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Role of primary settling tanks on SBR plants for secondary treatment

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Preliminary report

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Role of primary settling tanks on SBR plants for secondary treatment

The SBR technology is a modification of the conventional active sludge procedure based on the batch bio-reactor filling principle. The total required volume of the SBR reactor with the second level of treatment can be reduced using a primary settling tank in front of the SBR plant as the first level of treatment, which is especially pronounced for higher-capacity treatment plants preceded by a separate (sanitary) sewerage system. Construction of primary settling tanks before the SBR tanks results in a lower consumption of oxygen compared to SBR plants not equipped with primary settling tanks.

Key words:
wastewater, wastewater treatment plant, SBR, primary settling tank

Prethodno priopćenje

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Važnost prethodnih taložnica na SBR uređajima s drugim stupnjem pročišćavanja

SBR tehnologija predstavlja modifikaciju konvencionalnog postupka s aktivnim muljem na principu šaržnog punjenja bioreaktora. Smanjenje ukupnog potrebnog volumena SBR reaktora s drugim stupnjem pročišćavanja može se ostvariti uz prethodnu taložnicu kao prvi stupanj pročišćavanja ispred SBR reaktora, što je osobito izraženo kod uređaja za pročišćavanje većeg kapaciteta kojima prethodi razdjelni sustav odvodnje. Uz izgradnju prethodnih taložnica ispred SBR reaktora, smanjuje se potrošnja kisika u odnosu na SBR uređaje bez prethodnih taložnica.

Ključne riječi:
otpadne vode, uređaj za pročišćavanje, SBR, prethodna taložnica

Vorherige Mitteilung

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Bedeutung vorklärender Absetzbecken bei SBR Anlagen mit zweiter Reinigungsstufe

Die SBR Technologie stellt eine Modifikation des konventionellen Vorgangs mit aktivem Schlamm basierend auf dem Prinzip der Chargenfüllung des Bioreaktors da. Ein Abmindern des gesamten notwendigen Volumens des SBR Reaktors mit zweiter Reinigungsstufe kann durch vorklärende Absetzbecken vor dem SBR Reaktor in der ersten Reinigungsstufe erzielt werden. Dies ist besonders wichtig bei Kläranlagen größerer Kapazitäten, denen ein Trennsystem zur Entwässerung voransteht. Durch den Bau vorklärender Absetzbecken vor dem SBR Reaktor vermindert sich der Sauerstoffverbrauch im Vergleich zu SBR Anlagen ohne vorklärende Absetzbecken.

Schlüsselwörter:
Abwasser, Kläranlage, SBR, vorklärende Absetzbecken

1. Introduction

To ensure the high quality, efficient and long-term operation of wastewater treatment plants (WWTP), it is extremely important to select an optimum treatment technology (conventional activated sludge treatment, simultaneous stabilization, MBBR, biofiltration, MBR, SBR, etc.). Even if an optimum treatment technology is selected, it is highly important to choose appropriate technical and technological solutions for the complete water and sludge line. It is therefore necessary to define the function, number, layout, and size of individual facilities.

WWTPs using the activated sludge technology are usually designed with the continuous flow and have become widely accepted as an economical and efficient way of biological wastewater treatment. The SBR (Sequencing Batch Reactor) technology is a modification of the conventional activated sludge technology. It is based on the principle of batch (interval) work mode of bioreactor, which is an acceptable technological solution in Croatia. The SBR technology can successfully be applied for the second and third stages of treatment. This technology is also characterized by high efficiency of wastewater treatment (Table 1). Besides the treatment efficiency, the SBR technology also meets all other essential requirements regarding functionality, operation and maintenance, operating costs, etc.

Table 1. Treatment efficiency of SBR plants [1-7]

Parameter	Effluent concentrations (secondary treatment)	Effluent concentrations (tertiary treatment)
Suspended solids	< 10 mg/l	< 5 mg/l
COD	< 75 mg/l	< 70 mg/l
BOD5	< 20 mg/l	< 15 mg/l
Total phosphorus	< 10 mg/l	< 1 mg/l
TNK	< 40 mg/l	< 10 mg/l
Ammonia	< 5 mg/l	< 5 mg/l

The basic goals behind the SBR technology development have been to reduce total wastewater treatment costs and achieve higher operating flexibility. One of significant items in this context is the reduction of the total volume of wastewater treatment facilities, which primarily concerns secondary settling tanks as they are made unnecessary when the SBR technology is applied. Also, the primary treatment processes are an optional item on the SBR plants, which is the result of the configuration selected based on detailed calculations. Primary settling tanks (PT) are most often used as the first stage of treatment.

