Treatment of municipal wastewater UASB reactor effluent by unconventional flotation and UV disinfection

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Abstract Post-treatment of an UASB reactor effluent, fed with domestic sewage, was conducted using two-stage flotation and UV disinfection. Results were compared to those obtained in a parallel stabilisation pond. The first flotation stage employed $5-7.5\,mg\,L^{-1}$ cationic flocculant to separate off more than 99% of the suspended solids. Then, phosphate ions were completely recovered using carrier flotation with $5-25\,mg\,L^{-1}$ of Fe ($FeCl_3$) at pH 6.3–7.0. This staged flotation led to high recoveries of water and allowed us to separate organic matter and phosphate bearing sludge. The water still contained about 1×10^2 NMP/100 mL total coliforms, which were removed using UV radiation to below detection levels. Final water turbidity was <1.0 NTU, COD $<20\,mg\,L^{-1}$ O_2 and $71\,mNm^{-1}$, the liquid/air interfacial tension. This flotation-UV flowsheet was found to be more efficient than the treatment in the stabilisation pond and appears to have some potential for water reuse. Results were discussed in terms of the biological, chemical and physicochemical mechanisms involved.

Keywords Advanced flotation; municipal wastewater; UASB reactor; wastewater treatment

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Introduction

In warm climate countries, the high rate anaerobic process presents satisfactory treatment performance, even for diluted domestic wastewater, with many advantages, including reduction of green house gas emissions, energy gains, reduced excess sludge productions, stabilised sludge, and low space requirements (van Lier and Huibers, 2004). In particular, the upflow anaerobic sludge blanket (UASB) reactor is a reliable and simple technology for domestic sewage treatment (van Haandel and Lettinga, 1994).

Despite all those advantages, anaerobic processing cannot be considered as an unitary (one-step) treatment system, since its effluent requires further stages to improve water quality enough to reach discharge or reuse standards required by the Brazilian environmental standards (Chenicharo and Machado, 1998). Anaerobic systems effluents may still contain residual organic matter, nutrients and pathogens, which must be removed in a post-treatment stage (van der Steen *et al.*, 1999).

In the last decade, the use of high rate anaerobic reactors integrated to pond systems has achieved increasing relevance for domestic wastewater treatment in Brazil (Luduvice *et al.*, 2000; Cavalcanti, 2003). When efficient pre-treatment is used, the concentrations of organic matter and suspended solids are reduced to levels whereby the pond works more like a maturation pond, leading to bacterial decay (van Haandel and Lettinga, 1994).

In spite of this satisfactory pathogens decay, in ponds, the ever increasing presence of algae and residual phosphate in the final effluent might reduce the efficiency due to eutrophication effects (Mara *et al.*, 2001). Hence, the more accepted flowsheet for simultaneous algae and phosphate removal appears to be based on physicochemical methods, with emphasis on separation by dissolved air flotation using a phosphate carrier (Simmonds, 1973; Bare *et al.*, 1975; Edzwald, 1993; Monteggia and Tessele, 2001; Tessele *et al.*, 2004a).

Post-treatment of UASB reactors effluent using flotation

The conventional coagulation, flocculation and dissolved air flotation (DAF), using $FeCl_3$ and cationic polymer, presents fairly high efficiency in improving water quality from anaerobic reactor effluents (Penetra *et al.*, 1999; Reali *et al.* 2001).

Yet, this procedure results in significant volumes of mixed organic and inorganic sludge which may lead to complex post-sludge treatment either to reuse or dispose it (Tessele *et al.*, 2004b). This work presents an alternative for the sustainable domestic wastewater treatment, combining optimised biological and physicochemical processes.

When nutrient recovery is considered, the proposed two-stage flotation process brings the advantage of the production of two separated sludges, one containing biomass and the second containing a mixture of ferric phosphate and hydroxide. Results proved that, following this alternative flowsheet (selective process), it was possible to obtain fairly good quality water with low organic matter and phosphate in separated sludge.

Experimental set up

The study was conducted, during 20 months, in a pilot plant ($50\,m^3\,d^{-1}$), treating domestic wastewater provided by the municipal sanitation company (DMAE) at Porto Alegre (South Brazil). The studied flowsheet (Figure 1) comprises an up flow anaerobic sludge blanket reactor, a stabilisation pond, two-stage flotation (including the novel FF process and a high rate DAF-dissolved air flotation) and a final UV disinfection stage.

