

EFFECT OF FLOC POROSITY ON BIOSLUDGE SETTLING PROPERTIES IN PULP AND PAPER INDUSTRY ACTIVATED SLUDGE PROCESS

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SUMMARY

Porosity of flocs in activated sludge process was evaluated from microscopic images using computer vision. Image analysis of biosludge from five pulp and paper mill wastewater treatment plants revealed a correlation between floc porosity and sludge settling properties. More porous flocs with a wider porosity distribution exhibited higher sludge volume index (SVI) values, indicating poorer settling. Results from different mills were similar and the correlation between all measured average floc porosities and SVI values was notable ($R^2 > 0.5$). By monitoring floc porosity changes on daily basis with computer vision, the deterioration of activated sludge process could be identified in very early stages, enabling more time to react to ensure efficient wastewater treatment.

Keywords: activated sludge, computer vision, floc porosity, microscopy, settling properties

INTRODUCTION

Biosludge settling properties play a crucial role in the operation of the activated sludge process, which is a widely adopted method for treating wastewater in the pulp and paper industry [1]. Generally, it can be stated that if the settleability of biosludge is deteriorated, final effluent quality is compromised due to expected increase of suspended solids overflow from secondary clarification. Several factors influence the settleability of biosludge, including abundance of filamentous bacteria, structure of flocs, gas formation, and various other parameters. Traditionally, the biosludge quality has been evaluated in mill laboratory by measuring sludge volume index (SVI) and visually examining biosludge under a microscope [2]. These methods provide valuable information, especially regarding the settling properties, the abundance of filamentous bacteria and the changes in protozoan population species. However, the traditional approach often faces challenges in detecting structural changes in flocs, such as alterations in floc porosity, floc size or floc brightness. Additionally, it is important to note that the data obtained from visual evaluations of biosludge characteristics using microscopy is often limited and subject to substantial influence from human factors and errors.

Biosludge in an activated sludge process is a complex mixture of microorganisms, organic matter, inorganic matter, and other suspended particles present in the wastewater. The floc porosity quantifies the void spaces or gaps within biosludge flocs. As a result, the level of floc porosity directly impacts the density of the flocs. Increased floc porosity leads to lower floc density and a decelerated settling velocity under gravity. In addition, the porous floc structure is likely to have influence on solid-gas interactions involving gases such as oxygen, carbon dioxide or nitrogen gas. Under certain conditions this may cause or intensify rising sludge phenomenon in secondary clarification.

There are several methodologies for quantifying porosity from suspended solid samples including gas sorption, liquid intrusion, light scattering, and microscopy [3]. Computer vision techniques have been employed to measure and evaluate the porosity of suspended solids in several contexts [4,5]. Computer vision has also been tested to assess the floc porosity of activated sludge from microscopic images [6,7]. The procedure involves capturing microscopic images of biosludge, preprocessing the images,

segmenting the floc structures from the background, and quantifying porosity by analyzing the ratio of void spaces to the total floc area, typically ranging from 0 to 1.

In this study, the floc porosity of biosludge was measured using computer vision technology. Microscopic images were collected from pulp and paper industry wastewater treatment plants. The average floc porosity and floc porosity distributions gained from computer vision analysis from microscopic images were compared to sludge settling properties data. This comparative analysis aimed to establish correlations and provide insights into the relationship between floc porosity and biosludge settling properties.

EXPERIMENTAL

Microscopic images and process data

Microscopic images were collected from five different pulp and paper industry wastewater treatment plant from a period of one year, as presented in Table 1. The sample set contained 4-10 microscopic images per sampling point. It should be noted that there were variations in the sampling procedures between different mills with respect to microscopic evaluation. Furthermore, it is important to mention that the technical specifications of the microscopes utilized in this study were not provided.

Table 1. Source of microscopic images and SVI data.

