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MONIKA ŻUBROWSKA-SUDOŁ*

MOVING BED TECHNOLOGY AS AN ALTERNATIVE SOLUTION FOR REDUCING BIOREACTOR VOLUME

Impact of the amount of moving bed in the continuous flow bioreactor on the required bioreactor volume has been investigated with respect to conventional activated sludge bioreactors preceded with primary sedimentation or chemical precipitation. The investigation has been carried out for a fictitious plant of the size of 1999 people equivalent (PE). It was found that for the systems designed for removal of organic matter: the volume of the integrated fixed film activated sludge (IFAS) reactor with the 15% filling ratio is similar to the volume of the activated sludge reactor (ASR) preceded with primary settlement tanks operating at 2.0 h hydraulic retention time (HRT). The volume of the IFAS reactor with the 30% filling ratio is comparable with the volume of the ASR reactor preceded with an upstream chemical precipitation stage assumed to achieve 60% removal of organics.

1. INTRODUCTION

During design of wastewater treatment plants it is often required to restrict the size and the footprint of a bioreactor to the minimum possible value. The main factors influencing the size of the bioreactor are influent organic load and minimum allowed effluent quality as required by current legislation.

In order to reduce the volume of a bioreactor, a part of the influent organic load is removed in a mechanical treatment stage through sedimentation or chemical precipitation [1]. In both instances, sludge is generated as a by-product and needs to undergo further treatment. An additional drawback of chemical precipitation, often ignored one, is that it leaves trace amounts of coagulants in the effluent which makes this process one of the sources of micro-pollutants in the treated wastewater. Another possible way to reduce the size of a bioreactor is to introduce such a treatment process which will allow one to increase the amount of biomass in the bioreactor whilst not

*Faculty of Environmental Engineering, Warsaw University of Technology, Nowowiejska 20, 00-653 Warsaw, Poland; e-mail: monika.sudol@is.pw.edu.pl

increasing the volume. One of the solutions offering such an opportunity are membrane bioreactors where mixed liquor suspended solids (MLSS) concentrations are kept at the levels of about 12–16 kg SS·m^{-3} [2, 3]. In those bioreactors, due to processes of ultrafiltration and microfiltration, significant amounts of bacteria, viruses and micro-pollutants are additionally removed from the treated wastewater which distinguishes this process from other wastewater treatment methods. The process however still suffers from such operational problems as membrane fouling [4, 5]. Another disadvantage is still very significant costs of membrane modules. Much cheaper solution would be adding to the bioreactor a number of moving plastic carriers with a high specific surface area which offer good ground for the growth of additional biomass in the form of a biofilm [6–8]. This type of process is also offering other technological advantages over conventional treatment methods apart from a smaller bioreactor volume [6, 9, 10–12], such as:

- Biofilm growing on plastic carriers is a good biotope for the growth of slow-growing bacteria such as nitrifiers.
- Opportunity for the coexistence of an outer aerobic layer and an inner anoxic layer in the biofilm which allows simultaneous occurrence of nitrification and denitrification processes in one place.
- The process is not susceptible to loss of treatment at high hydraulic loading periods due to retention of biomass immobilised on the plastic carriers.

The purpose of the paper was to analyse the influence of the amount of moving bed in a continuous flow bioreactor on its total volume and to compare the IFAS process (hybrid moving bed biofilm reactor – MBBR) with a conventional activated sludge bioreactor preceded with primary sedimentation or chemical precipitation.

2. METHODS

Assumed size of the treatment plant. Calculations of the bioreactor volume were conducted under assumption that wastewater treatment plant receives an organic load corresponding to 1999 people equivalent (PE). This assumption results from the current Polish legislation (Regulation of the Ministry of the Environment from 28.01.2009 on the quality of WWTP effluents discharged to receiving bodies, Dz.U. Nr 27, pos. 169).

