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A pilot plant for the treatment of lemon industry wastewater

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Abstract A pilot plant with a 10-m^3 airlift reactor, a settler and a 300-m^3 pond were developed for the treatment of the lemon processing industry wastewater. The aim of this work is to evaluate reactor and pilot plant performance. We worked in a continuous system with activated sludge, using wastewater microorganisms and testing the most important parameters of the process (HRT, SRT, F/M, VRC, K_{La}). An outflow settler tube added to the reactor design increased sludge concentration in 25% at 200–500 l/h flow rates. At 600–800 l/h flow rates sludge concentration was 10–15% higher. Volumetric removal capacity of the suspended solid in the reactor was more than 6 kg BOD_5/m^3 day with lesser than 17 h hydraulic retention time. Maximum BOD_5 removal was 92% with 200 l/h flow. The reactor had a good mixing performance and a satisfactory volumetric mass transfer coefficient. Efficient reactor design made foam disposal easy. The effluent came out of the pond with DBO = 50 mg/l, i.e. a total BOD removal of 99% with 600 l/h flow. The pond also had a very important function: it completely eliminated reactor produced biomass by using a natural degradation process.

Abbreviations

SS	Suspend solid
Usg	Superficial air velocity
SVI	Sludge volumetric index
VRC	Volumetric removal capacity
K_{La}	Mass transfer coefficient
SRT	Sludge retention time
VSS	Volatile suspended solid
HRT	Hydraulic retention time
AFR	Air flow rate
F/M	Food to microorganism ratio

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Introduction

The activated sludge process is the most widely used biological method for domestic and industrial wastewater treatment. It transforms dissolved organic pollutants into biomass, carbon dioxide and water.

Airlift reactor applications are found in the literature for domestic and industrial wastewater treatment (Jiamping et al. 2005; Xianling et al. 2005; Meng et al. 2004).

Oxygen transfer plays an important role in the aerobic treatment of wastewater; the energy requirement for optimal oxygen transfer in the activated sludge process is around 70% of the total operating cost of the wastewater treatment plant. Consequently, mixing is a fundamental factor to be considered when designing and running an aerobic reactor (Hsium and Wu 1995). When producing juice, essential oil and dehydrated peel, the lemon industry generates a large volume of liquid effluents (340 l/lemon ton) with a total BOD_5 of about 6,000 mg/l.

Bibliographic information on aerobic treatment of these effluents has not been found. We consider that it is important to work on the design of a treatment process suitable to the particular characteristics of the lemon processing industry.

The purpose of this work is to evaluate reactor and pilot plant performance in the wastewater treatment at a lemon processing plant.

A pilot plant was designed to minimize power consumption and maximize kg BOD_5 degraded/(m^3 day). The system includes a modified airlift reactor with an overflow outlet pipe that also works as a settler to reduce biomass leakage and keep a high microorganism concentration. Work was carried out in a continuous system with sludge activated at different retention times and the most important variables were studied. The treated effluent that came out of the reactor went to a settler that separated clear liquid with low BOD from the one that had the activated sludge which were sent to an oxidation pond sown with two fish varieties.

Materials and methods

This work was carried out at Citromax saci, a lemon processing plant in Tucumán, Argentina.

The schematic diagram of the pilot plant is shown in Fig. 1. The airlift reactor is 1 m in diameter and 12 m high, with an inner cylinder 75 cm in diameter. There are two ports for pH and DO sensors. Air is sparged into the bottom of the reactor through four diffusers made with a neoprene membrane. The upper 2 m high part of the bioreactor widens to 1.50 m in internal diameter. The reactor outflow pipe is 22 cm in diameter at 50° angle from the ground. It works as an internal settler to prevent reactor biomass loss and it connects with another tube through which air and foam come out of the reactor and are discharged into the settler (Fig. 1). The settler is an 8-m^3 cylinder with a conic base. The 1 m × 10 m × 30 m pond was lined with a 300 μ plastic membrane. It was sown with 40 Cyphocharax spilotus and 100 Astyanax asuncionensis specimens. The sediment-feeding habits of the first and omnivorous diet of the second made them suitable to create a food chain by eating sludge together with a variety of organisms that naturally grow in the pond.

