Algal Research 5 (2014) 274–282

Contents lists available at ScienceDirect

Algal Research

journal homepage: www.elsevier.com/locate/algal

Indirect membrane-based bubbling as an alternative technique to increase the carbonation of microalgal media

Rosalam Sarbatly [1], Emma Suali *

Membrane Technology Research Group, School of Engineering and Information Technology, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form 1 April 2014
Accepted 5 April 2014
Available online 26 April 2014

Keywords:
Carbonation
Microalgae
Bioreactor
CO_2 uptake
Hydrophobic membrane

ABSTRACT

This work discusses an indirect membrane-based bubbling technique and operating conditions for using membranes for high carbonation efficiency and microalgae productivity. The technique resulted in 82% carbonation efficiency compared to 42% and 29% using a direct membrane-based bubbling and direct bubbling without using a membrane, respectively. The indirect membrane-based bubbling resulted in microalgae productivity that was approximately 10% higher than the typically accepted technique, prevented cell collection from fouling the membrane, and increased microalgae capacity to capture and use CO_2 for photosynthesis. This technique has significance not only for CO_2 mitigation progress but also for the biomass production of microalgae. This technique also decreases the amount of CO_2 that escapes into the bioreactor headspace and atmosphere during carbonation.

1. Introduction

The high CO_2 uptake and photosynthesis of microalgae compared to fast-growing terrestrial plants [1] makes it suitable to be used for CO_2 mitigation and as biomass producer [2]. The biomass can be incorporated into many fields including biofuel and pharmaceutics [3,4]. However, cultivation of microalgae under the addition of CO_2 is challenging mainly because of large bubble formation during carbonation. The formation of large bubbles causes CO_2 to escape into the headspace of the bioreactor or atmosphere, which decreases the potential of microalgae to capture and use CO_2 for photosynthesis.

Carbonation efficiency increases with the aid of a membrane [5] compared to without a membrane, which only utilizes 30% of the total CO_2 supply [2,6–8]. However, microalgae growth in the membrane bioreactor does not improve and is lower compared to direct bubbling bioreactors [9,10]. There may be many reasons for the low microalgae growth, and one reason may be that the CO_2 concentration in microalgal media is most likely insufficient for the growth of microalgae. The accumulation of microalgae cells and CO_2 in the membrane also affects microalgae growth and productivity.

The hydrophobic membrane typically used is made of thousands of microporous hollow fibers. During carbonation, the microalgal media passes through the fiber and exits the membrane as aqueous microalgal CO_2. However, the membrane design affects the success rate of microalgal media transfer from the membrane to the bioreactor, and up to 10% of the cells accumulate and are left dead within the membrane. The dead microalgal cells cause fouling and shorten the lifespan of the membrane, which increases the operating cost of carbonation. Thus, this work describes an indirect membrane-based bubbling as an alternative technique to carbonize microalgae without letting the microalgae contact the surface of the membrane wall. This study was conducted using microalgae-free media, and the microalgae were subsequently inoculated in the bioreactor. Thus, carbonation only occurred in the bioreactor. The carbonation was conducted as a batch process, and this process required a hydrophobic membrane that was made from thousands of hollow fibers. This work aimed to evaluate the indirect membrane-based bubbling technique to increase carbonation efficiency without decreasing the microalgae growth. This technique included suitable working conditions for small bubble formation during carbonation.

2. Materials and methods

2.1. Microalgae and culture condition

Chlorella sp., which has a high growth rate was isolated from the Tun Fuad Stephens Lake (located at 6°N and 116°E), was employed as a test subject in this work. The microalgae were cultivated under reduced carbon source in an adjusted Jaworski Medium (JM). The modified medium was used to conduct experimentations on the carbonation of microalgal media. The medium contained 0.02 gl^{-1} Ca $(NO_3)_2 \cdot 4H_2O$, 0.0124 gl^{-1} KH_2PO_4, 0.05 gl^{-1} $MgSO_4 \cdot H_2O$, 0.00225 gl^{-1} EDTAFeNa, 0.00225 gl^{-1} $EDTANa_2$, 0.00248 gl^{-1} H_3BO_3, 0.00139 gl^{-1} $MnCl_2.4H_2O$, 0.001 gl^{-1} $(NH_4)6Mo7O_{24} \cdot 4H_2O$, 0.00004 gl^{-1} cyanocobalamin,

