

Combination of advanced aeration system and membrane bioreactor for winery waste water treatment

G. Tanzi*, A. Mazzei**

* Sepra S.r.l., via Como 69/A, 20031 Cesano Maderno, Italy (e-mail: gctanzi@sepra.it)

** Mazzei Injector Co, LLC. , 500 Rooster Drive, Bakersfield, California 93307-9555, USA

Abstract Membrane bioreactor has been used on winery waste water to overcome difficulties that are typically met in this environment with traditional biological treatment: poor sludge settling, bulking related to high sugar concentration and variable load. This paper reports about an innovative approach to membrane filtration used in combination with injector aeration to make membrane bioreactor best suited for the specific requirements of wineries. By Combining the two technologies, it is possible to achieve ease in operation and still optimize energy consumption. High efficiency oxygen transfer is obtained by maximizing turbulence and pressure to increase the alpha factor.

Keywords Membrane bioreactor; ultrafiltration membrane; injector; mixing nozzle; alpha factor.

BACKGROUND

Effluents of wine production and bottling are difficult to treat with traditional activated sludge waste water treatment technology for many reasons.

First, the effluents include a very high loading of solids and soluble organic contaminants, especially during the peak season (September-December). Later on, contaminant load decreases substantially. Therefore, activated sludge systems must be designed with larger oxidation tanks to deal with the peak load, but also result in considerations for oversized vs. normal load.

It is also necessary to oversize the aeration system; in some cases it is necessary to use liquid oxygen as normal aeration cannot satisfy the very high oxygen requirements.

Variable load and random presence of sugars also cause bulking problems with difficulties in sludge settling and resulting in turbid effluent.

Finally, waste water treatment plants are quite large and difficult to manage. These are significant issues because many plants need to be operated by wineries that have limited space and no specialized human resources dedicated to waste water treatment.

The process well known as “membrane bioreactor” (we are not giving here more details about it, see for example “I reattori biologici a membrana ...” Gianni Andreottola et al.) allows one to overcome some of these difficulties. Having no settling tank ensures higher flexibility on sludge concentration and therefore makes it easier to handle a variable incoming load. Sludge concentration will increase during the peak season. It is also possible to overcome bulking problems as sludge settling is not as critical as with traditional plants.

Submerged membrane bioreactors still present critical management issues, mainly related to difficulty in membrane cleaning. Another important issue is sludge oxygenation; as increased sludge concentration brings a substantial decrease in the “alpha” factor (lower efficiency in oxygen transfer to the biomass) and also the lower efficiency of the membrane cleaning effected by air bubbles.

TUBULAR ULTRAFILTRATION MEMBRANES COMBINED WITH INJECTORS

This paper reports about a study to overcome above mentioned limitations and to allow full application of membrane bioreactor technology to winery waste water treatment. Extensive study on oxygen transfer was also carried on to identify the best aeration option. We refer to industrial scale experiments made in wineries and dairy factories in the period 2007-2008. European Patent procedure is covering this process.

Pretreatment

To allow for continuous membrane operation, we developed a self-cleaning pre-filter that allows complete removal of coarse solids and still ensuring low cost and very easy operation. Previous experience showed that major problems with membrane bioreactors were due to solids deposit in membrane channels and mechanical blockage; good prefiltration is a key issue for smooth membrane system operation.

At the same time we should consider that most wineries have limited quantity of waste water and a limited budget for filtration. The use of traditional drum filters is effective, but not cost competitive. For this reason we focused on static grids where the self cleaning effect is realized mainly by gravity and by water washing of the filtration media. A sieve bend screen filter was selected as best option, with 0,75 mm openings.



Fig. 1: sieve bend screen filter media

Membrane configuration

For sludge filtration we selected a configuration with external tubular ultrafiltration membranes (see fig. 1) as opposed to a more common hollow fiber submerged membranes.



Fig. 1: tubular membranes

First of all, external membrane configuration allows for very easy maintenance, like chemical cleaning and sanitization. This is an important issue when approaching wineries that have low volume of waste water, but a very high pollution level.

Mechanical characteristics and thickness of these tubular membranes also ensure high resistance and allow efficient operation with air/liquid mixture inside membrane channels. This produces high turbulence even with low liquid circulation rate and decreases membrane fouling.

For this reason it is possible to operate membrane bioreactors with a very high sludge load. We normally work in the 10-15 gr/l range but concentrations as high as 40 gr/l have been successfully tested. High sludge concentration may be significant during peak season when COD levels are very high. Flexibility on sludge concentration allows one to deal with the variable treatment load in the plant.

It is also important to note that with external membranes, it is possible to select a polymer with smaller porosity to achieve better quality of the final treated water. Best treatment efficiency is important as winery waste water can reach very high pollution level (e.g. COD concentration may reach values over 10,000 mg/l).