Microorganisms and preculture

The microorganisms used were those that came with the wastewater. They were cultivated in the same liquid enriched with nitrogen and phosphorus inorganic salts to maintain a BOD_5 (100)-N(5)-P(1) ratio.

Work was begun with a batch system; when the culture reached pH 8 and a microorganism concentration of 2 g/l, continuous feeding started with wastewater.

Wastewater composition

Average wastewater composition for the experiment was COD 6,850 mg/l; BOD_5 5,970 mg/l; pH 3.2; SS 3.75 mg/ml; DO 1 mg/l.

Operational parameters

Biochemical oxygen demand (BOD_s), volatile suspended solids (VSS), dissolved oxygen (DO) and pH were monitored in accordance with the standard methods for the examination of water and wastewater published by APHA, AWWA and WPCF (Eaton et al. 1995).

Other parameters were calculated as follows:

$$\mathrm{SRT} = \mathrm{VSS\ effluent} \times Q/\mathrm{VSS\ reactor} \times V$$
$$\mathrm{SVI} = (\mathrm{Volume\ settled/TSS}) \times 1,000$$
$$\mathrm{VRC} = \mathrm{BOD_5\ removed} \times Q/V$$

Mixing time: it was used to measure liquid mixing. A solution of sodium chloride was employed as the tracer for a pulse test. The tracer was added from the reactor top. Mixing time was determined as the time required for the

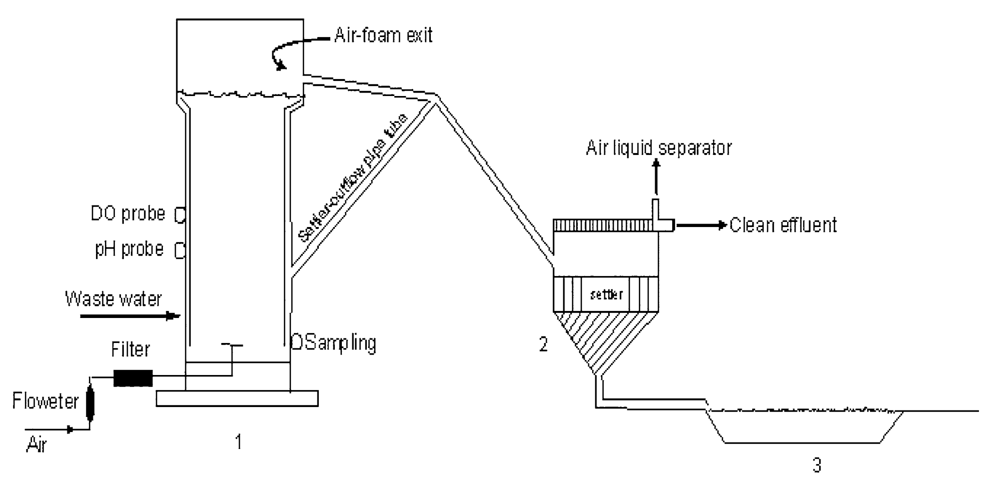

Fig. 1 Schematic diagram of the pilot plant. *1* airlift reactor; *2* settler; *3* lagoon

response curve to reach 95% of the final value and to remain within the limit (Prandit and Joshi 1984).

Mass transfer coefficient: it was determined by using the dynamic method (Atkinson and Mavituna 1983).

All samples were analyzed in triplicate. The R^2 coefficients in Figs. 2, 3, 4 and 5 show that the *y* total viability percentages are acceptably explained by the respective independent variables.

Results and discussion

High AFR values improve contact between the solid and gaseous phases; these effects are fundamental to achieve an efficient oxidation of the organic matter in the bioreactor since aerobic microorganisms need oxygen as an electronic acceptor. AFR influence on oxygen concentration in the reactor is seen in Fig. 2. As airing increases so do shear forces that may jeopardize cell integrity, but this effect is much lower than the one obtained when mixing is performed with a mechanical shaker.

