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INFLUENCE OF FLOC SIZE ON ACTIVATED SLUDGE VOLUME INDEX

Floc size (AFS) variations in relation to sludge volume index (SVI) were investigated at different intensities of bidirectional changes in organic loading of activated sludge. In the case of rapid increase and subsequent decrease of organic loading, SVI directly depended on AFS. Under the circumstances of relatively slow but long-lasting changes in organic loading, the correlation between AFS and SVI was less distinct. It has been concluded that floc size distribution is one of the most important factors influencing sludge volume index of non-filamentous activated sludge. Considerable, dynamic changes in floc size distribution can disturb the relationship between AFS and SVI.

1. INTRODUCTION

One of the most important factors influencing biological wastewater treatment is efficiency of separating an activated sludge biomass from the wastewater treated. In practice, the sludge volume index (SVI) is the main parameter characterizing settling properties of sludge and influencing significantly an appropriate control of activated sludge process. Although different definitions of settling index have nowadays been introduced (e.g. diluted sludge volume index, DSVI; stirred specific volume index, $SSVI_{3.5}$), SVI is still widely used as a control parameter in the wastewater treatment plants, because the SVI test can be easily carried out. In addition, most of the available literature data are generally related to SVI.

According to BISOGNI and LAWRENCE [5] the factors affecting settling characteristics of activated sludge can be divided into two categories. The first category is associated with the changes in physical or biochemical character of the bacterial or zoogleal population. The second category involves extreme population shifts from a normal bacterial or zoogleal type to a filamentous type.

Many studies have been carried out in order to explain the influence of filamentous microorganisms on sludge settling characteristics [12], [14–16], [20]. It has been found that the effect of filamentous organisms on floc structure is the following: fila-

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ments stretch out the flocs (diffused open structure) or form a bridging structure [13]. Thus, the filaments mechanically prevent flocs from a better compaction and can lead to filamentous bulking phenomenon.

However, studies concerning the relationships between sludge settleability and both biochemical and physical properties of flocs show that these problems are more complex [1], [6]–[8], [11], [19]. Sludge volume index is a function of various physical, chemical and complex biological factors of the processes occurring in aeration tank and clarifier. There is no perfect agreement on which features of flocs are essential in determination of settling properties of activated sludge. It is considered that the contents of extracellular polymers, which facilitate bioflocculation and keep flocs intact, can be such a factor. Simultaneously, floc properties are closely related to the operating parameters of aeration tanks. Some operating parameters, such as organic loading (or sludge age) and/or dissolved oxygen concentration in the aeration tank, influence the sludge settleability.

On the other hand, it is known that the size of flocs is very important parameter influencing mass transfer and biomass separation in the activated sludge process. LI and GANCZARCZYK [10] have found that the organic loading is the most significant factor affecting the size distribution of the activated sludge flocs. These conclusions have been confirmed by BARBUSIŃSKI and KOŚCIELNIAK [4]. Moreover, it has been found that the floc size distribution and average floc diameter are important parameters in assessing and controlling the activated sludge process.

These considerations suggest some possible interrelations between floc size and sludge volume index, which are connected with operating parameters of aeration tank. There are very few reports on that problem in literature. SADALGEKAR et al. [17] studied 30 sludge samples from full plants and laboratory-scale units. The analysis comprised detailed measurements of floc diameter, filament length, and filament number in relation to SVI. They suggested that the floc diameter could be used as an indicator for evaluating the performance of the process in place of SVI. ANDREADAKIS [1] examined floc properties in parallel bench-scale activated sludge units operated at different sludge ages. A correlation between SVI and mean floc size for non-filamentous sludges was obtained. Similar results have been reported by SEZGIN [18] and BARBER and VEENSTRA [3].

In the case of investigations mentioned above, the samples were taken from particular activated sludge systems operating under relatively constant conditions. The objective of this study, however, was to analyse floc size variations in relation to SVI, under dynamic conditions. The experiments were carried out at different intensities of bidirectional changes in organic loading, within the range of 0.2→1.0→0.2 kg COD/ kg MLSS/day.

