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PRELIMINARY STUDIES ON THE INFLUENCE OF NEGATIVE PRESSURE ON ACTIVATED SLUDGE FLOCS

A b s t r a c t

A sludge from municipal wastewater plant operated for biological contaminant removal was exposed to three different negative pressures (-200, -500 and -800 hPa) for three different duration times (30 second, 1 and 2 minutes). Sludge volume index, shear sensitivity of the sludge and activated sludge floc characteristic was the object of the study before and after negative pressure treatment. After the treatment the sludge settled better independently on the pressure value and duration time. The shear sensitivity changed the most when the pressure exposure of -800 hPa was 1 minute and longer. The flocs structure was more open after negative pressur and larger part of activated sludge was comprised by large flocs.

Keywords: negative pressure, activated sludge, floc features

INTRODUCTION

Settling ability of activated sludge is one of the most important parameters during wastewater treatment by activated sludge. It is one of the ways to separate biomass (activated sludge) from the treated wastewater. Problems with settling of activated sludge may causes many further technological disturbances. Degree of sludge settling influences the amount of suspended solids in the effluent, concentration of solids in return sludge and reaction chamber.

Degassing of activated sludge before its discharge to secondary clarifier improve the settling properties of activated sludge and enhance the efficiency of

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nutrient removal [Maciejewski et al. 2007; 2008; 2010]. Degassing occurs due to a short-term reduction of pressure according to Henry's law. The settling ability of activated sludge reflected by SVI after degasification can be up to 30% better than that for sludge not treated by negative pressure [Haghighatafshar et al. 2016]. Due to the settling improvement the concentration of suspended solids in the settled sludge is higher. Using the degasification unit the loading rates can be much higher as faster and better settling of activated sludge let operation with higher suspended biomass content in reaction chamber. The system maximizes biological nutrient removal rates as more active biomass is produced in the process [Maciejewski et al. 2007].

The aim of the research is to determine the effect of negative pressure on structure of activated sludge. During the transport of activated sludge through the degasification unit the activated sludge flocs are believed to be destroyed due to gas bubbles escaping the mixture and reflocculated suddenly after the pressure above the mixed liquor is atmospheric [Maciejewski et al. 2008]. There are only few literature data concerned on low negative pressure influence on activated sludge [Maciejewski et al. 2007; 2008; 2010; Haghighatafshar et al. 2016]. Degassication of activated sludge by vacuum of app. 950 mbar results in total nitrogen removal from concetrations above 20 mg/L to values lower than 10 mg TN/L [Maciejewski et al., 2010] and app. 50% decrease of ammonium concentration at the effluent [Maciejewski et al., 2007, 2008]. Activated sludge flocs from WWTP equipped with vacuum degassing (app. 950 mbar and 30 second of exposition) showed better compaction [Haghighatafshar et al. 2016]. The proposed research topic just because of the scarcity of data in the literature has shown the importance of research for the development of science. It is believed that low negative pressure have an impact on activated sludge flocs and microorganisms thus enhance the effect of degasification. It is also a question if there is dependence between the pressure value and degassication effect. It is worth for checking as the generation of lower negative pressures require less energy to be supplied.

METHODOLOGY

Several tests were performed on activated sludge taken directly from municipal wastewater treatment plant. In each test the activated sludge was divided into several subsamples and subjected to negative pressure. 700 mL of activated sludge was placed in a 1 L vacuum filtering flask and mixed by magnetic stirrer. The negative pressure treatment of activated sludge was reached by means of a vacuum pump that was connected to the flask. In each test different negative pressures of -200, -500 and -800 hPa were applied for 0.5; 1 or 2 minutes. Subsample not subjected to negative pressure served as a control. Each test cover analysis of sludge volume index and activated sludge floc analysis. All experiments were carried out at room temperature (app. 20^{o}C). The research is preliminary as the used negative pressures are lower than that used at WWTP to degasify activated sludge and was performed to predict the potential of the research project to be realized with more sophisticated methods for activated sludge characterization as image analysis and staining procedures.

Sludge volume index and shear sensitivity test

Sludge volume index (SVI) was performed classically by measurement of sludge settleability in 1000 ml cylinder during 30 minutes. SVI was calculated as a quotient of settled sludge volume and suspended solids mass (SS).

The shear sensitivity test rely on the shear treatment of activated sludge (sheared sample) followed by a sludge volume measurement after 30 minutes of settling (SV30) and comparison with the volume measurement of the not sheared sample (control). The activated sludge was sheared with a mixer for 10 minutes. The mixer used in this study was the commercially available mixer usually employed in the kitchen [Seka et al. 2003], Braun MR 400. The highest turnover of the mixer was used (12.500 rpm). The ratio (%) obtained by dividing the SV30 of the sheared sample by the SV30 of the control is used to express the shear sensitivity [Seka et al. 2003].