Chosen process configurations. Block diagrams of the analysed process configurations are shown in Fig. 1. In the process option A, influent wastewater is screened and degritted and then sent directly to the biological treatment stage which can either be a conventional activated sludge reactor (ASR) or an integrated fixed film activated sludge system with moving bed (IFAS). In both cases, MLSS concentration of 3 kg·m^{-3} has been assumed. Required volume calculations for IFAS reactors were carried out for different moving bed filling ratios ($V_{\%}$), 5, 10, 15, 20, 25 and 30% (IFAS-5%, IFAS-10%, etc.), respectively. It was assumed that specific the surface area of the applied moving bed is equal to 800 $m^2 \cdot m^{-3}$ which is equal to an active area of the EvU-Perl biofilm carriers [13].

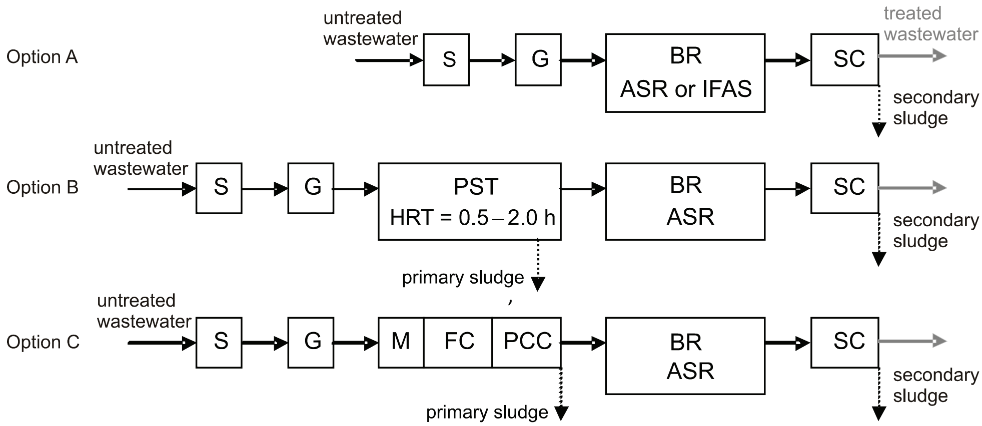

Fig. 1. Block diagrams of technological processes used to calculate the volumes of bioreactors: S – screen, G – grit chamber, BR – biological reactor, ASR – activated sludge reactor, IFAS – integrated fixed film activated sludge system with moving bed, PST – primary settlement tank, SC – secondary clarifier, M – mixing chamber, FC – flocculation chamber, PCC – post-coagulation clarifier

Table 1

Options of calculation depending on the effluent quality requirements set by the Regulation of the Polish Ministry of the Environment from 28.01.2009 (Dz.U. Nr 27, poz.169)

Treatment option	Effluent quality requirements	Process option
I	Removal of suspended solids and organic carbon. Effluent quality parameters[a]: $BOD_5 \leq 40$ mg·dm^{-3}, COD ≤ 150 mg·dm^{-3}, TSS ≤ 50 mg·dm^{-3}	A, B, C
II	Removal of suspended solids, organic carbon, nitrogen and phosphorus. Effluent quality parameters[b]: $BOD_5 \leq 40$ mg·dm^{-3}, COD ≤ 150 mg·dm^{-3}, TSS ≤ 50 mg·dm^{-3}, Total N ≤ 30 mg·dm^{-3}, Total P ≤ 5 mg·dm^{-3}	A
III	Removal of suspended solids, organic carbon, nitrogen and phosphorus with simultaneous sludge stabilisation. Effluent quality parameters[b] as for the treatment option II	A

[a]Effluent quality requirements for wastewater treatment plants of the size below 2000 PE discharging effluents to fluvial waters.

[b]Effluent quality requirements for wastewater treatment plants of the size below 2000 PE discharging effluents to lakes, their inlets or directly to artificial water reservoirs placed on fluvial waters.

In two other process configurations, the ASR reactor with the MLSS concentration of 3 kg·m^{-3} is preceded with a mechanical treatment process: sedimentation (option B) or chemical precipitation (option C) in order to reduce the amount of organic load entering into the ASR. In the process configuration B, the activated sludge reactor was preceded with primary settlement tanks (PST) operating under various hydraulic retention times (HRT), HRT = 0.5, 1.0, 1.5 and 2.0 h (process options B-0.5, B-1.0, B-1.5 and B-2.0). In the process configuration C, a chemical precipitation unit was placed upstream of the ASR. It was assumed that the chemical precipitation would enable 60% reduction in organic load entering the biological stage of the WWTP.

