A novel photobioreactor with internal illumination using Plexiglas rods to spread the light and LED as a source of light for wastewater treatment using microalgae

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Abstract

The nutrient removal using microalgae in wastewater has received more attention in the last years. Due to the optical loss of wastewater, the reactors for algae used in wastewater treatment, have a small depth and they need large surfaces (like open ponds). In this study it is proposed a novel photobioreactor with an internal illumination using LED lights and Plexiglas End-Lighten rods. The light is concentrated using a reflecting funnel and then fed inside the reactor. With this technique the illuminated surface may be optimized and adapted to the algae´s needs. Preliminary results obtained with *Scenedesmus* sp. and artificial wastewater show that grow rate and nutrient removal are comparable to previous results obtained with smaller 1-L batch reactor with external illumination. The use of this internal illumination source enhance the supply of light in a more efficient and economical way and improves the scalability of the photobioreactor.

Keywords: internal illumination, LED, microalgae, photobioreactor, Plexiglass, wastewater treatment.

Introduction

Microalgae have received more attention in the last years as an alternative treatment for wastewater (Lau, Tam et al. 1995; Wang, Min et al. 2009; Pittman, Dean et al. 2011). The algae system relies on the ability of the algae cells to uptake inorganic nutrients (N and P) from the wastewater and to assimilate them for their growth. This ability makes them attractive for sustainable and low cost wastewater treatment (Pittman, Dean et al. 2011).

Many experiments have been conducted to asses the feasibility of the green microalgae to live and to remove nutrients from wastewater (Wang, Min et al. 2009; Pittman, Dean et al. 2011). Usually *Chlorella* sp. and *Scenedesmus* sp. are used in these experiments. They have shown good vitality in urban wastewater and with grow rate similar to those reported in synthetic medium. They can live in a wide range of temperature and pH, making them versatile for sewage treatment (Tam and Wong 1989; Martínez, Sánchez et al. 2000). The microalgae assimilate high quantities of nitrogen and phosphorus during their growth due to the high protein concentration in the cells (45-60% dry weight) (Demirbas and Demirbas 2010). Moreover the intensive algal growth often causes an increase in pH which then leads to ammonia stripping and phosphate precipitation, which enhances the nutrient removal efficiency of the algal systems (Nuñez, Voltolina et al. 2001). Furthermore their ability to consume dissolved CO_2 during the photosynthesis makes them a candidate for CO_2

sequestration and greenhouse gas reduction (Franco 2010).

Photobioreactors

The reactors for microalgae are different from the reactors for bacteria because the light supply plays a key role in their design. The simplest system is the open pond (raceway system) and most of the large commercial scale micro algal production systems employ this system (Pittman, Dean et al. 2011). It requires high surface areas and low depth for the light supply. Moreover in the open pond no high concentration of biomass can be achieved and there is always the risk of contamination (Chen, Yeh et al. 2011).

The alternative is the use of closed photobioreactors. Normally the light supply is external and the reactor can have different shapes: tubular, flat panel or column (Carvalho, Meireles et al. 2006). Compared with open ponds these systems allows better mixing, optimized gas exchange and better illumination, leading to a higher biomass concentration and productivity (Borowitzka 1999; Demirbas and Demirbas 2010).

One of the most important parameter for photobioreactor is the ratio of surface illuminated to volume of the reactor (S/V). The higher the surface illuminated, the higher the cell concentration at witch the reactor can operate and also the volumetric productivity. The disadvantage of an external illumination is that the specific volume of the reactor decreases, when increasing the S/V ratio (i.e. smaller diameter of tubular reactor).

An alternative light supply technique is the use of an internal illumination system. The purpose of an internal illumination is to supply light energy in an efficient and economical way. They should minimize the variation in light regimes in time and space, giving the possibility to adapt the light intensity to the growth of the microalgae (Suh and Lee 2001).

The lamp can be placed inside the reactor inserted in a transparent tube (Suh and Lee 2001) or the light can be collected and concentrated outside the reactor and spread inside using fibre optics, glass, acrylic glass or other material (Janssen, Tramper et al. 2003).

Suh and Lee (2001) proposed an internally radiating air-lift photobioreactor illuminated with fluorescent lights sealed in Pyrex tubes. This reactor combines the advantages of an air-lift bioreactor and an internal radiation system. Other researchers build reactors that collect the solar light using lenses and parabolic mirrors and concentrate them into fibre optics (Ogbonna, Soejima et al. 2001). Janssen, Tramper et al. (2003) proposed a rectangular air lift photobioreactor where the light is first collected with parabolic dish and then is distributed towards fibre optics to redistributing plates. Most of these solutions are not easy to scale up due to the complexity of the reactor or the high number of single elements needed.

