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Advantages of compartmented anoxic/ anaerobic selectors in advanced SBR-based biological wastewater treatment plants: A review

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Abstract

The paper aims to analyze and evaluate the benefits of multi-cell or compartmented anoxic/ anaerobic bio-selectors in the performance of sophisticated sequential batch reactors based sewage treatment plants for excellent sewage sludge settling characteristics (lower SVI< 120 mL/ g) and significant scope for enhancing biological nutrient (TN and TP) removal efficiencies. The combination of return activated sludge (RAS) and a high amount of soluble, biodegradable substrate from influent sewage in the first compartment of a multi-sectional selector helps select floc-formers against filamentous organisms. It also offers improved results for Simultaneous nitrification and denitrification (SND). Also, it exhibits a platform for direct denitrification of residual nitrates from RAS and considerable phosphorus release during the biological phosphorus removal (BPR or Bio-P) process if proper operational conditions prevail in the plant. Several operating conditions need to be accessed and optimized for improving SND and BPR processes by bio selection mechanisms. They include dissolved oxygen (DO), oxidation-reduction potential (ORP), pH, and influent sewage parameters like fractions of readily biodegradable chemical oxygen demand to TN or TP ratios (rbCOD: TN and rbCOD: TP), soluble COD (sCOD), total COD, BOD_5, and incoming volatile fatty acids (VFA) concentrations in the influent wastewater which plays phenomenal roles in achieving the high nutrient removal efficiencies in the plants.

Keywords:
Simultaneous nitrification and denitrification, biological phosphorus removal, oxidation-reduction potential, dissolved oxygen, return activated sludge, readily biodegradable chemical oxygen demand.

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INTRODUCTION

Sequencing Batch reactors (SBR) technology is regarded as an alternative to conventional systems like conventional activated sludge processes for eliminating nutrients from sewage. SBR technology thrives in being applied in small wastewater treatment plants treating urban (Puig et al., 2007) and industrial (Vives et al., 2003) wastewaters. It is especially suitable for places with the considerable flow and load variability or where space difficulties are restricted (Metcalf and Eddy, 2003). Nutrient removal in SBR needs a combination of anaerobic–anoxic–aerobic phases. The mixed liquor suspended solids (MLSS), carbon, and nutrient (N and P) concentrations have been considered essential along with other parameters such as food to microorganisms ratio (F/M) and simultaneous nitrification and denitrification (SND) (Wang et al., 2009, Magdum et al., 2015). The role of microbes is very crucial in the SBRs, such as the role of nitrifiers, denitrifiers, and polyphosphate accumulating organisms (PAOs) together with phenomena such as SND and enhanced biological phosphorus removal (EBPR) (Kim et al., 2008).

Conventional SBRs are devoid of the selector zone, which helps numerous areas in their efficient advancement. The advanced type of sequencing batch reactors (improved technology than conventional SBR) for effective sewage treatment incorporates two zones: ‘zone 1’ signifies a multi-cell selector zone, and ‘zone 2’ represents the main aeration zone (Fig 1). The multi-cell selector zone is an incorporating basin or channel where return activated sludge (RAS) and influent wastewater (consisting of high readily biodegradable COD (rbCOD) or soluble BOD_5 ($sBOD_5$) content) mix before the aeration basin (Goronszy et al., 1999). Efficacious studies represent a one-fourth to half an hour of contact time for the RAS flow, and influent wastewater is aerated and attains more than ~80% removal of $sBOD_5$ through the selector and almost complete removal of rbCOD (Xin et al., 2008). The purpose is to grant a short-term, high substrate condition that supports certain floc-formers but counteracts filaments with excellent-settling biomass of low sludge volume index (SVI).

Aeration intensity is regulated during the aeration sequence by dissolved oxygen (DO) and oxygen uptake rate (OUR) control to ensure the optimum low value of redox potential during air-off operation to favor nitrogen and phosphorus removal mechanisms. The confined selector assures a feed-starve contact of the biomass, which is obligatory to promote the enzymatic transfer of soluble substrate and following conversion to storage compounds, which are essential to prevent the filamentous sludge bulking (Goronszy and Eckenfelder, 1988). This feature effectively removes the dependency on the fill-ratio operation to generate in-basin selector mechanisms practiced in other sequencing batch systems (Goronszy 1992). Denitrification and enzymatic transfer of available substrate during enhanced biological phosphorus release are also achieved in the anaerobic selector zone.

The three crucial roles of the anoxic/ anaerobic biological selectors are the following (Minnesota Pollution Control Agency, 2006)-

1) It generates an anoxic/ anaerobic environment for the denitrification of nitrates to occur (coming from the RAS).
2) It suppresses filaments from propagating by introducing anoxic fill conditions so that the natural selection of floc-forming bacteria can occur, resulting in exceptional sludge settling characteristics.
3) The soluble organics in the raw sewage are sequestered as intracellular compounds in the biomass. The stored substrate is then used for simultaneous nitrification and denitrification (SND) and biological phosphorus removal (BPR/ Bio-P) in managed cyclic aeration sequences in a sequencing batch reactor in the aeration zone.

