Innovative technologies for wastewater treatment in coastal tourist areas

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Abstract The selection of appropriate wastewater treatment technologies for coastal tourist areas is important in the sense that they have to meet stringent effluent limits in a simple and easy to operate flow scheme. This paper outlines different effluent standards implemented in sensitive coastal areas and briefly discusses the merit of a number of innovative technologies, namely the sequencing batch reactor, the intermittent aeration process, the moving bed reactor and the biofim-filter-sequencing batch reactor system, either as a batch or continuous flow process applicable in these areas.

Keywords Coastal tourist areas; effluent limitations; intermittent aeration; moving bed reactors; nutrient removal; wastewater treatment

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Introduction

In coastal tourist areas, the quality of the receiving water is, on the one hand, the prime concern for the value of the resort, and on the other hand, it is quite susceptible to pollution and especially to nutrients likely to create eutrophication problems. Coastal tourist areas are of primary concern because of the enormous population change for summer and winter seasons.

This population fluctuation is reflected in wastewater quality and quantity. The population mostly accumulates in small resort areas with a coastal line of special natural value that makes it eligible to be classified as a *sensitive zone*. Due to specific properties of these areas, there is a need for an efficient and yet convenient wastewater management strategy. This strategy must be planned with specific emphasis on the effluent limitations concerning nutrients, namely nitrogen and phosphorus and it should include reliable and rather easy to operate technologies.

Two different alternatives may be considered for the implementation of appropriate technologies in order to present an efficient wastewater management for the control of nutrients: (a) retrofitting existing plants for nitrogen and phosphorus removal, (b) constructing new small plants. It is not possible to convert the existing treatment systems designed for carbon removal into nutrient removal systems, by simple manipulation of the operational parameters. On the other hand, it is important that the selected treatment technology be capable of meeting prescribed effluent standards, despite the fluctuations in the wastewater quality and quantity. In this study, different effluent standards implemented in coastal tourist areas are outlined and the merit of three innovative technologies is briefly discussed. These treatment technologies are *the intermittent aeration process* (IAP) and the *sequencing batch reactor* (SBR), both very easily adaptable to retrofitting existing plants and offering the required potential for nutrient removal together with *moving bed reactors* and in particular, the *biofilm-filter-sequencing batch reactor* (BFSBR) providing a great flexibility in operation.

Effluent standards

Wastewater management of the coastal tourist areas should be based on applicable effluent standards. Feasible and economically justifiable treatment technologies must be developed in order to meet the discharge limitations that guarantee the quality of the receiving water body.

The parameters included in the effluent standards should be determined concerning eutrophication, which is one of the major problems in coastal areas. In this context, nutrients such as nitrogen and phosphorus compounds are the priority pollutants that are of vital importance to the eutrophication problem. Recently, the priorities of pollutants in sensitive coastal areas were re-evaluated as shown in Table 1.

Before 1990, various countries developed their qualitative effluent limitations with regard to this priority. It is important to note that these limitations are expressed as either discharge concentrations or removal efficiencies of nitrogen and phosphorus. The effluent standards applied in different countries are summarized in Table 2.

The year 1991 may be considered as the milestone for a unified basis of wastewater management in Europe through the promulgation of a new EEC directive for urban wastewater discharges. The introduction of the sensitive zone concept as "*natural freshwater lakes, other freshwater bodies, estuaries and coastal waters which are to be eutrophic or which in the near future become eutrophic if protective action is not taken*" was the major feature of the directive. With this initiative, permissible levels of conventional parameters such as BOD_5, COD and suspended solids in sewage discharges to receiving waters was reviewed and stringent limitations were imposed on nitrogen and phosphorus levels in sewage effluents, for their direct relationship and impact on eutrophication. These limitations, outlined in Table 3, not only introduced a new philosophy for wastewater treatment but also required a comprehensive revision of the *state of the art* technology so far accepted for the removal of organic carbon.

The major drawback of the directive is that it includes no provision for changes in wastewater quantity and quality due to seasonal population fluctuations. However, in the Mediterranean coastal region, 10 to 15-fold population increase is routinely observed in summer for some tourist resorts, requiring compatible appropriate technologies for the compliance of effluent standards.