Purpose of treatment. For all process configurations under consideration it was assumed that treatment would lead to the elimination of suspended solids and organic carbon (Option I, Table 1). Calculations carried out for this process option allowed one to compare the possibility of reducing the bioreactor volume through introducing plastic biofilm carriers and constructing primary settlement tanks or chemical precipitation units.

Additionally, for the process configuration A two other treatment variants were considered. The former treatment option assumed removal of nitrogen and phosphorus in addition to organic carbon (Option II, Table 1). The latter option additionally considered simultaneous sludge stabilisation in the bioreactor (Option III, Table 1).

Method of calculations. Calculations of influent loads and required ASR reactor volumes have been carried out in accordance to the ATV Design Manual [14]. This method is widely used in the engineering community for designing activated sludge wastewater treatment plants. In order to calculate the required volumes of IFAS reactors, design guidelines prepared by EvU Ltd. [13] have been used. These guidelines were used to design 16 municipal moving bed wastewater treatment plants of the size between 160 and 11 300 PE and which are currently under operation in Poland. These WWTPs were being commissioned from 2001 onwards and the majority of them are able to achieve the design effluent quality, provided that they are operated accordingly to specification. A detailed analysis of the operation of one of such treatment plants is described in [15] where the benefits of the application of moving bed technology have been explained.

3. RESULTS AND DISCUSSION

Figure 2 shows the required volumes of conventional ASRs as calculated for all treatment process configurations for removal of suspended solids and organic matter. The results show that construction of a primary settlement tank with HRT in the range of 0.5–2.0 h upstream of the ASR allows one to reduce the bioreactor volume 1.41–1.91-fold from 244 m^3 (option A) to 173 m^3 (option B-0.5) and 128 m^3 (option B-2.0), respectively. If primary chemical precipitation is used upstream of the biological process (option C), reduction of the bioreactor volume as high as 3.55-fold is possible. Data presented in Fig. 3 illustrate how much the bioreactor volume can be reduced if moving bed medium of the specific surface area of 800 $m^2 \cdot m^{-3}$ is introduced instead of using primary treatment. As little as 10% filling ratio allows one to obtain the IFAS bioreactor volume (V_{IFAS} =148 m^3) similar to the total volume of an ASR preceded with primary settlement tanks operating at 1.0 h HRT (V_{ASR} = 150 m^3).

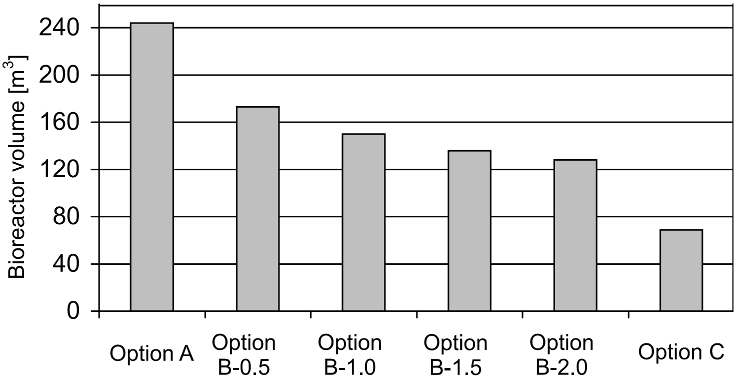

Fig. 2. Activated sludge reactor's (ASR) volume for various process options

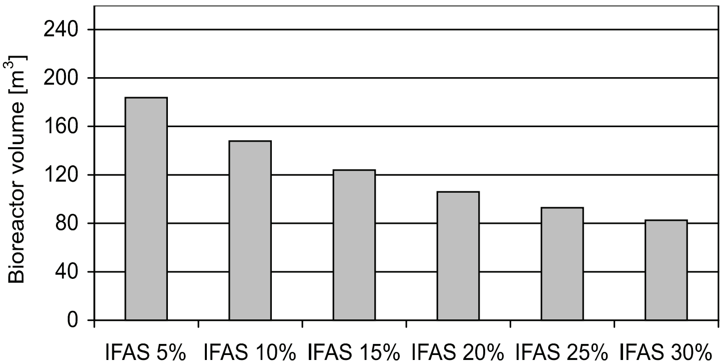

Fig. 3. Moving bed reactor's (IFAS) volume depending on moving bed filling ratio for treatment process A