Mill	Production	Total amount of sampling points (=sample size)
Mill A	TMP	127
Mill B	TMP, PAPER	63
Mill C	PULP	86
Mill D	PULP, PAPER	52
Mill E	PULP, BOARD	74

SVI values were collected from mill process databases. SVI is a laboratory measurement used to estimate the settling characteristics of biosludge in the secondary clarification during activated sludge process. The parameter quantifies the volume occupied by a specific amount of biosludge (ml/g), after a half hour settling period. It is possible that there were minor variations in the measurement procedures of SVI between different mills. Process data was exclusively used when corresponding microscopic images were available from the same date. The number of SVI measurements varied between 52 and 127, depending on the laboratory routines frequency of the respective mills.

Image analysis and floc porosity calculation

Image analyses were performed as described in our earlier study [7] with computer vision. The porosity of flocs was calculated per unit area of the flocs, excluding filaments, protozoa, fibers, and fine particles. The porosity scale ranged from 0 to 1, where a higher value indicated a floc with a greater number of open pores. The results from the image analyses are presented as the average porosity obtained from all the images collected at each sample. To illustrate this, Figure 1 showcases different levels of floc porosity, derived from a collection of images obtained from a single floc. It is important to note that the porosity value attributed to one floc represents the average porosity of chosen floc. In this instance, flocs exhibiting the most uniform quality were selected as examples.

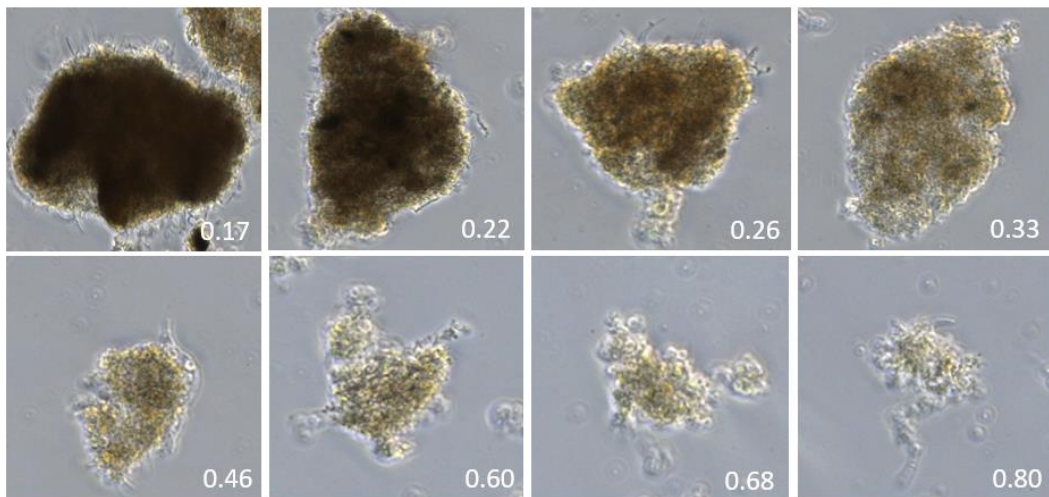


Figure 1: An example of floc porosity values with a single selected floc.

RESULTS AND DISCUSSION

In Figure 2, the area weighted average floc porosities are compared to the SVI values. The best fit between two parameters from whole data set were achieved with an exponential regression model ($R^2=0.57$). It is often considered within industry that the highest level for SVI to ensure stable activated sludge process is around 150 ml/g. With this definition, a good floc porosity level would be below 0.60. In contrast, when average floc porosity level surpassed 0.70, the occurrence of settling at a satisfactory level became very rare.