Table 1 Priorities of pollutants in sensitive coastal areas (Boland, 1993)

Priority	Pollutant groups	Examples
High	Nutrients	Nitrogen
	Pathogens	Enteric viruses
	Toxic organic chemicals	PAHs
Intermediate	Selected trace metals	Lead
	Other hazardous materials	Oil, chlorine
	Plastic and floatables	Beach trash, oil and grease
Low	Biochemical oxygen demand (BOD)	
	Solids	

Table 2 Effluent standards for sensitive zones in various countries (Orhon *et al.*, 1999)

Country	Nitrogen	Phosphorus
US	3–10 mg/l	0.18–2.0 mg/l (Total)
South Africa	10 mg NH_4-N/l	1.0 mg/l (Ortho PO_4)
Denmark	6–8 mg/l	0.5–1.5 mg/l (Total)
Austria	<50 mg NH_4-N/l	1.0 mg/l (Total)
	70% N removal above 12°C	
	60% N removal between 8–12°C	
Germany	18 mg/l total inorganic N	1.0 mg/l popln.>100,000
	70% N removal above 12°C	2.0 mg/l 20,000<popln.<100,000
	Max. 25 mg/l total N	

A comprehensive study was recently carried out on the southern Turkish coast, mainly to evaluate the appropriate wastewater treatment technology alternatives for sensitive areas (Orhon *et al*., 1996). The proposed effluent discharge limitations are outlined in Table 4. It should be noted that the European directive was essentially adopted for large communities but additional similar control measures were also proposed for small sewage discharges. These limitations basically involve full nitrification, partial nitrogen removal (40%) and full phosphorus removal (80%) aside from routine restrictions on conventional parameters.

Recent evaluations have shown that achievable nitrogen removal in small communities, either by retrofitting existing plants or by constructing new plants, may be improved to the level expected from large installations, (60–70%), by introducing rational design procedures for innovative technologies (Artan *et al*., 2001; Taşlı *et al*., 2001).

Conceptual basis for technology selection

At present, the majority of existing treatment plants in sensitive coastal areas (i) utilizes conventional activated sludge technology and (ii) is designed and operated for organic carbon removal. The design does not usually account for expected quality fluctuations. Consequently, conservative and largely over-designed plants are supplied, especially for small-size residential communities Extensive periods are commonly required for start-up and adjustment to full efficiency and this period extends through a significant portion of full season. These systems designed and constructed for COD and SS removal, cannot be readily converted into nutrient removal systems, simply by manipulating operational schemes. Similarly, new systems cannot be readily selected from the already existing wide choice of process alternatives promoted for large treatment systems, in the sense that they have to be simple to operate, require a minimum of maintenance, be affordable in terms of installation and operation expenses, and yet reliable in terms of process performance. On the other hand, all quantity and quality changes in wastewaters make it absolutely necessary that the treatment plant includes the required flexibility to cope with the varying

Table 3 European standards for sensitive zones (EEC, 1991)

Parameter	Concentration (mg/l)	Minimum percentage of reduction (%)
BOD_5	25	70–90
COD	125	75
TSS	35 (popln>10,000)	90
	60 (2,000<popln<100,000)	70
TN	15 (10,000<popln<100,000)	70–80
	10 (popln>100,000)	
TP	2 (10,000<popn<100,000)	80
	1 (popln>100,000)	

Table 4 Proposed effluent limitations for sensitive zones in Turkey (Orhon *et al*., 1996)

Parameter	Popln>10,000	Popln<10,000
BOD_5	25 mg l^{-1}	25 mg l^{-1}
COD	125 mg l^{-1}	150 mg l^{-1}
TSS	35 mg l^{-1}	60 mg l^{-1}
Ammonia nitrogen	–	2 mg l^{-1} (full nitrification)
Total nitrogen	75% removal	20 mg^{-1} or 40% removal
Total phosphorus	80% removal	2 mgl^{-1} or 80% removal
pH	6–9	6–9

character of the influent and yet to constantly ensure the prescribed effluent quality. This is already a difficult task for conventional carbon removal, but when it comes to nutrient removal and especially to nitrogen, it requires a very careful evaluation and understanding of the related treatment process.

