Characterization, management and treatment of wastewater from white wine production

B. Fernández*, I. Seijo, G. Ruiz-Filippi***, E. Roca*, L. Tarenzi**** and J.M. Lema***

*Department of Chemical Engineering, Univ. Santiago de Compostela, Spain
(E-mail: *belen.fernandez@irta.es*)

** 3R Ingeniería Ambiental S.L., Spain

*** School of Biochemical Engineering. Pontificia Universidad Católica de Valparaíso, Chile

**** ISEA S.R.L., Italy

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Abstract During a 16 months period, the characteristics of the wastewaters generated in a Rias Baixas winery (Spain) producing white wine were determined: The characterization study showed that white wine wastewater had an average CODt and TSS values of 7.3 and 5.2 kg/m^3, respectively being the ratio wastewater/wine produced of about 1.6–2.0 L/L and the ratio between load pollution and produced wine of 9.7 kg$_{CODt}$/m$^3_{WINE}$. A strategy for the management of wastes and wastewaters allowed for an important reduction of a 55% of wastewater generation to be achieved. In order to select a suitable technology for the treatment of wastewaters two configurations were tested at pilot scale: i) An Anaerobic Filter (AF) of 430 L followed by an activated sludge unit of 510 L and: ii) one activated sludge unit of 510 L. The results showed that the anaerobic/aerobic configuration was more flexible as it adapted quickly to the different loads and flows produced during the different phases through the year. Besides it allowed higher COD removals (98.5–99.2%) to be achieved and proved to permit a quicker re-start up after starvation periods.

Keywords Aerobic treatment; anaerobic treatment; effluent management; pilot plant; winery wastewater

Introduction

The Spanish wine industry applies the "Origin Denomination" (O.D.) concept, which characterises wines based on climate, process production and specific grape varieties inside a well defined geographic region. Different O.D. types of wine are produced in Galicia, in the northwest of Spain. One of the most important white wines is "Rías Baixas O.D.", which comprises 156 wineries with a total production of 9 million litres in year 2000. More than 50% of the wineries are small having a production lower than 1,000 hL$_{WINE}$/y. A Galician white wine winery, with a production of 1,500 hL/y has been selected as a representative model of "Rías Baixas O.D."

Owing to bad housekeeping practices and the lack of knowledge regarding waste pollution, important environmental problems need to be solved within the winery industry considering that wastes or byproducts comprise a 20–30% in weight of produced wine (AWARENET, 2001).

Several treatment alternatives for winery wastewater have been studied and applied. Conventional systems are activated sludge reactors (AS), SBR systems and aerobic biofilm systems such as RBC (Andreottola *et al.*, 2006). Systems operated under anaerobic conditions, such as UASB or hybrid anaerobic filters (AnF), have also been proposed. These technologies permit the operation at increased loading rates and avoid washing out of biomass (Andreottola *et al.*, 1997).

The objectives of this work were the characterization of the wastewater, the definition of a strategy for management of wastes and wastewaters and the comparison of two

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options (anaerobic/aerobic vs. aerobic) for the treatment of wastewater produced during "Rías Baixas O.D." white wine production process.

Materials and methods

Wastewater characterization and analysis

Wastewater flow was determined from water consumption and by direct measurement during the different operations. Composite samples were collected on different days representative of each phase of the process during the year. Samples were maintained refrigerated below 4 °C until analysis: pH, Total and Soluble Chemical Oxygen Demand (CODt, CODs), Total and Volatile Suspended Solids (TSS, VSS), Nitrogen (TKN) and Phosphate (P). All parameters were determined using Standard Methods (APHA-AW-WA-WPCF, 1995). Aerobic biodegradability was determined based on biological oxygen demand assay at 5 days (BOD_5) and anaerobic biodegradability was determined based on method of Soto *et al.* (1993).