Nitrate penetration is governed by its diffusion rate, which is of the order of ten times that of DO. Under aerated provisions, there is usually no nitrate constraint in the inner zone of the floc. Sufficient carbon availability for denitrification is accomplished through the carbon storage (biosorption- PHB) mechanism. The process can be regulated such that during the aeration phase, there is nitrification and denitrification taking place inside the bigger flocs. On the periphery of the sludge floc, nitrification prevails, and in the anoxic zones towards the center of the floc, denitrification occurs. Denitrification also takes place during the settling phase. Process control using in-basin respiration enables direct control over BPR.

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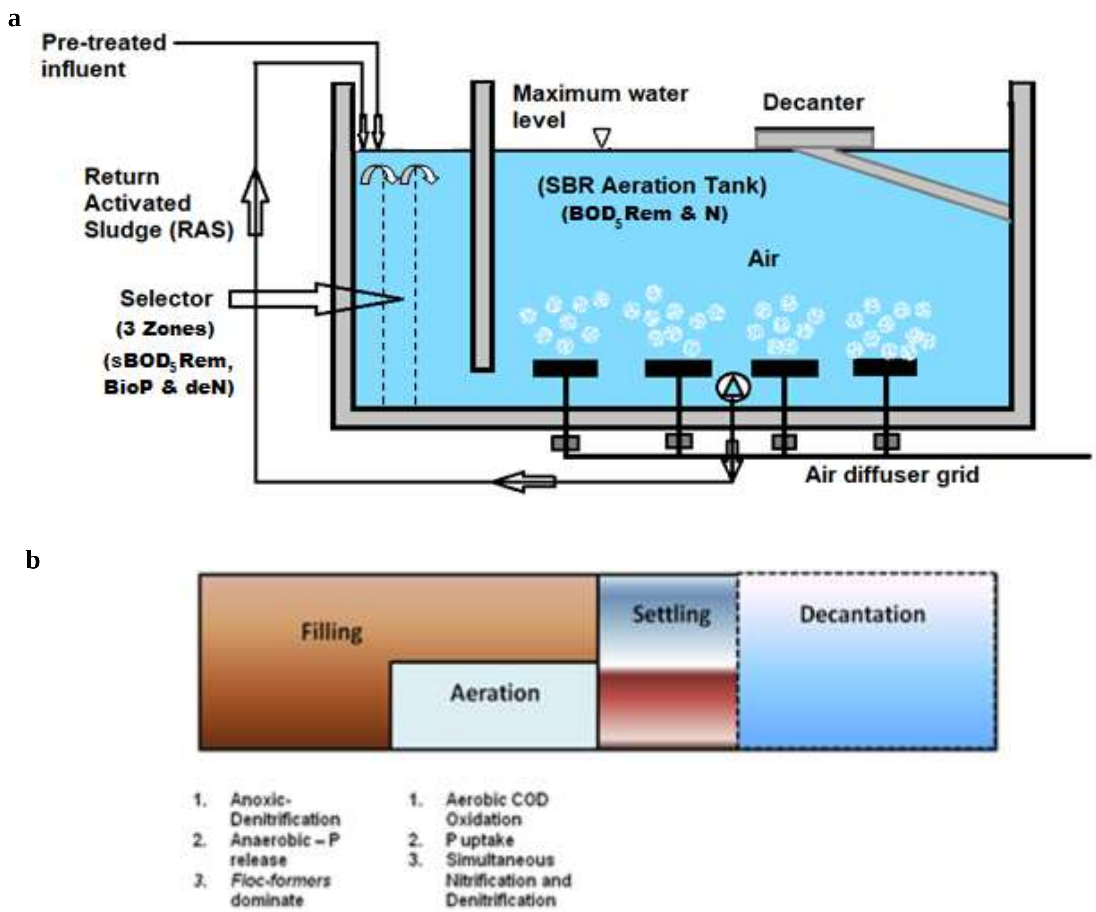

Fig 1: (a) Schematic diagram of pre-anoxic tri-sectional selectors based SBR plant
(b) Processes occurring in different phases (sections) of an SBR plant.

OBJECTIVE

The literature confirms that using a natural biological selection mechanism, bulking sludge conditions are controlled, the aeration and clarification capacity increases, the operation becomes further stable, effluent quality improves, and the process is trouble-free to manage. However, lesser literature is available demonstrating the selector's capacity to enhance nutrient removal by SND and BPR processes after optimizing the favorable conditions for microbiota governing these mechanisms. This review paper can throw light on some broad aspects of using bio selection mechanisms in nutrient removal while maintaining sludge settling characteristics concomitantly.

Thus, the overall study focuses on the role of selectors in the advancement of SBRs, which constitutes the three main objectives:

- Impacts of designing the multi-compartment selectors on reducing sludge volume index (SVI) and improvising the sludge settling characteristics, floc size, and microbial biomass composition.
- Anoxic bio-selectors' performance in biological nutrient (N and P) removal via SND and BPR (Bio-P) processes.
- The influence of operational factors/ parameters in optimizing the treatment systems includes DO, pH, ORP, and availability of volatile fatty acids (VFAs) (via fermentation of rbCOD).

