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MULTI-FUNCTION BIOSYSTEM BASED ON *ARTHROSPIRA PLATENSIS* FOR SPACE APPLICATIONS

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Abstract

This study presents an introduction in air revitalisation practice by using a microalgae-based biosystem. Althrough the study is developed in the light of space applications, it opens new horisons for implementing such systems for terestrial applications as well, where biotechnologies for addresing climate change and other issues associated with air pollution is in high demand. The experiments have been performed at laboratory-scale by using *Arthrospira (spirulina) platensis* as microalgae model. Influence of culture and illumination conditions, as well initial gas composition and other factors/techniques such culture filtration on the biosystem performance were investigated and the relevant results are presented and discussed. Based on the actual findings, future research needs are addressed.

Keywords*:* *Arthrospira platensis, biosystem, earth, environment, space, spirulina*

Introduction

This study re-brings to the forefront the photosynthesis, as a process well known since long time ago, but still very actual due to the mechanism of the biomass production at macro and micro-levels. Particularly, the microalgae development is based on this process and presents a huge potential to be engineered for both earth and space applications. Microalgae-based systems can be adapted for rehabilitation of environmental factors (air, water), mitigation of climate change, as well life-support in space and circular economy (Soreanu et al 2018, Caroling et al 2015).
Among the different available microalgae, *Arthrospira (spirulina) platensis* is one of the best candidates for space-related applications. This microalga is able to perform multi-tasking activities that support different applications: air revitalisation and treatment (not only carbon dioxide removal and oxygen production, but also removal of trace contaminants from air), wastewater treatment, development of valuable biomass for different purposes (e.g. as food, cosmetic and therapeutic ingredient, energetical valorisation) (Soreanu et al 2018, Juneja et al 2013).
The present study addresses some of the main aspects associated with *A. platensis* consideration in the multi-function biological systems, from the recent findings to the future research needs, highlighting the perspectives in air revitalization.

Influence of culture conditions (e.g. pH), illumination conditions (e.g. lighting source), initial gas composition (e.g. single versus mixed gases) and other factors/techniques such culture filtration (as part of bioreactor operation protocol) on the biosystem performance were investigated and the relevant results are presented and discussed.

Materials and Methods

Several experiments have been carried out in order to highlight the involvement of the biological component in air revitalization and the benefits associated with this process in the light of sustainability.

Conditioning air has been treated in a laboratory-scale sparged photobioreactor, by using *Arthrospira (spirulina) platensis* (Algae Research Supply) as a microalgae model. The photobioreactor was designed from a cylindrical column made in plexiglass (5 L culture capacity) and was equipped at the top with pH and temperature sensors coupled to a monitoring device (Vernier, model LABQUEST2). The processed air was fed into the nutrient solution at the bottom of the reactor via a medium bubble diffuser and the treated air was evacuated at the top. The nutrient solution consisted in a Zarrouk's medium free of $NaHCO_3$/NaCl, prepared from a stock concentrated solution (ALGOID Technol.) and distilled water. For initial pH adjustment (e.g. up to 10), a NaOH solution was added (an auto-buffering effect was further installed around the set pH). Except some relative short tests carried out to evaluate the system response under different experimental conditions, the reactor was operated continuously for few months at about 400 ± 50 ppm CO_2 and 0.5 L/min. An air pump (Tetra, model APS 100) was used for air supply and the flowrate was controlled by a flowmeter (Cole-Parmer, model PMRI-010919). Distilled water was added for compensating the water evaporation from the culture and the occasional samplings. The experiments were carried out at 2 Klux light intensity, assured by different illumination sources (described in next section). A digital luxmeter (Extech, Light Meter LT300) was used for the measurement of the light intensity. For a better light control, an aluminum folium was installed at a certain distance around the reactor.

A peristaltic pump (BETA Technology) and a micro-drip-system (GARDENA, model 1354-20) additionally equipped with a specific filtering material (polyester/polyamide –based microporous membrane, reusable) was used for culture filtration test at 0.1 L/min.

The synthetic gas mixture used in additional tests was prepared in 160 L plastic bags by mixing conditioned air with standardized gas from the commercial cylinder (1500 ppm NO_2/bal. synthetic air, Messer) and synthetic ammonia (obtained from concentrated NH_4OH solution). The obtained gas mixture was further diluted with conditioning air as carrier gas up to the desired concentration.