Tubular membranes used for this study have following features:

Membrane material	PVDF
Porosity	0.03 micron
Channel diameter	8 mm
Channel length	3,000 mm
Max pressure	8 bar
Cleaning (pH)	2<pH<10
Cleaning (temperature)	Tmax = 60 °C
Backwash	YES

Tubular membranes are enclosed in fiberglass housing with epoxy resin caps and are fed with a centrifugal pump. Typical water velocities that have been tested inside membrane channels are in the 1-2 m/s range.

Average membrane permeability that we achieved is in the 40 l/(hxm²) range. This permeability is maintained with a very low transmembrane pressure, normally lower than 0,5 bar. Permeate flow should be controlled with a valve or with a VFD pump, so that critical flux is not exceeded and membrane fouling can be controlled.

As a matter of fact, it appears that like in other membrane bioreactor applications, stable operation is related to maintaining a low transmembrane pressure and therefore a permeability far enough from a critical value. In addition, the system may still be operated but with frequent chemical cleanings.

This behaviour has been reported in many other waste water treatment membrane applications (Flux criticality ..., Guglielmi et al.).

Aeration

Finally, we come to the main process innovation presented in the paper. We introduced high efficiency air-liquid injectors (fig. 2) in the main circulation pipe before the membrane element and mixing nozzles (fig. 3) after membrane element. The same circulation pump that feeds the membrane element is also used to ensure sludge oxygenation and oxidation tank mixing.

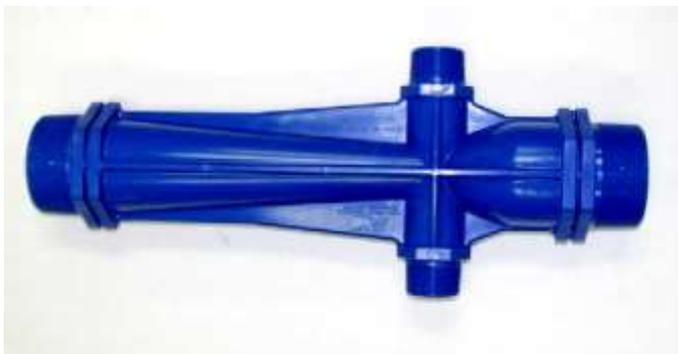


Fig. 2: injector



Fig. 3: mixing nozzle

Injectors generate high velocity and high turbulence. Air breaks into very small bubbles and gas/liquid interface is maximized.

Then water gas/mixture is moved into membrane channels, where oxygen transfer process continues at a high rate because air increase water velocity and therefore turbulence. At the same time air bubbles help to keep membrane surface clean and permeability high.

Finally, water gas/mixture is returned to the aeration tank via mixing nozzles, that break big bubbles into small ones and provide high mixing rate in the activated sludge tank.

This approach ensures an oxygen transfer rate that is much higher than what is normally experienced in high sludge concentration systems, mainly because this approach allows the system to operate with an alpha (α) factor that is quite high. This issue is better addressed in the following chapter.

Evaluation of alpha factor in injector based aeration systems

Oxygen transfer has been evaluated in cooperation with Mazzei Injector Corporation. The injector based Mazzei AirJection System for wastewater aeration has been exhaustively tested following the American Society of Civil Engineers, ASCE, Measurement of Oxygen Transfer in Clean Water, ANSI/ASCE 2-91 Second Edition.

Standard Oxygen Transfer Rate (SOTR) of an injector based aeration system was determined by measurement of non-steady state oxygen uptake in clean water, which is measured following the above mentioned test protocol detailed in the American Society of Civil Engineers.

SOTR is expressed in units of kg/hour of oxygen transferred into clean water under standard conditions, which are defined as:

- 20 °C water temperature
- 1.0 standard atmosphere pressure
- 0 mg/l dissolved oxygen

The SOTR is corrected to the Operating Oxygen Transfer Rate (OTR) under the actual operating conditions of a wastewater treatment facility following the procedures detailed in the WEF Manual of Practice, MOP, FD-13. Following is the formula used for correction of the SOTR to the OTR.

$$OTR = ((\alpha (SOTR) \theta) / C^*_{\infty 20}) \times ((\tau \Omega \beta C^*_{\infty 20}) - C_{op})$$

This formula accounts for the affects of water temperature; operating Dissolved Oxygen (DO), water chemistry etc. in the calculation of the OTR, where the following definitions apply:

- $C^*_{\infty 20}$ = Standard Conditions Saturation DO
- $C^*_{\infty T}$ = Operating Conditions Saturation DO
- C_{op} = Operating DO

The factors that affect the saturation solubility of oxygen in water are defined as follows:

- Tau (τ) = $C^*_{\infty T} / C^*_{\infty 20}$
- Omega (Ω) = Saturation DO at Operating Pressure Relative to Standard Pressure.
- Beta (β) = the effect of water chemistry on Saturation DO.