* Corresponding author. Tel.: +60 13 8670542; fax: +60 88 320348.
E-mail addresses: rslam@ums.edu.my (R. Sarbatly), emma.suali@gmail.com (E. Suali).
[1] Tel.: +60 88 320000x3990; fax: +60 88 320348.

http://dx.doi.org/10.1016/j.algal.2014.04.001
2211-9264/

0.00004 gl^{-1} thiamine HCl, 0.00004 gl^{-1} biotin, 0.08 gl^{-1} $NaNO_3$ and 0.036 gl^{-1} $Na_2HPO_4 \cdot 12H_2O$.

2.2. Membrane bioreactor setup

2.2.1. Equipment and apparatus used to conduct experiments

This study required a membrane that was able to transfer CO_2 from gas to a liquid phase. Thus, this work employed a hydrophobic membrane manufactured by GFD of Indonesia (model number UFS220), which was composed of 2400 polyethylene hollow fibers. Polyethylene is known to have excellent chemical resistance and it remains undamaged even if the membrane is involved in backwash using chemicals, thereby making it physically suitable for carbonation. In addition, polyethylene is hydrophobic which decreases the potential of cells being stored within the membrane.

The pressure on the membrane was measured using a low scale Omega pressure gauge that measures pressure from 0 to 30 psi (~2 atm) to keep the pressure below the breakthrough limit. The membrane was operated at an atmospheric pressure of 1 atm. The pressure inside the membrane on the liquid and gas sides was similar to the atmospheric pressure. The membrane was attached to the bioreactor setup as shown in Fig. 1. Two Philips fluorescence white cool lamps were used to provide illumination (at 296 $\mu Em^{-2} s^{-1}$) to the microalgal media. The illumination was measured using a lux meter (Lutron model LX-101). The air flow rate meter used for this work was a Cole Parmer low range flow rate and liquid flow rate meter (McMillan model S-144). Two bioreactors were used and labeled as BR1 and BR2 for comparison. The bioreactor dimensions of BR1 and BR2 are shown in Fig. 1, and the characteristic of the bioreactor and the membrane are listed in Table 1.

Both bioreactors were made from acrylic pipe with a thickness of 3 mm. The CO_2 unit was equipped with a gas mixer to control the CO_2 concentration that entered the bioreactor. A gas mixer (WeldRo model 300MX) was used in this study. This gas mixer was originally for mixing air and argon, but this mixer is also suitable to be used for mixing air and CO_2. BR1 was used for indirect and direct membrane-based bubbling and BR2 was used for direct bubbling. Media was pumped through the membrane using a Cole Parmer low gear pump (model 75211–15), which was used to replace a peristaltic pump. A preliminary experiment demonstrated that the low gear pump did not have a negative impact on microalgae characteristics and growth.

Table 1
Characteristics of the membrane and bioreactor.

Features	Membrane	Bioreactor*
Number of fibers	2400	N/A
Fiber pore size (μm)	0.5	N/A
Length (mm)	495	1000
Total surface area (m^2)	0.80	0.4
Shell internal/bioreactor diameter (mm)	60	80
Capacity (ls^{-1}) × 10^{-2}	2.7	N/A
Membrane/acrylic thickness (mm)	0.65	3
Shell side/bioreactor volume (l)	0.43	23
Volume occupies by hollow fiber (l)	2.5	N/A
Housing material	PVC	Acrylic
Membrane material	Polyethylene	N/A

Notes: *, N/A: Not applicable.