Activated sludge floc analysis

Analysis of activated sludge flocs was based on microscopic analysis (MOTIC BA400T microscope) that comprised manual assessment of floc size and floc characteristics (according to Eikelboom and Buijsen [1999]). At least 30 flocs found at randomly chosen fields of view were assigned according to their size (<100 µm, 100-500 µm and <500 µm), shape (round or irregular), structure (compact or open) and cohesion (weak or strong). Floc size was measured with a use of Motic Images Plus software (Motic China Group Co.). Percentage of flocs belonging to one of the group was calculated.

RESULTS AND DISCUSSION

Sludge volume index

The use of negative pressure of -200, -500 and -800 hPa for 30 second resulted in a decrease of sludge volume index (SVI) from 270 g/ml to approx. 180 g/ml compared to the activated sludge not subjected to negative pressure. After the activated sludge was exposed for 30 seconds to negative pressure of about -200, -500 and -800 hPa the SVI decreased of 24 to 41% (Fig. 1). It is comparable to 30% that was obtained for several activated sludges degasified in vacuum of 950 mbar for app. 30 sek [Haghighatafshar et al. 2016]. Elongation of negative pressure exposure exhibited different pattern for different negative pressure values used. SVI was the lowest when 2 minutes of -200 hPa was used, but when -500 and -800 hPa was applied for 2 minutes the SVI after was the highest among the tested durations. However, the standard deviation of triplication was quite high and ranged in 15-37%. Thus the differences between the samples treated by negative pressure are not statistically significant. The only significant difference was obtained for negative pressure of -500 hPa used for 30 seconds.

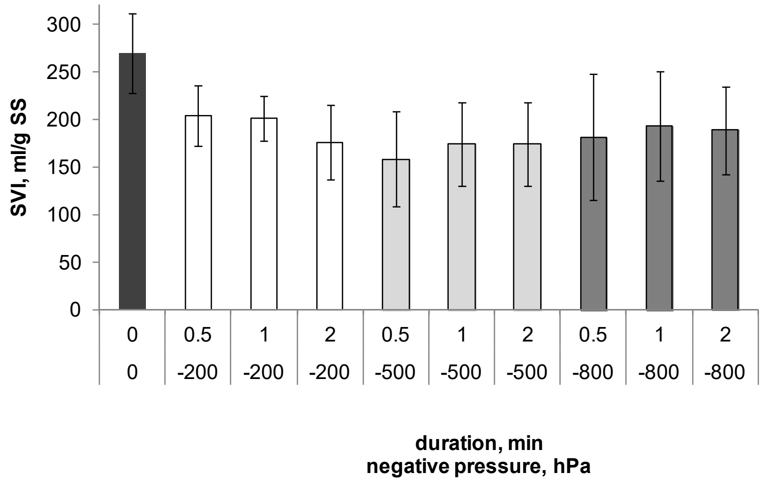

Fig. 1. SVI of sludges subjected to negative pressure
Rys. 1. Indeks objętościowy (IO) osadu pod wpływem podciśnienia

Shear sensitivity

The effect of a shear treatment on an activated sludge sample was used to assess its sensitivity to shear after a treatment by negative pressure. The shear sensitivity test rely on hypothesis that during shear pressure (intensive mixing) more week (sensitive) flocs become disintegrated and are resistant from separation from suspension. Thus less flocs remain to be settled and the sludge volume become lower [Seka et al. 2003]. The SV_{30} ratio for the not treated sludge was 41% (Tab. 1). Application of negative pressure of -200 or -800 hPa for 30 seconds revealed no effect on activated sludge flocs by the meaning of floc strength. Elongation of the negative pressure to 1 or 2 minutes resulted in decrease of SV_{30} ratio of 8 and 10% for -200 hPa and 20 and 30% for -800 hPa, respectively. It means that the activated sludge flocs after longer exposition to higher values of negative pressure are less strong and more susceptible for fragmentation. Unfortunately, due to high standard deviation the results cannot be statistically proved. Moreover, it has to be mentioned that the high standard deviation and not repeatable trend in series of negative pressure of -500 hPa may originate from the behaviour of the sludge after the shear treatment.

