# A novel bioscrubber for the treatment of high loads of ammonia from polluted gas

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**Abstract**

This work presents a novel bioscrubber configuration for the treatment of high ammonia loads at short contact times. The biological reactor was designed to work as a moving-bed biofilm rector (MBBR) increasing biomass retention time. This configuration is still unexplored for the treatment of waste gases. Long-term operation of a lab-scale bioscrubber under different inlet concentration of ammonia (60-570 $ppm_v$) and a gas contact time of 4 s was performed to study the system operational limits during 250 days. The effect of the dissolved oxygen concentration on the nitrification rate was also evaluated. Under these conditions a critical elimination capacity (EC) of 250 $NH_3 \cdot m^{-3} \cdot h^{-1}$ and a maximum EC of 300 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ were obtained. The maximum nitrification rate obtained was 0.5 kg $N \cdot m^{-3} \cdot day^{-1}$. However, this nitrification rate only was possible to be achieved under partial nitrification. For complete nitrification, the critical nitrification rate was 0.3 kg $N \cdot m^{-3} \cdot day^{-1}$. These results confirm that bioscrubber coupled to a MBBR is a good alternative to treat high ammonia loads with remarkable advantages, such as the retention of properly biomass concentration without auxiliary equipment.

**Keywords**

Ammonia

Bioscrubber

High loads

Nitrification rates

MBBR

Electrical conductivity

# 1. Introduction

The growth in world population has led to a significant increase in the generation of wastes (solid, liquid and gaseous). Waste gas is probably the major issue in the case of waste treatment, due to the fact that once the pollutant is emitted into the atmosphere, its recovery and treatment are both very difficult and expensive. In the last few decades, the biological treatments have been increasing their interest in this field. Biofilters and biotrickling filters have demonstrated their robustness on the treatment of industrial waste gas emissions (Dorado et al. 2015). However, when high loads of pollutant are treated by these systems the inhibition of biomass could occur (Blázquez et al. 2017). In order to overcome this limitations it is necessary to use reactors with a high volume, with the increase of the investment and operation cost that this represents. For this reason, it is necessary to explore new technologies which could represent a potential alternative, especially at high loads. Due to their configuration (two separate steps, absorption column and bioreactor) bioscrubbers seems to be a good option for highly soluble compounds like ammonia. Due to its configuration, a bioscrubber offers better options for controlling parameters such as pH, $O_2$ supply and nutrients addition. This configuration could be a good alternative to overcome the main limitations of the traditional biotreatment technologies (biofilter or biotrickling filters) (Morral et al. 2021).

Typically, a bioscrubber is a two-step reactor. In the first step, the pollutant is absorbed into a scrubbing solution (normally water or mineral medium) in an absorption tower. The liquid phase containing the dissolved pollutant is subsequently drawn off and transferred to a continuously stirred tank containing the active biomass. The second step takes place into the tank and the pollutants are degraded by the microorganisms suspended within. Water is constantly recirculated between the tank and the absorption column (Shareefdeen and Singh 2005). Similarly to wastewater treatment plants, in order to maintain the properly biomass concentration inside the bioreactor a settler must be used. In order to avoid the need of a settler, in the last years new configurations has been applied in wastewater treatment plants (Salvetti et al. 2006). Moving bed biofilm reactors (MBBR) has showed its effectivity for the treatment of waste water without the need to include a settler (Qaderi et al. 2018; Sonwani et al. 2019).

On a MBBR the carrier material is suspended and circulated into the stirring biological tank. The biomass is attached on the surface of the carrier material (Young et al. 2017). Thus, the MBBR can combine the advantages of the biofilm and the suspended biomass (Zhang et al. 2021). Due to that the biomass is attached on the surface of the carrier material, long biomass retention time could be used. Long biomass

retention time are especially indicated for biomass with slow grow rate, 0.6-0.9 $day^{-1}$ (like ammonia oxidizers)(Rittmann, Bruce E.; McCarty 2001; Piculell et al. 2016). For this reason MBBR are considered a good alternative for the nitrification step in wastewater treatment plants (Chaali et al. 2018). The percentage that is filled with carrier material normally ranges from 30 % to 70 % of the reactor volume (Lariyah et al. 2016). However, some authors recommend ratios of 45 % to achieve good circulation of the carrier material without accumulating in the reactors corners (Zhang et al. 2021). The specific areas of the carrier material ranges between 200 to 2500 $m^2 \cdot m^{-3}$ (Lariyah et al. 2016) allowing to achieve high biomass concentration inside the bioreactor without the use of a settler. This advantage makes possible to reduce the footprint of the treatment system as well as the investment costs (Barwal and Chaudhary 2014).

Despite that MBBRs has been demonstrated their robustness and viability for the treatment of wastewater treatment plants, MBBRs are still unexplored for the treatment of waste gases. Due to the characteristics mentioned above, it seems that MBBR could be a good option for the treatment of highly soluble compounds like ammonia. Bioscrubber seems to be the best technology for the implementation of MBBR into waste gases since it can be assimilated to previous wastewater treatment experiences. Although bioscrubbers have demonstrated their capability in the treatment of different polluted gases such as biogas desulfurization (San-Valero et al. 2019) or VOCs (Dobslaw et al. 2019), in the case of the ammonia, they are still poorly explored (Morral et al. 2021).

The aim of this work is to analyze the performance of a bioscrubber for the treatment of high loads of ammonia. The biological reactor of the system was adapted to a MBBR (filled with polyurethane foam cubes at a ratio of 50%). The performance of the system was evaluated in terms of elimination capacity, maximum loading rates and nitrification rates.

