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Development of photobioreactors for anoxygenic production of hydrogen by purple bacteria

Jacub Gebicki[a], Michael Modigell[a], Matthias Schumacher[a], Job Van Der Burg[b], Eugene Roebroeck[b]
[a]Aachener Verfahrenstechnik, RWTH Aachen University, Turmstr. 46, 52056 Aachen, Germany; Tel: +492418095478; email: jakub.gebicki@avt.rwth-aachen.de
[b]Technogrow B.V. Netherlands; Tel: +31162687320; email: job.van.der.burg@technogrowbv.com

Two main concepts of photobioreactors are considered: flat panel reactor and tubular reactor. Development and evaluation of both reactor types is carried out at small and large scale at RWTH Aachen University and by TECHNOGROW. The work at RWTH led to a preliminary conceptual design for a flat panel photobioreactor and TECHNOGROW developed the nearly horizontal tubular reactor.

1. Introduction

Besides the gasification of biomass or biomass derived feedstocks it is possible to produce hydrogen in a non-thermal way by using bacteria. In recent years, various hydrogen productive anaerobic fermentation and photo-fermentation processes have been developed and investigated (Das and Veziroglu, 2001). However, the operation of each of these processes on its own is economically not feasible. A combination of both process concepts, thus leading to a 2-stage bioprocess, seems to be a promising way to increase the hydrogen output (Tao et al., 2007). A dark fermentation step with thermophilic bacteria producing hydrogen, carbon dioxide and organic acids is combined with a photo-fermentation stage. The organic acid effluent of the dark fermenter is used as the substrate for the photo-fermentation, where the organic acids are converted to additional hydrogen and carbon dioxide (Claassen and deVrije, 2006). The photo-fermentation step is carried out in specially designed photobioreactors that allow for cultivating microorganisms and exposing them to a light source in an efficient way.

2. Design of the reactors

2.1. Flat panel reactor

One panel of the photobioreactor consists of a frame covered by a transparent plate on both sides as shown in Figure 2.1. The height of the panels is limited to 1 m in order to reduce the deflection of the transparent plates and to guarantee the gas-tightness of the enclosed volume, respectively. For this reactor PMMA plates of 8 mm in thickness were used since they are able to withstand the hydrostatic pressure at the bottom with a fairly low deflection. The flat panel reactor arrangement chosen for the experiments consists of four parallel panels which are arranged vertically as shown in Figure 2.2. Each panel has an illuminated area of 2 m² and the plate thickness of 20mm. This results in a total

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reactor volume of 100 l (4 x 25 l). The reactor was positioned on south side of a roof and the illuminated surfaces of the panels were facing in an east-west-direction.

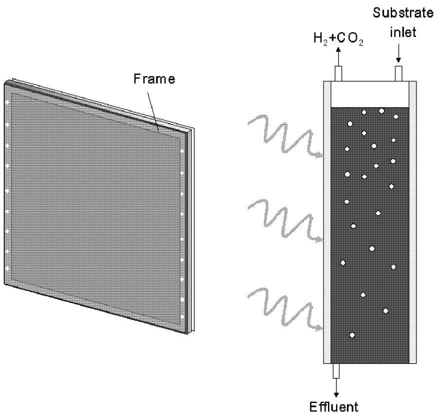

Fig.2.1 Sketch of one bioreactor panel

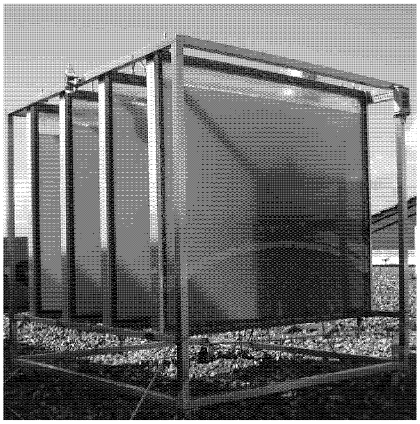

Fig.2.2 Modular arrangement

2.2. Tubular reactor

The tubular reactor consists of transparent tubes which are connected to the manifolds at the ends. The arrangement of the tubular reactor is near-horisontal with an inclination below 10 degrees. At Technogrow for the construction of the tubes LPDE film tubing with a thickness of 150 micron and a diameter of 60 mm was chosen. However, this might be too thin to reduce H_2-loss by diffusion to an acceptable level. Thicker films have the drawback that the light transmission will be less. For the manifolds of the photobioreactor installation PVC pipes with a diameter of ~20 cm were selected.

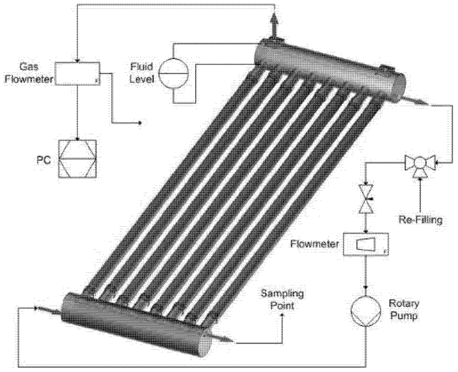

Fig. 2.3 Tubular reactor

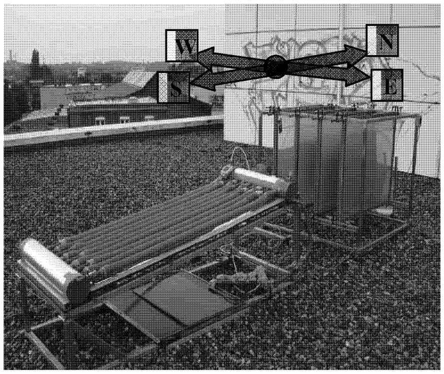

Fig. 2.4 Outdoor positioning

The tubular reactor arrangement chosen for the experiments consists of 8 LPDE tubes and has a volume of 65 l and the illuminated area of ~1m² as shown in Figure 2.3. The system is not stationary and the liquid is recycled by a rotary pump for 5 minutes per hour. The reactor was facing south as shown in Figure 2.4.

