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THE USE OF DISINTEGRATED FOAM TO ACCELERATE ANAEROBIC DIGESTION OF ACTIVATED SLUDGE

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Abstract: Hydrodynamic disintegration of the activated sludge and foam results in organic matter transfer from the solid phase to the liquid phase. Hydrodynamic disintegration caused an increase of COD value in activated sludge and foam of 220 $mg \cdot dm^{-3}$ and 609 $mg \cdot dm^{-3}$ – respectively, besides the degree of disintegration increases to 38% and 47% – respectively – after 30 minutes of disintegration. Hydrodynamic cavitation affects positively the degree of disintegration and rate of biogas production. Also addition of a part of digested sludge containing adapted microorganisms resulted in acceleration of the anaerobic process. Addition of disintegrated foam (20% and 40% of volume) to the fermentation processes resulted in an improvement in biogas production by about 173% and 195% respectively – in comparison to activated sludge without disintegration (raw sludge) and 142% and 161% respectively – in comparison to activated sludge with a part of digested sludge (80% raw sludge + 20% digested sludge).

INTRODUCTION

The aim of wastewater treatment is mineralization of organic matter and nutrients removal. Filamentous microorganisms present in the biological wastewater treatment processes are responsible for foam formation and activated sludge bulking [15]. Foaming is a common problem encountered in many wastewater treatment plants worldwide [1, 2, 4, 9, 13–15], especially in those designed for biological carbon and nutrients removal. The formed foam can cover the entire surface of biological reactors and secondary settling tanks. Also, the foaming problems are observed in anaerobic sludge digesters. Consequently, many investigators, and treatment plant operators, have given attention to control the foam forming process. In most wastewater treatment plants, the occurrence of foam is not only an aesthetical nuisance but causes serious problems such as: a) environmental pollution – if floating sludge cannot be held back, it considerably increases the effluent solids concentration; b) operational problems – a considerable fraction of the active biomass can be trapped in thick foam layers and therefore be excluded from the intended biological processes. This may limit the plant performance and make control of solids and sludge retention time (SRT) more difficult. Sticky foaming sludge often leads to malfunctioning of electrodes to measure dissolved oxygen and therefore may seriously affect treatment performance and process stability. In winter, foam can freeze and possibly damage mechanical equipment. Intensive foaming reduces the effectiveness of surface aerators. Severe foaming in anaerobic digesters that often occurs simultaneously with foaming in the activated sludge tanks may significantly reduce the usable reactor volume and therefore lead to serious sludge disposal problems; c) safety risks – foam may overflow onto walkways, creating slippery areas. Aerosols may spread suspected pathogenic bacteria (e.g. *Nocardia asteroides*) that are accumulated in the foam. Severe foaming in anaerobic digesters may block gas pipes; d) nuisances – foaming requires increased cleaning efforts (and therefore increased operating costs). In summer, stable foam may putrefy and cause odor problems.

The disruption of cells of activated sludge or foam microorganisms and addition to the digestion process leads to increase of biogas production. Anaerobic digestion is a common method for activated sludge stabilization carried out in a sequence of four phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Sludge anaerobic digestion results in the reduction of sludge volatile matter and the production of biogas. The main reason of slow degradation rate of activated sludge in the process of anaerobic digestion is the limiting step of sludge hydrolysis. Therefore, the pretreatment of activated sludge disintegration by physical (thermal), chemical (using e.g. acids; oxidation processes using ozone or hydrogen peroxide), mechanical (ball mill, ultrasonic), as well as biological treatment (using enzymes), can significantly improve the subsequent anaerobic digestion [5, 8, 11, 12, 16, 18]. Although the methods are different in nature, the aim of all of them is partial or complete bacteria cells disintegration, i.e. destruction and release of organic substances present inside cells to the liquid phase.

Disintegrated by hydrodynamic cavitation sludge or foam has a positive effect on the degree and rate of sludge anaerobic digestion.

