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Predicting Densification Index (DI), SVI and Clarifier Performances In Continuous Flow Bioreactors: Modeling Approach for Municipal WWTPs

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Granulation and densification of biomass using physical selectors has been demonstrated to be an economic and energy efficient way of achieving process intensification (Roche et al, 2021). For wider adoption of the granulation technologies by wastewater industry, it is very important to have a reliable model to quantify the degree of granulation and its impact on settleability. In this paper we describe a model that proposes a densification index (DI) to quantify granulation and densification of biomass in a biological treatment system and tie the DI to the settleability of the mixed liquor.

Effective separation of solids and liquid fractions is one of the key requirements for successful operation and performance of conventional activated sludge (CAS) systems. Poor settleability of the flocs leads to poor clarifier performance, lower treatment capacity and fragile effluent discharge compliance.

Densified biomass has been demonstrated to double and triple the surface overflow rate (SOR) and surface loading rate (SLR) limits of secondary clarifiers while reducing sludge blanket levels, increasing settled sludge concentration and lowering RAS rates (Roche et al, 2021). De-bottlenecking hydraulic limits and fragilities of secondary clarifiers by transitioning from CAS to densified biomass with external gravimetric selection is seen as the ideal way of process intensification for brownfield retrofit application. Densification can also increase the organic loading rate (OLR) limit of existing plants by means of higher MLSS handling capacities within the bioreactor. There is an urgent need for practitioners to better capture and predict SVI levels that can be achieved once densification reaches steady-state operation. This paper describes a model which considers the actual baseline operation performance, the current design configuration of the biological flowsheet and allows predicting the future SVI pattern and level made possible with densified biomass and external gravimetric selector. Software simulation models and other design tools need to be updated to account for the new hybrid consortium of granule-floc reality. This paper presents an approach based on the apparent Ks model (Baeten et al., 2018) for predicting SVI in continuous flow bioreactor when biomass is densified.

The settleability of flocs could be improved by selecting appropriate process parameters and configurations to encourage the formation of granular and denser biomass. Gravimetric selection technology that retains denser biomass while wasting out the lighter fraction of the biomass from the treatment system could also enhance granulation and densification of the mixed liquor suspended solids (MLSS). Gravimetric selection decouples the sludge retention time (SRT) of the granular and densified biological flocs from ordinary flocs. Increased density leads to improved settling characteristics, prevents the wash-out of total suspended solids (TSS) and subsequent noncompliance with phosphorus (P) and TSS effluent limit, especially during wet weather scenarios. Furthermore, by preferentially selecting the denser bacteria, organisms such as Phosphate Accumulating Organisms (PAOs) are naturally selected. Conventional mainstream Enhanced Biological Phosphorous Removal (EBPR) processes that consist of augmenting the fraction of PAOs by the presence of contact-anaerobic zones, have shown regular fragilities (peak daily, peak hourly) and seasonal volatile performances due to wash-out of PAOs, e.g., when flow suddenly increases and BOD concentration remains relatively low due to clear water infiltration or the effect from combined sewer network configurations. Densification provides the unique opportunity to achieve resilient Biological Nutrient Removal (BNR) and EBPR performances in the existing system while providing the ability to achieve chemical-free phosphorous removal.

The capacity of a given biomass to densify and achieve high densification performance is a function of multiple factors e.g., design characteristics, influent typology, operation baseline, ecosystem and external environmental conditions. To predict densification performance a densification model was created. The Densification model takes into account the feed water quality, process flow diagram and other variables that are specific to existing infrastructures and predict the degree of densification that could be achieved in any wastewater treatment plant. The degree of densification is indicated by an index that is referred to as "Densification Index" (DI) in our model. Higher degree of densification is indicated by higher DI. The model could accurately predict the impact of process configuration, e.g., hydraulic retention times and feed water quality, e.g., influent BOD/COD ratio on densification by gravimetric simulation.

DI of any plant could be directly calculated by conducting a sieve test. A simple and reliable protocol has been devised to measure the DI of existing bioreactors. DI is a measure of the granular and densified biomass retained on 200 µm sieve.

Our model provides a simple method of calculating and predicting DI on the basis of state variables from commercially available process simulators. In order to obtain DI, our model introduced separate growth kinetics for granular nitrifiers and PAOs that contribute significantly to the formation of denser and granular biomass (retained on 200 µm sieve). The PAO, AOB and NOB contributions to the granules are predicted by the model using the apparent Ks framework described by Baeten et al (2018). The contribution of influent inorganic suspended solids (ISS, > 200 um) was also incorporated in the model.

Higher selection factor was then assigned for granular biomass to simulate the selection of densified biomass by external selector. The degree of improved DI that can be achieved by gravimetric selection could be predicted using our Densification Model in combination with other commercially available process simulators.