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RESEARCH METHODOLOGY

The present review demonstrates an efficient and tentative means to investigate the bio-selectors' role in enhancing the inner processes, including SND and BPR, and simultaneously augment the sludge settling characteristics in the highly developed SBR systems. The information in this study is derived from the secondary data, and the secondary data source is collected using published articles, journals, books, the Internet, seminar materials, and web technologies, etc.

RESULTS AND DISCUSSION

(i) Bio-selectors design variables

The system is planned so that the sludge return rate originates from the approximate daily cycling of the total biomass through the selector zone. The mechanism in zone 1 and the internal sludge transfer remove the obligation for separate fill-ratio selectivity, anoxic, and anaerobic mixing periods necessary for the matured generic SBR configurations. The main reactor's absolute-mix nature provides flow and load balancing and tolerance to alarmed or toxic loading. The practice prevents solids washout during peak or wet weather hydraulic surges, which are not possible in conventionally designed clarifier activated sludge plants. It combines both aerobic–anaerobic phases in one unit and saves up to 25% of the aeration costs simultaneous with low sludge production.

If N removal without BPR is the main objective, the system should be operated with the shortest possible cycle time at high recycle ratios. However, if both BPR and N removal is required, a longer cycle time should be selected to operate with the minimum (sludge) recycle ratio (Singh et al., 2010).

Generally, in superior selector based SBR plants (where RAS mixes with the influent sewage), selectors are designed considering the numerous factors (SFC Environmental Technologies Pvt Ltd., 2020). Firstly, the contact time should be around 20-60 minutes (Metcalf and Eddy, 2003). Secondly, a baffle wall arrangement is offered in the selector to create several compartments (multi-cell) to mix arriving sewage with return sludge in a plug flow arrangement. Thirdly, each compartment's surface area in the selector is designed as sufficient vertical up-flow velocity is accessible to avoid sludge settlement (hence it is not similar to the primary sedimentation tank in SBRs). Vertical up-flow velocity should be five times the sludge settling velocity. Also, horizontal scouring velocity should be greater than 0.3 m/s to avoid settlement and also to ensure sufficient mixing. Fourth, a coarse air bubble grid is installed in the selector compartments of each basin, which is used to agitate and remove any accumulated suspended solids that want to settle in the selector compartment during the settling/ decanting phase when there is no inflow into the basin. The selector air valve is set to operate for 5 minutes at the start of each fill cycle. Finally, the selector cells are operated without aeration and are self-mixed under baffle 'jet' entrainment mixing. Mixing and vertical velocities exceed industry practice for scouring and solids deposition in pipelines and settling basin design.

In combination, the cells are in continuous fluid communication and hence function as a plug flow reactor, which is, by definition, an equivalent number of completely mixed reactors in series connection. It should be considered that the attached references do not contain any purpose sized mixing equipment or any sequences of operation devoted to non-aerated mixing (Goronszy 1992, Goronszy 1996). This is an advancement of the SBR from conventional SBR. It serves as a medium-as un-aerated fill time and purpose placed and operated mixer demanded by using that more complex alternative. This is a prerequisite for the SND and enhanced BPR processes. Conditions rapidly proceed to anaerobic in the later cells of the unaerated selector. By design and purpose of operation, the net reaction conditions of the selector's flow into the aeration zone having an ORP below 0 mV.

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(ii) Role of compartmentalization in bulking control and biological nutrient removal

In many cases, selectors can be installed within existing basins as a series of small compartments using 6% to 10% of the total aeration volume. The deficiency of this aeration tank volume is easily neutralized by the amplified MLSS and solids loading rates resulting from the modified process of the system at a lesser SVI.

The selectors most frequently consist of three/ four complete mix activated sludge reactors (zones) in a series for the initial contact of the return sludge and the influent wastewater to be treated. These small compartments will grant an F/M gradient, which has been revealed to be the essential feature in the environmental conditions benefitting in producing a non-bulking sludge. The general arrangement of bio selectors for an advanced wastewater treatment plant is shown in Fig 2. Mixing and aeration are provided by diffuser aeration. Heide and Pasveer (1974) displayed effective bulking sludge control by recycling oxidized MLSS from a subsisting oxidation ditch and interfacing the MLSS with raw wastewater in a six-stage external selector. There is an option for biological phosphorus removal (Bio-P), and the anoxic zone allows for the removal of the nitrates (denitrification) in the internal recycle (IR) stream. When nitrification (N) and denitrification (deN) are not required, the anoxic zones after the selectors and internal recycling are not employed. However, the selectors are equally effective in controlling bulking in conventional secondary treatment.