It can be seen that the OTR is affected by the saturation DO, $C^*_{\infty T}$, and operating DO, C_{op} . The operating DO, C_{op} , is dictated by the system requirements, typically about 2.0 mg/l for activated sludge systems.

The effect of water temperature, tau factor, on saturation DO concentration is well documented and these values are available from numerous sources.

The OTR under operating conditions in dirty water is also affected by factors expressed as the alpha and theta factors. The alpha and theta factors affect the mass transfer rate coefficient, $K_L a$, and they are defined as follows:

- Alpha (α) = Dirty Water/Clean Water $K_L a$
- Theta (θ) = Operating/Standard temp $K_L a$

The mass transfer rate coefficient, $K_L a$, is a function of the diffusion rate of oxygen across the

air/water interface. Chemicals such as detergents in process water can have a substantial affect on the K_{La} .

More than this, large variability should be expected on the alpha factor depending on the suspended solids load and there is not a standard procedure to evaluate this coefficient. In passive, diffusion type aeration systems such as coarse bubble diffusion, the alpha (α) factor can range from 0.2-0.8. Dirty water testing, as well as field results, indicates that the alpha factor for the AirJection System is approximately 1.0 due to dynamic agitation. theta is assumed to be 1.024 for most wastewater aeration systems unless empirical data suggest otherwise.

In order to determine alpha factor, several process water oxygen transfer rate (OTR) tests have been completed in a 5 m tall 11,000 liters poly tank using municipal wastewater at the Kern County Sanitation Authority WWTP in Bakersfield CA. Test conditions were under steady state dissolved oxygen conditions in 4.5 m of water. The oxygen transfer rate was determined via the mass balance method, i.e. the mass of oxygen injected into the tank per unit time relative to the mass of oxygen in the off gas from the tank.

The dirty water OTR values were compared to the standard oxygen transfer rates (SOTR) as determined in another test by GSEE, Inc. and several SOTR test runs in the 3000 gal poly tank under similar operating conditions.

Details about the test procedure can be found in a previous paper (see Process water oxygen transfer rate test results, A. Mazzei). The test procedures and test results were witnessed and reviewed by the professional engineers from GSEE Inc. The results have been deemed reasonable and appropriate relative to the test conditions employed following the procedures outlined in the Standard Guidelines for In-Process Oxygen Transfer as published by a joint committee of the WEF and ASCE aeration systems subcommittees.

These tests indicate that the alpha factor for the injector based process is likely to be about 0.93 with wastewater similar to the typical municipal sewage used for the testing. Since all of the process water testing was performed using raw primary effluent water, these results should be viewed as worst-case results. Normally process water oxygen transfer tests are performed in complete mix activated sludge basins where the quality of the process water is equivalent to the aeration basin effluent. Aeration basin effluent will typically be cleaner and less contaminant loaded than primary clarifier effluent, and hence will typically yield higher process water transfer rates and alpha's.

In order to evaluate more in depth the affect of suspended solids on the alpha factor for the injector process, a series of tests were conducted also in a sludge digester outfitted with the injector/nozzle aeration equipment (Butler County/Lesourdsville WWTP). The sludge digester typically is operated at an MLSS of approximately 17,000 mg/l (19,900 mg/l MLSS, 79% MLVSS on the test days). The tests allowed an accurate indication of the affect of suspended solids.

Details about the test procedure can be found in a previous paper (see process water aeration system efficiency test results, Butler County/Lesourdsville WWTP sludge digester tank, A. Mazzei). In this case, the test results indicate that the Alpha under the operating conditions in the sludge digester at Butler County is approximately 0.95.

This measured Alpha factor of approximately 0.95 in process water with high-suspended solids concentration, (19,900 mg/l MLSS, 79% MLVSS on the test days), represents one end of the spectrum relative to the affect of contaminants/suspended solids on the Alpha factor for the Mazzei

aeration process. The alpha factor of 0.9 that has been determined using primary clarifier effluent at a municipal WWTP with high contaminant concentrations, represents the other end of the spectrum.

Final considerations about aeration

Above mentioned test work proves that using injector/nozzle technology can provide high oxygen transfer rate even in biological oxidation tanks with high sludge concentration. Our field experience also proves that placing membrane between injector and nozzles, oxygen transfer efficiency can be increased approximately by another 10% in tubular membrane based systems.

Operating data are shown in the following chapter that shows real configuration of MBR systems based on injectors, tubular ultrafiltration membranes and mixing nozzles.