# 2. Materials and methods

### 2.1. Lab-scale bioscrubber setup

Ther lab-scale bioscrubber is composed of two units: an adsorption column and a MBBR. The absorption column was made with a transparent PVC pipe. The volume was 0.8 L with a diameter of 63 mm and a height of 27 cm. As a packing material, Pall rings (diameter of 16 mm) was used. At the bottom of the column, a buffer tank was installed (4 L). The aim of this tank was to avoid the direct pollutant gas bubbling to the biological tank. Gas stream was introduced into the column at a flow rate of 11 $L \cdot min^{-1}$ (EBRT of 4 s) controlled by a mass-flow controller (El-Flow Select, Bronkhorst, Nederland). Similarly, ammonia

concentration was introduced in a range from 0 to 600 $ppm_v$ from a pure cylinder (Ammonia TT 98%, Linde, Spain). Ammonia concentration in the gas phase was measured with an electrochemical sensor (GasAlertMicro 5, Honeywell, USA).

The biological tank reactor was configured as a MBBR with a total volume of 15 L. As a carrier material, polyurethane foam (PUF) cubes of 1.5-2 cm were used filling the reactor at 50% of the capacity. The liquid phase circulation between the biological tank and the absorption column was performed by means of a peristaltic pump (Masterflex L/S, Code Palmer, USA). In order to avoid the accumulation of ammonia oxidation subproducts, a continuous make-up water/nutrient solution flow rate of 0.7 $L \cdot dia^{-1}$ was kept. This corresponds to an hydraulic retention time (HRT) of 10 days (referred to the volume of carrier material). In the biological reactor, conductivity and pH probes (Multi 3420, WTW, Germany) were installed. The pH of the system was fixed at a value of 7.5±0.3 by an on/off controller adding either HCl (0.5 M) or NaOH (0.5 M). The dissolved oxygen concentration in the liquid phase was measured by an oxygen prove (OxiCell, WTW, Germany) and controlled by adjusting the air flow (El-Flow Select, Bronkhorst, Nederland). The mineral medium was prepared with tap water and contained ($g \cdot L^{-1}$) 0.04 $K_2HPO_4$, 0.02 $KH_2PO_4$, 0.04 $MgSO_4$, 0.07 $CaCl_2 2H_2O$, 0.02 KCl and 7 $NaHCO_3$.

### 2.2. Analytical methods

Ammonium, nitrite and nitrate concentration in the liquid phase was measured by a spectrophotometer (DR2800, Hach, USA). In the case of ammonium, the kit LCK 303 was used for the range of 0-42 mg $N\text{-}NH_4 \cdot L^{-1}$ and the kit LCK 302 for the range 42-162 mg $N\text{-}NH_4 \cdot L^{-1}$. Nitrover 2 and Nitraver 5 was used for the quantification of nitrite and nitrate, respectively.

### 2.3. Inoculation

Activated sludge obtained from an urban wastewater treatment plants (Manresa, Spain) was used for the inoculation of the bioscrubber. During the inoculation phase, 5 L of sludge with a concentration of 4 g $TSS \cdot m^{-3}$ was used. In order to favour the immobilization of the biomass on the surface of the carrier material, the biological tank was agitated only for two days (without the absorption column). Subsequently, the inlet water/mineral medium was connected and the unattached biomass was purged. During this period, a small quantity of ammonium (100 ppm $N\text{-}NH_4$) was fed with the mineral medium. After one week, once the liquid phase was clarified and accumulation of nitrate was observed, the absorption column was connected and the supply of ammonium with the mineral medium was ceased.

### 2.4. Nitrification rates

Nitrification is as a two-step process. The first step is the ammonium oxidation to nitrite (nitritation, equation (1)) on the second step, nitrite is oxidised to nitrate (nitratation equation (2)).

$$R_1 = \frac{N - NO_2 \cdot Q_W}{V} + R_2 \quad (1)$$

$$R_2 = \frac{N - NO_3 \cdot Q_W}{V} \quad (2)$$

Where $R_1$ and $R_2$ represents the nitritation and the nitratation rate in kg $N \cdot m^{-3} \cdot day^{-1}$, respectively. N-NO2 and N-NO3 represents the concentration of nitrogen in form of nitrite and nitrate in kg $N \cdot m^{-3}$, respectively. $Q_w$ is the purge flow rate in $m^3.day^{-1}$ and V is the volume of carrier material in $m^3$.

### 2.5. Elimination capacity

Elimination capacity represents the total amount of pollutant that is eliminated from the gas phase.

$$EC = \frac{C_{out} - C_{in}}{V_c} \cdot Q$$

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Where EC represents elimination capacity in g $NH_3 \cdot m^{-3} \cdot h^{-1}$. $C_{out}$ and $C_{in}$ represents outlet and inlet concentration of ammonia in the column in g $NH_3 \cdot m^{-3}$, respectively. Q represents the gas flow in $m^3 \cdot h^{-1}$ and $V_c$ is the volume of the packing bed in $m^3$.

# 3. Results

### 3.1. Overall performance of the bioscrubber

The bioscrubber was operated for 8 months (245 days). During this period, the maximum ammonia elimination capacity as well as the maxim nitrification velocity were evaluated. Figure 1 shows the ammonium, nitrite and nitrate concentration in the liquid phase. For the gas phase, the inlet ammonia concentration and ammonia removal efficiency are also shown.