Hydrodynamic cavitation results in the formation of cavities (bubbles) filled with vapor – gas mixture inside the flowing liquid, or at the boundary of a constrictive device due to rapid local pressure drop. Downstream of the constriction (valve or nozzle) the pressure recovers and subsequently causes cavities to collapse. The collapse of the cavitation bubbles is defined as an implosion with associated forces causing mechanical and physicochemical effects. The physical effects include the production of shear forces and shock waves, whereas the chemical effects result in the generation of radicals, e.g. formation of reactive hydrogen atoms and hydroxyl radicals. These radicals can converted to the hydrogen peroxide. Hydrodynamic disintegration can activate the biological hydrolysis process and, therefore, significantly increase the biogas production in anaerobic stabilization [6, 7, 17].

The new concept described in this paper is based on the combined process of foam hydrodynamic disintegration prior to anaerobic digestion. The aim of carried out experiment on sludge digestion was to show the possibilities for improving and accelerating the anaerobic process.

MATERIALS AND METHODS

Activated sludge and foam samples were taken from a full scale municipal sewage treatment plant operated according to the EBNR (Enhanced Biological Nutrients Removal) process. The 30 dm^3 samples of activated sludge and foam were taken from bioreactor (exactly from the nitrification stage). The concentration of foam and activated sludge dry solids were approximately 18 000 mg·dm^{-3} and 5 500 mg·dm^{-3} – respectively.

The hydrodynamic disintegration

Mechanical disintegration of a 25 dm^3 samples of activated sludge or foam was executed in the process of hydrodynamic cavitation. The experimental set up consisted of a 12 bar pressure pump, rating 1.1 kW, output 500 dm^3·h^{-1}, which recirculated sludge from a container, through a 1.2 mm nozzle. To force 25 dm^3 of sludge through the nozzle 3 minutes were required. Scheme of the experimental set up is given in Figure 1. Disintegration was carried out for 15, 30 and 60 minutes. Chemical Oxygen Demand (COD) was measured for samples before and after each time of disintegration.

The degree of disintegration

In order to have a quantitative measure of the effects of disintegration, Kunz and Wagner [8] have proposed a coefficient which they called the Degree of Disintegration (DD). Later this coefficient was modified by Müller [10].

Here the degree of sludge disintegration was determined according to that given by Müller [10] as follows.

$$DD = [(COD_1 - COD_2) / (COD_3 - COD_2)] \cdot 100\ [\%]$$

where:

DD – degree of disintegration,

COD_1 is the COD of the liquid phase of the disintegrated sample,

COD_2 is the COD of the original sample (activated sludge or foam samples without disintegration),

COD_3 is the value after chemical disintegration.

Chemical disintegration was done in this case by treating the sludge samples for 10 min at 90°C after adding NaOH, 1 M, in ratio 1:2.

Chemical Oxygen Demand (COD, COD_1, COD_2 and COD_3) value was determined for samples before and after each time of disintegration according to the 19th edition of Standards Methods for the Examination of Water and Wastewater [3] procedures, using standard potassium dichromate solution. Centrifugation is done in all cases for 10 min with 30 000 g and samples were filtrated always using filter paper (0.45 μm).

The fermentation experiments

The anaerobic digestion experiments were performed in five glass fermenters (25 dm^3) operated in parallel at a temperature of 33 ± 2°C. Residence time was 22 days. The production of biogas was measured daily. Different rates of raw and disintegrated activated sludge and foam were applied:

Fermenter 1 was fed with raw activated sludge (symbol: S), (COD value 77 mg O_2·dm^{-3}, volatile solids 5.64 g·dm^{-3}, percentage of the feed 62.48%),

Fermenter 2 was fed with raw activated sludge (80% volume of fermenter), and digested sludge (20% volume of fermenter), (symbol: 80% S + 20% SD; COD value 198 mg O_2·dm^{-3}, volatile solids 8.91 g·dm^{-3}, percentage of the feed 55.26%).