The main objective of sewage treatment plants serving sensitive coastal sensitive zones is to achieve simultaneous nitrogen and phosphorus removal. The available technologies for N removal rely mostly on biological processes. For P removal, *enhanced biological phosphorus removal* (EBPR) and chemical processes have so far proved equally applicable. In the case of simultaneous removal by means of biological processes, N and P essentially compete for the same organic carbon pool, denitrification largely inhibiting or totally blocking EBPR. Then, biological conversion in an activated sludge reactors proceeds in a well defined *denitrification/EBPR* sequence.

The practical difference between systems designed for organic carbon and nutrient removal is the provision for a non-aerated, mixing zone including successive anoxic/anaerobic phases, aside from the basic aerated volume. Significant parameters for a rational design may be listed as θ_X, V_M/V_T, V_D, V_{AN}, and COD/N, COD/P ratios. For P removal the available fermented substrate concentration, S_A, is important. For N removal the denitrification potential, N_{DP} and the available nitrate N_A must be accurately calculated. Conventionally, nutrient removal is secured by providing a non-aerated zone/phase prior to aeration in continuous-flow activated sludge systems, biofilters or sequencing batch reactors, (SBR). For each system, the particular application for P and N removal needs to be adjusted on a rational basis, depending upon the balance between N_{NP} and N_A.

Innovative technologies

Efforts to promote innovative technologies have so far been mostly empirical, testing system performance on a trial and error basis. A rational approach should involve identification of appropriate parameters specifically associated with the selected new technology. It should basically define the sludge age, θ_X and then provide a mechanistic definition of N_{DP} and N_A for all technology alternatives. The adopted approach is bound to be markedly different for retrofitting existing plants to nutrient removal as compared to designing new systems.

Sequencing batch reactor

The sequencing batch reactor (SBR), is a well studied process for nutrient removal (Morgenroth and Wilderer, 1998; Artan *et al.,* 2001). It functions very much like a predenitrification system on a temporal basis. The SBR process has a cyclic nature, each cycle consisting of several phases. In the fill phase, T_F, wastewater is fed into the reactor on the settled biomass remained from the previous cycle. After fill, additional time, T_R, is provided for biological processes. Biomass is allowed to settle in the next settle phase, T_S; the clear supernatant is discharged in the draw phase, T_D, and the system is left idle for a short period, T_I, until a new cycle starts. The total cycle time, T_C, is the sum of these five phases. The biologically active period is T_P, the sum of fill and react phases. In nutrient removal SBR systems, the process time, T_P consists of the aerated period, T_A and the mixed period, T_M. Depending on the presence or absence of nitrate, the mixed period can be anoxic (T_{DN}) or anaerobic (T_{AN}).

A conventional SBR operating for nutrient removal is schematically illustrated in Figure 1.

Nitrogen removal by providing a post-anoxic period for denitrification after aeration is an obvious operation strategy. Under this condition the denitrification rate is controlled by the endogenous respiration activity of the mixed liquor. If a low effluent nitrate nitrogen concentration is not required, then a post-anoxic phase would not be necessary. In this case a significant amount of nitrate may be removed in a pre-anoxic period during fill with the influent

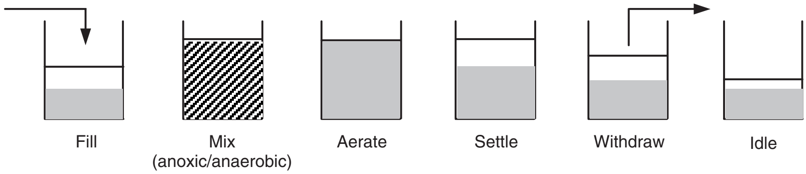


Figure 1 Sequencing batch reactors operating steps for biological nutrient removal

organic carbon driving the denitrification reaction. The ratio of fill volume to the total SBR volume would determine the nitrogen removal level possible using pre-anoxic treatment methods. The smaller the ratio of fill volume, to the total volume, the greater would be the nitrogen removal, assuming all the oxidized nitrogen is reduced before aeration begins.