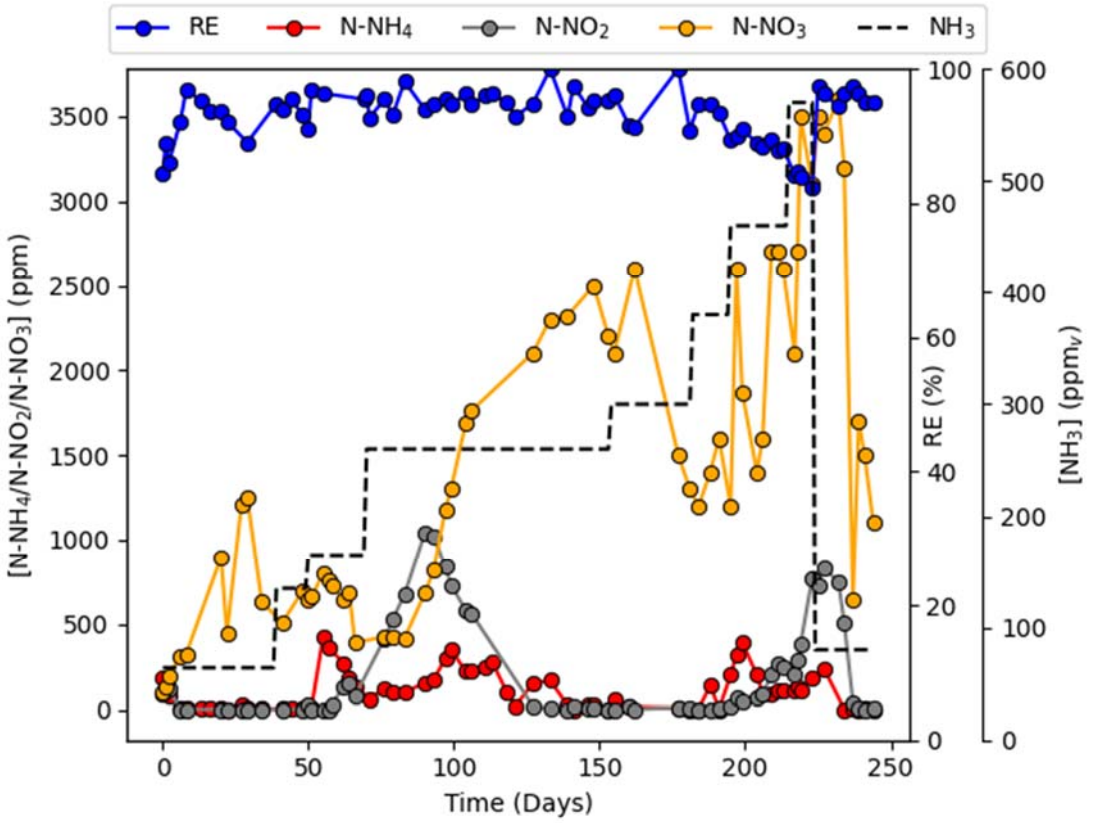



Figure 1: Evolution of ammonium, nitrite, nitrate (liquid phase), ammonia RE and inlet amonia cocentration steps (gase phase)

In the first 38 days of experimentation, the system was operated under an ammonia inlet concentration of 64 $ppm_v$ (corresponding to an ammonia loading rate of 41 g $NH_3 \cdot m^{-3} \cdot h^{-1}$). In this first phase, it could be possible to observe that the complete nitrification (no accumulation of nitrite or ammonium) occurred. From day 38 of the experiment, the inlet concentration was increased to 135 $ppm_v$ (ammonia loading rate of 86 g $NH_3 \cdot m^{-3} \cdot h^{-1}$). Again, during this period, no accumulation of nitrite and ammonia was also observed. Since the system was still achieving full nitrification on day 50, a new increase of ammonia inlet concentration was made. In this new step, the inlet ammonia concentration was increase up to 165 $ppm_v$ (loading rate of 105 g $NH_3 \cdot m^{-3} \cdot h^{-1}$). From the first days of this new step, it was possible to observe that an accumulation of ammonium (up to 400 ppm) occurred in the bioreactor. However, once this concentration was reached, the ammonia concentration decreased to values below 50 ppm. This phenomenon may indicate that at first the ammonia-oxidizing biomass was partially inhibited, but after few days the microorganisms adapted to the new operating conditions and completely degraded the accumulated ammonia. This phenomenon is in accordance with that observed by Ramaswami et al. (2019) and Soliman et al. (2016) in a bioreactor when the inlet concentration of ammonia was increased from 350 to 500 ppm and from 500 to 700 ppm,

150 respectively. Once the system achieved full nitrification again (day 70), a new step of ammonia inlet
151 concentration (up to 260 $ppm_v$) was made.