Tab. 1. Results of shear sensitivity test of vacuum exposed activated sludge
Tab. 1. Wyniki testu podatności osadu czynnego na ścinanie pod wpływem podciśnienia

Exposition time, minutes	No vacuum	200, mbar	500, mbar	800 mbar
0.5	41±8	41±2	42±3	44±17
1		38±2	29±8	33±11
2		37±3	45±7	27±8

The test procedure rely on the settling for 30 minutes of 10-times diluted, previously thickened sludge (SV_{30} control) and settling of the same part of sludge but sheared before settling (SV_{30} sheared). It is presented by Seka and Vertraete [2003] that normal, non-amorphous sludges have the SV_{30} ratio (SV_{30} sheared: SV_{30} control) lower that 100%. The more weak flocs in the sludge the more flocs undergone fragmentation during the shear treatment and the more flocs or its fragments stay in the supernatant after settling. As a consequence, the SV_{30} sheared is thus lower than SV_{30} control. In case of this study there were no sludge that settled down. However, there were a part of sludge that could be distinguished from the supernatant but it was flocculated to the top of the cylinder. Thus, not the settled but flocculated part of sludge was taken to calculate the SV_{30} ratio, taking in mind that is not really settled sludge but sludge separated from the supernatant. Possible reason of the situation can be to high power of the used mixer comparing to that used in the study of Seka and Verstraete [Seka et al. 2003]. The used mixer had 25% higher power and other blazer type thus the shear force was also higher. Moreover, in comparison to results of Seka and Verstraete [2003] obtained SV_{30} ratio for control sample seems to be quite low as such values of the parameter were gained by the authors after strong destructive treatment of the used sludges.

Activated sludge flocs characteristics

The activated sludge flocs were characterized by four parameters: size, shape, structure and cohesion. The microscopic analysis of activated sludge revealed changes in characteristics of activated sludge flocs (Table 2).

The flocs were rather irregular (more than 82% flocs characterized as irregular) and weak (maximally 5.6% flocs were strong). Due to such high contribution of weak flocs the influence of negative pressure and its duration was impossible to distinguish. However, after the exposition to negative pressure the shoreline of flocs became less stable and more blurred (picture not available). The shape of the flocs did not change significantly due to exposition to negative pressure, beside its value and duration.

Tab. 2. Characterisation of activated sludge flocs exposed to vacuum (relative standard deviation was always below 10%)

Tab. 2. Charakterystyka kłaczków osadu czynnego poddanych działaniu podciśnienia (względne odchylenie standardowe zawsze wynosiło poniżej 10%)

Pressure, mbar	0	200	200	200	500	500	500	800	800	800
Duration, min	0	0.5	1	2	0.5	1	2	0.5	1	2
size										
>500, µm	25.6	23.3	21.1	31.1	34.4	31.1	48.9	45.6	43.3	48.9
100-500, µm	58.9	60.0	68.9	56.7	57.8	58.9	44.4	51.1	54.4	46.7
<100, µm	15.6	16.7	11.1	12.2	7.8	10.0	6.7	3.3	5.6	5.6
characteristics										
irregular shape, %	82.2	84.4	91.1	90.0	90.0	85.6	93.3	91.1	87.8	87.8
open structure, %	88.9	91.1	94.4	90.0	90.0	92.2	93.3	93.3	96.7	97.8
week cohesion, %	96.7	96.7	94.4	97.8	96.7	97.8	95.6	98.9	96.7	98.9

The highest difference was visible for size and structure of the flocs. Even the structure was highly opened (more than 89% of the not treated activated sludge flocs had open structure) the elongation of the negative pressure exposure time while application of negative pressure of -500 or -800 hPa resulted in further loose of sludge compactness. The percentage of open structure flocs increased to 91-93% after exposition to negative pressure for 30 seconds. Elongation of negative pressure duration to 2 minutes resulted in further increase of share of large flocs (Figure 2). Surprisingly, under the influence of negative pressure there where more large agglomerates in the sludge. The share of flocs larger than -500 µm increased from 25 to 49% and despite the lack of statistically significant differences between control and the negative pressure treated samples the higher value of negative pressure the higher participation of large flocs in activated sludge. In the light of literature information [Maciejewski et al. 2003], as the data claim fragmentation of the flocs due to massive escape of gas bubbles from surrounding and interior of flocs, an increase of small flocs share was rather expected in the degasified sludge. Meanwhile, only looseness of the flocs was observable and share of small flocs was diminishing. However, the results not express quantity of flocs but only the percentage. Thus it is probable that the number of flocs per volume of sludge after negative pressure exposition is lower due to complete destruction of small flocs. To confirm the hypothesis more attention should be taken on sludge supernatant after degassification (for example turbidity) and more advanced methods of sludge flocs characterization should be used in the future research. Perhaps, further elongation of negative pressure duration let observe the further disintegration of flocs. It is worth to remind that the negative pressure value at wastewater treatment plants where the degassing system is installed is much higher than that used in this study and it is -950 hPa and more. However, application of more sophisticated methods based on advanced microscopic image analysis would be favorable in this case to provide statistically significant and more reliable results not affected by subjective decision of microscopic analysis performer.