2. MATERIALS AND METHODS

The experiments concerning bidirectional changes in sludge loading were carried out in four parallel bench-scale, completely mixed activated sludge units. Each of these units consisted of 6.5 dm^3 aeration basin connected with 3.5 dm^3 clarifier. Compressed air was introduced into aeration basins through porous stone diffusers. The air flow intensity was controlled by rotameters to ensure a constant level of mixing. Thus, the content of dissolved oxygen (DO) in each aeration basin was maintained at approximately 2 mg/dm^3. Activated sludge used in those experiments was taken from a municipal wastewater treatment plant. The microorganisms were adapted to synthetic wastewater consisting of peptone as the carbon source and mineral components at the organic loading value of 0.2 kg COD/kg MLSS/day. In this phase, the units were operated for a period three times as long as the sludge age to establish steady-state conditions. At the end of this phase, an additional test, comprising sludge volume index and floc size, was carried out for a few days to confirm real stabilization of these parameters.

After an adaptation period, four parallel series of proper investigations have been performed at different rates of bidirectional changes in organic loading of activated sludge, within the range of 0.2→1.0→0.2 kg COD/kg MLSS/day. Changes in loading were produced by altering the wastewater concentration (COD). In each experimental series, total period of loading changes comprised gradual increase of organic loading and following gradual decrease to the initial level. The effective time of the loading changes was, depending on the series, from 32 to 2 days (table 1). Acting in the manner of successive reducing the duration of total period of full loading changes, more and more rigorous conditions were being created. The operating parameters of the activated sludge process in particular series were shown in table 1. The MLSS concentration was maintained at approximate level of 2500 mg/dm^3 by removing the excess sludge from the reactors once or twice per day (depending on sludge growth rate). The pH within the reactors was in the range from 6.8 to 7.2.

Table 1

Operating conditions of the laboratory-scale activated sludge units

Series	Total duration of loading changes* [days]	Frequency of loading changes [hours]	HRT [hours]	Changes in organic loading [kg COD/kg/day]
I	32	24	6	0.20→1.05→0.20
II	16	24	6	0.20→1.00→0.21
III	4	12	6	0.20→0.96→0.20
IV	2	6	4	0.20→1.04→0.18

* – including gradual increase and then gradual decrease of loading.
HRT – hydraulic retention time.

The analytical procedures comprised measurements of chemical oxygen demand (COD), dissolved oxygen (DO), mixed liquor suspended solids (MLSS), sludge volume index (SVI) and pH according to Standard Methods [2]. SVI was determined by sludge settlement for 30 min in unstirred 1 dm^3 graduated cylinders. SVI measurements were performed in duplicate. The values reported are the average of the two samples.

In order to measure the size of flocs, they are examined under the microscope. BARBUSIŃSKI and KOŚCIELNIAK [4] have concluded that this method can practically be applied in controlling the activated sludge process. The activated sludge was sampled from laboratory units using wide-tip opening pipette in order to prevent the flocs from crumbling while their flow through it [4], [9]. In order to avoid flocculation of flocs, resulting in the formation of larger agglomerates, the activated sludge samples were diluted 10 times with tap water before examination. A single microscopic slide was then prepared from each sample, and the parameters of the flocs were measured. Sampling, dilution and slide preparation were repeated for an appropriate number of measurements. Each time 100 flocs were analyzed. The average diameter of individual floc was expressed as a half-sum of its longest and shortest dimension. After analyzing 100 flocs, the average floc size (AFS) was calculated as a mean value of their average diameters.

Among many important factors influencing SVI the quantitative relation between floc-forming and filamentous microorganisms is very essential. In this study, the SVI changes were not associated with an excessive growth of filamentous microorganisms, although at organic loading higher than 0.6 kg COD/kg MLSS/day a slight growth of filaments was observed. Nevertheless, at higher values of organic loading the activated sludge could be characterized as non-filamentous bulking.

3. RESULTS AND DISCUSSION

The size of activated sludge floc followed, with some delay, changes in organic loading. In all cases, the values of average floc size (AFS) did not coincide with the phases of increase and decrease in organic loading, but they formed a hysteresis curve. When the rate of loading changes in successive series increased, the AFS values corresponding with the phases of increase and decrease in loading approached each other. It was caused by a faster response in floc size changes to the substrate overloads introduced. Similar regularities were observed for sludge volume index (SVI). This means that both floc size and SVI changes are characterized by a certain inertia in relation to rapidity of organic loading changes. AFS and SVI quantities, corresponding with particular values of organic loading, are smaller during the phase of dynamic growth of loading than during the phase of its decrease.