This paper analyzes the cost-effectiveness limits of PT application within SBR plants using secondary treatment depending on the size of the plant (number of population equivalents - PE) and the type of the sewerage system (separate or combined). This is taken into account in the context of the required volume of specific facilities within the water line. In addition, the operating costs of the WWTP are considered, primarily through oxygen demand (for SBR aeration).

2. SBR plant

2.1. Configuration of SBR plant

The first phase of wastewater treatment in SBR plants is the mechanical pre-treatment, which is usually identical to that of a conventional process based on the activated sludge technology. Depending on the technical and technological solution selected, the mechanical pre-treatment may include screens (coarse and fine) and aerated grit and grease chambers. It is also possible to apply different mechanical pre-treatment solutions, which are integrated together within the primary treatment (e.g. micro-screens etc.).

Primary treatment within SBR plants is optional, i.e. it is not necessary to ensure the first stage of treatment at the water line. In other words, the SBR plants may or may not have the primary treatment [8]. Primary treatment ensures elimination of total suspended solids (TSS) by at least 50 % and the removal of organic matter (BOD_5) by at least 20 % and, additionally, the total nitrogen and phosphorus content is reduced, although to a lesser extent (by about 10 %). The primary treatment ensures reduction of load sent to SBR tank. PT is the most commonly used form of primary treatment. An additional advantage of the PT application is the reduction of hydraulic load at SBR tanks, in case the PT is formed and dimensioned as an equalization tank. With PT, it is also possible to apply different primary treatment solutions – lamella clarifier, modified lamella clarifier (such as Aciflow-Veolia), micro-screens (e.g. Salsnes filter or similar), etc. The advantages of these alternative primary treatment solutions are particularly highlighted in case there is a lack of free space available for the construction of the entire WWTP. Regardless of the above mentioned, only the application of traditional PTs as primary treatment on SBR plants will be considered in this paper. The secondary and tertiary treatments are provided at SBR plants within SBR tanks where biological and chemical processes for the removal of organic matter (secondary treatment), and additional removal of nutrients like nitrogen and phosphorus (tertiary treatment), are carried out. The settling process (separation of activated sludge from effluent) takes place in the same reactors, and there is no need for additional secondary settling tanks. Reactors are equipped with aeration (providing aerobic conditions for degradation of organic matter, nitrification, etc.) and mixing equipment.

The operation of SBR tanks (dynamics of filling, reaction, settling, discharge/decanting, mixing, aeration etc.) is checked using sophisticated control mechanisms [8]. In other words, SBR plants require a high level of control and maintenance but offer higher flexibility in operation compared to simpler wastewater treatment processes (conventional process, extended aeration, etc.) [9]. Only SBR plants with secondary treatment will be considered in relation to the topic of this paper.

The effluent is discharged from SBR tanks by decantation, while sludge settles at the tanks and is transported for further treatment (thickening, stabilization-optional, dewatering).

2.2. Operating principle of SBR used for secondary treatment

The operation of the SBR tanks takes place in batches, i.e. in cycles. The cycle is the time interval required for filling the SBR tank with wastewater, reaction (biological and chemical processes), settling (separating activated sludge from effluent), and discharging the effluent and transporting the sludge for further treatment [10, 11]. Each cycle is divided into a series of processes or phases.