Pilot plant

A flexible and modular pilot plant, comprising an anaerobic hybrid UAF-UASB reactor with 429 L and two activated aerobic sludge units with 510 L each, was designed and constructed by 3R and ISEA S.R.L. (Figure 1). Seven different tanks provide enough flexibility to operate the plant at different configurations and different working conditions (residence time, organic loading rate, nutrient addition, etc). Two basic configurations were chosen: configuration (I) comprising an Anaerobic Hybrid Filter (AnF) and Activated Sludge (AS1), and configuration (II) with an Activated Sludge (AS2).

Results and discussion

Characterization and management of winery wastewater

Winery wastewater sampling was focused on the various winery production periods throughout the year: vintage, vinification, stabilisation and bottling. Total volume, flow and characteristics of wastewater produced by the winery are summarised in Figure 2.

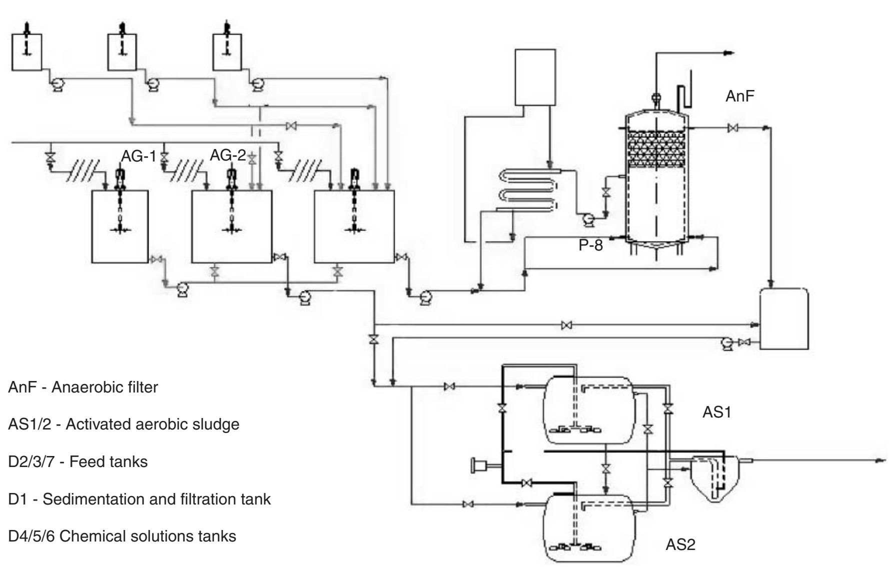

Figure 1 Flow diagram of pilot plant

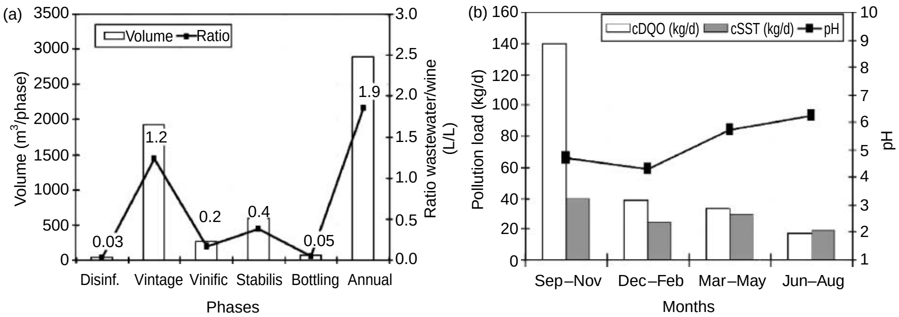

Figure 2 Parameters of wastewater characterization: (a) volume and wastewater:wine ratio, in each phase production of white winery process; (b) pollution load and pH average values

Wastewater had a seasonal generation, in parallel with phased production, having an annual average ratio wastewater:wine of 1.9 L_{WW}/L_{WINE} (Figure 2(a)). The highest organic pollution on vintage period, from September to November, with an average flow of 26 m^3/d, (Figure 2(b)). In this period two thirds of the annual wastewater volume was generated. Wastewater had a lower load from January to August and it was related to washing operations of specific equipment (filters and centrifuges), with an average flow of 1–8 m^3/d. These effluents had inorganic suspended compounds such as bentonite or diatomea earths, to which organic matter (mainly protein) attached. The suspended volatile solids represented 49–77% of organic content of wastewater.