Fermenter 3 was fed with raw activated sludge (60% volume of fermenter), and activated sludge after hydrodynamic disintegration (DS), (20% volume of fermenter), and digested sludge (20% volume of fermenter), (symbol: 60% S + 20% DS + 20% SD; COD value 248 mg $O_2 \cdot dm^{-3}$, volatile solids 8.83 $g \cdot dm^{-3}$, percentage of the feed 59.93%)

Fermenter 4 was fed with raw activated sludge (60% volume of fermenter), and foam floating on the surface of bioreactors after hydrodynamic disintegration (20% volume of fermenter), and digested sludge (20% volume of fermenter), (symbol: 60% S + 20% DF + 20% SD; COD value 383 mg $O_2 \cdot dm^{-3}$, volatile solids 10.51 $g \cdot dm^{-3}$, percentage of the feed 64.14%)

Fermenter 5 was fed with raw surplus activated sludge (40% volume of fermenter), and foam floating on the surface of bioreactors after hydrodynamic disintegration (40% volume of fermenter), and digested sludge (20% volume of fermenter), (symbol: 40% S + 40% DF + 20% SD; COD value 555 mg $O_2 \cdot dm^{-3}$, volatile solids 11.64 $g \cdot dm^{-3}$, percentage of the feed 65.53%).

The aim of carried out experiments of sludge digestion was to show the possibilities for improving and accelerating the anaerobic process. A scheme of the experimental configuration shows Figure 1.

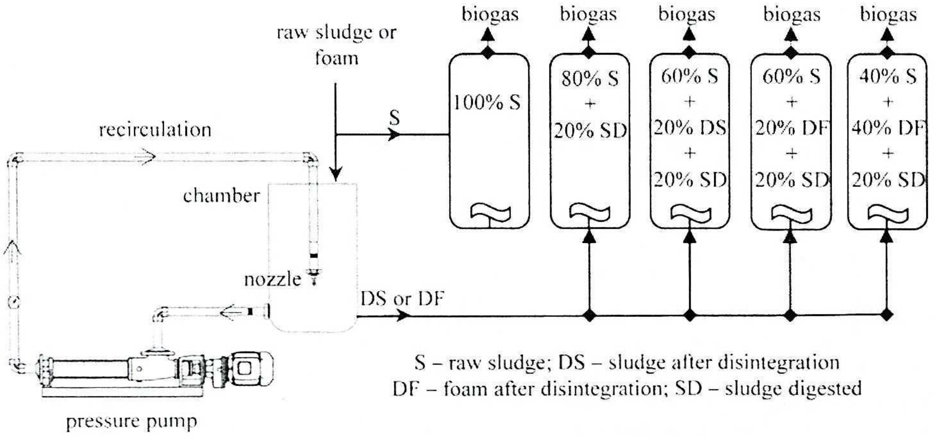

Fig. 1. Scheme of the experimental configuration

The results presented here were performed in 10 stages, and arithmetic average and standard deviation were carried out. Standard deviation was determined according to estimator of highest credibility in STATISTICA 6.0.

RESULTS AND DISCUSSIONS

Hydrodynamic cavitation treatment of activated sludge caused disruption of flocs structure and resulted in different degrees of disintegration (DD). The effect of hydrodynamic cavitation time on sludge disintegration was determined. The results of the experiments are presented in Figure 2.