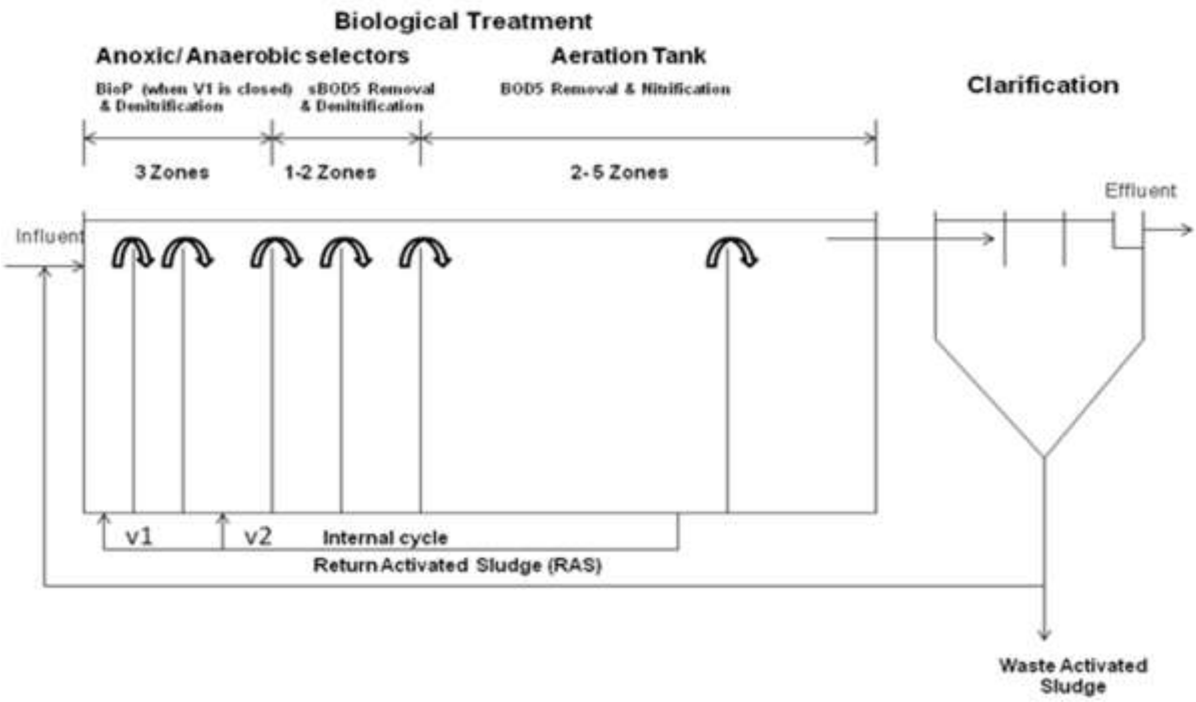

Fig 2: Semi-Aerobic Process for Bulking Control and Nutrient Removal by Heide and Pasveer (1974)

The compartment sizing of the selectors to generate an F/M gradient has evolved considerably. Still, the general mechanistic concept of selection using an F/M gradient initially presented by Chudoba et al. (1973a, 1973b, 1974) and the design of Heide and Pasveer (1974) is regarded as appropriate. It is essential to eliminate unmanaged back mixing between the selector zones (Albertson 2002). The design should employ submerged walls to prevent floating material capture in the compartments. The anoxic selectors require lesser F/M than aerobic selectors (Table1).

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Table1. Three types of selector designs (Metcalf and Eddy 2003)

Design Parameters	Aerobic Selector	Anoxic Selector	Anaerobic Selector
$(F/M)_i$	For the first stage loading control of viscous bulking: 8~12 g COD/ g MLSS. day The general fraction of F/M: 12/6/3 g COD/g MLSS .day	6/3/1.5 g COD/g MLSS .day	For first stage loading control of viscous bulking: < 6 g COD/ g MLSS. day Verification is required for the smallest compartment (fraction 1 in 1/1/2).
Hydraulic retention times (HRT)	10-20 minutes	~60 minutes (for municipal wastewater)	45-120 minutes
Reactor staging (1/1/2)	Required	May be/ may not be required.	Required
Internal recycle	-	NO_3^- supplied by RAS and mixed liquor recycling	No
Denitrification rate	-	5~10 mg NO_3^--N/g MLSS.hr (at 20°C)	Rapid denitrification rates same as anoxic selectors
Mixing/ aeration	Aeration	Mixing	Mixing
Number of compartments	Three (1/1/2)	Three (1/1/2)	Three (1/1/2)

Donaldson (1932a, 1932b) has distinguished filaments as the 'weeds of activated sludge,' appropriately examined that backflow mixing of long and rectangular (plug flow) basins contributed to the development of filaments and therefore proposed to baffle the aeration basin into different compartments. British Water Pollution Laboratory (1969), Bhatla (1967), and Ryder (1973) all analyzed that low DO in the preliminary zone of aerated, extended, rectangular staged basins (selector) would be helpful in offering bulking control. Koller (1966) and Pasveer (1969) rediscovered that intermittent supplying of batch reactors would limit filamentous organisms' growth. The researchers further observed that the organic loading gradient in the initial compartments of the treatment process was the solution to bulking sludge control. The effect of compartmentalization on SVI from their studies is exhibited in Fig 2. As the number of compartments was expanded in the biological reactor, the maximum level of soluble chemical oxygen demand (sCOD) in the MLSS increased in the first compartment (Table 2). The presence of 70 to 120 mg/L sCOD due to an increased F/M in the smaller initial contact zone (ICZs) was an important factor in the control of bulking organisms. Rensink (1974) also confirmed earlier investigators' observations regarding the benefits of staging the reactor zones to reduce sludge bulking.