The specific organic pollution was very much dependent on the type of activity in each phase production: 0.29 kg_{CODt}/hL_{WINE} (vintage), 0.02 kg_{CODt}/hL_{WINE} (vinification), 0.06 kg_{CODt}/hL_{WINE} (stabilisation) and 0.05 kg_{CODt}/hL_{WINE} (bottling). The annual average flow was 10.7 m^3/d and the wastewater has the following average values: 7.3 g_{CODt}/L, 5.2 g_{TSS}/L and pH 5.2.

Figure 3 shows the average values of CODt, CODs and BOD_5 during the vintage, stabilisation and bottling periods. The average ratio BOD_5/CODt was higher than CODs/CODt ratio during vintage operations, indicating that a considerable proportion of the biodegradable matter was in particulate form. Anaerobic assays showed that all effluents have a high biodegradability, with BOD_5/CODt, between 43–93% depending on

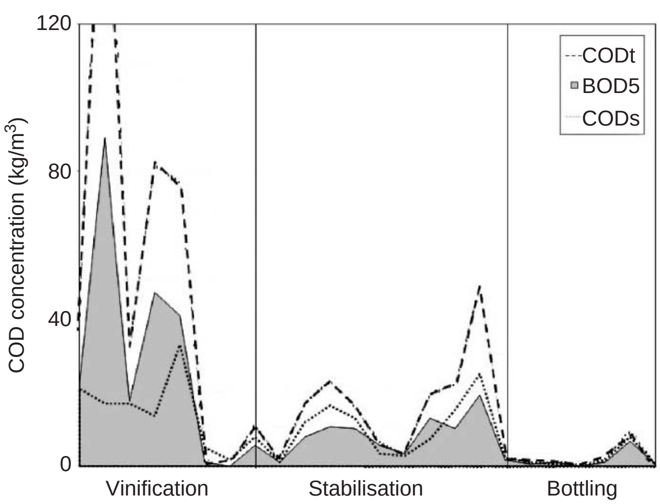

Figure 3 Comparison between CODt, CODs and BOD5 of wastewater in three main phases

Table 1 Average BOD_5/CODt and nutrients ratios of phased wastewater

Phase	BOD_5/CODt (g/g)	CODt/TKN/P
Vintage	0.52–0.93	–
Vinification	0.44–0.68	100/7/0.01
Stabilisation	0.40–0.81	100/9/0
Bottling	0.43–0.81	100/1/0

particulate content (Table 1). Ratios BOD_5/CODt and CODs/CODt were very similar the rest of the year, except those effluents from washing cold clarification tanks due to the protein content.

Pilot plant study

The pilot plant was operated during 480 days, including two vintage campaigns. The operation performance of both configurations is shown in Figures 4–8 and it comprised for periods: (i) start-up (first vintage: September–November); (ii) high organic loading with starving periods (vintage and vinification months: December–April); (iii) restart-up and low organic load (stabilisation and bottling months: April–August; second vintage: September–November). Both configurations were compared in terms of start-up time required for a stable steady-state operation, COD removal efficiency, and behaviour at unsteady-state conditions after overloading and reactivation.

Start-up period. The anaerobic filter was inoculated with sludge from an UASB treating brewery wastewater (with an initial 9 g_{VSS}/L) and aerobic reactors AS1 and AS2 were inoculated with sludge from a fish canning wastewater treatment plant. Pilot plant operation started in vintage period. These influents had high suspended solids and CODt. In a first period (until day 55), where CODt degradation was low (<50%), biomass adapted to wastewater characteristics (Figures 4 and 5).