Biosystem performance has been assessed by monitoring the composition of the processed gas in inlet and outlet ports of the bioreactor. The AQ-Expert (E Instruments, USA) multifunctional indoor air monitoring monitor and the APNA370 (Japan) have been used in this regard (e.g. CO_2/O_2 and NO_x/NH_3 analysis, respectively).

Biomass development was evaluated via a pre-established method for estimation of biomass concentration as a function of the turbidity, where turbidity was measured with a Hach DR/2000 spectrophotometer (Soreanu et al 2018).

Performance in air revitalization was expressed in terms of removal efficiency (RE, %) and elimination capacity (EC, $g \cdot m^{-3}d^{-1}$) (Soreanu et al 2018).

Table 1. Performance criteria

Criteria	Equations		Terms
RE, %	$(c_{IN}-c_{OUT}) \cdot 100/c_{IN}$	(1)	c_{IN} = inlet concentration c_{OUT} = outlet concentration F_v = air flowrate V = culture volume
LR, $g \cdot m^{-3}d^{-1}$	$c_{IN} \cdot F_v/V$	(2)	
EC, $g \cdot m^{-3}d^{-1}$	$(c_{IN}-c_{OUT}) \cdot F_v/V$	(3)	

Results and Discussion

Influence of pH and illumination conditions on system performance

A. platensis is one of the few microorganisms that are able to grow under high alkaline conditions. This particular condition can be used as a strategy against biological contamination (Soreanu et al 2018). Moreover, it is known that microalgae development depends on the illumination conditions (light source, light intensity, light spectrum), which are key aspects to be considered in the photobioreactor design for a specific purpose.

In this study, the system performance has been evaluated in terms of CO_2 removal efficiency at pH 8 and pH 10. As can be seen in Figure 1, the system performance was favoured at pH 10, although the system still performs at pH 8, without being suppressed. In practice, it should be thus important to consider the system operation at pH above 8, especially when a risk in pH drop is envisaged (e.g. due absorption of acid gases at high concentrations). Overall, pH value can favour or affect the retention of certain contaminants in the culture and thus their availability to the microalgae, at a rate that is subject to the contaminant type, culture salinity, gas concentration, gas flowrate etc. Some of such aspects are described (Juneja et al 2013).

Also, the system response to several illumination conditions has been evaluated, as it is shown in Figure 1. For instance, white-like light sources have been considered for evaluation, such as: fluorescence lamp, LED lighting tube (2m), natural light. One side illumination was applied when using the fluorescence lamp. For the experiments with LED tube, two reactor configurations have been evaluated (for the same tube size): one with external tube (around the reactor) and one with immersed tube (into the reactor). Except for the test with natural light, an aluminium folium was used around the reactor in order to avoid the light dissipation and to simulate a natural light fond under controlled conditions. In contrast to the artificial light that was continuously provided, the natural light implicitly involved a night/day illumination regime. The most favourable effect on CO_2 removal efficiency was observed for the Ext. LED tube, followed by the FL lamp. The favourable effect could be attributed to the better light distribution around the reactor. The use of Int. LED tube didn't enhance the system performance, probably due to a photoinhibition phenomenon or the excessive heating of the culture (e.g. slightly above the optimum temperature of 35 °C) (Jimenez et al 2011). Some aspects concerning the mechanism of these phenomena are described in (Juneja et al 2013). Moreover, switching for natural light conditions (including night/day regime) drastically affected the system performance in terms of CO_2 removal performance (e.g. values below 5% have been recorded). Further returning to appropriate artificial illumination conditions resulted in a fast recovery (e.g. about one day) of the initial performance (results not shown). This behaviour indicates that the biological component is able to adapt to stress conditions via a metamorphosis physiology.