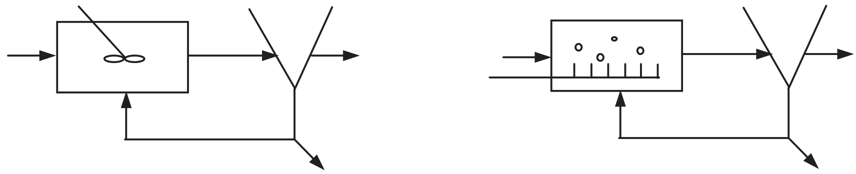
Fill changes the mixed liquor volume in the reactor from V_0 to V_T. The duration of fill time can range from a small fraction of total cycle to total process time, or even to the total cycle time. The shorter the fill time, the more pronounced becomes the alternation of feast and famine conditions within a cycle. Such transient conditions are proposed to favor growth of floc-foaming organisms. A shorter fill time principally implies a greater number of reactors or a larger equalization volume. Process conditions that promote biological nutrient removal in continuous flow systems can conceivably be simulated in an SBR operation. The wastewater influent can be mixed with the remaining sludge during and after the fill period to provide the anaerobic contact period shown necessary for biological phosphorus removal. Depending on the presence of nitrate, the mixed period can be anoxic or anaerobic. Anoxic conditions entail conversion of nitrate to nitrogen gas through biological denitrification, while anaerobic conditions are a prerequisite for developing enhanced biological phosphorus removal.

The basic feature associated with SBR is that it is structurally impossible to alter the anoxic/anaerobic sequence during the non-aerated phase. The initial reactor volume, V_O and the fill volume in each cycle, V_F may be considered as the significant parameters of the SBR process. V_O is the pool of available N_A for the following anoxic phase. V_O/V_F is the counterpart of the total recycle ratio in conventional continuous nutrient removal systems. V_F is the major parameter, together with T_M/T_P, defining N_{NP}. A high V_O/V_F ratio is usually needed for effective N removal. With a lower V_O/V_F ratio, the N removal efficiency is likely to drop at the expense of additional EBPR (Taşlı *et al.*, 2001).

Intermittent aeration process

A promising alternative to SBR in continuous systems for nutrient removal is the *intermittent aeration process* (IAP), which involves an operating cycle consisting of a sequence of *aerobic* and *non-aerated* periods as shown in Figure 2. Nitrification takes place in the aerated period. The non-aerated period may be adjusted to sustain denitrification and EBPR. The process offers an excellent opportunity for retrofitting existing systems simply by installing a mixing device to the aeration tank.

The intermittent aeration process incorporates two additional parameters, *the aerated fraction*, AF and *the cycle time ratio* defined as the ratio of the cycle time to the hydraulic detention time, (T_C/θ_h). The literature recognizes these two parameters but reports erratic performance results for arbitrarily selected AF and CTR values (Heduit *et al.*, 1990; Hanhan, 1999). Basically, AF, or more precisely (1 – AF) is the decisive parameter for ensuring the necessary aerobic sludge age, θ_{XA} for full nitrification. Furthermore, it sets N_{DP}. CTR is the other key parameter for defining N_{DP} or N_A limiting conditions for systems operation. It was demonstrated that 1/(1 – AF)CTR is the equivalent of the internal recycle ratio in conventional continuous-flow plants (Hanhan *et al.*, 2001). Effective N removal



(a) Anoxic/anaerobic period *(b) Aerobic period*

Figure 2 Schematic configuration of IAP operation for nutrient removal

may be achieved under N_{DP} limiting conditions, where S_{NO} is not totally depleted during the non-aerated phase. This condition is satisfied for

$$CTR \frac{S_{NO}}{(1-AF)\cdot CTR}$$

In fact, short cycle times and optimum aeration periods as low as 10–20 min are recommended in the literature. Rittmann and Langeland (1985) observed high nitrogen removal efficiencies at 10–30 min cycle times. High CTR values induce N_A limitation and consequently creation of an anaerobic phase at the end of the non-aerated zone, providing additional P removal. It should be noted that CTR is defined in relation to θ_h. Therefore, a low θ_h for a given T_C value also favors P removal.

From a practical standpoint, system efficiency depends upon the absence/presence of dissolved oxygen in alternating aerobic and anoxic/anaerobic phases. Dissolved oxygen above 0.5 mgl^{-1} is reported to inhibit denitrification (Nakajima *et al.*, 1984) and similarly low dissolved oxygen concentrations below 0.2–0.5 mgl^{-1} have been observed to affect nitrification rate (Stenstrom and Poduska, 1980; Stenstrom and Song, 1991).