The AnF and the AS1 were operated at organic loading rates (OLR) between 0.5 and 0.7 $kg_{CODt}/m^3 \cdot d$ and feed-to-microorganisms ratio (F/M) between 0.3 and 0.9 kg_{CODt}/-$kg_{VSS} \cdot d$, respectively (Figure 4(a) and (b)). The aerobic unit AS1 had a shorter adaptation period than AS2, reaching high average COD removals (>90%) before day 55. The F/M ratio for AS2 was maintained between 0.10 and 0.50 $kg_{CODt}/kg_{VSS} \cdot d$, attaining an average removal of 88%.

Steady-state. Aerobic reactor AS2 needed nutrients adjustment to avoid a poor biomass flocculation and separation. In this case, the applied COD/N/P ratio was 100/8/0.8, quite

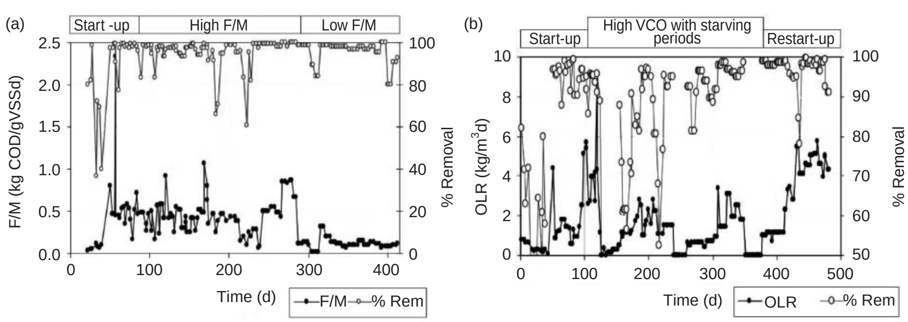

Figure 4 Operation performance of anaerobic/aerobic pilot plant (configuration I): (a) weekly average values of feed-to-microorganisms (F/M) and COD removal in aerobic activated sludge; (b) weekly average values of organic loading rate (OLR) and COD removal in anaerobic filter

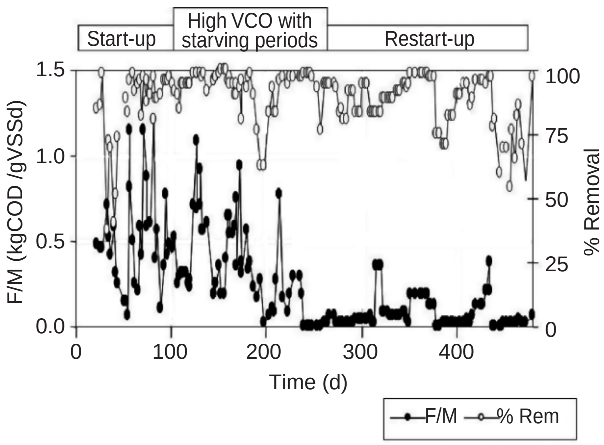

Figure 5 Weekly average values of feed-to-microorganisms (F/M) and COD removal of aerobic activated sludge (configuration II)

different ratio from others reported in bibliography (Müller *et al.*, 1994; Andreottola *et al.*, 1997).

At the end of vintage period, anaerobic OLR was increased up to 6–9 $kg_{CODt}/m^3 \cdot d$ (day 100) resulting in a decrease of the removal efficiency down to 60% (Figure 4(b)) and an increase of alkalinity ratio (IA/TA) up to 0.8 (Figure 6).

When vinification period began (after day 150), AnF operated at very stable conditions with an alkalinity ratio of 0.3 and average removal efficiency of 85%. In order to avoid clogging, feeding to AnF was previously decanted in the feeding tank. Besides the system was operated at OLR lower than 4 $kg_{CODt}/m^3 \cdot d$. The final quality of effluent of configuration I had a negligible suspended matter and a COD of 150–250 kg_{COD}/m^3, thus account for a COD removal of 99%.