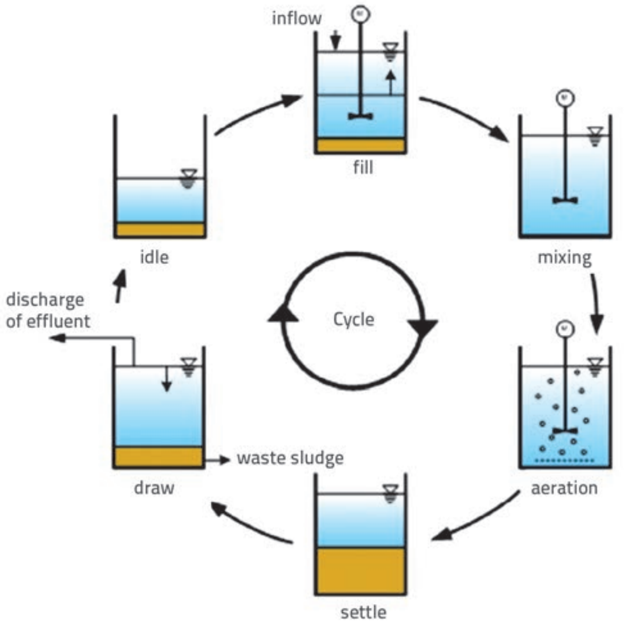

Figure 1. Phases of SBR cycle

The first phase involves filling the SBR tank with wastewater from the mechanical pre-treatment or from the primary treatment. The second phase is the mixing phase in which the entire content of the SBR tank is mixed, ensuring better contact between the activated sludge and organic load (food). The mixing phase may be completely or partially simultaneous with the filling phase. The third phase is the aeration phase within which oxygen is blown in, which is necessary to maintain aerobic conditions suitable for degradation of organic substances and, possibly, to achieve complete nitrification. Depending on the mode (technological characteristics) of the aeration selected, the mixing phase may also take place simultaneously with the aeration phase. The aeration phase is followed by the fourth phase – settling, in which the activated sludge is separated from effluent. The fifth phase, following after the settling phase, involves discharge of effluent (decanting) and extraction of sludge that is transported for further treatment [8-10, 12]. Depending on the configuration of the plant and the mode selected, an inaction phase may optionally be implemented before the start of the next cycle. In this phase, the SBR tank waits for a new loading. The aeration of reactor can be carried out by mechanical or diffused aeration systems. The SBR aeration is the most significant energy consumption item at the plants of this type [9].

3. Basic guidelines for dimensioning SBR plants for secondary treatment

3.1. Primary settling tank, PT

The PT is dimensioned according to standard guidelines based on the selected time of wastewater retention in the PT. This is a function of the waste removal efficiency (Table 2), wastewater inflow (the relevant hydraulic load – Q_{rel} and mean daily inflow – Q_{md}) and surface load of the settling tank (v_0) for relevant inputs ($v_{0,qmax,h}$; $v_{0,Qmd}$).
The required volume of settling tanks (V_{req}) has to be determined as a part of the PT dimensioning process, and from the aspect of relevance to this paper. This volume is calculated using the equation:

$$V_{req} = Q_{rel} \cdot t \cdot 3600 \ [m^3] \qquad (1)$$

where :
Q_{rel} - relevant hydraulic load [m³/s]
t - selected wastewater retention time in the PT [h].

The relevant hydraulic load (Q_{rel}) is calculated depending on the type of sewerage system (separate or combined) applied in the catchment area of WWTP, using the following expressions:

Table 2. Efficiency of wastewater treatment in PT, depending on the water retention time [13]

Water quality indicators	Unit load values in raw wastewater [g/PE·day]	Load values at the exit of PT [g/ES·day]	
		Water retention time in PT within the range 0,5 - 1,0 h (at Q_{rel})	Water retention time in PT within the range 1,5 - 2,0 h (at Q_{rel})
BPK_5	60	45	40
KPK	120	90	80
TSS	70	35	25
TKN	11	10	10
TP	1,8	1,6	1.6

$$Q_{rel} = f \cdot (q_{max,h,inhabitants} + q_{max,h,industry}) + Q_{infiltration}\ [m^3/s] \quad (2)$$

$$Q_{rel} = 2 \cdot (q_{max,h,inhabitants} + q_{max,h,industry}) + Q_{infiltration}\ [m^3/s] \quad (3)$$

where:

$q_{max,h,inhabitants}$ - maximum hourly inflow of wastewater from households [m^3/s]
$q_{max,h,industry}$ - maximum hourly inflow of wastewater from industry (industry, tourism etc.) [m^3/s]
$Q_{infiltration}$ - infiltration and illegal connections (usually calculated as $Q_{infiltration} = (0{,}2\text{-}1{,}0) \cdot Q_{sr,dn,uk}$) [m^3/s]
$Q_{md,total}$ - total mean daily inflow of wastewater ($Q_{md,total} = Q_{md,inhabitants} + Q_{md,industry}$) [m^3/s]
$Q_{md,inhabitants}$ - mean daily inflow of wastewater from households [m^3/s]
$Q_{md,industry}$ - mean daily inflow of wastewater from industry [m^3/s]
f - factor of increase in relevant hydraulic load during rainy period as a result of illegal connections and infiltration of rainwater through manhole covers, etc. (its value is usually selected within the range from 1.2 to 2.0)

3.2. Sequencing batch reactor (SBR)

German guidelines for SBR process dimensioning have been adopted in the professional practice in Croatia [14]. A part of the overall calculation also refers to German guidelines according to the working paper ATV-DVWK-A 131 [13].