While selectors will cause the removal of the bulk of the simple organics (alcohols, volatile acids, sugars, and amino acids) from solution before anoxic or oxic zones, the hydrolysis of colloidal and suspended organics in the following oxic zones may present an opportunity for filamentous organisms to nourish and develop. This phenomenon was introduced as 'secondary bulking' by Wanner and Grau (1988). Therefore they recommended a high to low F/M gradient (compartmentalization) in the aeration zones. This postulation may confirm why selectors are very useful when treating highly soluble industrial wastewater

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flows. The bulk of the influent COD (or BOD_5) is removed in the selectors, and the by-products of hydrolysis of the low level of particulates in the oxic zone are minimal. Thus, secondary bulking cannot occur, and this could be the reason that very low SVIs (20 to 50 mL/g) have been accounted for (Davidson, 1957; Okey, 1997) when treating extremely soluble industrial wastewaters including typically low molecular weight organics.

Table2. General design guidelines for selector sizing for aerated and anoxic selectors (after Albertson 2002)

Zone wise F/M			
	S_x-1 (1st compartment)	**S_x-2 (2nd compartment)**	**S_x-3 (3rd compartment)**
Kg COD/ Kg d	10-12	5-6	2.5-3
*Kg sCOD/ Kg d	5-6	2.5-3	1.25-1.5
Kg BOD_5/ Kg d	5-6	2.5-3	1.25-1.5
*Kg $sBOD_5$/ Kg d	2.5	3	0.63-0.75

* Best basis for selectors designing; COD/BOD_5 and sCOD/$sBOD_5$ range is presumed to be 1.8 - 2.2; the parameter COD, etc., is used such that it generates the least selector volume; and F/M criteria can be reduced if loadings are significantly high.

(iii) Operational parameters in selectors

The operational parameters in the selectors are DO, ORP, pH, temperature, recycle ratios, and HRT. Low DO and high substrate conditions favor floc-formers. Hence, the DO profile enables the SND feature of the process to occur where the fractional intra portion of the biomass is about 50% - 70% in the biomass. Other anoxic conditions are also developed in the settle and decant air-off sequence to about 20% of the sequence time (Goronszy 1992). Generally, in superior SBRs, once OUR and DO levels are measured in the basins, aeration intensity is regulated automatically according to actual demands of the process through the programmable logic controller and variable frequency drive connected to air blower to maintain desired DO levels in the basin. This methodology provides a true-in-basin method for efficient energy use and ensures 20% - 30% power savings.

Important to the design proposed is the recommendations that include designing an anaerobic functioning selector for as short a time as possible for which various times of 30 to 45 minutes are suggested. In the multi-cell selector technology used in advanced SBRs, each cell has a design retention time of 60 minutes for acceptable and proven floc loadings. A DO concentration of $\geq$ 0.2 mg/L has been stated to hinder denitrification for a pseudomonas culture (Skerman and MacRae (1957), Dawson and Murphy (1972)) for activated sludge treating wastewater. Denitrification is observed to be ceased in a highly dispersed growth at a DO concentration of 0.13 mg/L (Metcalf and Eddy, 2003). Rittman and Langeland (1985) reported that more than 90% removal of nitrogen in an activated sludge system for treating municipal wastewater occurs by SND at a higher HRT of greater than 25 hours (and high SRT) in the complete SBR process. Dissolved oxygen should be kept <1 mg/L in the anoxic/ anaerobic selector, and the nitrate supply should be within the range of 6-8 kg/ kg COD or 3-5 kg/ kg of BOD_5. The HRT in the selectors should be around 60 to 90 minutes (Harper and Jenkins, 2003; Metcalf and Eddy, 2003). It is also suggested that the aeration basin (main SBR tank) be designed so that DO never drops below 1.0 mg/L; otherwise, it can increase the SVI levels (Pitman 1991).

For Phosphorus removal (BPR), biomass needs anaerobic-aerobic sequencing, whereas, for Nitrogen removal and SND, it needs aerobic- anaerobic sequencing. Therefore repetitive and designed sequencing as anaerobic/ anoxic/ aerobic within the water line fulfills all of the requirements for both Bio-P and nitrogen removal in the activated sludge process and entirely complies with the spirit and intent of the selector based SBR systems. Aeration should be more than sufficient to provide for the sequestering of phosphorous following the enhanced BPR mechanisms.