The pilot plant integrating all processes started up in September 2002. Operational parameters, weekly monitored, for the biological steps (UASB and stabilisation pond), were: pH, ORP, alkalinity, temperature, COD, NH_4-N, PO_4, TSS (*Standard Methods*, 1995). Faecal and total coliforms were measured twice a month. The flotation tests were performed in a semi-continuous regime, with running times of approximately 6 h. Table 1 summarises general data of the staged process and their functions.

The two-stage flotation system

The two-stage flotation system was designed to treat the UASB effluent up to $50\,m^3\,d^{-1}$. Both columns were constructed in 0.5 mm acrylic, with 0.25 m diameter and 4 m high.

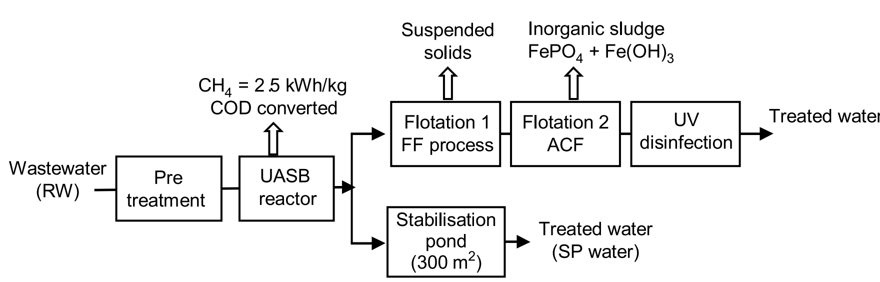

Figure 1 Schematic flowsheet of the pilot-scale wastewater treatment plant. Stabilisation pond runs as a parallel and alternative process to the two-stage flotation (TSF) system

Table 1 Pilot-scale wastewater treatment system

Step	General data	Function	Applied loadings	By-product
Anaerobic reactor	UASB, 15 m^3	COD removal, rough disinfection	0.8 kg COD m^{-3} d^{-1}	Stabilised anaerobic sludge and biogas
Stabilisation pond (SP)	300 m^2, 0.8 m depth	COD, NH_4^+-N and pathogens removal	36 kg NH_4^+-N ha^{-1} d^{-1}	Atmospheric emissions and bottom sludge
Flotation 1 (F1)	4 m height, 0.25 m diameter, 0.03 m^2 section	Algae and TSS removal	120 kg SST m^2 d^{-1} HLR = 65 m h^{-1}	Organic sludge (anaerobic biomass)
Flotation 2 (F2)	4 m height DAF, 0.25 m diameter, 0.04 m^2 section	Phosphate removal	9.7 kg PO_4 m^2 d^{-1} HLR = 51 m h^{-1}	Inorganic sludge $FePO_4 + Fe(OH)_3$
Ultraviolet system	Medium pressure, high intensity	Oxidation and disinfection		No external by-products

The first stage was to remove suspended solids by the FF (flocculation–flotation) process. This is a novel flotation technique, which was originally developed for oil removal (Rubio, 2003, Rosa and Rubio, 2005). The basis is the formation of aerated flocs, in the presence of high molecular weight polymer under high shear. The second-stage flotation was used to remove phosphate ions by precipitation and coagulation with Fe^{+3} ($FeCl_3$) and also as a polishing step, separating the residual fine solids. The removal of phosphate ions proceeds through adsorbing colloidal ($Fe(OH)_3$) flotation (ACF) adjusting medium pH (after $FeCl_3$ addition) between 5.5 and 6.5.

Results and discussion

The raw wastewater feeding the pilot plant was quite diluted, due to infiltrations of urban drainages on the collection network. Average COD was around 90 mg O_2 L^{-1}, with peaks in order of 400 mg O_2 L^{-1} during dry periods. The UASB reactor was inoculated with 1% p/p sludge from a gelatine manufacturer wastewater treatment.

UASB reactor operation

Because the pilot plant started up during spring (average water temperature of 20 °C), COD removal by the UASB reactor was noticeable in the very first days of operation (Figure 2). Yet, gas production was observed after approximately 60 days of operation.