As with other types of WWTP, the first step is to define relevant loads (hydraulic and waste matter) of the SBR tanks. The calculation of the required SBR tank volume is carried out in two basic steps:

The calculation of the equivalent bioreactor volume (V_{BAR}) is performed in the first step based on the conventional process (the conventional activated sludge or extended aeration process) using the equation:

$$V_{BAR} = \frac{MD_{BOD5}}{SS_{BAR} \cdot RFM}\ [m^3] \quad (4)$$

where:

MD_{BOD5} - mass inflow of BOD_5 into a bioreactor [kgBPK$_5$/day
SS_{BAR} - sludge concentration in a bioreactor [kgMLSS/m^3]
RFM - ratio of food and microorganisms in a bioreactor, represents the proportion of food biodegraded each day by microorganisms relative to their own weight [kgBPK$_5$/kgMLSS·day].
MLSS (eng. *Mixed Liquor Suspended Solids*) represents the suspended substance in the SBR tank and is the best measure for sludge concentration.

According to the conventional activated sludge treatment method, the value of SS_{BAR} is determined from the calculation of secondary settling tanks (ST) and depends on the recirculation ratio of the sludge from the bioreactor to ST. It is calculated depending on the sludge volume index and the thickening time of the sludge at the bottom of ST. Therefore, to calculate SS_{BAR}, the following equation is used:

$$SS_{BAR} = \frac{RSR \cdot SS_{RS}}{1 + RFM}\ [\text{kgMLSSm}^3] \quad (5)$$

where:

RSR - return sludge ratio, represents the ratio of return sludge flow rate and relevant hydraulic load to bioreactor (Q_{rel}) (RSR usually ranges from 0.5 to 0.75)
SS_{PM} - suspended solids concentration in the return sludge [kgMLSS/m^3] [kgMLSS/m^3]

SS_{RS} is calculated using equation:

$$SS_{RS} = 0.7 \cdot \frac{1000}{SVI} \cdot \sqrt[3]{t_{Th}}\ [\text{kgMLSSm}^3] \quad (6)$$

(for ST with sludge scrapers)

$$SS_{RS} = (0.5\ to\ 0.7) \cdot \frac{1000}{SVI} \cdot \sqrt[3]{t_{Th}}\ [\text{kgMLSSm}^3] \quad (7)$$

(for ST with suction facilities)

where:

SVI - sludge volume index [l/kgMLSS]
t_{Th} - time of sludge thickening at the bottom of the secondary settling tank [h].

The SVI defines the settling properties of sludge and it is desirable that SVI value is as small as possible. For the design and calculation purposes, it is recommended to choose SVI values within the range of 100 to 120 [l/kgMLSS].

The t_{Th} value varies depending on the required treatment efficiency and the technological process applied. For the secondary treatment without nitrification (removal of organic carbon compounds only) t_{Th} is within the range of 1.5 to 2.0 [h]. For the secondary treatment with nitrification (removal of organic substance with carbon and nitrogen compounds), t_{Th} is within the range of 1.0 to 1.5 [h].

In the case of extended aeration, SS_{BAR} within the range of 4.0 to 5.0 [kgMLSS/m^3] is selected. In case there is a free space at the WWTP site, it is recommended to select a value of 4.0 [kgMLSS/m^3] as it offers greater flexibility during plant operation. However, if the free space for building WWTP is limited, a value of 5.0 [kgMLSS/m^3] can also be selected. RFM is calculated using equation:

$$RFM = \frac{1}{t_{SS} \cdot SS_{C,BOD5}}\ [\text{kgBPK}_5/\text{kgMLSS dan}] \quad (8)$$

where:

t_{SS} - sludge age [day]
$SS_{C,BOD5}$ - sludge production for carbon removal referred to BOD_5 [kgMLSS/kgBPK$_5$].