152 In this step, which represents an ammonia loading rate of 163 g $NH_3 \cdot m^{-3} \cdot h^{-1}$, it was observed that de
153 dissolved oxygen concentration decreased at values below 1 ppm (figure 2). Under these conditions (0.3-1
154 ppm of dissolved oxygen) it is possible to achieve the partial nitrification of ammonium (Rahimi et al.
155 2020). In order to study the capacity of the system to operate under partial nitrification conditions, the low
156 oxygen concentration was kept for 40 days. Under these operating conditions, in the first days (65-77)
157 nitrite accumulated in the liquid medium, meanwhile nitrate concentration remained constant (see Figure
158 1). This increase of nitrite concentration could indicated that it is possible to achieve a stable partial
159 nitrification operation with the conditions tested. However, in the next days a new increase of nitrate was
160 onserved. The increase of the nitrate on the liquid phase could indicated that partial nitrification was not
161 properly controlled and other key parameters such as pH or hydraulic retention time had to be take into
162 consideration (Paredes et al. 2007). In order to avoid the partial nitrification, the air supply to the reactor
163 was increased to achieve a dissolved oxygen concentration higher than 3 ppm. Due to this increase in the
164 oxygen concentration into the bioreactor, a decrease in the concentration of nitrite and ammonia in the
165 liquid to values close to 0 ppm were observed. This means that, once the oxygen concentration is increased
166 above 3 ppm, the system is able to achieve the full nitrification of the entire ammonia input load rate (163
167 g $NH_3 \cdot m^{-3} \cdot h^{-1}$). At this point it is important to highlight that the maximum loading rate reported for
168 biotrickling filters are between 120-140 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ (Sakuma et al. 2008; Tsang et al. 2015). However,
169 when biotrickling filters are operated under this ammonia high loads, it is difficult to achieve the complete
170 nitrification (Blázquez et al. 2017). The fact that the complete nitrification was achieved, under high
171 ammonia loading rates, could indicate that bioscrubber are a good alternative to biotrickling filters for the
172 treatment of high loads of ammonia. However, the use of a bioscrubber had a higher footprint (more
173 devices) and consumption of energy (pumps and aerating systems) that biotrickling filters.

174 On figure 2, the concentration of inlet ammonia and the dissolved oxygen in the liquid phase, as well as de
175 nitritation ($R_1$) and nitratation ($R_2$) velocities are show.

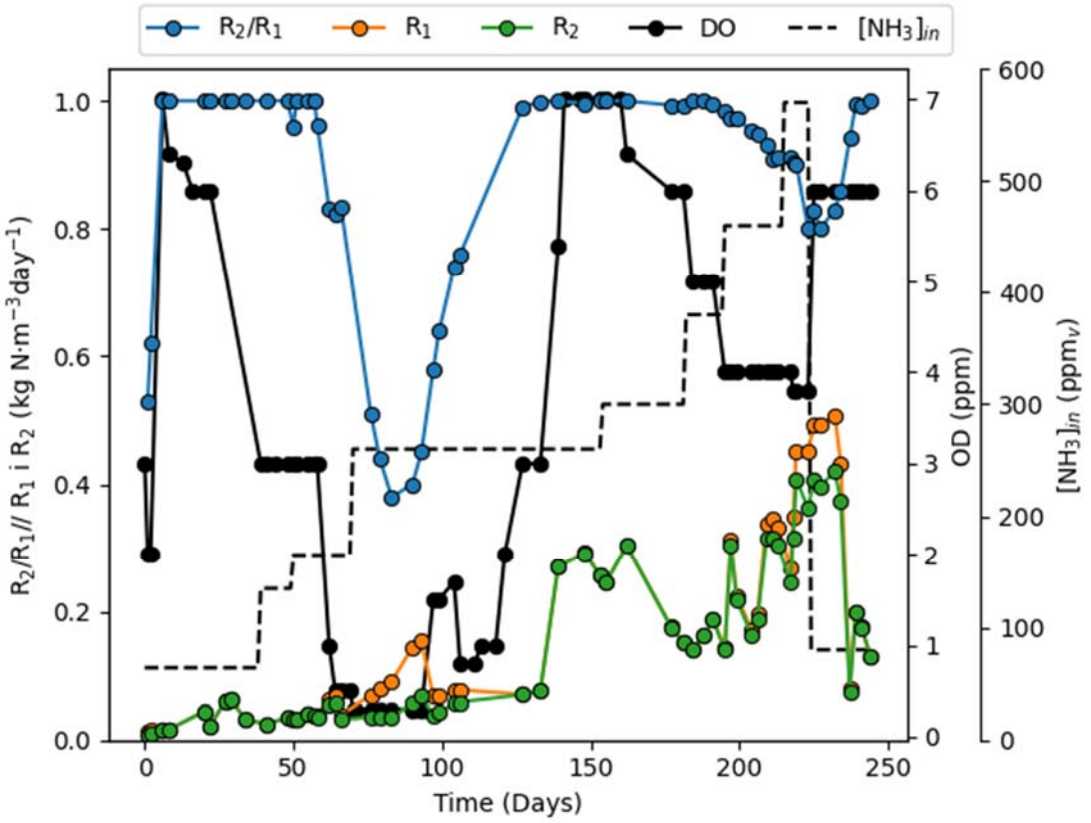



Figure 2: Evolution of the DO and inlet ammonia concentration and the nitrification velocities on the bioscrubber

Once full nitrification was resumed, and in order to determine the maxim elimination capacity that the system was able to treat, a new series of steps was applied (day 150). The system was able to achieve the full nitrification until ammonia concentrations of 380 $ppm_v$ (loading rate of 230 g $NH_3 \cdot m^{-3} \cdot h^{-1}$). When the system operated under an inlet concentration of 380 $ppm_v$ it was possible to observe an accumulation of ammonium (up to 400 ppm). However, without any change in the operational conditions, the ammonium concentration started to decrease (day 198) down to 100 ppm and kept close to this value during this step. This behaviour on the ammonium concentration is similar to that observed previously on days 50-67. This phenomenon may indicate that when there is an increase in the input concentration of the system the ammonia-oxidizing bacteria needs a period of acclimation to the new working conditions. Consequently, once the biomass is acclimated, the accumulated ammonium starts to be oxidized again. However, when the ammonia decrease occurred, the nitrite concentration started to increase, this phenomenon may indicate that the nitrite-oxidizing bacteria is partially inhibited by the ammonia concentration, since it is more sensitive to ammonia concentrations and environmental conditions than the ammonia-oxidizing bacteria (Paredes et al. 2007; Van Hulle et al. 2010). Thus, inhibitions of the biomass could occurred for

concentration between 0.1-1 $mg \cdot L^{-1}$ of free ammonia (nitrite-oxidizer bacteria) and 10-150 $mg \cdot L^{-1}$ of free ammonia (ammonia-oxidizer bacteria) (Anthonisen et al. 1976).