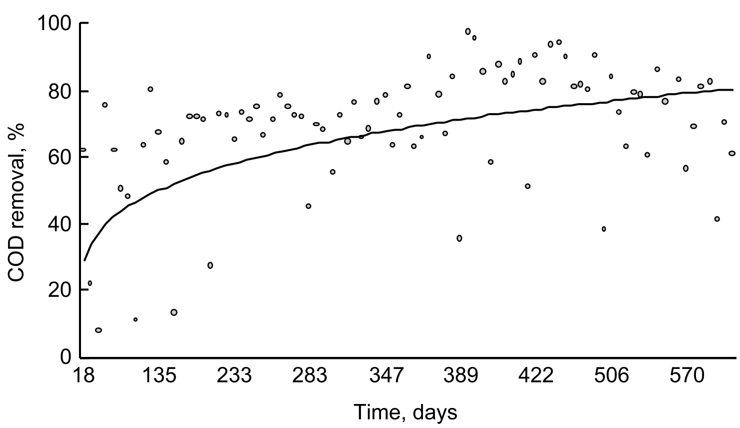

Figure 2 Chemical oxygen demand removal efficiency in the anaerobic reactor (UASB)

Stabilisation pond performance

During summer time (water temperature ranging between 28 and 33 °C) the stabilisation pond presented significant removal of ammoniacal nitrogen (Figure 3), giving values below $3\,mg\,L^{-1}$ for NH_4-N. In those hot days, the pH increased to the range 10–11, resulting in elevated reductions of NH_3 concentration via gas stripping (Powers, 1987).

Figure 3 allows to conclude that in sub-tropical regions, where temperature changes are very common, stabilisation ponds may not be as reliable as expected for NH_4-N removal. In winter time, when average water temperatures may reach 17 °C, alkalinity production decays due to the decrease in algae activity (less CO_2 consumption), leading to pH values in the range 6–7.

Two-stage flotation (TSF) system operation

The TSF system was operated in semi-continuous regime, during 6–8 hours each day. Process efficiency was monitored in situ by turbidity. During the experiments, chemicals concentrations varied from 0 to $25\,mg\,L^{-1}$ and 0 to $15\,mg\,L^{-1}$, for Fe^{+3} and flocculant, respectively. In the FF process (F1), the air flow rate was about $3\,NL\,min^{-1}$. In DAF (F2), recycle ratio was kept at 15% (volume ratio), at a saturation pressure $4.5\,kgf\,cm^{-2}$ and air flow rate of $0.9–1.2\,NL\,min^{-1}$.

Flotation 1 produced a high solid concentration (up to 11%) sludge which is mainly composed of anaerobic biomass and flocculant. Rising velocities were found to be very rapid with the formed aggregates very resistant to shear, allowing the system to attain $65\,m\,h^{-1}$ hydraulic loading rate, with residence time of 3.8 min, including the coagulation zone.

The flocculation-flotation system (FF) is composed of a turbulent "flocculator" to generate aerated polymeric flocs which feeds, in the present case, a column solid/liquid separation device. The basic concept is that of a contact reactor (zigzag flocculator) and a separator. The resulting flocs are rapidly formed inside the flocculator, are very light because of the trapped air and are generated only in the presence of high molecular weight polymers, bubbles (from the injected air), high shearing forces and a high head loss (Rosa, 2002, Rubio, 2003, Rosa and Rubio, 2005).

Main mechanisms and phenomena involved in the FF technique include: small bubble formation and their rapid occlusion (entrapment) within flocs; nucleation of bubbles at floc/water interfaces; and bubbles entrainment.

The aerated flocs looked like filamentous, elongated and "sticky" (plastic-like) units, and in the flocculator, plug flow type of mixing (flocculation) instead of perfect has been

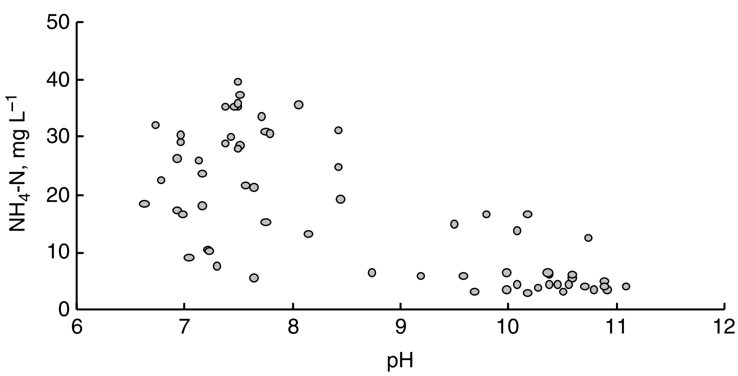

Figure 3 Ammoniacal-nitrogen concentration and pH changes in the stabilisation pond