In vintage and vinification periods F/M ratio of AS2 reactor increased noticeably, with peak values of 1.2 $kg_{CODt}/kg_{VSS} \cdot d$, thus affecting effluent quality (1 kg_{COD}/m^3), with an average COD removal below 80%.

Although the initial VSS concentration in aerobic reactors was low (Figure 7), biomass concentration increased once the nutrient requirements were adjusted. The sludge volumetric index (SVI) was determined to verify the settleability of aerobic biomass

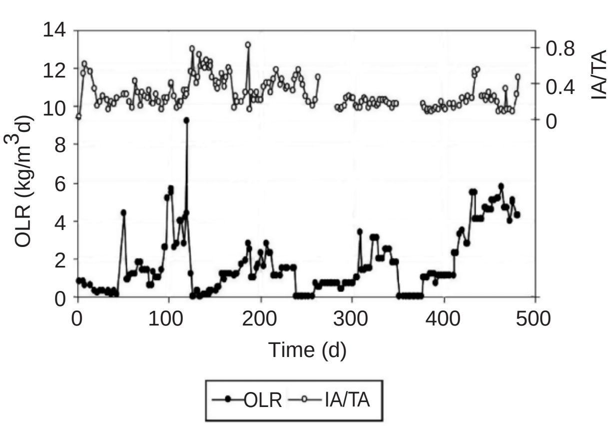

Figure 6 Alkalinity ratio and OLR applied to the anaerobic reactor (configuration I)

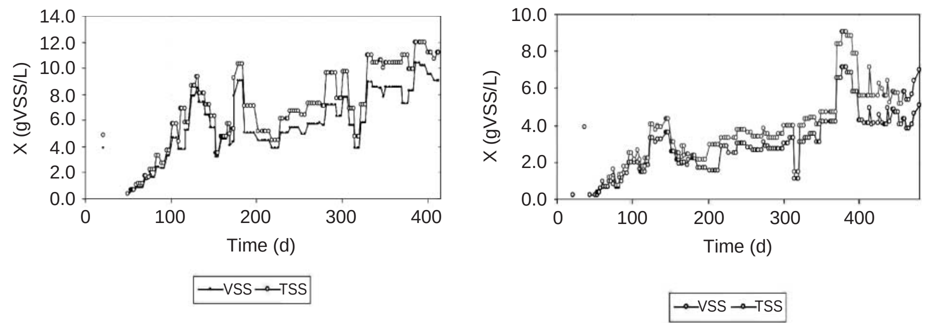

Figure 7 Volatile and total suspended solids in aerobic reactors of pilot plant: (a) configuration I anaerobic/aerobic; (b) configuration II, aerobic

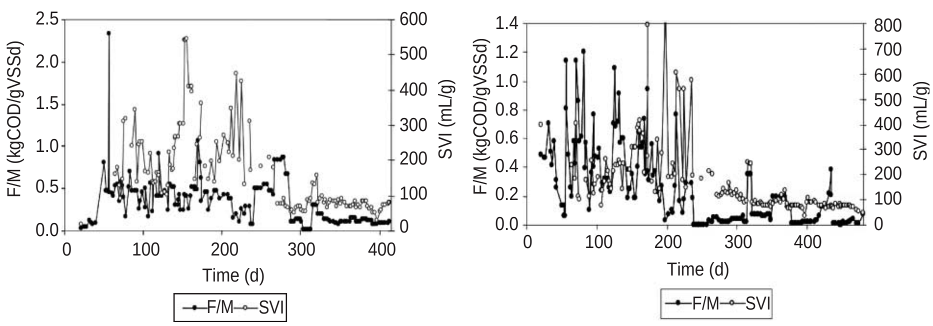

Figure 8 Sludge volumetric index (SVI) evolution in aerobic reactors of pilot plant: (a) configuration I-AS1; (b) configuration II-AS2

(Figure 8) which was mainly affected by two factors: CO_2 release and F/M ratio. Stripping of CO_2 from anaerobic effluent caused AS1 sludge to present poor sedimentation properties and, for minimising this bicarbonate was only added to AnF during unstable periods.