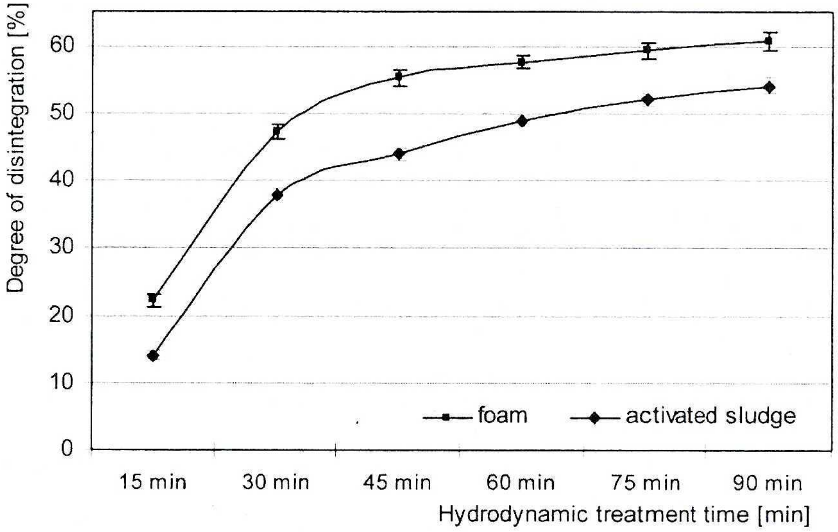

Fig. 2. Degree of foam and activated sludge disintegration

Within the range of explored time, between 15 min and 90 min, the degree of disintegration increased most rapidly in the first 30 min. The achieved degree of activated sludge and foam disintegration was about 38% and 47% respectively. The efficiency of sludge disintegration increased further for prolonged time (Fig. 2).

Increase of the DD was attributed to break-up of microbial cells leading to the release of intracellular materials.

The direct effect of intracellular and exocellular organic matter release can therefore be measured as soluble COD increase.

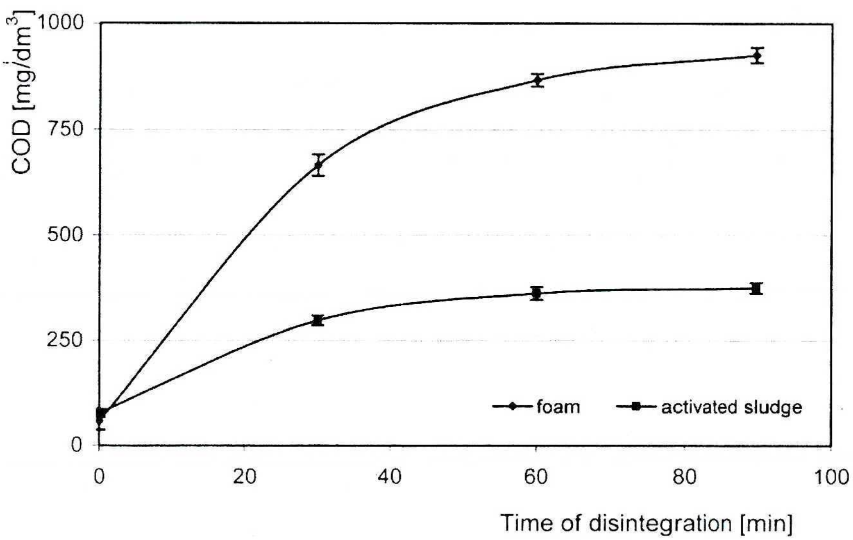

Fig. 3. Increase of COD in the foam and activated sludge supernatant after hydrodynamic treatment

Already 30 minutes of mechanical activated sludge flocs disintegration resulted in COD increase in the filtrate (filter paper) of 220 mg·dm^{-3} (from 77 to 297 mg·dm^{-3}), that is more than a treble increase. With increase of the disintegration time a further increase of soluble COD occurs (Fig. 3). Disintegration of foam (scum) floating on the surface of EBNR resulted in release of much larger amounts of organic matter (Fig. 3). Already 30 minutes of foam hydrodynamic disintegration resulted in COD increase in the filtrate (filter paper) of 609 mg·dm^{-3} (from 57 to 666 mg·dm^{-3}). This is probably due to the more fragile structure of filamentous organisms constituting the foam. The distinct differences between the foam and activated sludge biomass in release of organic matter, expressed as COD values, resulted from their different dry solids concentration.

Although the volatile fraction of the foam (70–72%) was higher than the volatile fraction of the activated sludge (62–63%) it does not explain the drastic difference in COD release. Obviously, the organic matter transferred by hydrodynamic treatment from the sludge solids and foam solids into the liquid phase were readily biodegradable. The predominant microorganisms in activated sludge are heterotrophic bacteria, however, foam consists much more of filamentous bacteria. The break-up of cell walls of the bacteria limits the degradation process. By applying hydrodynamic disruption the lysis of cells occurs in minutes instead of days. The intracellular and extracellular components are set free and are immediately available for biological degradation which leads to acceleration of the anaerobic process. Addition to experimental fermenters 3 and 4 of a part of already anaerobical digested sludge containing adapted microorganisms, resulted in the acceleration of the process. This is shown in Figure 4 by comparing the increase of biogas production in the anaerobic digestion.