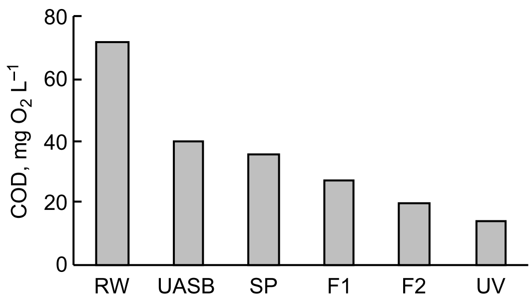

Figure 4 Comparative COD values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

observed. In the present flotation column separator the flocs float within seconds, as large units (some millimetres in diameter) having very low densities.

The second flotation stage (F2) aimed at removing both phosphate and the residual fine solids. The phosphate ions were co-precipitated and adsorbed onto the carrier colloidal ferric hydroxide precipitates which are formed from the hydrolysis of Fe^{+3} from the $FeCl_3$. Optimal coagulant dosage was dependent on the initial phosphate concentration and amounted to $15\,mg\,L^{-1}$ Fe^{+3} and medium pH 6.3–7 (no pH adjustment was required).

The phosphate ions might either precipitate as ferric phosphate with the soluble ferric ions or adsorb by chemical interaction with the ferric surface sites (adsorbing colloidal flotation). Coagula and precipitates are fragile aggregates, requiring mild, non-turbulent hydrodynamic conditions at the solid–liquid separation. This is accomplished using dissolved air flotation, with microbubbles (30–80 microns diameters) (Rubio *et al.*, 2002, Rodrigues and Rubio, 2003). DAF was performed in a column and the process hydraulic loading rate reached about $49\,m\,h^{-1}$, or 2 minutes residence time. This loading capacity is much higher than conventional, (rectangular) DAF circuits ($6–10\,m\,h^{-1}$).

After flotation 2 (F2), the effluent was disinfected with a low pressure UV lamp, operated at constant conditions, with a theoretical UV dosage of $25\,mJ\,cm^{-2}$ (according to the manufacturers). The results obtained (Figures 4–9) shows that the UASB-TSF-UV combination is more efficient than the UASB-SP option. Thus, the produced water presents low values in COD, phosphate ion concentration, turbidity and the air/water surface tension is as high as that of tap water.

The removal of ammoniacal nitrogen was not satisfactory accordingly to the Brazilian emission standards (Brasil, 1986). However, when water reuse is taken into account,

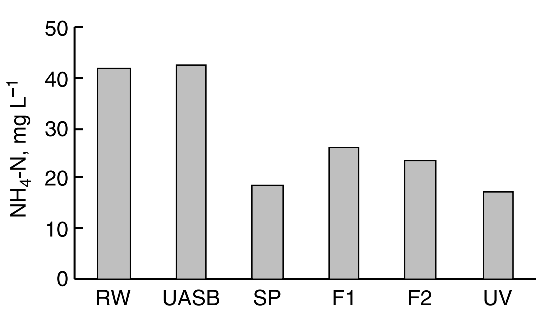

Figure 5 Comparative NH_4-N values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

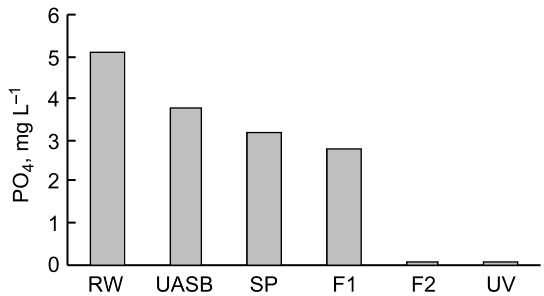

Figure 6 Comparative soluble PO_4 values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

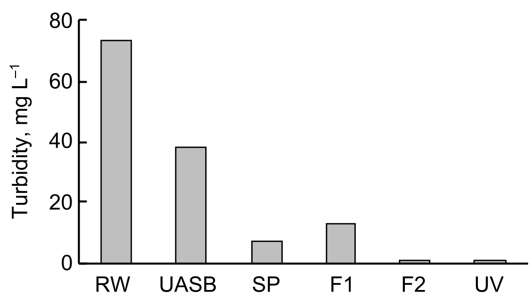

Figure 7 Comparative turbidity values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

