the total costs in such a manner that, despite the installation of an additional plant unit, the implementation of the innovative plant concept causes a reduction in total investment costs by 5%.

Additionally, the ozonization plant can be easily retrofitted into existing sludge treatment plants, because it is a relatively small plant unit with a low space requirement. In addition, the process is operated with ozone doses in the range of 0.1 kg O_3/kg DS, thus the employed ozone generator is relatively small and the related investment costs account for roughly 10% of total investment costs.

One special operational benefit of the innovative system that was taken into account is its potential for utilizing the resulting biogas for energy purposes. It can be assumed that the additional amount of biogas is enough to cover roughly 70% of the energy consumption of the total wastewater treatment plant. Moreover, due to the high degree of stabilization, the end product could be easily utilized for landscape construction without further treatment or discharged to landfill without harmful effects for the landfill site.

The total specific wastewater treatment costs per m³ of effluent of the model WWTP at 20,000 m³/d capacity are projected to be EUR Cent 37/m³, or about 12 percent lower than conventional technology. In view of the made assumptions, the payback period for the ozonization plant unit is about six years and there is a realistic potential for further reductions in investment and operational costs when the proposed process is further researched and developed.

CONCLUSION

As far as the total costs of ozonization technology are concerned, several aspects demand consideration. Firstly, ozone is a highly reactive oxidation agent and therefore, only small amounts of gas (0.1-0.15 g O_3/g DS) have to be injected, in order to carry out sludge disintegration. As compared with other types of municipal wastewater and sludge treatment plants, the ozonization unit is rather small. Moreover, further developments in the fields of (a) ozone generation, (b) gas injection system and (c) reaction tank design will lead to increased process efficiency. In view of these developments, the recent downward trend in investment costs is expected to continue.

In general, the feasibility of the innovative concept depends mainly upon local conditions. As far as total residual disposal costs are concerned, the combined anaerobic sludge treatment with ozonization is considered economically feasible for wastewater treatment plants where the specific sludge disposal costs exceed EUR 150 per metric ton of dry substance. Bearing in mind that (a) the costs for the reuse of residual sludge in agriculture are in the range of EUR 80-160 per metric ton of dry substance and (b) landfill costs are in the range of EUR 250-450 per metric ton of dry substance, the new concept may offer a competitive solution and clearly justifies further study.

REFERENCES

[1]   DICHTL N. et al.: Desintegration von Klärschlamm – ein aktueller Überblick. Korrespondenz Abwasser. 1997, Jg. 44, 10, 1726 – 1739
[2]   KUNZ P. M.: Behandlung von Schlamm. Vogel Verlag, Würzburg (1998)
[3]   NOWAK O., Personal communication. Vienna Technical University, Institute for Water Quality and Waste Management. April 2000
[4]   GOTTSCHALK, C et al. Ozonization of Water and Wastewater . Wiley VCH. 2000.
[5]   VRANITZKY, R. et al. Sludge Reduction Study with Special Emphasis on the Wastewater Situation in the cities of Shanghai and Chengdu. VA TECH WABAG. 2000

TABLES

Table 1 : Composition of sludge samples, (g per total volume of two litres)
Table 2 : Total reloading caused by sludgewater recharge to wastewater treatment, expressed as absolute values (g/d) and relative to the incoming wastewater load (%) in the course of the whole experiment

FIGURES

Figure 1: Principle of electrical corona discharge reaction [4]
Figure 2: Schematic experimental set-up
Figure 3: Biogas production of batch-tests, sample 1-4 (ml biogas / g VSS_{IN})
Figure 4: VSS concentration of thickened sludge prior to and residual sludge after anaerobic digestion in the course of the whole experiment
Figure 5: COD concentration of thickened sludge and residual sludge prior to and after anaerobic digestion in the course of the whole experiment
Figure 6: Course of biogas production during the whole experiment
Figure 7: COD concentration of incoming- and effluent wastewater (mg/l) and degradation efficiency (%) in the course of the continuous experiment
Figure 8: Total nitrogen (TN) concentration of incoming- and effluent wastewater (mg/l) and wastewater temperature (°C) in the course of the continuous experiment