Design and performance of full-scale iMBR plants treating winery wastewater effluents in Italy and Spain

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Abstract This paper provides an overview of full-scale immersed membrane bioreactor (iMBR) technology applied to Mediterranean wineries. It is based on the cumulative experience on design, commissioning and operation of 8 Spanish and 13 Italian references from 2003 to present day. In all of them Kubota membranes are employed. Market drivers for this treatment technology in the wine industry and comparison with alternatives are presented. The text covers wastewater characterization and flow patterns, different flowsheet configurations and pre-treatments, favoured biological conditions and membrane flux, common troubleshooting experiences and also running costs. In plants where reuse initiatives have been undertaken, feedback on water quality and potential uses are explained.
Keywords Design; immersed membrane bioreactor; performance; reuse; winery

INTRODUCTION

Kubota iMBR in Europe

Over the last 10 years, Immersed Membrane Biological Reactor (iMBR) technology has been gradually adopted in Europe for both municipal and industrial applications. At the time of writing this paper, the first municipal experience in Porlock (UK) and the first industrial site (a dairy wastewater treatment plant in the Republic of Ireland) were still running with their original Kubota membranes from 1998 and 1999 respectively.

At the end of 2008, Kubota could claim near 400 iMBR plants in Europe from which approximately 60% were industrial. Food and beverage industry accounted for 45% of the industrial references, and the largest contributor to this category was Wineries.

Kubota iMBR in Mediterranean wineries

All 22 European Kubota iMBR winery references were located in Italy (14) and Spain (8). The first reference was built in 2003 and the last two at the time of this paper in 2008.

Design average flows ranged from 14m^3/day to 200m^3/day to a total average treatment capacity of 1,260m^3/day. The wineries equipped with Kubota iMBR were as per Table 1.

Table 1. Kubota iMBR references in European wineries

Customer	Country	Av design flow (m^3/d)	Commissioning Year
BV	Spain	19	2003
CS	Spain	14	2004
MC	Spain	15	2004
Z	Italy	30	2004
DV	Spain	75	2004
JS	Spain	80	2004
C	Italy	17	2004
VA (I)	Italy	80	2004
C	Italy	18	2005
SM	Spain	43	2005
R	Italy	50	2005
F	Italy	110	2005
CS	Italy	60	2005
VA (E)	Spain	30	2007
SS	Italy	40	2006
GC	Italy	80	2007
C (2)	Italy	26	2007
V	Italy	100	2007
PP	Italy	200	2007
SU	Spain	60	2007
F (2)	Italy	34	2008
F (3)	Italy	140	2008

Although discharge limits could become tighter in the future, at the time of writing this paper both Spain and Italy enjoyed relatively loose standards that could be met with a wide array of technologies – in most cases winery wastewater treatment plants (WWTP) discharged into municipal sewerage collectors. Spanish discharge limits were 160mg/L for COD, 40mg/L for BOD_5 and 5 or 80mg/L for SS, with no mention to pathogens. Hence, drivers for iMBR technology in winery applications had to be found elsewhere: scarce available space, capacity enlargement of conventional treatment plants, minimisation of visual and odour impact, need for reduced civil engineering, treated effluent reuse for on-site cleaning or irrigation, etc.

DESIGN ASPECTS

Some of the challenges for the design of a WWTP using biological digestion are variable loads (daily and seasonal), and lack of nutrients. Particular problems for membrane filtration systems are presence of solids.

Pre-treatment

Winery effluents have presence of easily decantable suspended solids such as seeds, tartaric salts and/or filtration media (Flanzy, 2003). MBR plants generally do not have gravity settling tanks, hence in order to avoid abrasion problems with grape seeds circulating between the membranes, it is preferable to install a 1mm screening at the head of works. It is crucial to avoid screen by-passes with sound designs especially during high flow events.

Equalization or balancing tank

Even during the grape harvest, there are considerable fluctuations in flow and organic load. Therefore it is commonly accepted that a WWTP shall be supplied with appropriate equalization capacity. Kubota iMBR designs in Spain were provided with 24 hours' equalization volume at peak flow conditions.

pH is typically acidic, usually lower than 5, with punctual alkaline episodes due to the usage of chemical products for cleaning the tanks (Flanzy, 2003). Because equalization tanks are usually aerated and part of the waste sludge is sent there, pH neutralization at the equalization tank prior to the biological treatment can contribute to remove part of the organic load. Even without sludge seeding, aeration can help to reduce COD due to stripping of volatile compounds.