As a rule, for the series characterized by smooth changes of loading, maximal values of AFS and SVI were higher than those for the series with sudden but transitory substrate overloads. Maximal values of AFS decreased from 212 μm in the Series I to 124 μm in the Series IV, and maximal values of SVI dropped respectively from 208 cm^3/g to 137 cm^3/g (table 2). Due to certain inertia of biochemical and physical processes in activated sludge biocenosis, AFS and SVI values corresponding with particular loading values under dynamic conditions did not reach the equilibrium value for the steady state. Simultaneously, under more severe conditions, a change in the overloads introduced was associated with rapid changes in AFS and SVI, which led to lower maximal values.

Table 2

Changes in average floc size (AFS) and sludge volume index (SVI) in successive series of investigations*

Parameter	Series			
	I	II	III	IV
AFS [μm]	98→212→118	102→172→112	94→136→100	96→124→98
SVI [$cm^3 \cdot g^{-1}$]	70→208→ 98	72→185→101	68→146→ 75	74→137→71

*The particular quantities corresponding with initial, maximal and final values, respectively.

The analysis of time characteristics has revealed that under conditions of relatively smooth substrate overloads (Series I and II), the AFS values showed closer association with organic loading changes than SVI values. This regularity was especially visible while comparing maximal values of these parameters (figure 1). The increase in the rate of loading changes is caused by shorter time intervals between the AFS and SVI values. As a result, under more severe conditions (Series III and IV) the changes in both increasing and decreasing values of these parameters occurred at the same time.

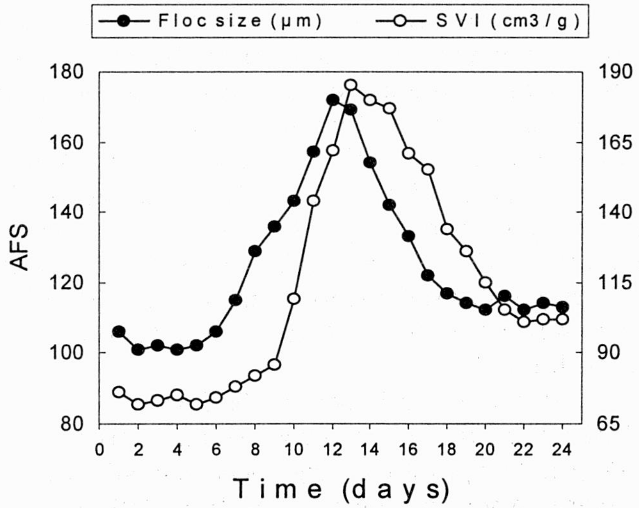

Fig. 1. Time delay of the sludge volume index (SVI) in relation to average floc size (AFS) for bidirectional changes in organic loading; Series II

Linear regression was applied and correlation coefficients were calculated to evaluate the relationship between AFS and SVI. The regression analyses proved that there existed clear linear correlation between the parameters investigated in the Series III and IV ($r = 0.95$ and 0.93, respectively). In the Series I and II, there was no statistically acceptable relationship between AFS and SVI. Much higher correlation between these parameters has been obtained after the time delay. This relation, however, was less exact than it was in the Series III and IV (table 3). Hence, it was ascertained that under conditions of rapid and continuous increase or decrease of organic loading, sludge volume index directly depended on a floc size. However, at smoother changes of loading, similar conclusion is controversial.

Table 3

Coefficients of linear correlation between average floc size (AFS) and sludge volume index (SVI)

Series			
I	II	III	IV
0.68 (0.84)*	0.72 (0.89)*	0.95	0.93

*The values obtained after the time delay between AFS and SVI was taken into consideration.

Influence of organic loading intensity on floc size in activated sludge process was studied by BARBUSIŃSKI and KOŚCIELNIAK [4]. They proved that long-term changes of activated sludge loading caused much stronger disturbances in floc size distribution (resulting even in a floc breakup) than violent but short-term changes. These observations have been confirmed by present investigations. Figure 2 shows two floc size distributions according to their frequency of occurrence in the Series I (one, observed at the beginning of the experiment, another for the maximal organic loading). With the increase in organic loading, the peak shift clearly tended towards larger sizes, while the value of peak frequency decreased. At the same time, the increase in the AFS values was also observed. Introducing a negative gradient of the activated sludge loading reversed the course of floc size distribution, but also after completing the changes of organic loading a final stabilization of the floc size distribution, similar to the initial distribution, was noted,. In the Series II, such tendencies in the floc size distributions were also observed.

On the contrary, the floc size distributions in the Series III and IV did not differ as much as in the Series I and II. The size range with the maximum frequency was the same, i.e. 75–100 μm throughout the experiment, and only occasionally shifted up to 100–125 μm range. Whole size range (from 10 to 350 μm) of the flocs analyzed did not change either. Floc size distribution typical of the Series IV was presented in figure 3.