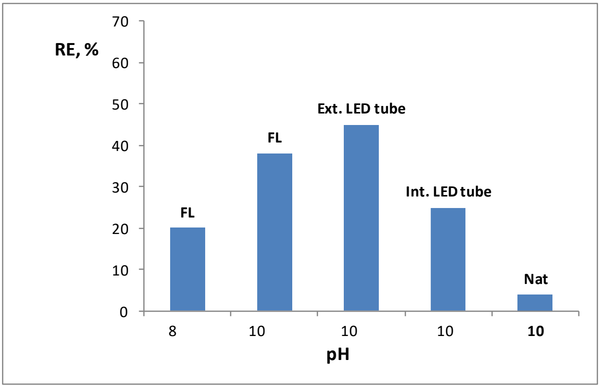

Figure 1. Influence of pH and illumination conditions on RE_{CO2}, observed at the same biomass concentration ($c_{biomass}$= 0.6 ±0.1 g/L); FL = fluorescence lamp (2 K); Ext. / Int. LED tube = external/immersed LED tube (2 m, 2 K); Nat = natural light fond (day/night regime)

Taking into consideration that the shading effect increasing due biomass development can limit the system performance, the next step is to determine the influence of the illumination factor on the performance of the system equipped with Ext. LED tube. For such configuration, this term could be defined as:

Illumination factor = Light amount*/biomass concentration (g/L) (4)

*expressed as LED tube size

Preliminary tests indicates that the illumination factor can play an important role in the system performance and enhanced performances can be obtained (results not shown).

Influence of culture filtration and recycling on the biosystem performance

A comparison between the system performance at the same biomass concentration with new and recycled culture (after filtration) on the system performance in terms of CO_2 removal is presented in Figure 2. It can be seen that at the same biomass concentration, the system exhibits quite similar performance in both cases, which indicates that this technique could be considered as part of the bioreactor operating protocol on a regular basis. When applied to an older concentrated culture exposed to shadding effect with affected performance, this technique can reabilitate the system (e.g. performance doubling). For the proposed technical solution, filtration efficiency above 90% can be obtained and biomass recovery is easy (results not shown). Such perfomance is in agreement (Drexler & Yeh 2014) that show the advantages and the disadvantges of different methods used for biomass harvesting.

The favourable effect of the filtration can be explained by the retention of the mature cells, while the recycling of the obtained permeate allow returnig the nutrients in the culture and the enhancing of the illumination factor (refreshing effect). Next step is to establish the filtration frequency, which should be also correlated with the illumination factor as well. Also, biomass valorisation options (Soreanu et al 2018, Juneja et al 2013) should be addressed as a complementary benefit associated with the investigated biosystem.

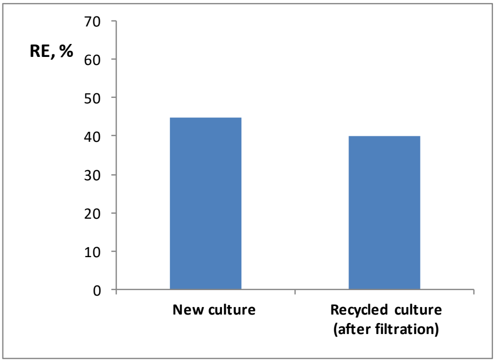

Figure 2. Comparison of RE obtained with a recycled culture (after filtration) versus that obtained with a new culture (Ext. LED tube illumination), observed at the same biomass concentration ($c_{biomass}$= 0.6 ±0.1 .g/L)

Influence of gas composition on the system performance

CO_2 is always present in indoors, being one of the indoor air quality indicators (Soreanu et al. 2018). In addition, traces of other gases can be detected in indoors, among NO_x and NH_3, but not limited to. In this study, the performance of the system in treating indoor air containing CO_2 was compared with the performance of the system in treating a synthetic gas mixture containing CO_2 (420ppm) and traces of NO_x (25 ppb) and NH_3 (25 ppb) (balance air), which are in the range of acceptable levels for indoor air (e.g. WHO 2005, Honne et al 2014, Bonino 2016, Jarnstrom & Saarela 2002). The performance in CO_2 removal (considered as a relevant benchmark in system development) was not affected by the the presence of other contaminants in air (Figure 3). Moreover, a significant reduction is observed in the case of NO_x, while NH_3 was only slightly diminushed. For instance, the alkaline conditions could favour the NO_2 uptake via physical process (as a pre-step in NO_2 uptake), but not the NH_3 uptake, which can explain the obtained performances (e.g.

EC for CO_2, NO_2 and NH_3: 43.03, 0.0055 and 0.00077 $g\cdot m^{-3}d^{-1}$, respectively). The oxygen content in the processed air was not affected by the biological process.

The presence of such NO_x traces in the processed indoor air could supply a part of the required nutrients for microalgae development under indoor conditions. Based on preliminary results (results not shown), an increase in CO_2 concentration above ambiental limits is associated with an increase in nutrients consomption rate, thus the system becomes faster deprivated in nutrients at a demanding overcoming the availability of NO_x in indoor air. Other studies (dedicated to flue gas treatment) highlighted also the potential of various microalgae in the removal of contaminants such as NO_x and CO_2 (e.g. Giordano & Wang 2018).