Biological treatment

Nutrient deficit. High BOD_5/TN and BOD_5/TP ratios (Flanzy, 2003) mean there is a need to dose N and P as to complete biological digestion. For WWTP iMBR systems, nutrient addition was in the form of urea and phosphoric acid, dosed at the balancing tank with either automated dosing pumps or, more often, manually. BOD_5 levels were reduced to below 25 mg/L at the effluent.

Seasonality. According to Flanzy (2003) 60-70% of the total effluent is produced during the 3 months following harvesting, that is towards end of summer and autumn in the northern hemisphere. Spanish experience shows that grape harvest period can last for two or three months, and approximately half of the flow and 80% of the total organic load of the year are produced in this period.

In Table 2, the combined effect of higher pollutant concentrations and flows in August implied organic loads factored by 11, 2.6 and 3 for BOD_5, TN and TP respectively, as compared to January. Most organic load was soluble, therefore the variations affected directly to the biological dimensioning and could not be minimized with a strong mechanical pre-treatment.

Table 2. Inlet wastewater characterization at an Italian winery WTP

.		Jan-07	Aug-07
Flow	m^3/h	15	44
TSS	mg/L	536	780
COD	mg/L O_2	1,327	3,978
BOD_5	mg/L O_2	610	2,295
TN	mg/L	36	32
TP	mg/L	7	7
Temperature	dC	12	22
pH		7.71	10.10

Membrane filtration system

Dimensioning of membrane systems needs to be optimized in order to be economical. Also, it has to be flexible enough to cope with average flows that differ by a factor of 3 between harvesting season and low season. Design flux is dependent on liquor temperature, viscosity and sludge conditions. It is therefore advisable to perform a pilot test to determine the optimal plant design. Table 3 shows examples of flux in some Kubota iMBR plants.

Table 3. Flux designs for Spanish WWTP.

	Membrane area	Peak Flux	Average Flux
Reference	m^2	$m^3/m^2/d$	$m^3/m^2/d$
BV	60	0.76	0.33
DV	240	0.75	0.3
JS	240	0.80	0.3
MC	40	0.90	0.38

Ancillary equipment

Kubota iMBR process uses dedicated duty blowers for nitrification and membrane cross-flow filtration, and one additional standby blower for both purposes. PLC control loops would stop the plant upon membrane blower failure. Permeation pumps (which are optional given that Kubota iMBR can filter by gravity) are also doubled as duty-standby. In certain plants, aeration and suction systems were supplied with frequency inverters for further economies. Permeation pumps were controlled by level transmitters at membrane tanks.

Configurations

The Kubota iMBR references taken in this analysis confronted seasonality in three different ways: Hybrid, Modular and Buffered Compact plants.

Hybrid MBR plant. Winery F(3) in Italy was a retrofit over a previously existing conventional activated sludge plant. In 2008 the plant capacity was enlarged by converting part of the treatment line into iMBR. At the head of works there was an equalization tank from which the influent could take 3 different routes: a small-scale iMBR for low load season (retrofitted in the old denitrification tank, Fig. 1 Left), a large-scale iMBR for high load season (retrofitted in one nitrification tank, with membranes inside the old clarifier, Fig. 1 Right) and an old non-modified nitrification tank with its clarifier for emergencies. The new iMBR plant during low season used less than 1/3 of the volume of the past, thus substantially reducing power consumption.

Fig. 1. (Left) iMBR plant for Low Load operation. (Right) iMBR plant for High Load operation.

Modular iMBR plant. Winery DV in Spain was a new-construction plant (Fig. 2 Left). An equalization tank provided enough volume for a hydraulic retention time (HRT) of approximately 1 day in peak flow regime. In order to adjust the biological reactor volume to the different operating conditions, there were two pre-aeration reactors which could operate alternatively or simultaneously. During low season one reactor was maintained running and the other was emptied for servicing. During harvesting season both reactors would run in parallel. A single membrane tank would operate all year-round regardless the hydraulic load (Fig.2 Right). Membrane surface area was dimensioned for harvesting peak load, therefore during low season membranes would filter for a reduced amount of time.

Fig 2. (Left) Modular iMBR plant under construction. (Right) Kubota Submerged Membrane Units.

Buffered Compact iMBR plant. Small wineries in Spain with little available footprint were designed this way. Following a generous equalization tank, a single membrane tank provided enough volume for complete biological digestion during peak season. The reactor volume was constant. Having the same reactor volume for all operating conditions would oblige to operate at variable HRT and SRT throughout the year. During low season, lower purging frequency and lower F:M ratio would mineralize the sludge. Specific aeration requirements in low season would certainly be less optimized than for other more flexible design flow sheets such as a hybrid or modular iMBR plants (Fig. 3).

Fig. 3. Two examples of buffered compact iMBR plants in Spanish wineries.