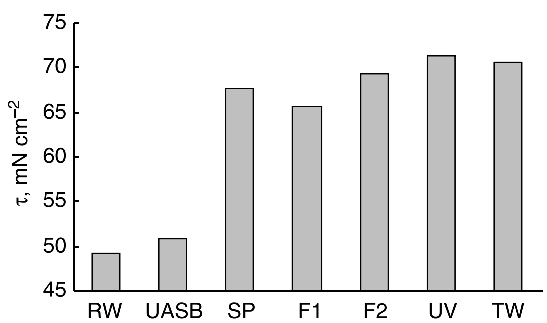

Figure 8 Comparative interfacial tension values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

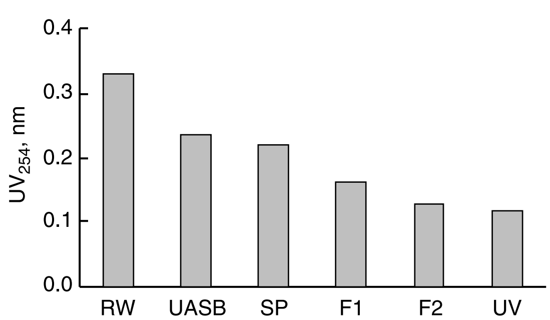

Figure 9 Comparative UV_{254} values in the staged treatment. RW = raw wastewater; UASB = after UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

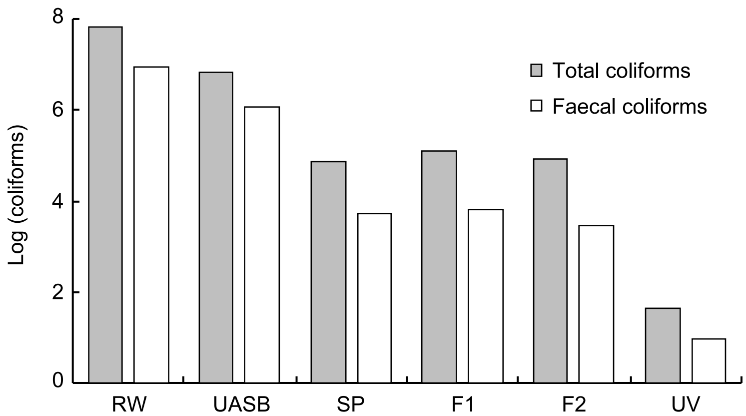

Figure 10 Comparative total and faecal coliforms in the staged treatment. RW = raw wastewater; UASB = UASB reactor; SP = after stabilisation pond; F1 = after flotation 1; F2 = after flotation 2 and UV = after UV disinfection

many uses are allowed with the average concentration reached ($<$20 NH_4-N mg L^{-1}). The possible uses of the treated wastewater would be in agricultural and landscape irrigation, groundwater recharge, environmental and recreational uses, industrial water, washing of, among others, vehicles, tanks, hangars (US EPA, 2004). Coliforms concentrations (Figure 10) were below the emission standards and its removal may be optimised via the UV dosage adjustment, if needed for more strict uses.

Conclusions

The 20 months operation cycle showed that the proposed staged process, treating an UASB effluent, produced, at high hydraulic rates, good quality water and two different sludges: the first containing organic matter and the second containing mainly phosphates. The flotation techniques were very efficient (high loading rates) for the solid/liquid separation (high split) and nutrient removal. In addition, the scheme proposed here yielded better water quality, when compared to the stabilisation pond effluent and appears to have a good potential in domestic water treatment and reuse. The possible uses of the treated wastewater would be in agricultural and landscape irrigation, groundwater recharge, environmental and recreational uses, industrial water, among others.

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References

Bare, W.F., Jones, N.B. and Middlebrooks, J.E. (1975). Algae removal using dissolved air flotation. *JWPCF*, **47**(1), 153–169.

Brasil (1986). Conselho Nacional do Meio Ambiente. Resolução CONAMA No 20 de 18 de junho de 1986.

Cavalcanti, P.F.F. (2003). Integrated application of the UASB reactor and ponds for domestic sewage treatment in tropical regions. Doctoral Thesis, Wageningen Agricultural University, Wageningen, The Netherlands, 139 p.

Chenicharo, C.A.L. and Machado, R.M.G. (1998). Feasibility of the UASB/AF system for domestic sewage treatment in developing countries. *Wat. Sci. Tech.*, **38**(8–9), 323–332.