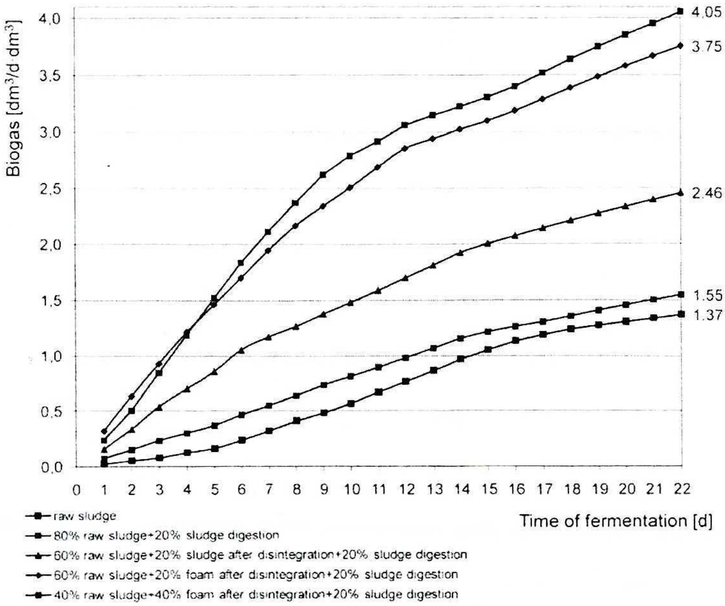

Fig. 4. Production of biogas during fermentation

Higher amounts of biogas were produced in the fermenters fed with disintegrated activated sludge (20% volume of fermenter), plus disintegrated foam (20% or 40% volume of fermenter), plus digested sludge (20% volume of fermenter). Significantly higher production of biogas was observed in the fermenters fed with disintegrated foam. The gas production during the sludge digestion depends on volatile solids, degree of disintegration (expressed as COD) and fermentation time. Disintegration of foam (scum) floating on the surface of EBNR resulted in release of much larger amounts of organic matter (Fig. 3). This is probably due to the more fragile structure of filamentous organisms constituting the foam.

Furthermore, the disintegration of foam/scum in the aeration tank and the foam from the secondary settling tanks can lead to reduced bulking of activated sludge [10]. Therefore, problems with foam forming in digesters can be reduced as well.

The performance of various disintegration methods can be compared with each other using the specific energy, which is defined as the amount of mechanical energy that stresses a certain amount of sludge [10]. The results presented in Müller [10] are definitely not the final ones concerning the ultimate performance of the methods. All disintegration methods are still under investigation in order to improve their application for sewage sludge treatment. Therefore a remarkable improvement of the performance can be expected. Besides the energy consumption, there are other factors like investment costs or the suitability of the machine for practical application on a wastewater treatment plant, which greatly affect the selection of method. Clogging and other operational problems caused by coarse and fibrous particles in the sludge were observed at the homogenizing gap of the high pressure homogenizer.

Looking at the release of COD and the specific energy used in our disintegration method, it can be observed that medium degree of disintegration is reached with a relatively low energy input (Fig. 5). This is of course a lab scale of investigation and there should be much lower energy consumption on technical scale.

