# Utilization of Model Power Plant Flue Gas for Cultivation of *Chlorella vulgaris* and Scenedesmus*obliquus*: Effect of Gaseous Pollutants on Biomass Production and $CO_2$ Biofixation

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Received: 2016-11-22 Revised and accepted:2017-06-12

**Abstract**

Power plants are considered a major contributor to carbon dioxide emissions. Moreover, flue gas of power plants contains other compounds such as $NO_x$ and $SO_x$ that can affect growth rate of microalgae. Therefore, in this study the effect of $CO_2$ in different concentrations of 0.04%, 5% and 15%, $NO_x$ in 100ppm and $SO_x$ in 60ppm was investigated simultaneously on biomass production and carbon dioxide fixation of two industrially important microalgae, *Chlorella vulgaris* and *Scenedesmus obliquus*. At $CO_2$ concentrations of 0.04%, 5% and 15%, the maximum $CO_2$ fixation rate was 0.768, 0.73 and 0.69 g/l/d for *Chlorella vulgaris* and 0.311, 0.53 and 0.212 g/l/d for *Scenedesmus obliquus*, respectively. the results showed that at 15% of $CO_2$, maximum $CO_2$ fixation rate ($RCO_2$) of *Chlorella vulgaris* was decreased from 0.69 to 0.65 g/l/d by adding 100 ppm of $NO_x$ to culture medium, also a reduction from 0.69 to 0.212 g/l/d was observed when 60 ppm of $SO_x$ was injected to $CO_2$ stream. However, In the case of *Scendesmus obliquus*, an increase in $RCO_2$ from 0.212 to 0.36 and 0.212 to 0.24 g/l/d was achieved in the presence of the same amount of $NO_x$ and $SO_x$, respectively. At the same culture conditions, *Chlorella vulgaris* shows higher fixation rate than *Scendesmus obliquus*. $CO_2$ fixation rate increasing by *Scendesmus obliquus* in the presence of acidic gases ($NO_x$ and $SO_x$) shows that *Scendesmus obliquus* tends to grow in lower pH.

**Keywords:** Flue gas, $CO_2$ Biofixation, Gaseous pollutant, *Chlorella vulgaris*, *Scnedesmus obliquus.*

## Introduction

Among greenhouse gases, carbon dioxide, although a non-toxic gas is the largest contributor in terms of emissions (Boucif et al., 2010). Concentration of $CO_2$ in flue gas emitted from thermal power stations is about 500 times higher than that in the atmosphere (Yun et al., 1997), as in 2006 associated $CO_2$ emissions were 29 Gtonnes (Brennan and Owende, 2010). Therefore, $CO_2$ capture from flue gas of power plants will be an effective way to control these emissions (Davison, 2007).

The United Nations promoted the Kyoto Protocol (1997) with the objective of reducing greenhouse gases by 5.2% on the basis of the emission in 1990 (Gutierrez et al., 2008; Wang

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et al., 2008), which have pushed the identification and development of new technologies for $CO_2$ separation, capture, and seque-stration in geologic formations or chemical, biological, and technological utilization (Dibenedetto, 2011; Lee and Lee, 2003). Several chemical and physical methods that can be applied with the aim of $CO_2$ capture in large source of $CO_2$, such as power plants, are: (i) absorption; (ii) adsorption; (iii) gas-separation membranes; and (iv) cryogenic distillation (Kanniche and Bouallou, 2007; Pires et al., 2012). These methods present significant challenges, including either high amount of energy consumption, irreversible regeneration of solvent (mostly MEA) in desorption process, need to pre-treat the flue gas before channeling to absorber in adsorption processes, cooling of hot flue gas, moisture removal in most processes, high pressure requirements, or being not cost effective when up-scaled to commercial stage (Knudsen et al., 2009; Pires et al., 2011).

An ideal alternative solution would be to microalgal capture of $CO_2$ in biomass (Pacheco et al., 2015; Ryu et al., 2014). Microalgae can uptake the carbon dioxide from effluent gas as the carbon source for photosynthesis. Microalgae are fast-growing unicellular microorganism that able to divide their cells within 3-4 h, but mostly divide every 1-2 days under favorable growing conditions (Aguirre et al., 2013). Due to their simple cell structure and fast growth rate, microalgae are expected to have $CO_2$ bio-fixation efficiency of 10-50 times higher than terrestrial plants (Li et al., 2008). Furthermore, their produced biomass contains high amount of lipid, protein, fiber and other valuable components so that they can be utilized in production of medications, food additives and biofuel (Jin et al., 2006; Gouveia and Oliveira, 2009). Most of the research studies that have done recently on using different microalgae strains for $CO_2$ capture, shows positive effect of growing microalgae with pure $CO_2$, real or simulated flue gas towards carbon fixation rate and biomass productivity (González-López et al., 2012; Sydney et al., 2010).

The flue gas of power plant passes through electrostatic precipitator and desulfurization unit. As estimated by the IPCC criteria, the $CO_2$ concentration of effluent is up to 15%, $SO_x$ up to 60 ppm and $NO_x$ is up to 150 ppm (Kim et al., 2009). An early review on flue gas tolerance by microalgae indicated that high levels of $CO_2$ were tolerated by many microalgal species and that moderate levels of $SO_x$ and $NO_x$ (up to 150ppm) were also well-tolerated but higher concentration can inhibit their growth owning to pH increase in cultural medium and biological reduction in the capacity of algal cell for $CO_2$ sequestration (Negoro et al., 1991).