Edzwald, J.K. (1993). Algae, bubbles, coagulants, and dissolved air flotation. *Wat. Sci. Tech.*, **27**(10), 67–81.

Luduvice, M., Neder, K. and Pinto, M.T. (2000). Utilização de lagoas rasas no pós-tratamento de efluentes de reatores anaeróbios de fluxo ascendente (UASB). *Pós-Tratamento de efluentes de reatores anaeróbios – Coletânea de artigos técnicos* vol 1, FINEP/PROSAB pp. 43–56.

Mara, D., Pearson, H., Oragui, J., Arridge, H. and Silva, S.A. (2001). Research Monograph No. 5: Development of a new approach to waste stabilization pond design. University of Leeds, Leeds, UK.

Monteggia, L. and Tessele, F. (2001). Remoção físico-química de algas e fósforo de efluentes de lagoas de alta taxa. In: Chenicharo, C. *Pós-Tratamento de efluentes de reatores anaeróbios – Coletânea de artigos técnicos* – vol. 2, 97 – 102, FINEP/PROSAB, in Portuguese.

Penetra, R.G., Reali, M.A.P., Foresti, E. and Campos, J.R. (1999). Post-treatment of effluents from anaerobic reactor treating domestic sewage by dissolved-air flotation. *Wat. Sci. Tech.*, **40**(8), 137–144.

Powers, S.E. (1987). Modeling and aerated bubble ammonia stripping process. *JWPCF*, **94**, 92–100.

Reali, M.A., Penetra, R.G. and Carvalho, M.E. (2001). Flotation technique with coagulant and polymer application applied to the post treatment of effluents from anaerobic reactor treating sewage. *Wat. Sci. Tech.*, **43**(8), 205–212.

Rodrigues, R.T. and Rubio, J. (2003). New basis for measuring the size distribution of bubbles. *Miner. Eng.*, **16**(8), 757–765.

Rosa, J.J. (2002). Tratamento de efluentes oleosos por floculação pneumática em linha e separação por flotação – Processo FF. PhD Thesis, PPGEM-Universidade Federal do Rio Grande do Sul, Porto Alegre – Brazil, 145p. (in Portuguese).

Rosa, J.J. and Rubio, J. (2005). The FF (flocculation – flotation) process. *Miner. Eng.*, in press.

Rubio, J., Souza, M.L. and Smith, R.W. (2002). Overview of flotation as a wastewater treatment technique. *Miner. Eng.*, **15**(3), 139–155.

Rubio, J. (2003). Unconventional flocculation and flotation. In: *Flotation and Flocculation: From Fundamentals to Applications*, Proceedings from Strategic Conference and Workshop, Hawaii, 2002, Edited by J. Ralston, J. Miller and J. Rubio, pp. 17–32.

Simmonds, M.A. (1973). Experience with algal blooms and the removal of phosphorus from sewage. *Wat. Res.*, **7**, 255–264.

Standard Methods for the Examination of Water and Wastewater (1995). 19th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Tessele, F., Monteggia, L.O. and Rubio, J. (2004a). Selective nutrient and water recovery from municipal wastewater combining advanced treatment techniques. *International Conference on Wastewater Treatment for Nutrient Removal and Reuse*. Pathumthani, Thailand, January 26–29, vol. 1, pp. 180–187.

Tessele, F., Da Rosa, J. and Rubio, J. (2004b). Avanços da flotação no tratamento de águas, esgotos e efluentes industriais – Parte I: Fundamentos e mecanismos. Saneamento Ambiental, n. 102 Jan/Fev, 30–36.

US EPA (2004). U.S. Environmental Protection Agency – EPA/625/R-04/108 September 2004 *Guidelines for Water Reuse*.

Van der Steen, P., Brenner, A., Joost, M., van Buuren, M. and Oron, G. (1999). Post-treatment of UASB reactor effluent in an integrated duckweed and stabilization pond system. *Wat. Res.*, **33**(3), 615–620.

Van Haandel, A.C. and Lettinga, G. (1994). *Anaerobic Sewage Treatment; A Practical Guide for Regions with a Hot Climate*, John Wiley and Sons, Chichester, England.

Van Lier, J.B. and Huibers, F.P. (2004). Agricultural use of treated wastewater: the need for a paradigm shift in sanitation and treatment. *Risk Assetment of Re-use on Groundwater Quality*. Proceedings of symposium HS04 held during IUGG2003 at Sapporo, Japan, July. 2003. IAHS Publ. 285.