PERFORMANCE

Process stability

iMBR proved adaptable to different loads from a biological point of view. Episodes of viscous bulking happened as a result of sudden increases of the organic load, where nutrients were not dosed.

Despite poor sludge condition or bulking, no biomass would be lost in membrane systems. Sludge production was believed 0.3kg MLSS/kg BOD_5 although there was no return on experience on this. Long sludge ages were estimated to reduce VSS/MLSS ratio down to 60%, however sludge filterability always remained acceptable.

It was important that during peak flows the membrane system performed well. It might be necessary to carry out chemical cleans before harvesting flows entered the plant. Cumulated experience showed that chemical cleans occurred every two to six months (depending on the season) and permeability was typically fully recovered. The chemical used for membrane cleaning was sodium hypochlorite at 0.5% by weight concentration.

Simplicity of operation and maintenance are important for industrial wastewater plants which often are not sufficiently manned. Kubota iMBR allows for operation at higher MLSS concentrations than other systems as successfully run for extended periods above 20g/L. This is a useful feature when there is not a frequent control on sludge purges.

Effluent quality and reuse

Kubota iMBR effluent quality was consistently compliant with the usual discharge consents for wineries at the time of writing this paper. Also, it suited a number of reuse applications as stated in national and international standards. Two of the assessed plants in Spain reused their effluents for crop irrigation, with COD in the range 50 – 300mg/L, BOD_5 <10mg/L and SS<2mg/L.

Depending on the reuse application and local regulations it may be necessary to provide additional safety barriers such as UV or residual chlorine disinfection.

Cost trends against conventional biological systems

*Civil. i*MBR could be very cost-effective to retrofit in existing plants, as treatment capacity would improve in both quality and flow within the old footprint.

Energy. It is accepted that power consumption for municipal iMBR is higher than similar activated sludge processes due to the aeration required to generate a cross-flow effect on the membranes. The energy consumption difference between a conventional activated sludge process and iMBR in wineries should be minor than in municipal applications based on the "kg BOD_5 removed / m^2 membrane filtration area" ratio. In other words, higher influent concentrations help towards iMBR economical viability.

Chemicals. iMBR process is arguably less sensitive to filamentous bacteria than conventional systems, given that there is no exposure to sludge settleability. In addition to this, longer sludge age contributes towards sludge stabilization. It was believed that these facts would have a positive impact on the cost of sludge conditioning, however there were no field data available to back this up.

Operational problems and membrane replacement rates

Operational problems. Given the non-productive nature of industrial wastewater treatment plants it is often found that operation and maintenance are insufficient. Staff may not be properly trained or motivated for the correct operation of such process plants. In addition to this, equipments may not be used in the way they were designed for and there is little or no operational feedback nor preventive maintenance nor requests for technical assistance. Samples are taken very seldom and process checks such as sludge characterization tests are never performed.

The most common sludge-related problem was bulking, which causes could be various:

- deficient pH adjustment due to dirty electrodes,
- nutrients were not added when needed or were dosed in the wrong proportion,
- fluctuations in organic loads, which happened because the equalization tank´s level was kept too low.

Apart from sludge bulking, other reasons for poor membrane filtration were either control-related blower failures or presence of harmful substances:

- diffuser flushing deactivated from the PLC, which eventually caused uneven cross-flow filtration and clogging. Full permeability recovery was achieved after physical and chemical cleaning,
- PLC did not detect blower failure. The effect was membrane dead-end filtration and severe membrane clogging. Full permeability recovery was achieved after physical and chemical cleaning,
- usage of silicon-based antifoaming agents which damaged the membranes,
- presence of diathomea sand (used to filter wine) which required manual cleaning of the membranes. Afterwards full permeabillity recovery was

achieved.

Replacement rates. At the time of writing this paper, total replacement of Kubota cartridges for the European winery industry corresponded to 1.6%. In actual fact, only one winery had required membrane replacements and that was due to improper use of foaming control agents which caused irreversible damages on the membrane surface.

CONCLUSION

Kubota membranes for iMBR have been successfully applied in 22 European winery wastewater treatment plants since 2003. The experience to-date shows iMBR as a reliable solution for the wine industry offering easy retrofit to existing plants, flexibility against seasonality, process stability, high effluent quality and possibility to reuse the treated effluent.

Main operational problems were identified and were considered avoidable with good design and operator's training. Kubota's membrane replacement rate across the European wineries was less than 2% of the total installed at the time of writing the paper.

BIBLIOGRAPHY

Flanzy, C. (2003). *Enología: Fundamentos Científicos y Tecnológicos*. AMV Ediciones, Mundi-Prensa