Photobioreactor Technology for Microalgae Cultivation To Support Humans in Space with Oxygen and Edible Biomass

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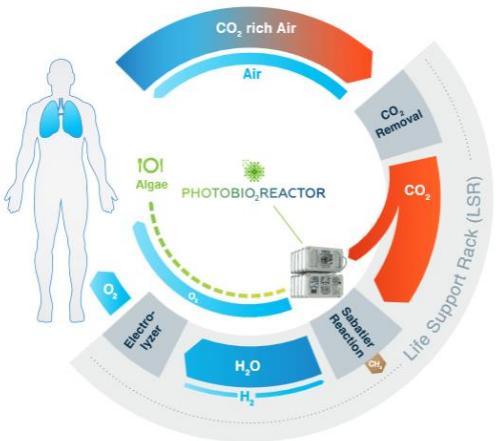
1. Microalgae cultivation

Microalgae cultivation in space enables an essential step to close the carbon loop in future advanced life support systems (LSS), which is important for future and far-distant exploration missions. Utilization of photosynthesis and the combination with existent physicochemical technologies offer a wide potential of benefit for LSS. *Chlorella vulgaris* as a promising microalgae species allows for cultivation in pumped loops to produce oxygen and edible biomass from carbon dioxide and water. Further nutrients such as ammonium and phosphate are needed. Microalgae offer various advantages compared to higher plants for first integrating steps of biological components into the LSS. Microalgae have a higher harvest index (> 90%), higher light exploitation (9% of microalgae, higher plants 4-6%, 19% upper biological limit), more rapid growth (five to ten times), lower water demand, mostly higher photosynthetic quotient (PQ), and a well controllable metabolism [4], [5]. Long-term cultivation and stability of the algae culture are one of the most critical development steps.

2. Photobioreactor technology for space

Encouraged by the positive results of several pre-studies on long-term cultivation of microalgae and synergetic integration in LSS at the Institute of Space Systems (IRS), University of Stuttgart/Germany in collaboration with the German Aerospace Center (DLR), the spaceflight experiment Photobioreactor at the Life Support Rack (PBR@LSR) was initiated in 2014 and kicked off in 2015 [1], [2], [3]. DLR, Airbus DS and IRS are aiming to establish a PBR system as a biological component to be connected with the physicochemical LSR to increase system closure and to demonstrate operational feasibility, see Fig. 1 (left). Technological demonstration of the ability to control microalgae cultivation under space conditions in a photobioreactor is the main focus of the spaceflight experiment PBR@LSR on the International Space Station (ISS), especially to prove the functionality and feasibility of a hybrid system in a real environment (CO_2 from astronauts), the short- and long-term performance of photosynthetic conversion of concentrated CO_2 into biomass and O_2, and the stability of the algae system under microgravity and radiation impact.

The cultivation in a 650 ml loop shall last half a year, and the CO_2 for the algae is extracted from cabin air by the CO_2 concentration unit of the LSR. The photobioreactors and LED panels, the algae liquid loop with the pump and tubing, and the required sensors (CO_2, O_2, pH value, temperature, humidity and pressure) are housed in a middeck locker, see Fig. 1 (right).



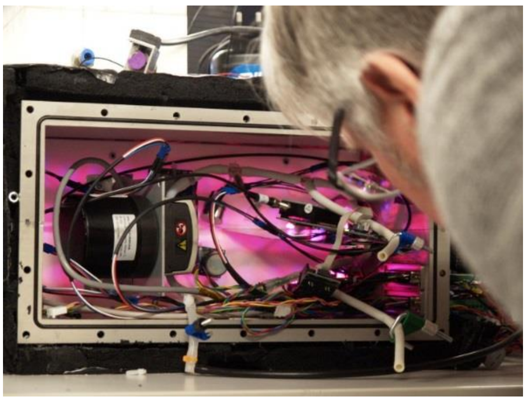


Figure 1: The integration of the photobioreactor in the LSR (left). Breadboard model for testing the long-term cultivation on-ground (right).

3. Long-term cultivation in space and on-ground

During the breadboard experiments, the settings of cultivation parameters (e.g. upper and lower CO_2 and O_2 concentration inside the 'well balanced' experiment compartment, temperature limits), operational techniques (inoculation, feeding and harvesting, termination and storage) and the development of tools for the astronaut for regular liquid exchange were investigated and developed. Besides station accommodation and safety requirements these results are shaping the design. The breadboard activities are on a very good way to finalize the proto flight model by end of 2017. A successful long-term cultivation over 186 days was performed from September 2016 until March 2017, see Figure 2 (left). Regular CO_2 consumption and O_2 production could be achieved. Further long-term cultivation in ground-based flat plate airlift reactors proved the feasibility of long-term cultivation of *C. vulgaris* in batch and continuous modes, see Figure 2 (right). The PQ during the high-performance phases are quite equal at 0.5-0.6.

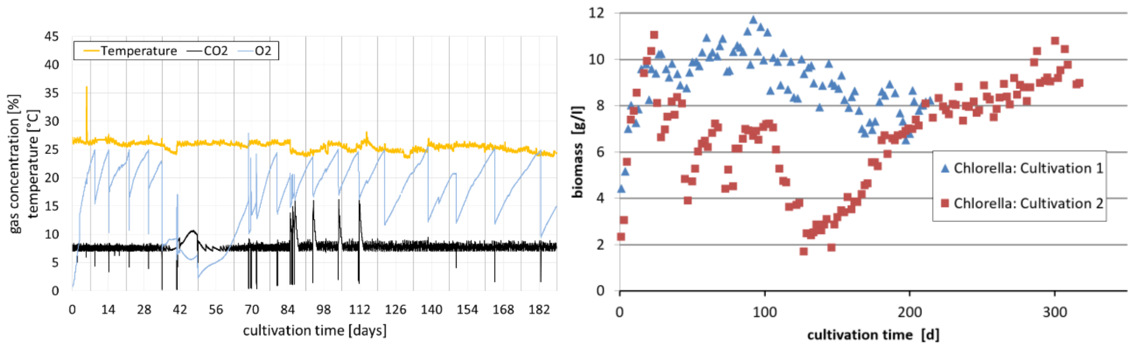


Figure 2: CO_2 consumption and O_2 production during the long-term cultivation of 186 days in the breadboard at IRS (left). Growth development during two long-term cultivation cycles in a flat plate airlift PBR at IRS (right).

4. Conclusion

The long-term cultivation on-board of the ISS offers the great opportunity to investigate the growth behaviour and metabolic performance of *C. vulgaris* under realistic operating conditions in space. A return of selected algae suspension samples and sequencing of isolated genetic material and possible changes in the genome of *C. vulgaris* enhanced or caused by µg and radiation could be investigated by effects on photosynthesis associated genes. Regarding its genetic stability *C. vulgaris* could be finally evaluated for its permanent application as a biological component in a hybrid life support system.

5. References

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Short Summary

Utilizing photosynthesis, microalgae are easier to control and more efficient than higher plants. Cultivation of microalgae (Chlorella vulgaris) in photobioreactors enable a first step to close the carbon loop in future life support systems. The spaceflight experiment PBR@LSR is in preparation and shall prove technological readiness for future exploration missions.