The required sludge age depends on the required treatment efficiency, WWTP capacity and relevant wastewater temperature and is determined using Table 3.

Table 3. Determining the required sludge age (days) [13]

Efficiency of wastewater treatment	Sludge age (days)			
	WWTP capacity			
	< 20.000 PE		> 100.000 PE	
Relevant temperature of wastewater	10°C	12°C	10°C	12°C
Removal of organic matter without nitrification	5		4	
Removal of organic matter with nitrification	10*	8.2*	8*	6.6*
Simultaneous sludge stabilization (extended aeration)	25		not recommended	

For the removal of organic matter without nitrification, for relevant temperatures of wastewater greater than 12°C, for safety reasons, the same sludge age values as for 12 °C can be selected. For removal of organic matter with nitrification, t_{SS} is calculated using the equation:

$$t_{SS} = 3.4 \cdot SF \cdot 1.103^{15-T} \text{ [days]} \qquad (9)$$

where:

SF - safety factor for nitrification dependent on the capacity of WWTP
SF = 1.80 for WWTP larger than 100,000 PE
SF = 1.45 for WWTP smaller than 20,000 PE
For WWTPs with a capacity between 20,000 and 100,000 PE, it is necessary to interpolate the SF value within the range of 1.45 to 1.80.
T - relevant temperature of wastewater (mean low annual wastewater temperature) [°C].

$SS_{C,BOD5}$ depends on the relation of the relevant load TSS (MD_{TSS} - mass inflow of the total suspended solids in the bioreactor [kgTSS/day]) and BOD_5 (MD_{BOD5} - mass inflow of the BOD_5 in the bioreactor [kgBOD_5/day]) and t_{SS}. In a simplified form, $SS_{C,BOD5}$ is determined using Table 4.

Table 4. Determining specific sludge production $SS_{C,BOD5}$ [13]

$\frac{MD_{TSS}}{MD_{BOD5}}$	**Specific sludge production $SP_{C,BOD}$** [kgMLSS/kgBOD_5]					
	Sludge age [days]					
	4	**8**	**10**	**15**	**20**	**25**
0,4	0,79	0,69	0,65	0,59	0,56	0,53
0,6	0,91	0,81	0,77	0,71	0,68	0,65
0,8	1,03	0,93	0,89	0,83	0,80	0,77
1,0	1,15	1,05	1,01	0,95	0,92	0,89
1,2	1,27	1,17	1,13	1,07	1,04	1,01

The required volume of the SBR tank (V_{SBR}) is calculated in the second step. The calculation of V_{SBR} is carried out in two stages. In the first stage, the $V_{SBR,1}$ is calculated in relation to the SBR tank load with waste material, primarily with organic matter. In the second stage, $V_{SBR,2}$ is calculated in relation to hydraulic load of the SBR tank. The higher value of the previously calculated $V_{SBR,1}$ and $V_{SBR,2}$ is adopted as the relevant V_{SBR} value,. $V_{SBR,1}$ is calculated using the following equation:

$$n \cdot V_{SBR,1} = \frac{V_{BAR} \cdot SS_{BAR} \cdot t_c}{SS_{SBR} \cdot t_R} \quad [m^3] \qquad (10)$$

where:

n - number of SBR tanks
V_{BAR} - volume of the equivalent bioreactor calculated according to eq. (4) [m^3]
SS_{BAR} - sludge concentration in the equivalent bioreactor [kgMLSS/m^3] according to eq. (5)
t_c - duration of one cycle in the SBR tank [h]. The t_c depends on the selected number of cycles within one day and is to be selected in such a way that there is a constant number of cycles within one day. t_c is most often selected from the values of 4, 6, 8, 12 or 24 [h].
SS_{SBR} - sludge concentration in the SBR reactor [kgMLSS/m^3]. It is recommended to choose a value ranging from 4.0 to 5.0 [kgMLSS/m^3], regardless of whether it is desired to provide simultaneous stabilization of sludge in the SBR reactor.
t_R - reaction time [h]. The reaction time equals the time of air blowing in the SBR tank, i.e. the time of biological processes aimed at aerobic degradation of organic matter. The reaction phase ends with the end of the aeration and the beginning of the settling phase. t_R is calculated after the durations of all other phases are defined within one cycle using the equation:

$$t_R = t_c - t_{fill} - t_{settle} - t_{disc} - t_{idle} \quad [h] \qquad (11)$$

where:

t_{fill} - duration of SBR tank filling phase [h]
t_{settle} - duration of settling phase within SBR tank [h]
t_{disc} - duration of phase for the discharge of effluent and removal of excess sludge from the SBR tank [h]
t_{idle} - duration of idle phase [h].