Within this study, an innovative technology is proposed for the internal illumination within a reactor utilizing Plexiglas rods and LED as a source of light. This technology improves the light distribution and also the surface to volume ratio obtaining efficient light energy transfer with minimal heat generation.

The LEDs match with the narrow light emission spectra for photosynthetic needs (Chen, Yeh et al. 2011) (for instance, the adsorption wavelength of blue LED and red LED are around 450–470 nm and 645–665 nm, respectively). If the light source has a narrow spectral output that overlaps the photosynthetic absorption spectrum, the

emission of light at unusable frequencies would be eliminated, therefore improving the overall energy conversion (Chen, Yeh et al. 2011). LEDs are light and small enough to fit into virtually any photobioreactor, and their other advantages include energy efficency, longer life-expectancy, lower heat generation, higher conversion efficiency (Chen, Yeh et al. 2011). Red LED light shows a comparable grow rate with solar spectrum lamps (Katsuda, Lababpour et al. 2004). Consequently LED diodes have been used for microalgae cultivation (such as *Hematoccocus pluvialis* (Jeon, Cho et al. 2005), *Chlorella vulgaris* (Lee and Palsson 1996) or also cyanobacteria (Wang, Fu et al. 2007)) in lab-scale photobioreactors.

Methods

A reactor with a single Plexiglas rod has been assembled (Fig. 1). The reactor has 30 cm of diameter and a maximum volume of 35 L. The Plexiglas bar has a central position in order to spread uniformly the light in the reactor. A mechanical stirrer is placed on one side of the reactor. In order to improve the mixing three small breakwater barrier have been placed as shown in Figure 1.

The rod used in this study (PLEXIGLAS® End-Lighten, EVONIK, 91% of transmission) have a diameter of 20 mm and they can spread the light up to 1000 mm of depth. The rod is illuminate from a single side with an LED lamp (15W). This lamp has two blue LED lights (455 nm) and 8 red LED lights (660 nm) that match with the narrow light emission spectra for photosynthesis. The light was concentrated using a specific reflecting funnel (Fig. 2) and then fed inside the reactor using the Plexiglas bar.

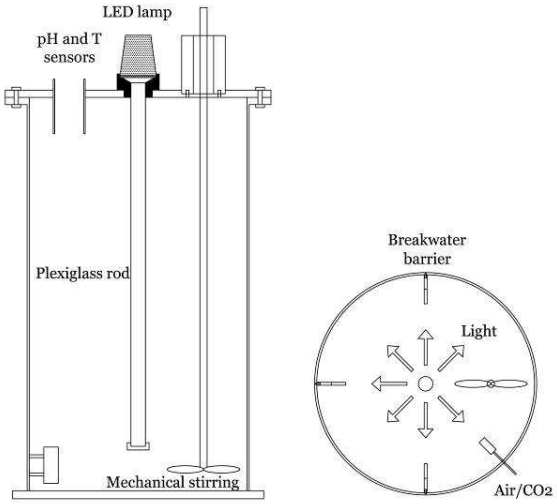

Fig. 1 Schematic model of the photobioreactor: the light is concentrated in the reflecting funnel and then spread in the reactor with the Plexiglass rod.

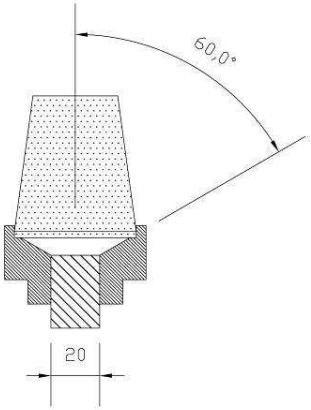

Fig. 2 Reflecting funnel for LED lamp (with a beam angle of 120°) used to concentrate the light into the Plexiglass rod.

A mirror cap is placed on the opposite side of the rod in order to reflect the light and enhance the illumination. The rod is submerged in the algal suspension except for the upper part and it can be cleaned easily. The advantage between Plexiglas rods and fibre optics relies on the reduced number of elements to be submerged into the liquid and the easiness of cleaning. Consequently with

Plexiglas rods the scalability of the reactor is improved.

Scenedesmus sp. was used in the experiment. It was cultivated using BG11 media then harvested with centrifugation (4,000 rpm, 10 min at 4 °C). After that it was inoculated into the reactor. The artificial wastewater was prepared dissolving the appropriate amounts of KH_2PO_4, NH_4Cl in sterilized tap water in order to give concentrations similar to mean values of urban wastewater (30 mgN-NH_4/L and 6 mgP-PO_4/L). The algal density was determined by measuring the optical density of the algal culture at 650 nm the OD_{650} (Xin, Hong-ying et al. 2010) using a Hach-Lange spectrophotometer. The absorbance at 650 nm was calibrated by measuring the weight of dried *Scenedesmus* sp.. Then, the weight of dried biomass was obtained from the prepared calibration curve.