Densification is closely correlated with the Sludge Volume Index (SVI). Higher densification is associated with lower SVI. An example of improved clarifier capacity of an existing municipal WWTP (Plant C), as predicted by DI Model, is provided in Figure 2. A database of DI and SVI has been created by collecting data from a wide range of existing wastewater plants (Figure 3).

Once the baseline in terms of DI and SVI of a plant is known, our Densification Model can predict the improved densification that could be achieved using external selection. The new DI can then be used to predict the improved SVI of the plant. The improved SVI can be used to predict increased hydraulic loading capacity, Solids Loading Rate (SLR) and Surface Overflow Rate (SOR) for the clarifier.

The densification model has been calibrated using data from several full-scale wastewater treatment plants where external selector had been in operation for several years. The model was then used to predict the improved densification and consequent increased operating envelop of the clarifiers of several other plants (Table 1).

References: Baeten, J. E., van Loosdrecht, M. C., & Volcke, E. I. (2018). Modelling aerobic granular sludge reactors through apparent half-saturation coefficients. Water research, 146, 134-145.

Roche, C., Donnaz, S., Murthy, S., Wett, B. (2021) Biological Process Architecture in Continuous-Flow Activated Sludge by Gravimetry: Controlling densified biomass form and function in a Partial-Granulation Process at Dijon WWTP, France, Water Environment Research, https://doi.org/10.1002/wer.1664

Table 1: Comparison of clarifier capacity increase (SLR, SOR etc.) of two plants with different feedwater characteristics (BOD/COD ratios, flowrates etc.) before and after densification via gravity selection.

		Plant 1				Plant 2			
		Case A		Case B		Case C		Case D	
Flow, Q	m3/d	9464		15142		11100		15000	
Temperature	°C	12.6		12.6		17		17	
P removal%	%	90%		95%		99%		98%	
N removal%	%	70%		69%		91%		95%	
MLSS to clarifier	mg/L	3000		4065		4517		4870	
Total SRT/ Aerobic SRT	day	6.45/ 4.53		5.26/ 3.87		13.5/ 5.97		10.43/4.58	
BOD/COD	-	40%		40%		45%		45%	
Anaerobic Zone	%	8%		8%		16%		16%	
Clarifier - operation SLR	kg/m2/h	3.6		7.9		2.3		3.4	
Clarifier - operation SOR	m/h	0.6		1		0.3		0.4	
		Before	After	Before	After	Before	After	Before	After
Clarifier - SLR limit	kg/m2/h	9	11.3	9	11.3	7	9.7	7	9.7
Clarifier - SOR limit	m/h	2.1	2.3	1.2	1.7	0.9	1.3	0.8	1.2
Clarifier - sludge blanket	m	2	1.7	3.5	2.8	3.1	1.8	4	2.2
Clarifier - storm flow limit	m3/h	1027	1413	757	1041	1553	2369	1440	2197
DI (%)	%	0.2	0.3	0.2	0.3	0.07	0.26	0.07	0.26
SVI	mL/g	100	80	100	80	129	93	129	93

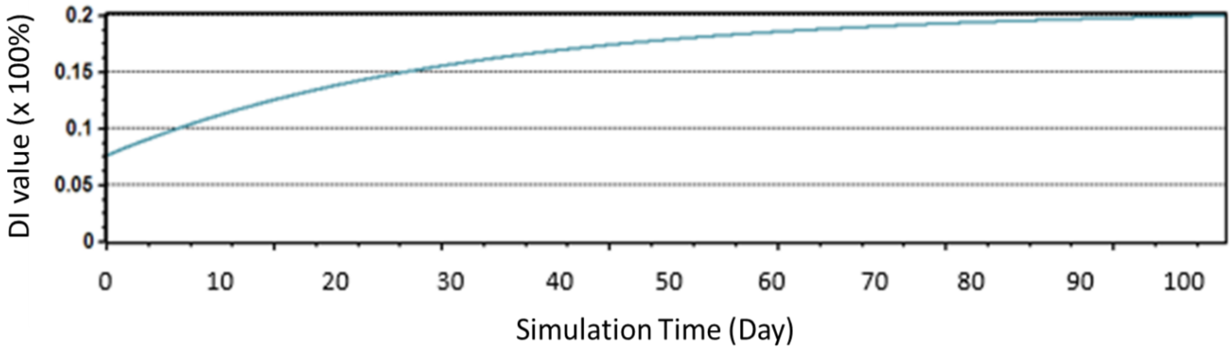

Figure 1: Trend of granular nitrifiers & PAOs % after 100-day simulation of densification process

