Integrated photo-anaerobic bioprocess for the treatment and valorization of a winery wastewater

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Nowadays industrial traditional wastewater treatment plants are high energy-demanding and solely focused on the depuration of the wastewater. Most industrial plants rely on the conventional and old-fashioned such as the activated sludge. Aerobic wastewater treatments have many limitations, one of which is the energy requirement for the process. According to Ranieri et al., 2021, the energy consumption of the aerobic sludge treatment is 1.02 kWh/m^3, compared to the average energy demand of anaerobic biological processes that is about 0,43 kWh/m^3. Therefore, anaerobic biological technologies are considered a sustainable alternative to reduce energy consumption and CO_2 emissions. In this work, an alternative anaerobic bioprocess was studied in order to treat a winery wastewater coupling a UASB reactor (Upflow anaerobic sludge blanket) with a continuous photo-anaerobic bioreactor using purple phototrophic bacteria (PPB). Purple phototrophic bacteria (PPB) represent an interesting group of microbes for anaerobic wastewater treatment. The application of PPB for anaerobic treatments form an interesting alternative to reduce costs from aeration and carbon footprint. PPB are metabolically versatile microorganisms and they can use a wide variety of carbon and nitrogen sources. PPB are typically exploited in photoheterotrophic mode under anaerobic conditions (Blansaer et al., 2022). These growth conditions of the PPB are suitable for applications in wastewater treatment. The application of PPB in wastewater treatment is a promising alternative to the aerobic treatments because of their high resistance to potential toxic compounds present in wastewater (Hülsen et al., 2016). A relevant problem of the industrial wastewater treatment is the fluctuation in organic load during the year, especially for winery wastewater. As a consequence, volume and organic loads vary over the year requiring a versatile treatment system to face the loading and stream fluctuation (Bolzonella et al., 2010). In industrial contests such as those involving organic load fluctuations during the year, the PPB are offered as a viable alternative since they are not dependent on high organic load to maintain their growth. Specifically, in the case of the winery wastewater, the organic load undergoes significant fluctuations during the harvest period when the organic load is higher. The main aim of the research is to establish the performance of the photo-anaerobic reactor by using purple phototrophic bacteria integrated with a UASB reactor in order to treat a winery wastewater.

The designed process consisted of two anaerobic reactors, which treated a wine solution (blend of white and red wine) that reproduce the composition of winery wastewater. The first reactor was a UASB reactor (Volume=5L, Area=95cm2) with a very low HRT about 2,5 hours, where long chain elongation takes place. This process allows the elongation of the carbon chain length of the carboxylate with C2 at a time (Spirito et al., 2014). Therefore, through the process of long chain elongation, the effluent of the UASB reactor gets rich in medium chain volatile fatty acids (VFAs) such as valeric and caproic acids. The medium chain VFAs, represent effective donors of electrons for the photo-heterotrophic metabolism of PPB present in the second reactor. In particular, the long chain elongation process was carried out because valeric and caproic acids represent a greater donor of electrons than shorter chain such as the acetic and propionic acid.