K_{La} and mixing time values with reference to superficial air velocity are shown in Fig. 3. The data obtained on K_{La} are higher than the results published by Deckwer et al. (1974) and were up to 90% higher than data reported for bubble columns (Krishna et al. 1991). Mixing time decreased and mass transfer coefficient was higher with increasing superficial air velocity.

HRT is one of the most important variables influencing residual BOD: when reactor feedflow increases so does F/M ratio while removed BOD% decreases. Figure 4 shows HRT variables of BOD removal % at Usg of 5 cm/s. At HRT of 2 days, BOD residual % is less than 10%.

Gas holdup data of the reactor increases with AFR occupying 16.28% of reactor volume with an AFR of 5 m^3 air (m^3/h). BOD_5 maximum removal percentage (92%) was obtained with 200 l/h flow rate. With an 800 l/h flow, equivalent to an HRT of 0.50 h, the percentage decreased to 50%. The highest VCR value was 6.14 kg/(m^3 day) with an HRT of 0.58 days. Lower values were reported in the treatment of city effluents with airlift reactors (Roessink and Eikelboom 1997).

Control runs for various operational parameters of the reactor working with wastewater from a lemon processing plant are shown in Table 1. As reactor feedflow increases, the F/M ratio and residual BOD grow proportionally while VRC rises up to a 700 l/h flow and then it begins to decrease.

SRT was always higher than HRT due to the reactor settler. This is because there is a 5–25% variation between reactor VSS and the VSS in the liquid coming out of it,