The sequencing is achieved in the overall given cycle time. It takes place in an approximate sinusoidal format during the fill-anoxic (/anaerobic) phase in the selectors to oxic and then settling and decanting phase in the aeration basin as -120 mV to -150 mV to about +200 mV and down to about -120 mV to -150 mV, which is repeated continuously by the repetitive cycle of operation (i.e., fill, aeration, settle, decant) (Fig 3). However, recent studies suggest that ORP values of less than -50 mV are needed to denitrify effectively. The ORP readings of -75 mV to -100 mV have been examined to attain complete denitrification of the nitrates (Ron Trygar 2009). The necessary wastewater conditions of enhanced BPR process regarding total, soluble, readily biodegradable COD to P ratios are observed in the studies of Mino et al., 1998 and Barnard et al., 2007. ORP should reach the ranges of negative values up to -200 mV in the anaerobic zone, between -50 mV to +50 mV in the anoxic phase, and positive values up to +300 mV in the oxic zones (Burkhardt 2012). The metabolic processes at different ORP ranges are shown in Table 3.

Table3. Different ORP ranges and metabolic processes occurring during the treatment of wastewater after Goronszy (1992)

S. No.	Process	Approximate ORP Range (mV)	Electron Acceptors	Conditions
1	Organic carbon oxidation	~+50 to ~+220	O_2	Oxic or Aerobic
2	Polyphosphate development	~0 to ~+250	O_2, NO_3^-	Oxic or Aerobic, Anoxic
3	Nitrification	~+100 to ~+330 (or >300)	O_2	Oxic or Aerobic
4	Denitrification	~-50 to ~+50	NO_3^-	Anoxic, Anaerobic
5	Polyphosphate breakdown	~-10 to ~-200	NO_3^-, SO_4^{2-}, Carbonaceous organics	Anoxic, Anaerobic, Fermentative Anaerobic
6	Sulfide formation	~-50 to ~-250	SO_4^{2-}, Carbonaceous organics	Fermentative Anaerobic
7	Acid formation	~-90 to ~-220	SO_4^{2-}, Carbonaceous organics	Fermentative Anaerobic
8	Methane formation	~-190 to ~-340	SO_4^{2-}, Carbonaceous organics	Fermentative Anaerobic

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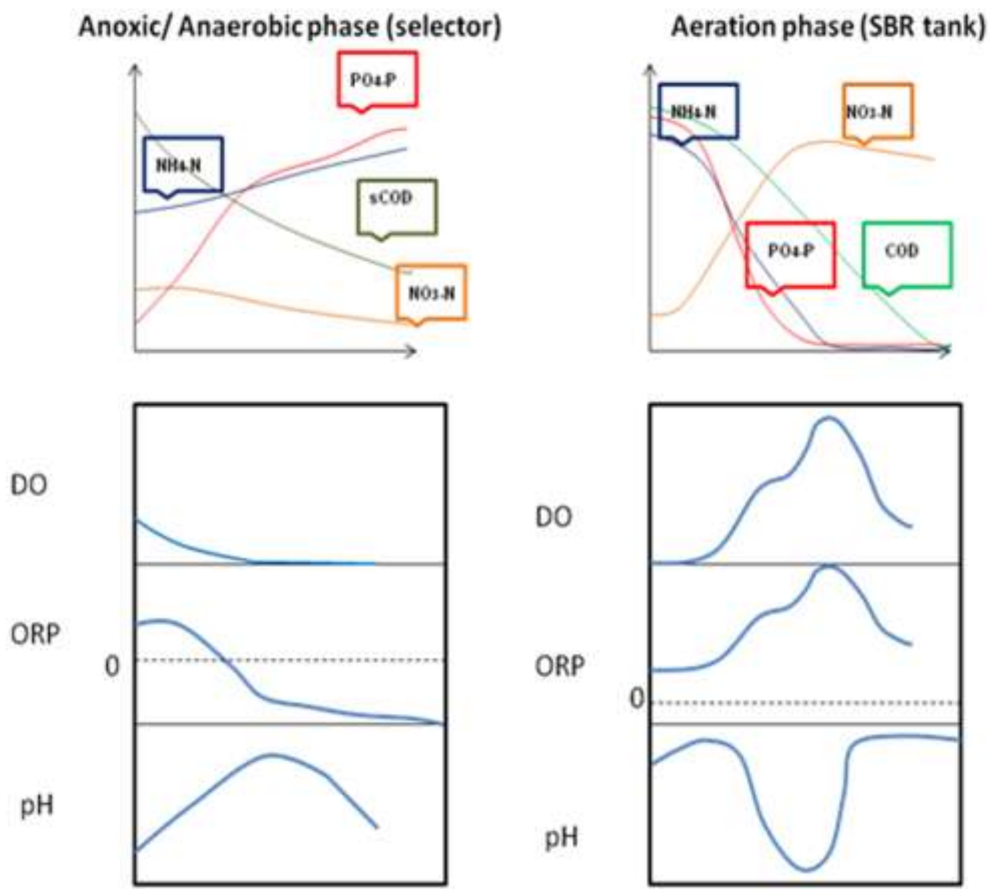

Fig 3: Illustrative patterns of DO, ORP, pH, on substrate removal in general selector based SBRs.

There is also the dependence of anaerobic HRT of selectors and recycle ratios on the plant's phosphorus removal and generally exhibits an increasing relationship (Randall et al., 1992).