3. Material and methods

The bacterial strain used in the experiments was *Rhodobacter capsulatus* (DSM 155) grown on an artificial medium containing sodium glutamate as a nitrogen source and acetate in the concentration of 22mM and lactate in the concentration of 3.8 mM as carbon sources. One fifth of the bacteria suspension was exchanged by fresh medium every day.

Both reactors were equipped with light and temperature sensors. The gas flow rate of the tubular reactor was measured with a flow meter. Temperature, light intensity and gas flow were monitored online by a computer. The purity of the collected gas was measured by gas chromatography every two days. In order to determine the pH-value, chemical composition of the bacteria suspension samples were taken every day.

4. Results

4.1. Hydrogen Productivity for panel and tubular reactors

An important issue for the comparison of both reactors is the hydrogen productivity during a long period. In Figures 4.1 and 4.2 the hydrogen productivity over 25 days period depended on the suspension temperature is presented. After 3 days in the panel reactor and 7 days in the tubular reactor the growth process was completed.

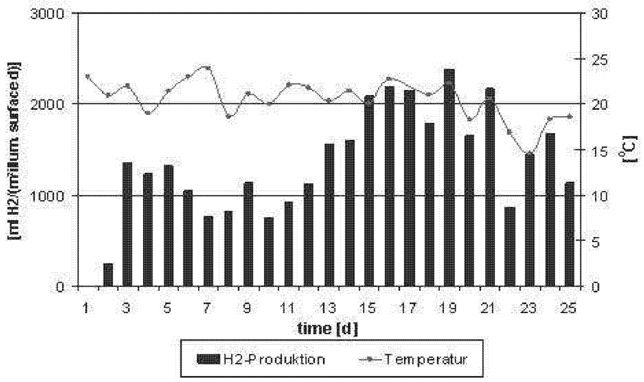

Fig. 4.1 Hydrogen productivity over a 25 days period for the panel reactor, mean hydrogen productivity = 1250 [ml H_2/ ($m^2_{illum.\ surf}$ d)]

Hydrogen productivity listed in Table 4.1 is related to the volume, illuminated reactor surface and ground area. A key index characterising the photo-biological systems is the gas productivity divided by the illuminated reactor surface. The obtained results shows that th value of this index is very similar for both reactors. The mean hydrogen productivity for the panel reactor is 1250 ml $H_2/(m^2_{illum.\ surf}$ d) and for the tubular one 1100 ml $H_2/(m^2_{illum.\ surf}$ d). In the panel reactor, about 8 m² of the illuminated area can be installed on 1 m² of ground space but in the tubular one - about 0.9 m² only, this indicating the advantage of the panel reactor concept.

Tab. 4.1 Hydrogen productivity of both reactors

	[ml $H_2/l_{culture}$*h]	[ml$H_2/(m^2_{illum.surf}$ d)]	[ml$H_2/(m^2_{ground\ area}$ d)]
panel reactor	8	1250	10000
tubular reactor	3.3	1100	1210

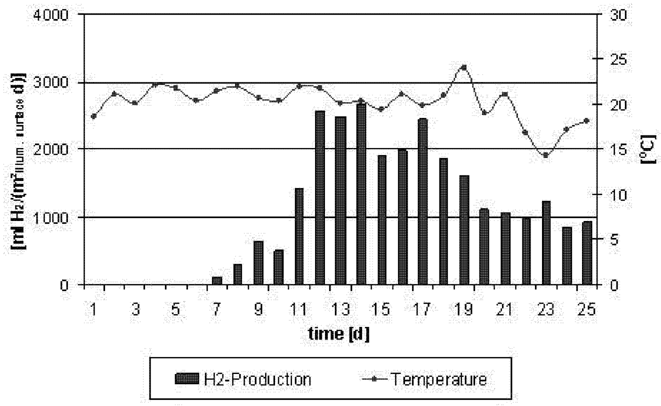

Fig. 4.2 Hydrogen productivity over a 25 days period for the tubular reactor, mean hydrogen productivity = 1100 ml $H_2/(m^2_{illum.\ surf}\ d)$

4.2. Composition of product gas

The product gas was analyzed every two days by means of gas chromatography. The composition of the gas produced was similar for both reactors containing around 80-92 vol. % of hydrogen diluted by 20 - 8 % carbon dioxide.

5. Conclusion

Two reactor types have been investigated under outdoor conditions. Experimental results show comparable productivity per illuminated surface area for both reactors. To design the plant as compact as possible, the design of a photobioreactor must aim to a maximal ratio of illuminated surface area to land space covered by the reactors. Since the illuminated surface area per unit ground space area is about 8.5 times higher in the panel reactor than in the tubular system, the former concept has to be followed in the future studies.

6. References

Claassen, P.A.M. and deVrije, T., 2006, Non-thermal production of pure hydrogen from biomass: HYVOLUTION. Int. J. Hydrogen Energy, 31, 1416 – 1423

Das, D. and Veziroglu, T. N., 2001, Hydrogen production by biological processes: a survey of literature. Int. J. Hydrogen Energy, 26, 13-28

Tao, Y., Chen, Y., Wu, Y., He, Y., and Zhou, Z., 2007, High hydrogen yield from a two-step process of dark- and photo-fermentation of sucrose. Int. J. Hydrogen Energy, 32, 200 – 206

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