System configuration

The following figure 4 presents a simplified flow sheet of a membrane bioreactor based on above described process, i.e. with injector, external tubular membrane and mixing nozzles. Normally a denitrification step is not needed, as winery waste water is poor in nitrogen compounds. On the contrary, nitrogen addition may be needed, i.e. in the form of urea.

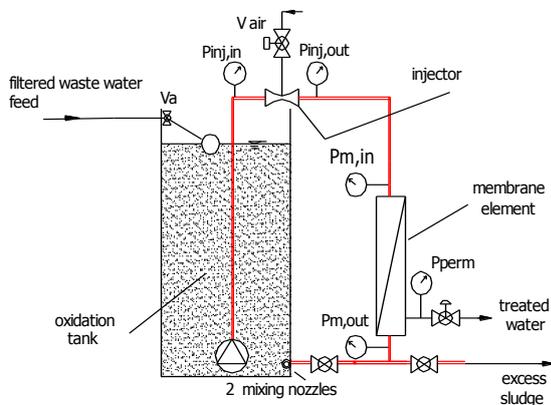


Fig. 4: system configuration

It should be pointed out that this configuration requires only pumping energy, as the same pump provides velocity in membrane channels and aeration/mixing of the biomass. No blowers or auxiliary equipment are needed. Energy consumption and maintenance requirements are minimized, because membrane are operated with residual pressure left after the injector and therefore require non extra energy input.

Oxygen transfer rates measured in real MBR conditions are shown in figure 5. It is very important to point out how high oxygen rate is achieved with water depth over 5 m. This is very important, because with injector based technology energy consumption is almost independent from water level.

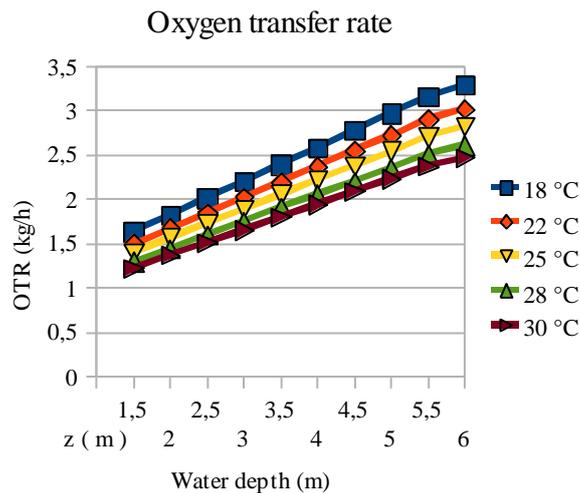


Fig. 5: oxygen transfer rates

Based on membrane permability and on above mentioned oxygen transfer rate, we experienced overall energy consumption next to 3 kW/m³ of effluent treated. Variability relates mainly to COD concentration, as most energy is used to provide oxygen for organic substances biological oxidation: we experienced typical values of 3,000-4,000 mg/l COD concentration, with peak values of 10,000 mg/l. COD removal has been always > 95%.

System is completed by a chemical cleaning station and/or by an automatic membrane backwashing station. Membrane backwashing can be performed with filtered water alone or with filtered water treated with oxidant (chlorine, hydrogen peroxide).

Waste water treatment system is at the same time efficient, compact, easy to manage and low in energy consumption. High treated water quality (water is biologically treated and also ultrafiltered) make possible water reuse, i.e. for irrigation.

CONCLUSIONS

We believe that membrane bioreactor used in combination with injector/nozzle aeration is a very effective approach to treating waste water produced from wineries. Very simple operation makes it suitable for both large and small wineries, while high energy efficiency also allows treatment of higher volumes. The results show that the treated water has a very high quality and is compatible with discharge requirements in surface water and/or reuse.

REFERENCES

- “I reattori biologici a membrana per il trattamento delle acque reflue. Principi ed applicazioni.” Gianni Andreottola, Martina Ferrai, Giuseppe Guglielmi, Giuliano Ziglio. Università degli Studi di Trento. Dipartimento di Ingegneria Civile e Ambientale
- “Flux criticality and sustainability in a hollow fiber submerged membrane bioreactor for municipal waste water treatment”, G. Guglielmi, D. Chiarani, S.J. Judd, G. Andreottola, Journal of membrane science, 289 (2007)
- American Society of Civil Engineers, ASCE, Measurement of Oxygen Transfer in Clean Water, ANSI/ASCE 2-91 Second Edition

Water Environment Federation, Manual of Practice, MOP, FD-13

“Wastewater Engineering, Treatment, Disposal & Reuse”, Third Edition Metcalf & Eddy

“Process water oxygen transfer rate test results”, A. Mazzei

“Process water aeration system efficiency test results, Butler County/Lesourdsville WWTP sludge digester tank”, A. Mazzei