Moving bed biofilm reactors

Moving bed biofilm reactor (MBBR), is a continuous biofilm reactor operated with a low head loss and a high specific biofilm surface area. It offers the advantages of the biofilm process (compact, stable removal efficiency, simplicity of operation) without its drawbacks (channeling and clogging of the medium). There is no need for backwashing or recycling of biomass. In this system, biofilm grows on small carrier elements that move along with the water in the reactor by aeration (aerobic stage) or by mechanical stirring (anoxic/anaerobic stage). The carrier elements are kept in the reactor by means of a sieve. MBBR has all the prerequisites for retrofitting existing overloaded treatment plants into nutrient removal systems.

As for all fixed-film systems, the superiority of MBBR is the ability to sustain a substantially higher biomass in the same reactor volume, as compared to suspended growth activated sludge processes. This feature however is not properly documented to be evaluated for design. The main design parameters of the system are defined as the *filling ratio* and the *specific biofilm surface area*, together with the hydraulic retention time and the overall volumetric loading rates expressed for organic carbon and ammonia nitrogen. Dissolved oxygen concentration and temperature are also reported as important parameters affecting carbon and nitrogen removal efficiencies.

Performance efficiency of MBBR has been investigated in a number of studies in the last decade. Ødegaard *et al.* (1994) tested the system for both domestic sewage and various industrial wastewaters and reported removals of 96% for BOD_7, 94.5% for COD, 97.1% for total P and 41.5% for total N in a small treatment plant designed for 250 persons and operated at an organic loading of 18.8 g COD $(m^2.d)^{-1}$. Similarly, COD removals in the range of 70 to 97.5% were obtained for different industrial wastewaters.

Biofilm-filter-sequencing batch reactor system

The *biofilm-filter-sequencing batch reactor* (BFSBR) was recently developed by Brinke-Seiferth (1998) as a new attached growth technology. This system is operated as moving bed, fixed bed and as a filter and thus provides great flexibility for handling the variations in the quality and treatment requirements of wastewater in sensitive areas. The BFSBR functions in Sequencing-Batch-Mode discontinuously. The first phase is the fill phase of the reactor and the circulation tank. The moving bed phase is operated by recirculating wastewater between the tank and the reactor until the biological treatment of the desired extent. The reactor is filled again by downflow and the effluent is discharged from the bottom so that the system functions both as a fixed bed and a filter in the last phase. The operational scheme of the system is shown in Figure 3.

Highly concentrated wastewater flows are often encountered as a problem for small coastal residential areas. In this context the need for the multi-unit treatment systems yields very high investment and operational costs to ensure the required effluent standards. The BFSBR system enables the co-existence of the various treatment steps in one reactor. The system is capable of tolerating the fluctuations and shock loads with the easy operation and handling scheme. The system results in a significant reduction in treatment plant area due to its variable sequence of operations for carbon and nitrogen removal and filtration. The advantage of the system in terms of nitrification is qualitatively shown in Figure 4 where the nitrification rate versus effluent ammonia nitrogen concentration is compared for moving bed and fixed bed biofilm systems.

Conclusion

Environmental concern for coastal tourist areas necessitates consideration of innovative treatment technology alternatives for nutrient removal, either for retrofitting existing plants or construction of new small plants. For small residential areas, 20 mgl^{-1} total N or a minimum of 40% removal and 2 mgl^{-1} total P or a minimum of 80% removal are recommended as applicable effluent standards. Phosphorus limitations can best be achieved by chemical treatment which also secures effluent stability in terms of conventional parameters. The performance of suspended-growth activated sludge technologies such as *sequencing batch reactor* and *intermittent aeration* for nitrogen removal can be evaluated and controlled in terms of parameters that are meaningful from the standpoint of process stoichiometry and system operation. For biofilm systems such as *moving bed reactor* there is adequate practical experience translated into design parameters for effective N