An increase in the filling ratio ($V_{\%}$) from 10% to 15% requires a two-fold increase of the HRT in the primary tank to 2.0 h if the same levels of treatment are to be achieved in the conventional ASR + PST system. 30% filling ratio reduced the required volume of the IFAS bioreactor to 82.7 m^3. This volume is only 13.9 m^3 larger than the volume of the ASR reactor obtained for the process option C (activated sludge reactor preceded with a chemical precipitation stage). Process configuration A with the IFAS-30% bioreactor is however simpler and more compact.

Data presented in Figure 3 also show that for higher filling volumes reductions in the bioreactor size due to addition of more carriers become smaller. Calculated volume of the IFAS bioreactor at 10% $V_{\%}$ is 1.24-fold smaller than the volume of the IFAS-5% bioreactor. The ratio between volumes of the IFAS-25% and IFAS-30% is only 1.12.

Table 2

Calculated bioreactor volume depending on moving bed filling ratio and the type of treatment (for process configuration A)

Reactor type	MLSS concentration [kg m^{-3}]	Moving bed filling ratio [%]	Bioreactor volume [m^3]		
			Option I C removal	Option II C, N and P removal	Option III C, N and P removal with simultaneous sludge stabilisation
ASR	3.0	–	244	444	990
IFAS	3.0	5	184	324	543
		10	148	255	374
		15	124	210	285
		20	106	179	230
		25	92.9	158	193
		30	82.7	138	166

Table 2 presents the results of calculations of the bioreactor volume for three different degrees of treatment. It can be deduced that upgrading the level of treatment from removal of organic carbon to removal of C, N and P leads to nearly two-fold increase in the volume of a conventional activated sludge reactor (comparison of treatment options I and II). In order to avoid the construction of an additional bioreactor volume, the reactor can be filled with plastic carriers and converted into IFAS process. This conversion increases the amount of biomass in the bioreactor thus reducing the food to microorganisms (F:M) ratio which then allows nitrification and subsequent denitrification to take place in the reactor. In this case study, the ASR reactor of the volume of 244 m^3 designed for carbon removal would have to be filled with $V_{\%}$ = 15% of the carrier medium (Table 2). It is worth noting that by increasing the filling ratio $V_{\%}$ from 15% to 20% it is possible to carry out simultaneous sludge stabilisation in the same bioreactor volume. This solution greatly simplifies sludge management at the WWTP level.

If we compare the bioreactor volumes calculated for treatment options II and III (Table 2), we can see that in case of a conventional activated sludge system, simultaneous sludge stabilisation requires a two-fold increase in volume. An alternative solution would be to employ the moving bed technology. Only 10% moving bed filling ratio in the bioreactor would allow simultaneous sludge stabilisation without any expansion of the bioreactor volume. It is also interesting to point out that the MBBR reactor's volume with filling ratio of 30% calculated for the treatment option with removal of C, N and P and simultaneous sludge stabilisation is significantly smaller than the volume of a conventional activated sludge bioreactor for removal of only the organic compounds.

Moreover, data presented in Table 2 indicate that larger differences in bioreactors' volumes working at $V_{\%}$ of 0% (ASR) to 30% (IFAS) have been attained for the treatment option III. The ASR bioreactor volume was in that case almost 6 times larger than the IFAS's volume with a 30% filling ratio. These differences for treatment options II and I are respectively 3.2 and 2.95 fold. We can therefore say that the more advanced treatment is carried out in the bioreactor, the larger reduction in the bioreactor volume is possible by addition of plastic biofilm carriers.