$V_{SBR,2}$ is calculated in the scope of an iterative procedure using equations (12), (13) and (14). The calculation procedure implies presumption of the f_A value (in the first iteration step it is recommended to select the value of f_A = 0.4), and the calculation is conducted according to equation (12). Then the calculated value $n \cdot V_{SBR,2}$ is included in equation (13), and the resulting value is included in expression (14). The iterative process is repeated until the value of f_A (calculated according to equation 14) becomes equal to the assumed value of f_A, which is included in equation (12).

$$n \cdot V_{SBR,2} = \frac{Q_{rel} \cdot t_c}{f_A} \qquad (12)$$

$$\Delta V = (n \cdot V_{SBR,2}) - (n \cdot V_{SBR,1}) \ [m^3] \qquad (13)$$

$$f_A = \frac{\Delta V}{n \cdot V_{SBR,2}} \qquad (14)$$

where:

f_A - maximum share of purified water volume discharged from the SBR tank in one cycle

$V_{SBR,1}$ - volume of SBR tank calculated according to equation (10) [m^3]

DV - maximum volume of effluent discharged from the SBR tank in one cycle [m^3]

In most practical cases, the calculation of the relevant SBR tank volume is made based on hydraulic load ($V_{SBR,2}$). Nevertheless, the calculation in relation to the hydraulic load should be understood conditionally because it also contains the factor "f_A" which is, based on equation (13), dependent on relevant organic load (in relation to parameter $V_{SBR,1}$).

4. Problem analysis and results

Depending on the WWTP capacity, the wastewater composition, and relevant inflows, it is questionable whether and to what extent the configuration of plant with the PT as primary treatment is more advantageous compared to plants without the PT. According to guidelines for dimensioning SBR plants for secondary treatment, it can be expected that, after construction of the PT in front of the SBR tanks, the required volume of the SBR tank will be reduced (as a consequence of reducing waste material load of the SBR tank) and that the plant operating costs will be lowered (lower aeration requirements, which is the most important item in the total energy needs on the plants of this type). Calculation results for SBR plants with secondary treatment and capacity ranging from 1,000 to

Table 5. Relevant input parameters

WWTP capacity [PE]	**Specific inflow of wastewater** [l/inhabitant·day]	**Total oscillation of wastewater inflow** (multiplicity of coefficients of daily and hourly inequality)	**Infiltration inflow** [m^3/h]	**Mean daily inflow of industrial wastewater** [m^3/day]	**Relevant hydraulic load at WWTP** [m^3/h]	
					separate system	**combined system**
1.000	100	3.0	2.0	0.0	15.0	27.0
2.000	100	3.0	4.0	0.0	29.0	54.0
5.000	100	3.0	10.0	0.0	73.0	135.0
10.000	100	2.0	20.0	0.0	103.0	187.0
20.000	100	2.0	50.0	480.0	258.0	463.0
50.000	125	1.75	150.0	1.200.0	693.0	1.236.0
100.000	125	1.5	300.0	2.400.0	1.231.0	2.163.0
200.000	125	1.5	600.0	4.800.0	2.463.0	4.325.0

Table 6. Relevant sizes of SBR tank and PT for different scenarios and plant capacities

WWTP capacity [PE]	**Combined sewerage system**			**Separated sewerage system**		
	without PT	**with PT**		**without PT**	**with PT**	
	SBR [m^3]	**PT** [m^3]	**SBR** [m^3]	**SBR** [m^3]	**PT** [m^3]	**SBR** [m^3]
1.000	292	27	216	242	15	161
2.000	584	54	432	483	29	322
5.000	1.460	135	1.080	1.208	73	806
10.000	2.575	187	1.778	2.259	103	1.450
20.000	5.532	465	3.914	4.667	258	3.129
50.000	13.015	1.237	9.892	10.874	693	7.703
100.000	23.378	2.163	17.475	19.700	1.231	13.873
200.000	46.757	4.325	34.600	39.400	2.463	26.622

200,000 PE are presented below, for the scenarios with and without PT. Analyzes were carried out separately for both types of sewerage systems in front of WWTP – separate and combined. Input parameters relevant for dimensioning are shown in Table 5.