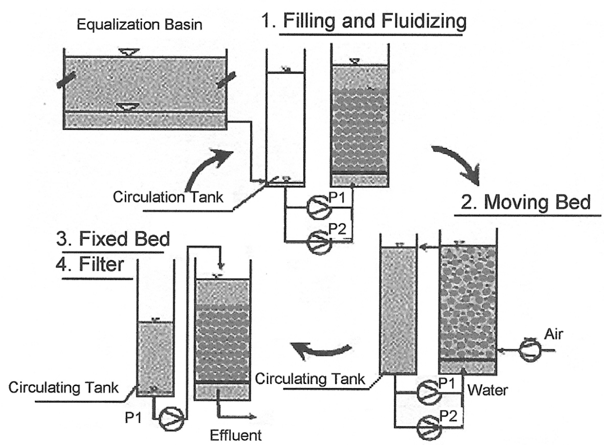


Figure 3 Schematic illustration of BFSBR functions

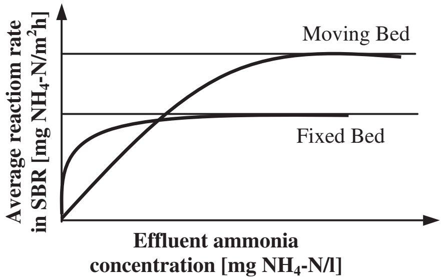


Figure 4 Nitrification rate versus effluent ammonia nitrogen concentration in SBR

removal. As a newly developed system *the biofilm-filter-SBR* technology (BFSBR) has many advantages compared with other suspended-growth and biofilm technologies for its flexibility of operation.

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References

Artan, N., Wilderer, P., Orhon, D., Morgenroth, E. and Özgür, N. (2001). The mechanism and design of sequencing batch reactor systems for nutrient removal – The state of the art. *Wat. Sci. Tech.* **43**(3), 53–60.

Boland, J.J. (1993). "*Management of wastewater in coastal urban areas*" National Research Council, National Academic Press, Washington D.C.

Brinke-Sieferth, S. (1998). Beitrag zur Erhöhung des Reinigungsvermögens und der Flexibilität von Biofilmreaktoren (Festbett, Schwebebett, Filter). PhD Thesis, Hamburg Technical University, Harburg, pp.126 (in German).

EEC L31/1 (1991). Council Directive of 21st May 1991 Concerning Urban Wastewater Treatment, 91/271/EEC.

Hanhan, O. (1999). *Modelling and Design of Nitrogen Removal in Intermittently Aerated Continuous Activated Sludge Systems*. PhD Thesis, İstanbul Technical University, pp. 157 (in Turkish).

Hanhan, O., Artan, N., Orhon, D. and Özgür, N. (2001). Mechanism and design of alternating activated sludge process for nitrogen removal. *Water SA* (submitted for publication).

Heduit, A., Duchene, Ph. and Sintes, L. (1990). Optimization of nitrogen removal in small activated sludge plants. *Wat. Sci. Tech.* **22**(3/4), 123–130.

Morgenroth, E. and Wilderer, P.A. (1998). Sequencing batch reactor technology – concepts, design, experience. *J. CIWEM*, **12**(5), 314–321.

Nakajima, M., Hayamizu, T. and Nishimura, H. (1984). Inhibitory effect of oxygen on nitrification and denitrification in sludge from oxidation ditch. *Wat. Res.* **18**(3), 339–343.

Orhon, D., Tünay, O., Germirli, F., Artan, N., Sözen, S., Taşlı, R., Ubay Çokgör, E. and Görgün, E. (1996). *Wastewater management and appropriate treatment technologies in sensitive areas*. Technical Report, 208 pp, Turkish Technology Development Fund (in Turkish).

Orhon, D., Sözen, S., Görgün, E., Ubay Çokgör, E. and Artan, N. (1999). Technological aspects of wastewater management in coastal tourist areas. *Wat. Sci. Tech.* **39**(8), 177–184.

Ødegaard, H., Rusten, B. and Westrum, T. (1994). A new moving bed biofilm reactor – applications and results. *Wat. Sci. Tech.* **29**(10–11), 157–165.

Rittmann, B.E. and Langeland, W.E. (1985). Similtaneous denitrification with nitrification in single-channel oxidation ditch. *J. Water Poll. Cont. Fed.* **57**(4), 300–308.

Stenstrom, M.K. and Poduska, R.A. (1980). The effects of dissolved oxygen concentration on nitrification. *Wat. Res.* **14**(6), 643–649.

Stenstrom, M.K. and Song, S. (1991). Effects of oxygen transport limitation on nitrification in the activated sludge process. *J. Water Poll. Cont. Fed.* **63**(3), 208–219.

Taşlı, R., Artan, N. and Orhon, D. (2001). Retrofitting SBR systems to nutrient removal in sensitive tourist areas. *Wat. Sci. Tech.* **44**(1), 121–128.