The second factor was related to F/M ratio and when it increased SVI was seriously affected in both aerobic reactors, especially in AS2 (Figure 7), indicating F/M and biomass bulking (Table 2). SVI in AS2 varied between 200 and 550 mL/g when BOD_5/CODt was 0.4–0.7 in vinification period, while SVI decreased down to 100 mL/g in stabilization and bottling periods with higher BOD_5/COD (0.8).

Overall results showed that COD removal was quite similar in both configurations (Table 2), although the anaerobic/aerobic configuration reached slightly better values (96–99% initial CODt) than aerobic configuration (93–95% initial CODt) in all periods. Due to CODt being mainly degraded in AnF (85–90% initial CODt), VSS excess was lower in configuration I than in configuration II.

Restart-up period. Starving and low organic loading periods began at day 259 for the AS2. The anaerobic reactor AnF had two starving periods: first at day 259; second at day 350. The main result was the time to reach stationary operation after being without feed: 15 and 17 days for configuration I and II, respectively.

Table 2 Average control and operation parameters of configuration I (AnF + AS1) and configuration II (AS2). Solid concentration (VSS) – g/L; sludge volumetric index (SVI) – mL/g_{VSS}; nm – not measured

Wine	Vintage		Vinification						Stabilization/bottling			Vintage			
	Start-up					High load					Low load				
C.I	LR	RT	Bg	AR	%R	LR	RT	Bg	AR	%R	LR	RT	Bg	AR	%R
AnF + AS1	0.7	6	nm	0.27	87	3.2	8	173	0.20	99	1.4	16	141	0.19	96
	F/M	RT	VSS	SVI	%R	F/M	RT	VSS	SVI	%R	F/M	RT	VSS	SVI	%R
AnF + AS1	0.35	60	0.81	398	71	0.05	45	4.9	75	98	0.09	45	3.29	116	91
C.II	F/M	RT	VSS	SVI	%R	F/M	RT	VSS	SVI	%R	F/M	RT	VSS	SVI	%R
(AS2)	0.11	65	0.92	169	88	0.45	45	5.67	230	95	0.12	45	7.94	76	93

Conclusions

The average wastewater flow was 10.7 m^3/d, with an acid pH (5.2) and average CODt and TSS values of 7.3 and 5.2 kg/m^3, respectively. There was a great difference between vintage and other phases: while flow rate in the vintage period was 26 m^3/d, during the rest of the year this flow dropped to 3–8 m^3/d. The ratio wastewater/wine produced was about 1.6–2.0 L/L and the ratio between pollution and produced wine was 9.7 kg_{CODt}/m^3_{WINE}. The vintage phase represented 67.5% of the annual organic pollutant content of the wastewater.

These ratios were used as indicators for designing the strategy of the management program at the winery. A main result of this study was the implementation of good practices, especially during vintage phase (washing step, optimization of energy exchange by recycling water,…), achieving a 55% decrease on wastewater production. Besides, the separation of suspended solids during vintage and stabilization allowed COD and TSS to be reduced by 30% and 77%, respectively.

The removal efficiencies of both configurations were quite similar, although the anaerobic/aerobic configuration reached slightly better values (98.5–99.2% initial CODt) than aerobic configuration (96.3–97.9% initial CODt). Besides, the effluent from the anaerobic/aerobic treatment never exceeded 0.15–0.25 kg_{COD}/m^3 while the aerobic treatment generated effluents with 1.0 kg_{COD}/m^3 in periods of overloading.

The anaerobic/aerobic configuration proved to adapt better and quicker against modifications of the wastewater characteristics and flow fluctuations, although it was necessary to make some adjustments (to neutralize wastewater pH and to separate suspended matter). The anaerobic/aerobic configuration readapted very well to high organic loads after a low organic loading and starving period in less than 2 weeks.

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