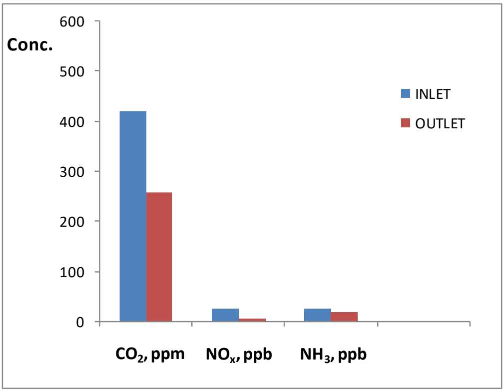

Figure 3. Example of indoor air pollutant diminushing* by the microalgae system (FL illumination). *other performances may apply, subject to system conditions

These observations offer a promising perspective for further development of a multi-function biosystem based on microalgae in order to be particularly integrated in closed environments such as spacecrafts cabins.

Conclusions

The screened bioprocess with *Arthrospira (spirulina) platensis* as microalgae model exhibits promising performances for air revitalization in closed environments such as spacecrafts cabins. The proposed bioprocess is sustainable, with forecasted benefits for both space and terrestrial applications. Based on the actual findings in this study, future research needs are addressed.

This investigation is being carried out within a RDI project funded by Romanian Space Agency (ROSA) and could present a special interest for different specialists acting in the field (e.g. biologists, chemical and environmental engineers etc. from the universities, research centers, other space agencies, environmental agencies etc).

Acknowledgements

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References

Bonino, S 2016, *Carbon Dioxide Detection and Indoor Air Quality Control*, available from: https://ohsonline.com/articles/2016/04/01/carbon-dioxide-detection-and-indoor-air-quality-control.aspx

Caroling, G, Vinodhini, E, Ranjitham, M & Shanthi, P 2015, 'Biosynthesis of copper nanoparticles using aqueous *Phyllanthus Embilica (Gooseberry)* extract - Characterization and study of antimicrobial effect', *International Journal of Nanotechnology and Chemistry,* vol.1, no.2, pp.53-63.

Drexler, ILC & Yeh, DH 2014, 'Membrane applications for microalgae cultivation and harvesting: a review', *Review in Environmental Science and Bio/Technology,* vol.13, pp.487–504.

Giordano, M & Wang, Q 2018, *Microalgae for Industrial Purposes*. Chapter 6, In: Biomass and Green Chemistry, S. Vaz Jr. (ed.), Springer International Publishing AG. S. Vaz Jr. (ed.): 133-167, available from: https://doi.org/10.1007/978-3-319-66736-2_6

Honne, A, Schumann-Olsen, H, Kaspersen, K, Mosebach, H & Kampf, D 2014, 'Air quality monitoring for the International Space Station applicable to aircraft cabins and cockpits', *Journal of Biological Physics and Chemistry,* vol.14, pp.94–102.

Jarnstrom, H & Saarela, K 2002, 'Indoor air quality and material emissions in new buildings', *Proceedings: Indoor Air 2002*, pp.201-206.

Jimenez, C, Belen, R, Coss, R & Xavier, NF 2011, 'Relationship between physicochemical variables and productivity in open ponds for the production of *Spirulina*: A predictive model of algal yield', Aquaculture, vol.221, pp.331-345.

Juneja, A, Ceballos, RM & Murthy, GS 2013, 'Effects of environmental factors and nutrient availability on the biochemical composition of algae for biofuels production: A review', *Energies,* vol.6, pp.4607-4638. doi:10.3390/en6094607

Soreanu, G, Cretescu, I, Diaconu, M, Ignat, M, Harabagiu, V, Cojocaru, C & Samoila, P 2018, 'Monitoring of CO_2 uptake by microalgae in indoor environment', *In: GLOREP 2018 Conference Proceedings, Politehnica Publishing House (Global and Regional in Environmental Protection Conference*), 15-17 November, Timisoara, Romania, pp.255-259.

World Health Organization WHO 2005, *Air quality guidelinesf or particulate matter, ozone, nitrogen dioxide and sulfur dioxide,* Global update 2005.