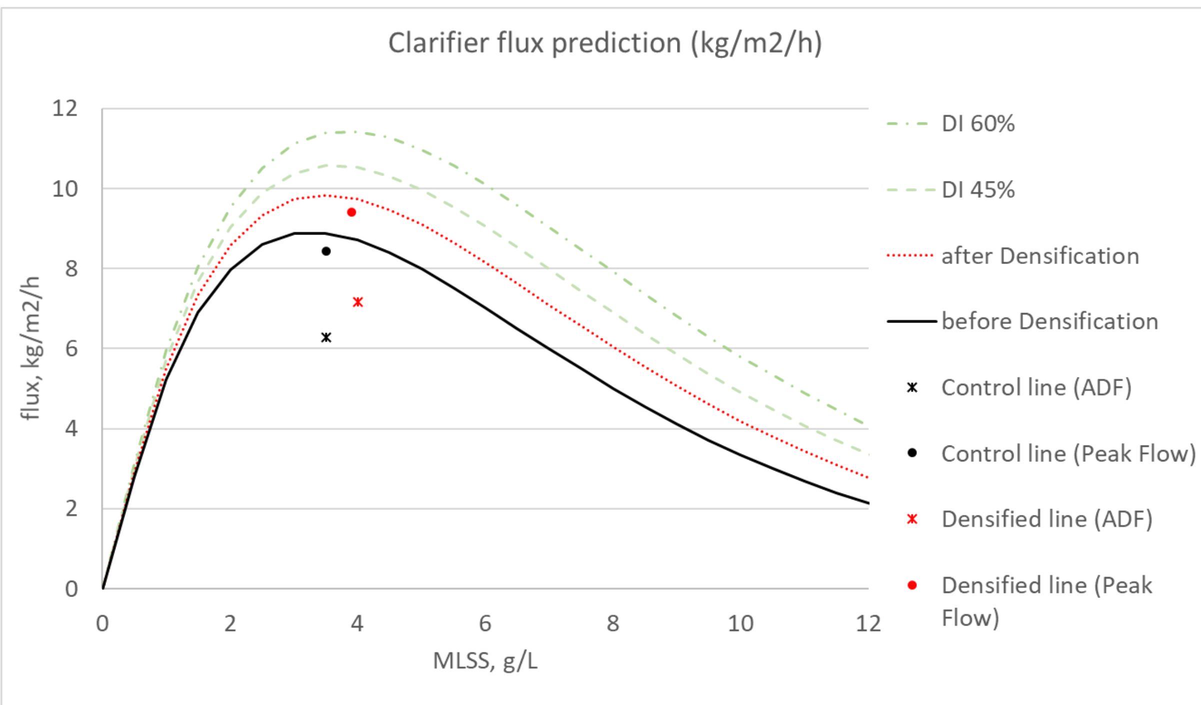

Figure 2: Improved clarifier performance (i.e. flux) as predicted by DI Model (Plant C). Solids limit rate (SLR) capacity increases due to densification which removes clarifier fragilities.

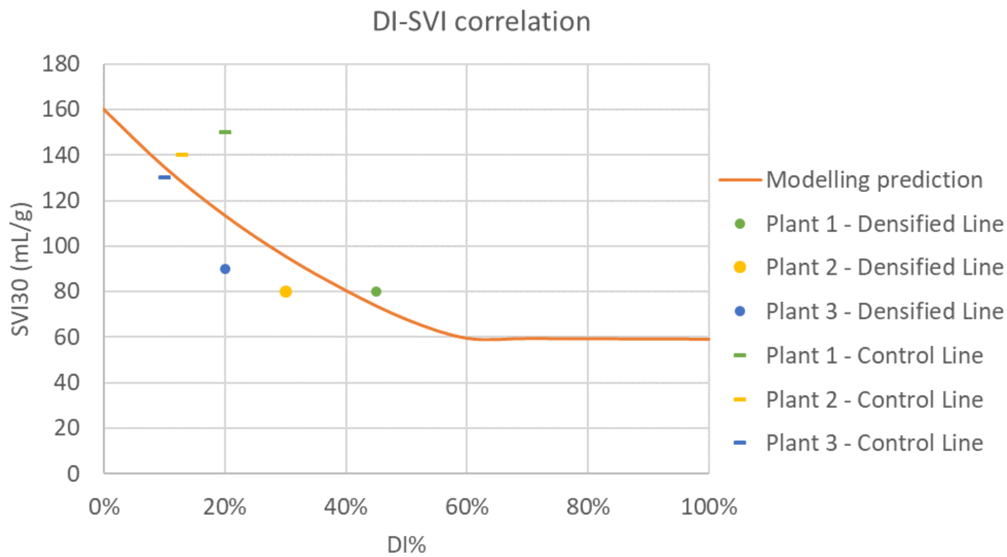

Figure 3: DI-SVI correlation: modelling prediction and full-scale plant data