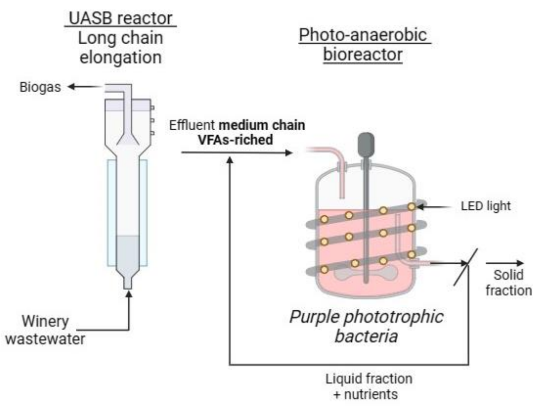

Figure 1. Set-up of the designed process

The second anaerobic reactor was a continuous photo-anaerobic reactor characterized by the presence of purple phototrophic bacteria. The main aim of this reactor is to remove the residual COD (~1,8 gCOD/L) through the metabolism of the PPB. In particular, a 2,5L photo-anaerobic bioreactor (dimensions height = 248 mm × diameter = 136 mm) was used to test the COD removal capacity of the PPB from the effluent of a UASB reactor. The photo-anaerobic bioreactor was illuminated with a LED strip of white light (24W). The bioreactor was operated at ambient temperature (25°C). The influent was characterized by a recycled effluent enriched with a 25% of DSMZ 27 culture medium. The proportion between DSMZ and UASB-effluent was chosen following preliminary batch growth tests. The COD/N ratio of the influent in the photo-bioreactor was about 9-10. The bioreactor was inoculated with PPB inoculum until a concentration of 0,1 OD was reached in the solution. In this study, an experiment was run examining the performance of photo-anaerobic reactor, in terms of hydraulic retention time, COD removal efficiency and sludge production. Hydraulic retention times of 5; 4; 3; 2 days were considered.

The best performance for COD removal was obtained at HRT 5 days, removing almost all of the residual COD present in the VFAs enriched-effluent of the UASB reactor. As a result of each HRT test, COD removal was greater than 49%, however, growth levels were low (under 50%). Among the relevant results was the productivity, where low productivity values were observed. Hence, this technology is capable of removing high levels of COD, but with low growth rates and low levels of sludge production. During the experiment, from the PPB-photoanaerobic bioreactor as a result of the photo-heterotrophic metabolism, a 4% of hydrogen was measured. As reported in Table 1, at hydraulic retention time of 2 days the wash out condition of the suspended biomass was recorded. In this condition, only the 3% of the total COD was removed only by the biofilmed biomass and not by the suspended biomass.

The VFAs reported in figure 1 are derived from the long chain elongation process that happens in the UASB reactor by using a very low HRT (2,5h). In particular, figure 1 shows a focus of a VFAs (C2-C6) removed for each HRT tested. Specifically, as the HRT decreases, the VFAs removal increases. At HRT of 5 days, the greater VFAs removal was obtained. Specifically, at HRT 5 days, for the diverse VFAs tested, a removal of greater than 90% was observed. There was a small reduction in the removal of VFAs at HRT of four days. In fact, a decrease in butyric acid and valeric acid was measured. An important decrease was observed at HRT 3 days, where the percentage of VFAs removal with longer chain (C5-6) are lower than the percentage of VFAs with shorter chain. This means that, C5-6 VFAs need more time to be metabolize by the PPB, due to their greater molecular complexity. As a matter of that, a completely removal of VFAs with C5-6 was observed only at HRT 5 days. Only the shorter chain VFAs can be removed completely at HRT lower than 5 days.

Table 1. Main results obtained for each HRT tested of the PPB-photoanaerobic bioreactor.

HRT [d]	COD removed [%]	Growth rates [gVSS/gCOD]	Productivity [gVSS/L×d]
5	84,0 ± 0,6	0,45 ± 0,06	0,14 ± 0,01
4	67,5 ± 0,1	0,35 ± 0,02	0,09 ± 0,01
3	49,0 ± 0,2	0,31 ± 0,01	0,08 ± 0,04
2	3,0 ± 0,05	-	-

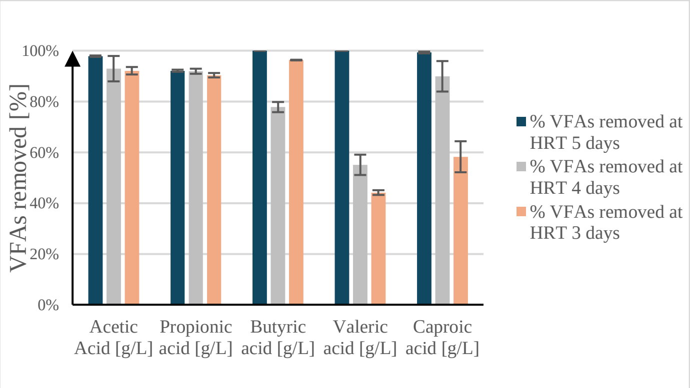

Figure 2.Volatile fatty acids removed for each HRT tested.

In conclusion, the winery solution was successfully treated by the ideated photo-anaerobic processes. PPB-photo anaerobic bioreactor can be applied to treat industrial wastewater by varying the HRT according to the organic load of the wastewater. The important advantage of this process is the lowest sludge production per unit of COD removed compared to the common aerobic processes.

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