The absorption capacity of the system was kept higher than 90% until an ammonia concentration of 570 $ppm_v$ (363 g $NH_3 \cdot m^{-3} \cdot h^{-1}$) was introduced into the system. At this point, the removal efficiency of the absorption column decreased to values close to 80%. Besides, at these conditions nitrite accumulation was again produced in the liquid. These two phenomena indicate that the system had already reached the critical treatment capacity and started to be overloaded. Once the ammonia concentration was reduced to 80 $ppm_v$ (51 g $NH_3 \cdot m^{-3} \cdot h^{-1}$), the ammonia removal efficiency increased to values close to 95 %. Also ammonium and nitrite concentration quickly dropped to values lower than 10 ppm for both species, indicating that the nitritation and nitratation capacity of the system was recovered.

As can be observed in figure 1 the inlet ammonia concentration (and, thus, the loading rate to the system) plays a key role in the overall performances of the bioscrubber. In this regard, Figure 3 shows the relationship between the loading rate and the elimination capacity, both referred to the absorption column volume. The dashed line represents a removal efficiency of 100 %.

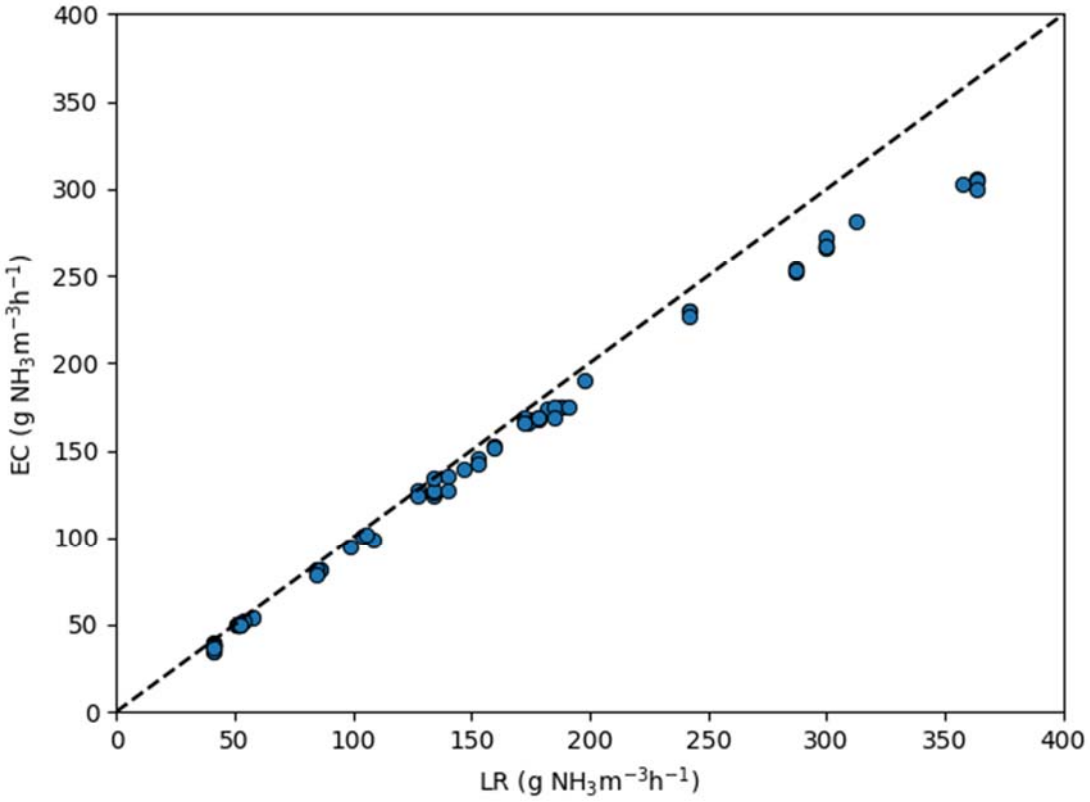


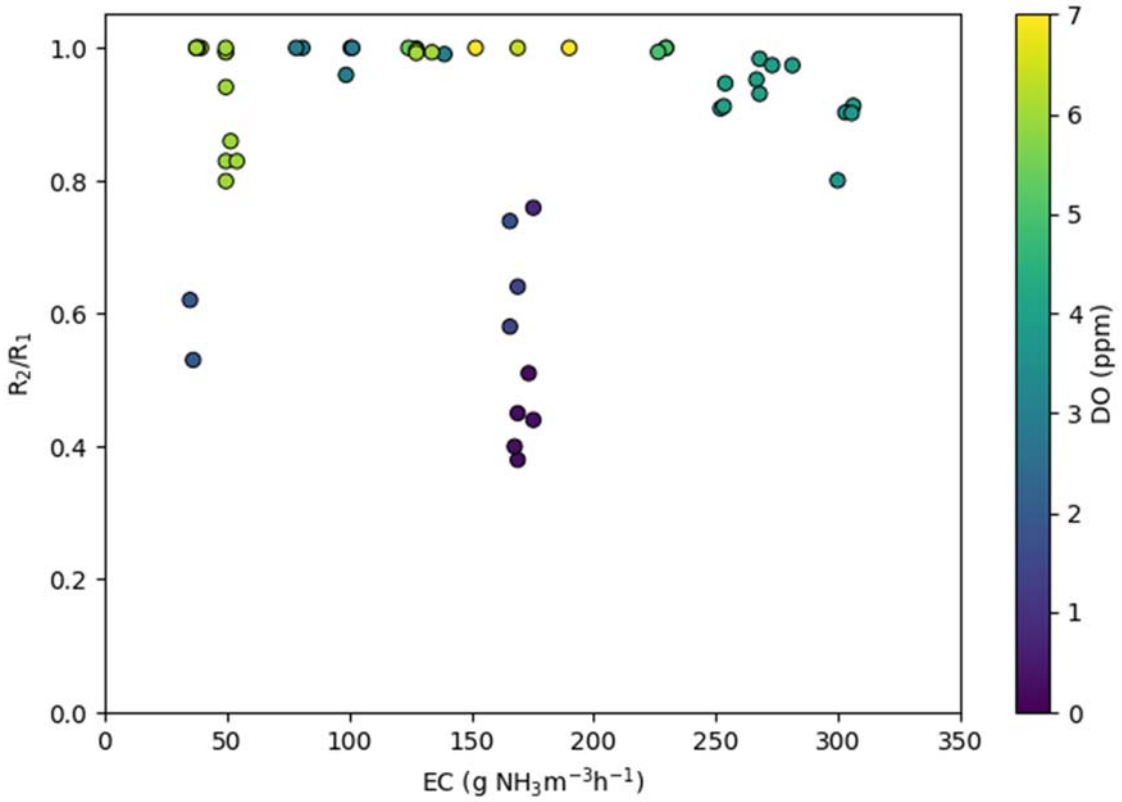

Figure 3: EC vs LR of the bioscrubber

As can be seen in the figure, the treatment capacity of the system is close to 100 % at loads lower than 250 g $NH_3 \cdot m^{-3} \cdot h^{-1}$. At higher loads the system starts to be unable to reach 100% RE. Thus, for loads between 250 and 300 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ the treatment capacity decreases to values of 90 %. The maximum treatment capacity of the system was observed at values close to 300 g $NH_3 \cdot m^{-3} \cdot h^{-1}$, which indicates that loads above this value will lead to a reduction in the absorption capacity of the system, as observed for loads of 350 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ (RE 80%). The treatment capacities obtained in this work are higher than those reported for biotrickling filters, which are are between 120-140 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ (Sakuma et al. 2008; Tsang et al. 2015).

### 3.2. Nitritation and nitratation velocities

Despite the elimination capacity in the absorption column is an important parameter for the proper design of a bioscrubber, the loading rate introduced into the biological reactor also plays a critical role in the performance of the system, since the biomass used for nitrification can be inhibited by both concentrations of ammonia as well as nitrite (Anthonisen et al. 1976).