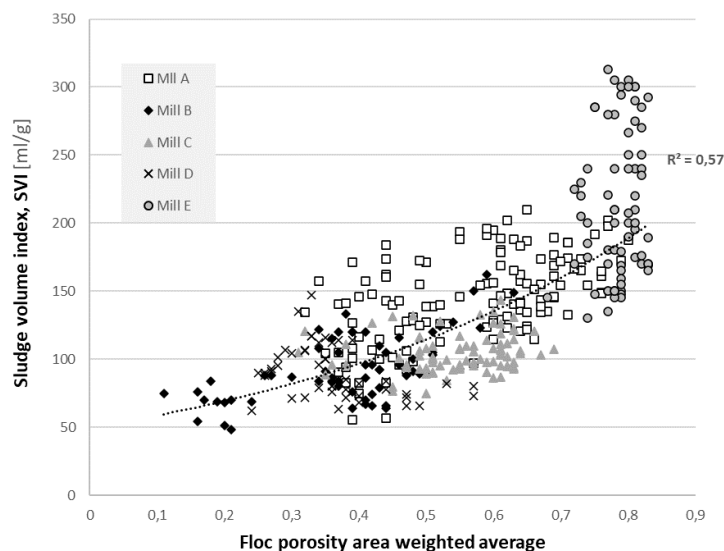


Figure 2: Correlation between floc porosity area weighted average and SVI.

Figure 3 illustrates the floc porosity distribution profiles for mills that encountered both favourable and unfavourable biosludge settling periods in the data set (Mill A and Mill B). Floc porosity is divided into

10 equal size categories from 0 to 1. As it can be seen, floc porosity profiles reveal noticeable variations between low and high SVI levels. At lower SVI levels, a substantial portion of the flocs exhibits low porosity. However, as the SVI increases, the distribution profile undergoes a significant reversal, leading to a pronounced shift where most of the flocs display higher porosity. Earlier studies [8] have also highlighted that the floc porosity distribution profile rather than the mean porosity value controls the advective flow.

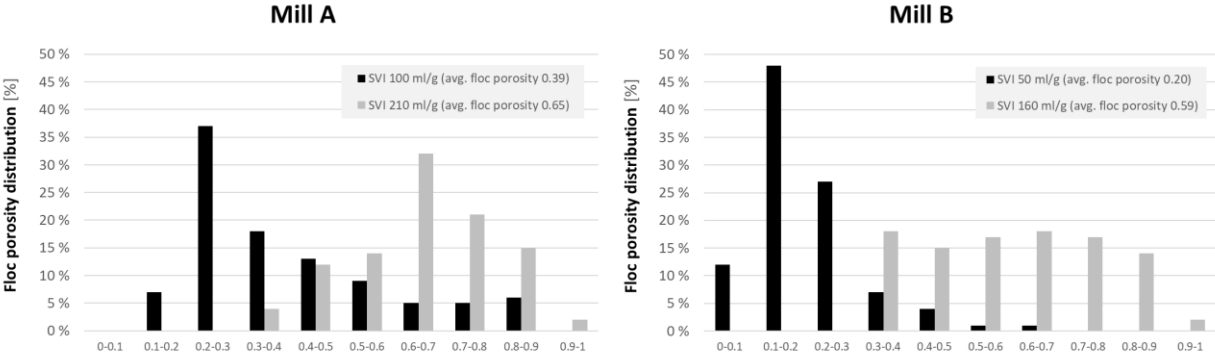


Figure 3: Floc porosity distribution in mills that included notably good (black) and poor (grey) settling time periods.

Figure 4 presents the average floc porosity distribution profiles at different SVI levels, calculated from the entire sorted dataset. Notably, the average porosity profiles demonstrate similarities to the comparison obtained from a single mill, as shown in Figure 3. The comparison made using the entire dataset also highlights the significance of high floc porosity in relation to elevated SVI levels (>150 ml/g).