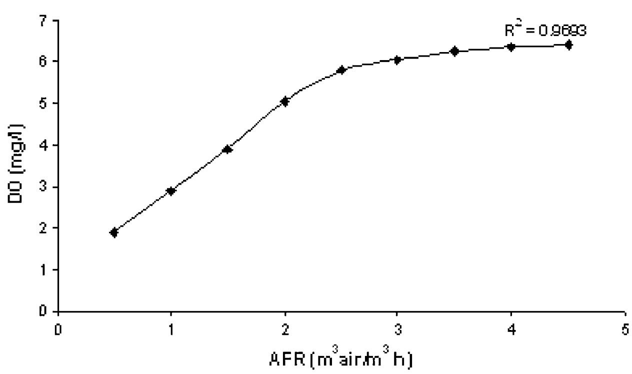

Fig. 2 Relation between AFR and DO

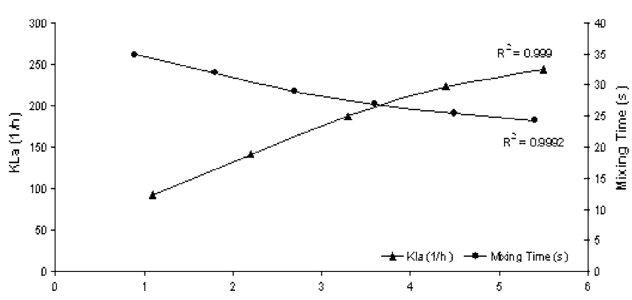

Fig. 3 Mass transfer coefficient and mixing time versus superficial air velocity

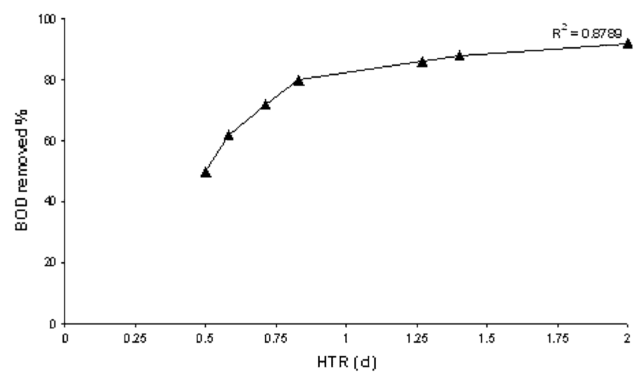

Fig. 4 BOD removed % versus hydraulic retention time

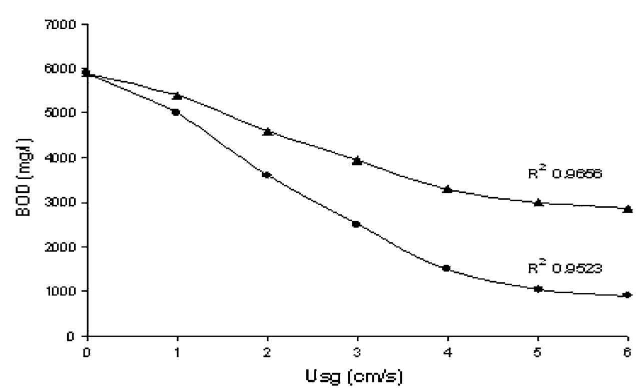

Fig. 5 Relation between Usg and BOD for two HRT values: (*filled circle*) 2.08 and (*filled triangle*) 0.50 days

Table 1 Values of the operational parameters

Q (L/h)	BOD_5 residual (mg/L)	F/M ($kgBOD_5$/kgVSS day)	kg BOD_5 (removed /m^3 day)
200	472	0.67	2.60
300	590	0.94	3.81
400	767	1.30	4.87
500	1,180	1.70	5.66
600	1,652	2.29	6.12
700	2,242	3.09	6.14
800	2,950	4.19	5.66

depending on feedflow. SRT is one of the important factors exerting great effect on the airlift bioreactor performance.

At flow rates over 600 l/h settling problems appeared: SVI values were higher than 500 mg/l, and VSS diminished in the reactor.

When compared with the conventional airlift reactor, the proposed reactor with a settling outflow pipe reached a sludge concentration 25% higher at flow rates between 200 and 500 l/h and a concentration 10–15% higher at flow rates between 600 and 800 l/h.

Mass transfer between phases gradually improved when increasing Usg, resulting in the decrease of residual BOD_5.

Figure 5 shows that BOD in the reactor decreases when Usg increases and that reduction depends on HRT. Higher superficial air velocity leads to more sufficient DO, which has a positive effect on the removal of BOD.

Biomass average produced per kg of removed BOD_5 was 0.52 kk^{-1}.

There were no foam problems in the reactor and the addition of antifoam compounds was not necessary since the air and foam outflow systems worked successfully.

When working with feedflows up to 600 l/h, the BOD at the pond discharge was not higher than 50 mg/l. A 45% of the volume entering the settler was poured as a clear liquid with a BOD lower than 150 mg/l, while the remaining 55% with the activated sludge formed by biomass and residual lemon pulp was discharged into the pond. The intake and outflow channels are at opposite ends of the pond. It works like a piston flow reactor where BOD decreases as it leaves the feed point. The food chain naturally formed was complemented with the fish. The results obtained by feeding them with the activated sludge from the pilot plant have already been published (Lopez et al. 2005) as well as the paper on the growth of ciliated organisms in an effluent treatment process for the citrus industry (Juarez et al. 2002).

Conclusion

It may be concluded that the pilot plant with an airlift reactor works efficiently in the citrus industry residual water treatment. The settler outflow tube added to the reactor obtained a higher microorganism concentration than did the conventional airlift and no biomass recycling was necessary. The principal process variables were thus considerably improved.

Effluent characteristics (high BOD and low pH) limit working with lower HRT values. The optimum operating condition of the reactor was selected as pH 7.6; HRT 1.5 days and Usg 4 cm/seg. HRT value was selected taking into consideration the initial capital investment and operating costs.

The reactor had a good mixing performance. The gas space at the top of the reactor allowed foam to break or to flow out through the reactor side tube.

It is not necessary to adjust effluent pH in this process; the reactor is fed at the original pH and is neutralized by the microbial metabolic activity.

Outflow pH was adequate to be discharged in aquifer beds (between 7.3 and 7.8).

The oxidation pond reduced effluent BOD and biomass by means of a food chain that progressively transforms organic matter into CO_2 and H_2O.

The optimum flow rate for the pilot plant was 600 l/h, with a VCR of 6.12 kg/(m^3 day).

The proposed process not only achieves a high percentage in BOD reduction; it also solves the problem of final disposal of the sludge by using a natural degradation process.

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