The relationship between the velocities $R_2$ (nitrification velocity equation (2)) and $R_1$ (nitrification velocity equation (1)) gives an idea of the system tendency in terms of nitrification. Values close to 1 indicate that complete nitrification (nitrate accumulation) is achieved in the system; on the other hand, values close to 0 indicate that the system is working in partial nitrification conditions, so, nitrite accumulation in the liquid phase is occurring. Figure 4 shows the percentage of the relationship between the nitrification rate ($R_1$) and the nitration rate ($R_2$) at different DO concentrations.

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227 Figure 4: Relationship between nitrification velocities and elimination capacity of the column

228 Figure 4 shows how the system was capable to achieve complete nitrification (as long as a minimum
229 concentration of dissolved oxygen of 3 ppm was maintained) for EC values lower than 230 g $NH_3 \cdot m^{-3} \cdot h^{-1}$.
230 When this value was exceeded, a reduction of the nitratation rate was observed (nitrite stared to accumulate
231 in the liquid phase) with the load of pollutant absorbed in the column increases. Thus, when the elimination
232 capacity was 300 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ the $R_2/R_1$ ratio drops to values below 0.9, even though the oxygen
233 concentration was higher than 3 ppm. Therefore, the nitrification rate reduction was produced by the
234 increase of ammonium concentration rather the oxygen limitation.

235 In the cases when the system was operated under concentrations of dissolved oxygen lower than 2 ppm an
236 important reduction of the $R_2/R_1$ ratio was observed. Thus, for elimination capacities of 160 g $NH_3 \cdot m^{-3} \cdot h^{-1}$
237 $R_2/R_1$ ratios between 0.4-0.6 could be observed. This fact indicated that oxygen limitations could produce
238 a reduction on the nitrification capability with the subsequently increase of the ammonia or nitrite
239 concentration in the liquid phase. This increase in the concentration of ammonia or nitrite could inhibit the
240 biomass. At an elimination capacity of 50 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ it was possible to find some points with a $R_2/R_1$
241 ratio of 0.8, although the oxygen concentration was close to 6 ppm. These points belong to the last step

(day 224) of the ammonia inlet concentration (reduction from 570 to 80 $ppm_v$). As can be seen in the figure 1, once the reduction of the ammonia concentration was done, the removal efficiency was quickly recovered. However, in order to recover the biological capacity ($R_2/R_1$ ratio close to 1) more time was needed. This delay in the recuperation could be produced by the fact that the biomass needs to degrade the ammonia and nitrite accumulated during the previous step.