Ammonia and orthophosphate were measured using Hach-Lange cuvette test (LCK303 and LCK349 respectively). pH and temperature were monitored using IKS pH and temperature sensors. The pH was regulated bubbling pure CO_2 during the experiment. This was made in order to lower the pH and maintain it between 7 and 9. The room-temperature was between 23° and 25°C during the experiment. The day-night cycle was set to 16:8 hours and the photon flux was measured with Apogee Quantum Meter MQ-200 sensor.

Results

The initial pH was 6. The pH increased rapidly during the experiment due to the CO_2 and HCO_3^- consumption of the microalgae for the photosynthesis. It was necessary 4 times during 10 days to bubbled pure CO_2 in the algal suspension in order to lower the pH from above 9 to 7. This shows that the photosynthetic activity was vigorous.

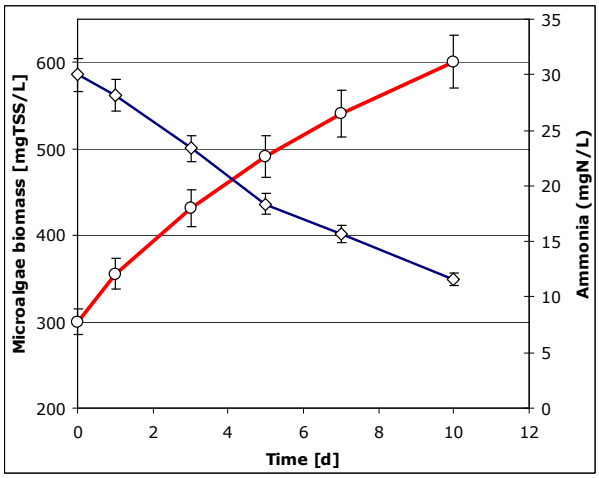

Fig. 3 Biomass concentration of *Scenedesemus* sp. and Ammonia removal during the experiment. The biomass increase from 300 mgTSS/L to 600 mgTSS/L and the Ammonia decreased from 30 mgN-NH_4/L to 11 mgN-NH_4/L.

The starting concentration of microalgae was 300 mgTSS/L. With this concentration the average photon flux was 30 µmol/m^2/s in the first 10-12 cm around the rod. The biomass concentration increase during the 10 days of treatment up to 600 mgTSS/L (Fig. 3). The average grow rate was 29 mgTSS/L/d. These values are analogous to the values found in the literature: Park, Jin et al. (2010) made diverse experiments with different seeding concentration of 0,5-1,5 g/L and reported a grow rate of 45-56 mgTSS/L/d in a 1L reactor. The same study reported a grow rate of 20-80 mgTSS/L/d with different starting concentration of ammonia. Xin, Hong-ying et al. (2010) achieved a grow rate of 9 mgTSS/L/d starting with a lower seeding concentration (20mg/L).

As shown in Fig. 3 the Ammonia decreased constantly from 30 mgN-NH_4/L to 11 mgN-NH_4/L. The average ammonia

removal rate was about 1,9 mgN-NH_4/L/d achieving a total removal of 62%. This values are comparable to other studies: Jinsoo Kim, (2010) reported a degradation rate of 1 mgN-NH_4/L/d starting from a lower concentration, Wang, L., M. Min, et al. (2009) achieved a 2,3 mgN-NH_4/L/d with real urban wastewater.

The phosphorous concentration decreased from 6 to 3 mgP-PO_4/L with a removal rate of 0,3 mgP-PO_4/L/d. Other studies reported a degradation rates from 0,11 to 0,15 mgP/L/d in a 100mL batch reactor (Xin, Hong-ying et al. 2010). Wang, L., M. Min, et al. (2009) reported a higher degradation rate of 0,5 mgP/L/d using real urban wastewater in a 250mL reactor.

These value of biomass production and nutrient removal are comparable to the values obtained with smaller reactor volume and with an external illumination system with higher PFD (Photon Flux Density) (Wang, Min et al. 2009; Jinsoo Kim 2010; Park, Jin et al. 2010; Xin, Hong-ying et al. 2010).

Discussion and Conclusions

An alternative light supply technique for cultivation of microalgae is presented. The proposed system use LED and Plexiglass End-Lighten rod to concentrate and spread the light inside a column photobioreactor. The experiment showed that microalgae can grow well with this kind of illumination and they have a nutrient removal comparable to other experiments with smaller reactors and higher PFD.

The use of this illumination system improves the scalability of the photobioreactor and enhance the supply of light in an more efficient and economical way with the use of LED lights.

The future purposes are to test this system with real wastewater and, ncreasing the number of elements, to build a larger photobioreactor.

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