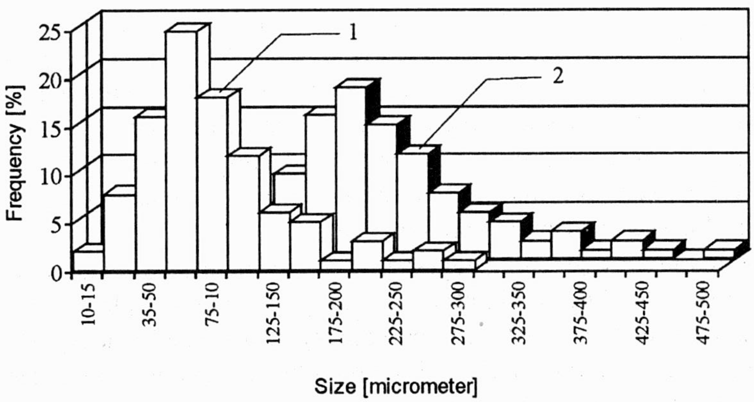

Fig. 2. Size distribution histograms for average diameters of activated sludge flocs in Series I; 1 – at the beginning of experiment, 2 – corresponding with maximum organic loading

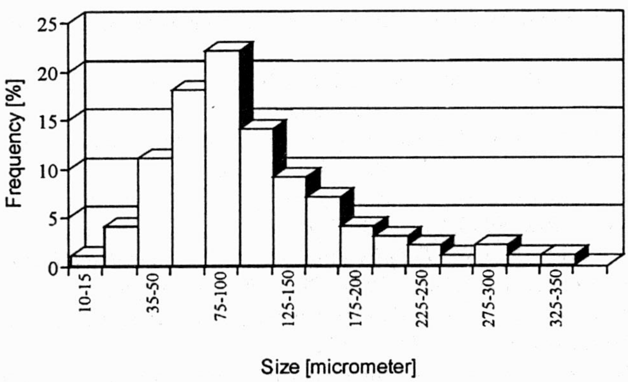

Fig. 3. Histogram of typical size distribution for average diameters of activated sludge flocs in Series III and IV

Analysis of floc size distributions in particular experiments confirms the assumption that wide-range dynamic changes in floc size distribution can disturb the interrelationship between AFS and SVI. Such conditions may appear, for example, during long-lasting substrate overloads. Short-term overloads, however, do not cause considerable changes in floc size distribution. As a result, SVI is primarily influenced by floc size.

4. CONCLUSIONS

On the basis of the study results the following conclusions can be drawn:

• Floc size distribution is one of the most important factors influencing volume index of non-filamentous activated sludge. Considerable, dynamic changes in floc size distribution can disturb the relationship between AFS and SVI.

• It has been found that for rapidly increasing and subsequently decreasing values of organic loading, SVI is directly connected with AFS. Under these circumstances, floc size distribution do not vary much and the changes of both AFS and SVI proceed simultaneously. SVI increases with increasing AFS and vice versa.

• Under conditions of relatively slow but long-lasting changes in organic loading, the correlation between AFS and SVI is less distinct. At the same time considerable fluctuations in floc size distribution are observed.

• Results of the experiments suggest that in practical situations, where high irregularity in organic loading and in other operating factors takes place, AFS cannot be an adequate parameter to estimate the settleability of activated sludge. AFS changes, however, can give general information about possible deterioration or improvement of settling characteristics of activated sludge.

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WPŁYW WIELKOŚCI KŁACZKÓW NA INDEKS OBJĘTOŚCIOWY OSADU CZYNNEGO

Badano zmiany wielkości kłaczków i ich wpływ na indeks objętościowy osadu (SVI) dla różnej intensywności dwukierunkowych zmian obciążenia substratowego osadu czynnego. Wykazano, że gdy szybko zwiększa się, a następnie zmniejsza obciążenie, wtedy zmiany SVI są bezpośrednio związane ze zmianami AFS. W warunkach stosunkowo wolnych, lecz długotrwałych zmian obciążenia korelacja między zmianami AFS i SVI była mniej wyraźna. Stwierdzono, że rozkład wielkości kłaczków jest jednym z najważniejszych czynników, które wpływają na indeks objętościowy osadu nie zawierającego nadmiernych ilości bakterii nitkowatych. Istotne zmiany rozkładu wielkości kłaczków mogą zakłócać zależność między AFS i SVI.

osad czynny
kłaczki