Figure 2 and figure 4 shows that while the dissolved oxygen concentration in the liquid phase was higher than 2 ppm and the ammonia loading rate lower than 230 g $NH_3 \cdot m^{-3} \cdot h^{-1}$, full nitrification ($R_2/R_1$ ratio close to 1) could be achieved. Under these conditions, the highest observed nitrification rate was 0.30 kg $N \cdot m^{-3} \cdot day^{-1}$. The maximum nitritation rate ($R_1$) observed was 0.51 kg $N \cdot m^{-3} \cdot day^{-1}$, when the inlet ammonia concentration was 570 $ppm_v$ (g $NH_3 \cdot m^{-3} \cdot h^{-1}$). At the same operational conditions, the nitratation rate ($R_2$) was 0.41 kg $N \cdot m^{-3} \cdot day^{-1}$, which represents a $R_2/R_1$ ratio of 0.8. This reduction in the nitratation rate could be produced by the accumulation of the ammonia in the liquid phase. It is well known that the nitrite-oxidizer bacteria are more sensible to ammonia concentration than the ammonia-oxidizer bacteria (Paredes et al. 2007). The lower $R_2/R_1$ ratio observed was close to 0.4, with a nitritation and nitrtatation rate of 0.06 and 0.014 kg $N \cdot m^{-3} \cdot day^{-1}$, respectively. This values were observed when the bioscrubber operated under oxygen limitation (<1 ppm) (days 65 to 80). Table 1 shows a comparison of the volumetric nitrification rates reported for different technologies used for wastewater treatment plants.

Table 1: Comparison of nitrification rates between previous literature-based studies and present work

| **Configuration** | **T (ºC)** | **Nitrification rate** $\mathbf{kg\ N \cdot m^{-3} \cdot d^{-1}}$ | **Reference** |
|---|---|---|---|
| Granular biomass | 20 | 1.3 | (Ren et al. 2017) |
| Granular biomass | 25 | 2 | (Wang et al. 2017) |
| Immobilized biomass | 30 | 0.16 | (Benáková et al. 2018) |
| Activated sludge | 25 | 0.12 | (Ishimoto et al. 2020) |
| MBBR | 15-30 | 0.25-0.5 | (Piculell et al. 2016) |
| MBBR | 15-20 | 0.13 | (Gustavsson et al. 2020) |
| Fixed bed | 25 | 0.7 | (Ramaswami et al. 2019) |
| MBBR | 25 | 0.5 | This work |

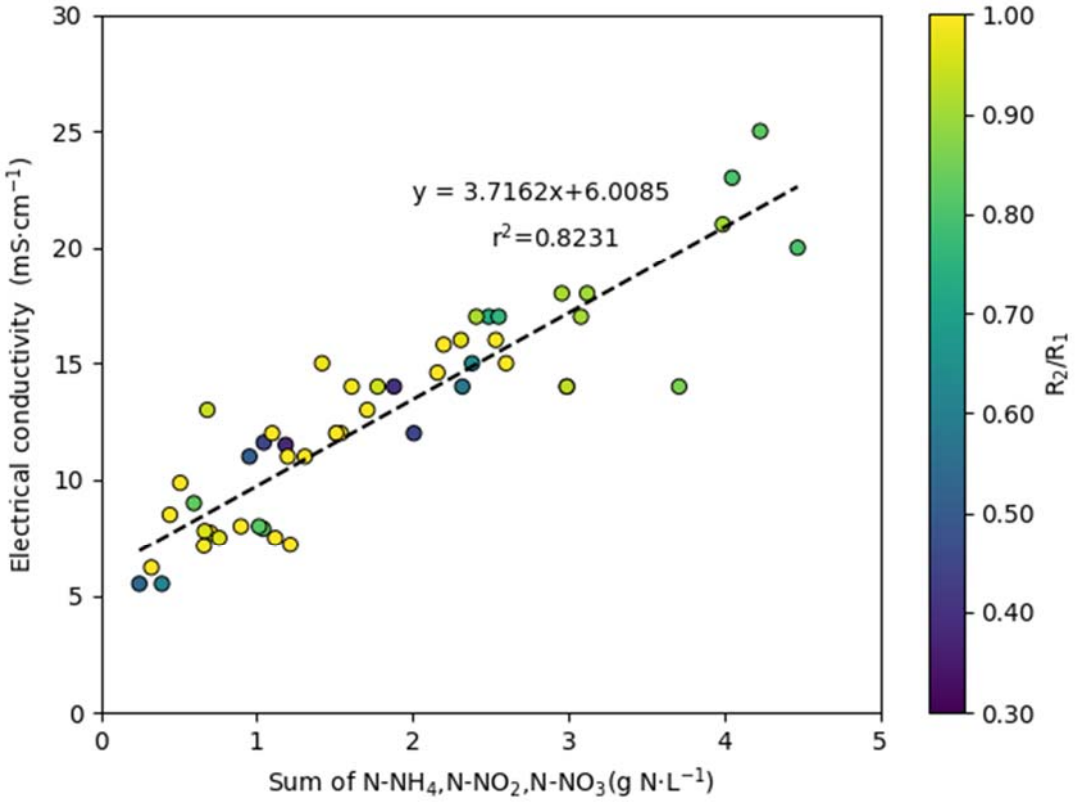
As can be seen in the table, the velocities obtained in this work are within the range of reported velocities by other authors. The reported velocities are very varied and are largely influenced by the technology used, the operational conditions as well as the characteristics of the wastewater to be treated. Thus, it is possible to find granular biomass systems capable of reaching a velocity up to 2 kg $N \cdot m^{-3} \cdot day^{-1}$. However, in the case of MBBR for ammonia treatment, the nitrification velocities range between 0.13 to 0.5 kg $N \cdot m^{-3} \cdot day^{-1}$.