It can also be emphasized that WWTPs with the capacities of 1,000 PE to 10,000 PE are in most cases not so interesting from the aspect of the issues considered in this text, because these WWTP capacities usually imply the use of a simultaneous stabilization technology that directly excludes PT application. However, these analyses may be interesting under certain circumstances that exclude the need for sludge stabilization at the WWTPs, and are therefore presented as an integral part of the overall results. The calculation for all variants was carried out according to the guidelines presented in Section 3. In addition, calculations were conducted using the AquaDesigner (BITControl) software package, version 6.3, in order to additionally verify calculation values. The volume calculation results for individual WWTP structures are presented in Table 6 and schematically in Figure 2.

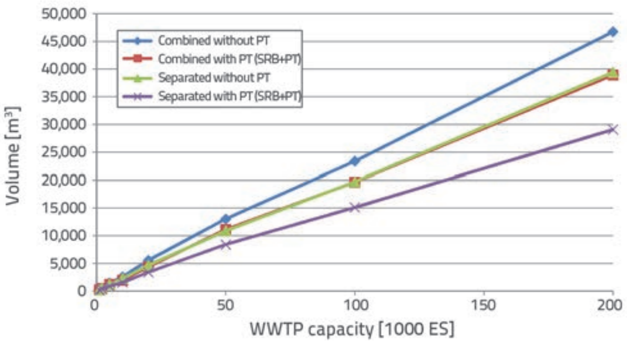

Figure 2. Required volumes of WWTP facilities (SBR tank and PT) depending on WWTP capacity and applied configuration

The detailed analysis of the data presented shows the advantage of configurations of SBR plants with PTs, which is especially evident in case of larger-capacity plants. Namely, the total required volume (SBR tank + PT) is smaller than the required volume of the SBR tank without PTs for all considered scenarios. Also, these differences between scenarios are more pronounced in the scenarios with separate sewerage systems. In configurations with PTs, the total required volume is by 14 to 24 % lower for combined systems, and by 23 to 31 % for separate sewerage systems. Regardless of the type of sewerage system used, oxygen demands for aeration are the same for the WWTPs of the same capacity, depending only on organic load, and so there are differences between SBR plants with PTs and without PTs. In addition to the oxygen demand analysis, the total air volume and blower power requirements were also analyzed in accordance with the presently available types and the number of aerators for the selected configuration of the plants. The AquaDesigner (BITControl) computer software, version 6.3 was used for these analyses. The results are shown in Table 7 and graphically in Figures 3 to 5. The oxygen demand for the SBR tank aeration is lower by about 25 % for configurations with PTs, regardless of the WWTP capacity. The total required air volume is lower by 15 to 25 % for SBR plants with PTs, depending on the WWTP capacity. The required blower power for the reactor aeration in relation to the number of tanks and oxygen requirements, and based on available types of blowers, is lower by up to 38 % for SBR plants with PTs (or 20 % on an average).

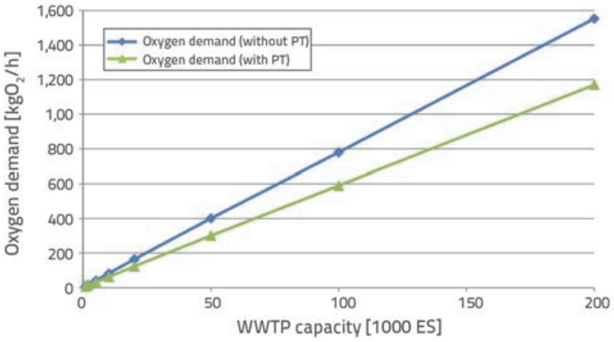

Figure 3. Comparison of oxygen demand in SBR of different capacities, with and without PT

Table 7. Comparison of aeration requirements for different scenarios and capacities of WWTP

WWTP capacity [PE]	**SBR without PT**			**SBR with PT**		
	Oxygen demand [kgO$_2$/h]	**Required air volume** [m^3/h]	**Required blower power** [kW]	**Oxygen demand** [kgO$_2$/h]	**Required air volume** [m^3/h]	**Required blower power** [kW]
1.000	8	190	8	6	144	8
2.000	16	378	15	12	285	12
5.000	41	945	30	31	709	22
10.000	82	1.891	60	61	1.419	37
20.000	163	3.776	110	122	2.832	74
50.000	401	7.300	222	300	6.020	180
100.000	780	12.100	390	590	10.235	330
200.000	1.554	21.465	720	1.170	17.550	640