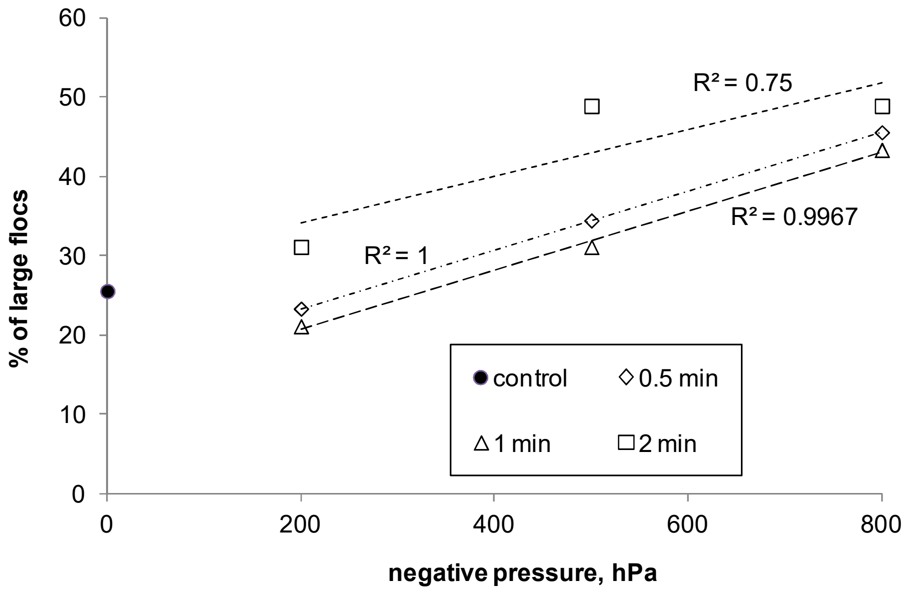

Fig. 2. Share of large flocs (>500 um) in activated sludge after treatment with vacuum
Rys. 2. Udział dużych kłaczków (>500 µm) w osadzie czynnym eksponowanym na podciśnienie

It is also worth to mention that the effect of negative pressure can be different if the negative pressure is applied for the first time to the particular sludge or constantly and periodically. The users of the degassing unit appreciate the system also due to smaller extend of problems with filamentous bacteria. The activated sludge constantly treated with negative pressure is believed to have less filamentous bacteria but no detailed research was performed. However, it is stated that flocs reach in floc-forming bacteria show less capacity for refloculation after break-up than the flocs with more filamentous organisms present in their structure [Govoreanu et al. 2003]. The microscopic analysis of flocs was performed directly after the negative pressure sludge treatment. It is not known how long the flocs needs to reflocculate and this aspect should also be taken under consideration.

CONCLUSIONS

Reduction of pressure under the atmospheric value results in sludge and wastewater degassing as the solubility of gases at lower pressure is lower. After activated sludge degasification the concentration of dissolved gases (preferably nitrogen) in wastewater is very low and activated sludge flocs are free of gas bubbles entrapped in their structure. However, during the lowering of pressure the floc features can be affected. The improvement of sludge settling after degasification was confirmend. Despite the fact that the used negative pressure values were much lower than that used at WWTP the observed improvement of sludge settling was app. 30% and was not related to negative pressure value and duration. The analysis of shear sensitivity needs further research to improve the repeatability and effect of shear power. Nonetheless, it was found that at higher negative pressure values and longer exposition times the flocs can be less strong and more susceptible for deflocculation and destruction. This observation was strengthened by the data form microscopic observations of activated sludge flocs. Exposition of activated sludge to negative pressure causes deterioration of all flocs by affecting floc structure. As the percentage of large flocs increases with negative pressure value and shear of small flocs diminishes it is supposed that the smaller flocs are totally destructed and the larger flocs stretched hence its size is higher and structure more opened. As the character of the study is preliminary designed to predict potential for future research that should be made with more sophisticated methods and more complex.

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BADANIA WSTĘPNE NAD WPŁYWEM PODCIŚNIENIA NA KŁACZKI OSADU CZYNNEGO

Streszczenie

Osad z biologicznego etapu oczyszczalni ścieków komunalnych wystawiony był na działanie trzech różnych podciśnień (-200, -500 i -800 hPa) i trzy różne różne czasy ekspozycji (30 sekund, 1 i 2 minuty). Przedmiotem badań był indeks objętościowy osadu, wrażliwość osadu na ścinanie oraz charakterystyka kłaczków osadu czynnego przed i po ekspozycji na podciśnienie. Stwierdzono, że po ekspozycji na podciśnienie osad lepiej sedymentował, niezależnie od wartości podciśnienia i czasu ekspozycji. Wrażliwość na ścinanie zmieniła się najbardziej, gdy ekspozycja na podciśnienie -800 hPa *wynosiła 1 minutę i dłużej. Struktura kłaczków była bardziej otwarta po podciśnieniu, a duże kłaczki stanowiły większą część osadu czynnego.*

Słowa kluczowe: podciśnienie, osad czynny, charakterystyka kłaczków