(iv) Impact on sludge settling characteristics

The process benefits of a lower and stable SVI are well known to plant operators. Management of the activated sludge process is simplified, and the effluent quality is more stable with nominal sludge blankets in the clarifier. Also, the biological average and peaking capacities of the biological system are increased. The selector reduced the required aeration volume and clarifier area. Without selectors, the aeration volume would need to be 16.7% larger, and the clarifier surface area would be raised by 60%. It is expected that the smaller plant with selectors would also produce a better effluent quality (Pitman 1991, Albertson 2002). Furthermore, the process at ≤ 120 mL/g SVI will be more stable, produces a higher quality effluent, and will be easier to control. There is a more significant potential for the SVI to increase from 150 mL/g to above 250 mL/g without selectors, but with selectors, the more probable USVI (unstirred) is ≤ 100 mL/g (Albertson 2002, Parker et al., 2003).

(v) SND by the selection of floc-formers

The selective mechanism is to contact the return activated sludge (RAS) and an internal recycle when employed with the influent wastewater in an initial contact zone (ICZ) of the biological reactor with limited or no molecular oxygen available. In these zones, heterotrophs remove the low molecular weight, soluble substrates from the solution. Since the favored substrate (small, soluble organics/molecules) of the filamentous bacteria is limited in the heavily aerated oxic zones following the selectors and anoxic (denitrification) zones (if employed), their growth is inhibited. The presence of a limited quantity of filamentous bacteria is generally desirable as they can help produce a more substantial and larger floc structure (Palm et al., 1980), which will easily settle and compact favorably in the secondary clarifier. The larger floc sizes in the aeration zone help in simultaneous nitrification and denitrification (Bakti and Dick, 1992), as illustrated in Fig 4.

For the SND process to take place in the aeration tanks, denitrifiers need a carbon source ($sBOD_5$ or rbCOD), which is made available to them in the ICZ of the selector. Therefore parameters like COD/ TN, BOD_5/TN, rbCOD/ TN, and rbCOD/ sCOD all play a significant role in getting higher denitrification rates and SND in the plants (Khursheed et al., 2018).

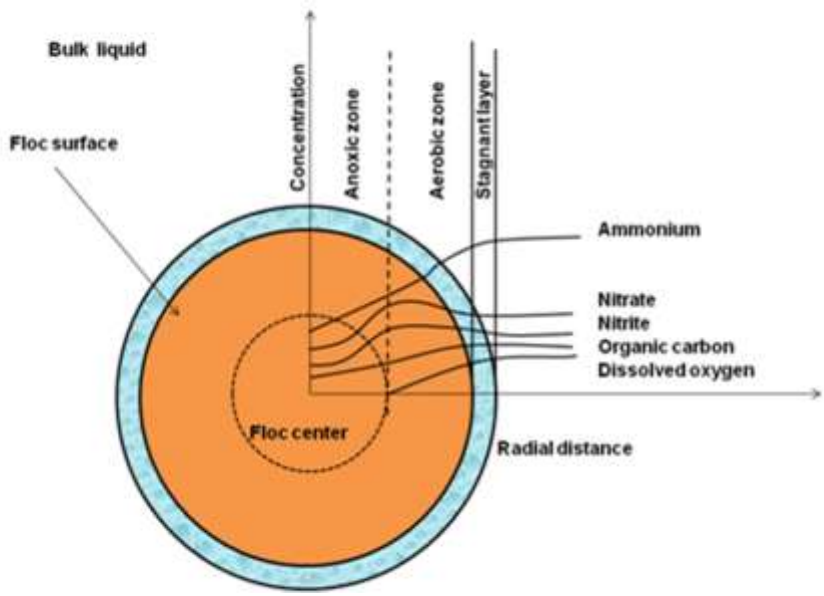

Fig 4: Different substrate concentration profiles in a microbial floc showing simultaneous nitrification and denitrification.

(vi) Scope of BPR in anoxic/ anaerobic selector based SBRs

The general arrangement of selectors for an advanced wastewater treatment plant displayed in Fig 2 can be an option for biological phosphorus removal (Bio-P). Even the anoxic zone allows for the removal of the nitrates (denitrification) in the internal recycle (IR) stream. Some enhanced biological phosphorus removal can also be perceived intermittently in the anoxic zones if sufficient rbCOD becomes available (Naidoo 2000).

The best performance for Bio-P is with mixing only and without internal recycling. The matter of whether the low DO aeration or anoxic mode results in a smaller, more consistent SVI is yet to be examined. The unaerated volume requirements for Bio-P removal are more extensive than required for bulking sludge control. Bioselectors designed for bulking control, with and without denitrification, will generally reduce the total effluent phosphorus (TP) to 1.5 to 3.0 mg/L, depending on incoming wastewater characteristics and the nitrogen inventory in the system (Albertson 2002).

When denitrification is required, the air rate is more limited in the selectors, and about 30% to 35% of the internal recycle (IR) is discharged to the initial contact zone through Valve V1 (Fig 2). If partial (65% -80%) phosphorus removal is the target, then the internal recycling should be released either to the third selector stage or the anoxic zone after the selector. Further, it is unknown whether the eminent (best) process design for selection and bulking control will permit the optimization of phosphorus removal. Table 4 illustrates that it is desirable to have minimal DO in the influent to the initial contact zone and low nitrates in the RAS. There is no internal recycling of nitrates to the selector zones whenever Bio-P is to be optimized.