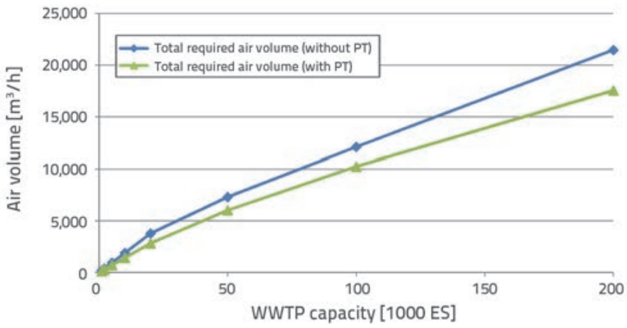

Figure 4. Comparison of total required air volume for SBR plants of different capacities, with and without PT

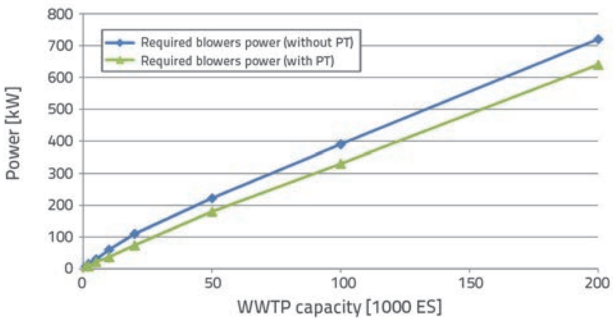

Figure 5. Comparison of required blower power for SBR tanks at plants of different capacities, with and without PT

With regard to oxygen demand analysis conducted for SBR aeration, it should be noted that any possible oxygen consumption for the treatment of sludge (aerobic sludge stabilization) was not considered. The analyses carried out in this paper are relevant only for WWTPs with simultaneous sludge stabilization (extended aeration) or with separate anaerobic sludge stabilization, or for WWTPs where, for some reasons, sludge stabilization is not necessary (e.g. if sludge is to be incinerated). Namely, if sludge stabilization is required and if aerobic stabilization is implemented, then the savings in oxygen consumption in the SBR tanks obtained by incorporating the primary settling tanks will partly be lost in the process of aerobic sludge stabilization.

5. Conclusion

The number of SBR wastewater treatment plants is increasing on the global scale, and also in Croatia. When defining the SBR configuration on a water line, it is necessary to choose variants with or without primary treatment, where PT construction is most often considered. Only SBR plants for secondary treatment, not including aerobic sludge stabilization, are analyzed in this paper. Based on the calculation results presented in the paper, the advantage of different solutions of SBR plants with PTs is emphasized, which is particularly evident in case of larger-capacity WWTPs (in excess of 100,000 PE). Also, configurations with PTs show somewhat greater advantages in the case of separate sewerage systems. These advantages are primarily reflected in the reduced SBR tank load with waste material and in the reduced total required volume of plant facilities (SBR tanks + PTs, compared to SBR tanks without PTs), for about 25 % on an average. Furthermore, the analysis results show that the oxygen requirement of SBR tanks with PTs is lower by about 25 %, resulting in the reduction of the required blower power for SBR tanks (reduction in initial investment), and reduction in the total energy consumption. If the sludge stabilization is needed, and if it is carried out aerobically, it should be noted that the savings in oxygen consumption at SBR tanks obtained by incorporating PTs will partially be lost in the aerobic sludge stabilization process. That is why it is important to conduct further and more detailed analyses of the described problem. It can therefore be concluded that, from the technical and economic aspects, the construction of PTs is justified on a water line of the SBR plants for secondary treatment without aerobic sludge stabilization, in particular for larger WWTPs and for those preceded by separate sewerage systems. This conclusion suggests that at least two different solutions - with the primary treatment and without it (in front of the SBR tanks) - should be analyzed in detail already at the level of study analyzes when application of SBR plants for secondary treatment is considered. Given that a significant number of plants for tertiary treatment are also planned, which also involves the possibility of using SBR technology, further analysis of the described problem should focus on the cost-effectiveness of PT construction on SBR plants for tertiary treatment.

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