2.2.2. Operating procedure

Fig. 1 shows a general setup of the membrane bioreactor that was used to conduct three different operating procedures. PG1 and PG2 indicate the pressure gauges that were used to measure pressure in the membrane. Moreover, an air flow rate meter (AFM) and liquid flow rate meter (LFM) were used to control gas and liquid flow into the membrane and bioreactor. Each bioreactor was differentiated with a symbol of BR1 and BR2 for bioreactors either direct bubbling or direct and indirect membrane-based bubbling, respectively. In Fig. 1, H indicates the height of the bioreactor, and DO indicates the dissolved O_2.

The usual method of carbonation requires microalgal media to capture CO_2 from within the membrane. This technique often causes the membrane to be at risk of fouling due to the micron size of microalgae. Thus, this work introduced a technique to capture CO_2 without requiring microalgae to pass through the membrane. This technique is indirect membrane-based bubbling that used microalgae-free medium instead of microalgae-rich medium to pass through the membrane. This

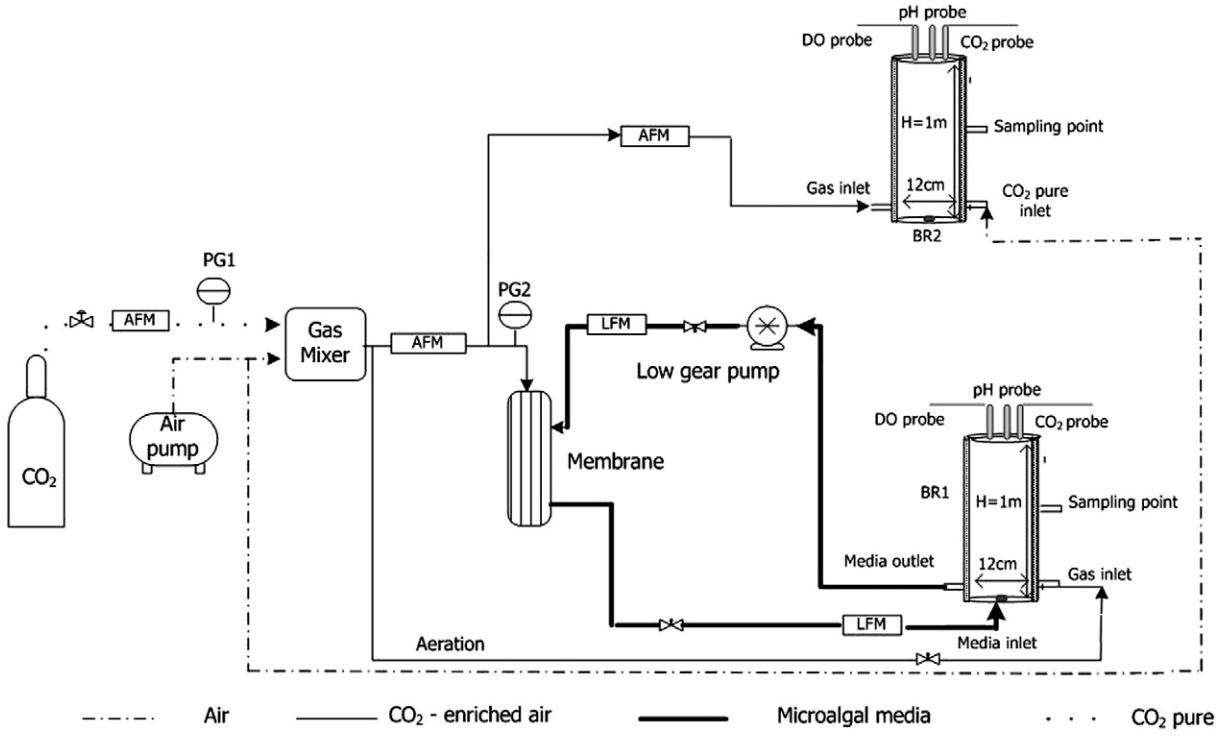

Fig. 1. Membrane integrated microalgae cultivation setup.