The nitrifications rates obtained in this work (0.30 kg $N \cdot m^{-3} \cdot day^{-1}$ for full nitrification and 0.5 kg $N \cdot m^{-3} \cdot day^{-1}$ for the partial nitrification) are within the range reported for other MBBR systems, which was used for the wastewater treatment. This fact suggests that the system studied in the present work (bioscrubber with a biological tank configured as an MBBR), could be a good alternative for the treatment of gaseous polluted with high ammonia loadings rates, since it has been possible to reproduce nitrification rates comparable to the MBBR currently used for wastewater treatment.

### 3.3. Relationship between electrical conductivity and the nitrogen concentration in the liquid phase

Parameters such as dissolved oxygen, pH or ammonia, nitrite and nitrate concentration are useful to get relevant information about the state of the bioscrubber performance. However, it is not always possible to use on-line or continuous measurements of these parameters, mainly the concentration of nitrogen species (ammonia, nitrite and nitrate). Ammonia and nitrite concentration in the liquid phase plays a key role on the bioreactor performance. For this reason, it is necessary to find easy and cheap methods for the estimation (on-line) of the nitrogen species concentration in the liquid phase (Dumont et al. 2020).

In the recent years some authors reported that it is possible to use the electrical conductivity of the liquid phase as an estimate of the nitrogen species concentration when a biotrickling filter was used for the treatment of ammonia emissions (Melse et al. 2012; Pongkua et al. 2020). In order to explore whether similar correlations could be observed on a bioscrubber used for the treatment of high ammonia loading rates, the electrical conductivity of the liquid phase was monitored. Figure 5 shows the relationship between the nitrogen concentration of the liquid phase (sum of ammonia, nitrite and nitrate) and the conductivity. The colour bar represents the $R_2/R_1$ ratio observed in each point.

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288 Figure 5: Relationship between nitrogen concentration and electrical conductivity

289 As can be seen in the figure 5, it is possible to establish a direct relationship between the electrical
290 conductivity and the concentration of ammonia, nitrite and nitrate in the liquid phase. Thus, meanwhile the
291 concentration of nitrogen keeps lower than 3 g $N \cdot L^{-1}$, the electrical conductivity was below to 20 $mS \cdot cm^{-1}$
292 and the $R_2/R_1$ ratio remains close to 1, which means that the system was achieving full nitrification of the
293 whole absorbed ammonia. At this point it is important to highlight that there are some points that show a
294 $R_2/R_1$ ratio lower than 0.7. All of these points was obtained when the system was operated under low oxygen
295 concentrations (figure 4), so, this reduction of the $R_2/R_1$ ratio is produced for the oxygen limitations rather
296 than the biomass inhibition produced by the nitrogen concentration in the liquid phase. On the other hand,
297 when the electrical conductivity was higher than 20 $mS \cdot cm^{-1}$ (nitrogen concentration greater than 3.5 g
298 $N \cdot L^{-1}$) a decrease of the $R_2/R_1$ ratio (down to 0.8) was observed, indicating the beginning of nitrite
299 accumulation produced by the biomass inhibition. Thus, it could be possible to define a setpoint of 20
300 $mS \cdot cm^{-1}$ as the maximum electrical conductivity that the bioscrubber should not exceed. This value is very
301 similar that some authors used when biotrickling filters were used. Liu et al. (2017) operated different
302 biotrickling filters for the treatment of pig house emissions. On their work, the authors used a setpoint of

22 $mS \cdot cm^{-1}$. Once the electrical conductivity exceeded the setpoint, water with half volume of each recirculation tank was discharged and fresh water was filled up.

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# 4. Conclusions

The viability of a bioscrubber plus a MBBR for the treatment of high loads of ammonia was demonstrated. The maximum nitrification rate obtained was 0.5 kg $N \cdot m^{-3} \cdot day^{-1}$. However, this nitrification only was achieved under partial nitrification. The critical nitrification rate ($R_2/R_1$ ratio equals to 1) was 0.3 kg $N \cdot m^{-3} \cdot day^{-1}$. For the absorption column, the maximum elimination capacity was close to 300 g $NH_3 \cdot m^{-3} \cdot h^{-1}$. A critical elimination capacity (RE 100%) of 250 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ was obtained. This results shows that a bioscrubber could be a good alternative for the treatment of ammonia emission.

Also the effectiveness of the electrical conductivity as a cheaper method to evaluate the general performance of the bioscrubber was tested. Thus, to achieve a full nitrification electrical conductivity has to be lower than 20 $mS \cdot cm^{-1}$ (nitrogen concentration lower than 3.5 g $N \cdot L^{-1}$). Beyond this electrical conductivity, the biomass stars to be inhibited due to the nitrite or/and ammonia accumulation.

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## 414 5. Declarations

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