The increase in the net biomass yield would, in part, be due to the accumulation of excess phosphorus (Bio-P) in the selector arrangement. While the anaerobic mode provides the highest removal level, Bio-P removal in anoxic and low DO selectors is typically 65% to 80%. For each surplus kg of TP removed, about 4 to 4.5 kg of waste sludge will be produced and increase total waste sludge proportionally. The anaerobic zone volume is often defined by criteria for Bio-P removal, which requires a longer retention time than bulking sludge control. However, lower SVIs are associated with higher phosphorus content in the MLSS (Bio-P) (Albertson 2002).

Wastewater characteristics affect a lot in biological phosphorus removal. Total COD/TP, BOD_5/TP, and a readily biodegradable component of COD (rbCOD) to TP ratios play a significant role in biological phosphorus removal in the plants (Broughton et al. 2008, Majed et al. 2019). The readily biodegradable COD undergoes fermentation, and VFA formation occurs. Anaerobic selectors have been flourishingly utilized in plants that are nitrifying. In these cases, the concentration of volatile fatty acids in the influent to the secondary process must be adequate to both support denitrification of the nitrate in the return sludge as well as to sustain the energy cycling of the BioP organisms responsible for choosing against filamentous organisms (Albertson 2002, Parker et al., 2003). VFA should be either present in the wastewater through long anaerobic sewer lines, or rbCOD must be sufficient which can be fermented to VFAs. They are then stored in the form of polyhydroxy butyrate (PHB) simultaneously with phosphorus release by PAOs in the anaerobic zone. Additional uptake of the phosphorus occurs in the aerobic zone, and the stored products (PHB) are utilized for energy in the absence of exogenous substrates (Mino et al., 1998).

Table4. Different types of selectors and their role in biological phosphorus removal

Type of selector	Conditions	Effects on biological phosphorus removal
Aerated, Low DO selectors.	Lack of DO in the initial length of long, rectangular basins	It is related to the biological removal of phosphorus (luxury uptake) and the control of SVI. The low DO in the initial 20%-30% of the basin length encourages biological phosphorus removal (Bio-P removal), as well as produces reduced SVIs.
Anoxic selectors	DO by aeration or by recycling of nitrates to the initial contact zone.	When oxygen is introduced into the initial contact zone, the loss of selectivity is noticeable from the decrease in the level of phosphorus removal in aerated (high or low) and anoxic selectors.
Anaerobic selectors	No DO	To optimize phosphorus's biological removal, the introduction of free and combined sources of oxygen into the selector zone must be minimized. These type of selectors maximizes the availability of $sBOD_5$ (sCOD) for the Bio-P reactions.

Further, it is unknown whether the best process design for biological selection and bulking control will permit the optimization of phosphorus removal. However, it is desirable to have minimal DO in the influent to the ICZ and low nitrates in the RAS. There should include no internal recycling of nitrates to the bio selector zones whenever Bio-P is to be optimized.

(vii) Effects of anoxic selectors on filamentous bacterial growth

Certain organisms that cause bulking and foaming can be prohibited by using multi-cell anoxic/ anaerobic selectors (Table 5). But some filamentous growth cannot be controlled if it is caused by either nutrient deficiency (under-loaded condition) or industrial wastewater mixing in raw sewage (higher influent oil and grease concentration).

Table5. Effectiveness of anoxic selectors in controlling filamentous organisms (Cha et al., 1992)

Organisms	Responsible for	Effective / Not always effective
S. natans	Foaming, filamentous bulking sludge	Effective
type 1701	Filamentous bulking sludge	Effective
type 021 N[a]	Filamentous bulking sludge	Effective
Thiothrix spp.	Filamentous sulfur bacterium causes filamentous bulking sludge.	Effective
type 0041	Filamentous bulking sludge	Not always effective
type 0675	Filamentous bulking sludge	Not always effective
type 0092	Filamentous bulking sludge	Not always effective
N. limicola	Filamentous bulking sludge	Effective
H. hydrossis	Filamentous bulking sludge	Effective
M. parvicella	Foaming, filamentous bulking sludge	Not always effective
Type 1851	Filamentous bulking sludge	Effective
Nocardia spp.	Foam formation	Effective
[a]Not effective when caused by nutrient deficiency		

CONCLUSION

It was observed that the multi-sectional selectors are effective in enhancing the biological nutrient removal as well as bulking control (lower SVIs) if suitable operating conditions are managed. The anaerobic-anoxic-aerobic phases in the SBR system, if properly designed along with controlled wastewater parameters, can behave as a systematic biological treatment system as a whole. However, effective optimization and detailed design parametric studies of selectors in SBR plants should also be done at the pilot-scale level. Biological phosphorus removal is quite complicated because the favorable conditions (enough VFA sources) should be balanced along with DO, pH, and ORP control in the different sections of advanced SBR systems. Lastly, tertiary treatment and further polishing of treated effluent are needed after the secondary biological treatment to gain the best results of final effluent reuse.

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