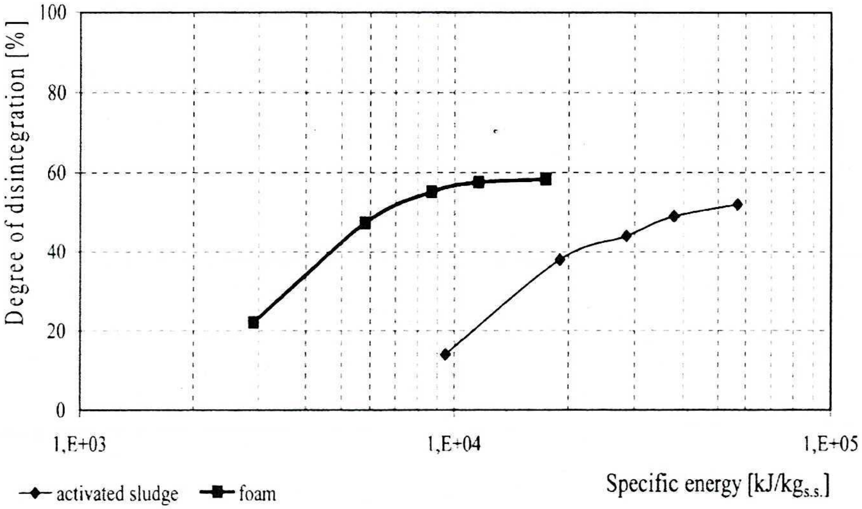

Fig. 5. Degree of disintegration of activated sludge and foam as a function of specific energy

Calculations of energy consumption and cost show that hydrodynamic disintegration process can be cost effective. The surplus gas can be used for power and heat production. A part of the energy yield can be used for the hydrodynamic disintegration of activated sludge and/or foam.

The reduced cost for the sludge and foam disposal, enhanced fermentation rates and acceleration of biogas production should lead to a practical use of hydrodynamic disintegration as a new technology.

CONCLUSIONS

In this study, hydrodynamic disintegration of foam was examined in order to accelerate anaerobic digestion of activated sludge. The most important conclusions are:

1. The degree of disintegration increased most rapidly in the first 30 min. The achieved degree foam disintegration was about 47%.
2. The hydrodynamic disintegration of activated sludge and foam destroys the structure of sludge and disrupts the foam microorganisms. As a result of disintegration, organic matter was transferred from the sludge solids into the liquid phase (expressed as COD). A higher increase of COD observed after disintegration was achieved for foam comparing to activated sludge. For example, already 30 minutes of mechanical disintegration resulted in COD increase of 220 mg·dm^{-3} and 609 mg·dm^{-3} – respectively in activated sludge and foam liquid.
3. The addition of disintegrated foam to the fermentation process after 22 days of anaerobic process caused an acceleration of the anaerobic digestion process and increase in biogas production. The higher biogas production was observed in the fermenter fed with disrupted foam microorganisms (3.75 dm^3·d^{-1}·dm^{-3}) as compared to the fermenter fed with disrupted flocs of activated sludge (2.46 dm^3·d^{-1}·dm^{-3}).

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WYKORZYSTANIE DEZINTEGROWANEJ PIANY DO PRZYSPIESZENIA BEZTLENOWEJ FERMENTACJI OSADU

Dezintegracja hydrodynamiczna osadu czynnego oraz piany powoduje uwolnienie materii organicznej z fazy stałej do fazy ciekłej. Dezintegracja 30 minutowa osadu czynnego i piany skutkuje wzrostem wartości ChZT w cieczy odpowiednio o 220 mg·dm^{-3} i 609 mg·dm^{-3}, a tym samym wzrostem stopnia dezintegracji do 38% i 47% w przypadku osadu czynnego i piany. Kawitacja hydrodynamiczna skutkuje wzrostem stopnia dezintegracji i tempa produkcji biogazu. Ponadto dodanie przefermentowanego osadu z zaadoptowanymi mikroorganizmami przyczynia się do przyspieszenia procesu beztlenowego. Dodatek dezintegrowanej piany (20% i 40% objętościowych) do procesu fermentacji powoduje wzrost wydajności produkcji biogazu odpowiednio o 173% i 195% w porównaniu do produkcji biogazu z osadu czynnego niepoddanego dezintegracji (osad surowy) i o 142% i 161% w porównaniu do próby osadu czynnego z udziałem objętościowym osadu przefermentowanego (80% osadu surowego + 20% osadu przefermentowanego).