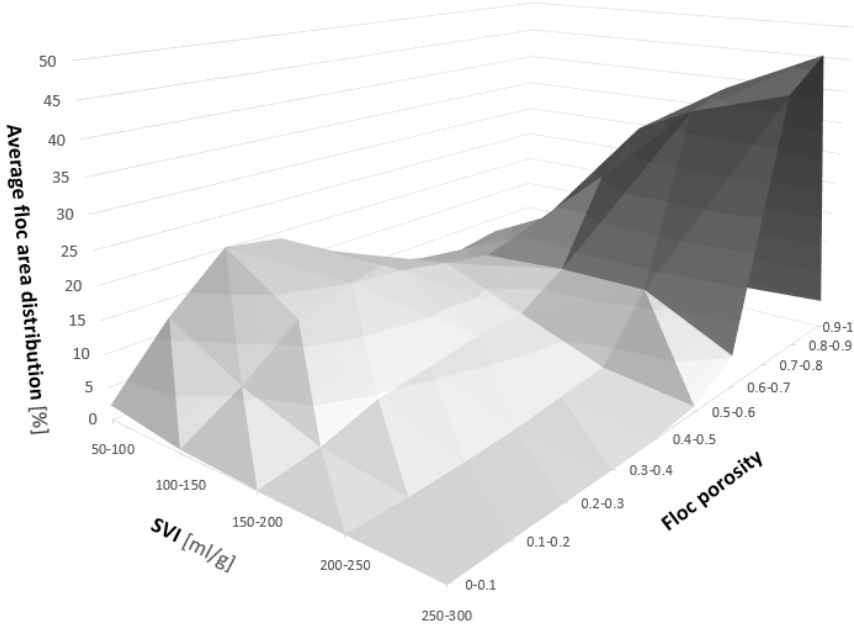


Figure 4: Average SVI levels compared to floc porosity distribution profiles.

Table 2 presents the correlation between SVI and specific floc porosity levels. It was seen that lower porosity levels exhibit a negative correlation coefficient, while levels exceeding 0.6 showed a positive correlation coefficient. Intermediate porosity levels between 0.5 and 0.7 displayed minimal correlation with SVI. The strongest correlation with SVI was observed within the porosity range of 0.7-0.8, whereas the highest negative correlation was found within the porosity range of 0.3-0.4.

Table 2. Correlation between SVI and different floc porosity levels.

Floc porosity level	Correlation coefficient	R ²	Average floc area [%]
0 – 0.1	-0.23	0.06	0.9 %
0.1 – 0.2	-0.39	0.15	6.3 %
0.2 – 0.3	-0.56	0.31	11.9 %
0.3 – 0.4	-0.60	0.36	12.7 %
0.4 – 0.5	-0.51	0.26	11.3 %
0.5 – 0.6	-0.34	0.11	9.5 %
0.6 – 0.7	0.11	0.01	10.0 %
0.7 – 0.8	0.72	0.52	16.1 %
0.8 – 0.9	0.66	0.44	18.8 %
0.9 – 1.0	0.43	0.18	2.1 %

If the floc porosity is to be considered as a novel parameter for monitoring the activated sludge process performance, it is important to ensure that sample preparation and microscopic examination routines are consistent. It is also important to note that the floc porosity profiles alone do not determine the settling properties of biosludge. For example, it is generally known that the abundance of filamentous bacteria decreases biosludge settling properties significantly. Since the quantification of filamentous bacteria can be determined using computer vision technology [7], it is strongly recommended to address these parameters in conjunction. By integrating the assessment of both floc porosity and filamentous bacteria, a more comprehensive understanding of the factors affecting biosludge settling properties could be obtained.

CONCLUSIONS

The results of this study highlight the influence of floc porosity as a contributor on the settling properties of biosludge in the activated sludge process. With computer vision technology, the specific floc porosity distribution profiles were successfully identified, providing more comprehensive data into settling properties compared to average floc porosity measurements alone. By implementing daily monitoring of floc porosity profiles with computer vision technology in mill laboratory, it could be possible to detect the early formation of undesirable solids, enabling a proactive response and ensuring efficient wastewater treatment. However, it would also be beneficial to combine floc porosity data with other parameters obtained from computer vision analysis, such as floc size and number of filamentous bacteria, to form an even more accurate prediction of biosludge settling properties.

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