It is worth to point out that such calculations which allow to compare the required bioreactor volume as a function of process configuration and the type of the bioreactor are very useful in practice. Even at the initial stages of feasibility studies, conceptual designs, or specifications of wastewater treatment plant retrofits and new-builds, these calculations allow the investors and future operators to assess the following: 1) the possibility of using the existing reactor volumes 2) required additional footprint for a construction or modernization of existing assets, 3) the compactness and flexibility of the new treatment plant.

Further analysis of possible benefits of adding moving bed carriers to the bioreactors for wastewater treatment in order to reduce their volume will include economical aspects such as investment and operational costs. Additionally new and feasible bioreactor designs with optimum treatment performance and economy will be sought for a variety of treatment plant sizes and treated effluent quality standards.

3. CONCLUSIONS

- MBBR technology is a simple process solution which allows reduction of the bioreactor volume in newly built as well as retrofitted WWTPs.
- Introduction of plastic carrier medium of the specific surface area of $800\ m^{-2}\cdot m^{-3}$ up to 15% of the reactor's volume allows one to obtain the same treatment efficiency as in the conventional activated sludge bioreactor of the same volume but additionally preceded with a primary sedimentation tank of 2 h HRT. Therefore, conversion of the conventional process to IFAS allows one to remove primary settlement tanks from the process whilst maintaining the same bioreactor volume.
- Volume of the IFAS reactor with 30% filling ratio is comparable with the volume of a conventional activated sludge reactor preceded with upstream chemical precipitation stage achieving 60% removal of organic substances for the C removal treatment option.

• Reduction of the bioreactor's volume through introduction of plastic carriers depends on the percent moving bed filling ratio ($V_{\%}$) and the required level of treatment.

• Together with increasing filling ratios, differences in the bioreactor volume become less noticeable.

• Highest reduction in the bioreactor size caused by addition of carriers occurred for treatment option with removal of C, N and P and simultaneous sludge stabilisation. The smallest differences were observed for organic carbon removal systems.

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REFERENCES

[1] TCHOBANOGLOUS G., BURTON F.L., STENSEL H.D., *Wastewater Engineering*, 4th Ed., Metcalf & Eddy Inc., New York, 2003.
[2] STEPHENSON T., JUDD S., JEFFERSON B., BRINDLE K., *Membrane Bioreactors for Wastewater Treatment*, IWA Publishing, London, 2000.
[3] MELIN T., JEFFERSON B., BIXIO D., THOEYE C., DE WILDE W., DE KONING J., VAN DER GRAFF J., WINTGENS T., Desalination, 2006, 187, 271.
[4] LE-CLECH P., CHEN V., FANE T.A.G., J. Membrane Sci., 2006, 284, 17.
[5] DREWS A., LEE C.H., KRAUME M., Desalination, 2006, 200, 186.
[6] ØDEGAARD H., RUSTEN B., SILJUDALEN J.G., European Water Manage., 1999, 2 (3), 36.
[7] PEUKERT V., Abwasser, 2001, 48 (12), 1751.
[8] FALLETTI L., CONTE L., MILAN M., Proc. 2nd IWA Specialized Conference *Nutrient management in wastewater treatment processes*, Cracow, 2009, 803.
[9] SILYN-ROBERTS G., LEWIS G., Water Res., 2001, 35 (11), 2731.
[10] CHRISTENSSON M., WELANDER T., Water Sci. Technol., 2004, 49 (11–12), 207.
[11] WANG X.J., XIA S.Q., CHEN L., ZHAO J.F., RENAULT N.J., CHOVELON J.M., Proc. Biochem., 2006, 41, 824.
[12] ØDEGAARD H., Proc. 2nd IWA Specialized Conference *Nutrient Management in Wastewater Treatment Processes*, Cracow, 2009, 749.
[13] *Design Guidelines for dimensioning Moving Bed Bioreactors*, Materials provided by EvU Poland Ltd.
[14] KAYSER R., Commentary to ATV-DVWK Design Manuals A131P and A210P; Dimensioning of single stage activated sludge plants and sequencing batch reactors, Seidel–Przywecki, Warsaw, 2002.
[15] ŻUBROWSKA-SUDOŁ M., KUJAWA P., KOZŁOWSKI P., Gaz, Woda i Technika Sanitarna, 2006, 7–8, 29.