Gouveia et al. (2009) Reported lipid content of 5.1%, 16.7% and 17.7%, lipid productivity of 7.4 mg/l/d, 20 mg/l/d, and 15.9 mg/l/d, and also biomass productivity of 0.18 g/l/d and 0.09 g/l/d for *Chlorella vulgaris* and *Scenedesmus obliquus*. Due to high biomass and lipid productivity, these species of microalgae can be considered as the ideal candidates for biofuel production. The purpose of this study was to determine the effect of gaseous pollutants on biomass production and $CO_2$ fixation of *Chlorella vulgaris* and *Scenedesmus obliquus*.

## Materials and Methods

Microalgae cultivation In this study, *Chlo-*

*rella vulgaris* and *Scenedesmus obliquus*, two freshwater strains were cultivated. The cultures were enriched and maintained in BG11 medium (Spolaore et al., 2006).

*Inoculum preparation*

Two samples of 50ml of the sub-cultured strains were centrifuged and the cell pellet was collected and re-suspended in Erlenmeyer flasks containing 250mL of BG11 medium. The initial inoculation was 5% v/v and initial pH was adjusted to 7.

*Standard growth medium*

Standard BG11 medium was prepared in two 2l Erlenmeyer flask, with pH adjusted to 7 and 150 ml of the medium were transferred to each of 6 standard 250ml Erlenmeyer flasks. The flasks were closed with cotton, wrapped with aluminum foils and sterilized in autoclave.

*Cultivation conditions*

Cultivation flasks were controlled at 30°C with a (24h light/0h dark) photoperiod during 14 days. Continuous $CO_2$/Air mixed streams with the rate of 20ml/min was provided for flasks, filtered (22µm) and bubbled through the cultural medium from the bottom of flask.

*Growth determination*

The dry weight of culture samples was determined after centrifugation at 4550g for 40min, rinsing of the algae with de-ionized water, re-centrifugation under the same conditions, oven-drying at 60˚C overnight, and desiccation to constant weight in a vacuum desiccators (Mata et al., 2010). The optical density was measured by spectrophotometry at 650nm wavelength. Then, the correlation between OD and biomass concentration was established and therefore, the biomass concentration was estimated from the optical density (OD) data of the culture.

*Theoretical calculations of performance metrics*

Biomass productivity, Pb g/l/d in batch mode was estimated from the following equation:

$$P_b = \frac{X_f - X_i}{T} \quad (1)$$

Where $X_f$ and $X_i$ are the final and initial dry biomass concentrations (g/l), respectively in the batch test period T (day).

$CO_2$ fixation rate per unit culture volume, $RCO_2$ ($gCO_2$ /l/d) can be estimated as:

$$Rco_2 = aP_b \quad (2)$$

Where a is the mass of $CO_2$ fixed by unit biomass and defined as (Borowitzka, 1999):

$$a = C_C \times \left(\frac{MCO_2}{MC}\right) \quad (3)$$

Where Cc is the average carbon content in dry biomass, $MCO_2$ and Mc represented the molecular weights of $CO_2$ and elemental carbon, respectively. Due to proposed general structure for microalgae $CO_{0.48}H_{1.83}N_{0.11}P_{0.01}$ by Chisti (Chisti, 2007), carbon content (Cc) is about 50% and the relation for $RCO_2$ summarized to:

$$Rco_2 = 1.87P_b \quad (4)$$

**Results**

*Microalgae growth in batch mode*

Figure 1a shows a comparison of *Chlorella vulgaris* and *Scenedesmus obliquus* growth curves from cultures sparged with ambient air and with $CO_2$-enrichments of 5% and 15%.

As summarized in Table 1, maximum specific growth rate, maximum biomass and consequently maximum $CO_2$ biofixation rate were observed at a $CO_2$ enrichment of 5% for *C. vulgaris*. *C. vulgaris* shows higher $CO_2$ fixation rate in all cultivation condition and represents

minor variation in amount of $CO_2$ fixation rate a

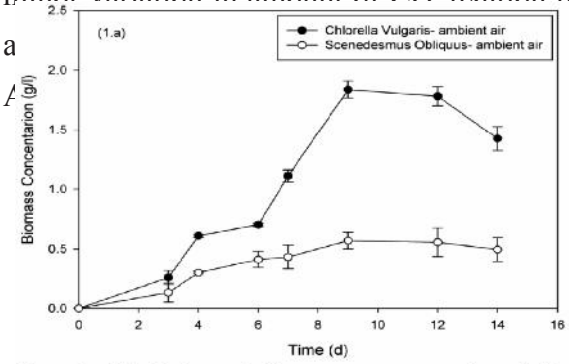


**Fig. 1a.** Variation of biomass concentration (g/l) in batch cultivation of *Chlorella vulgaris* (●) and *Scenedesmus obliquus* (○) at various $CO_2$ content of inlet feed gas, (a) ambient air

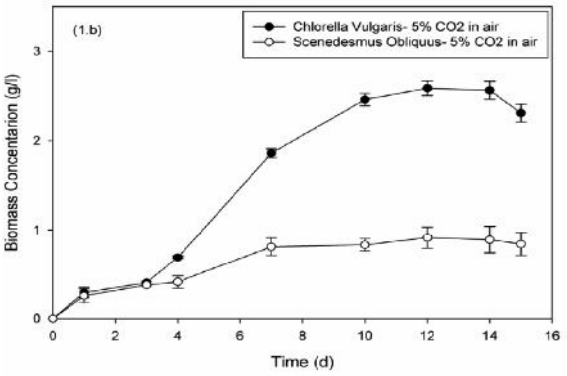


**Fig. 1b.** Variation of biomass concentration (g/l) in batch cultivation of *Chlorella vulgaris* (●) and *Scenedesmus obliquus* (○) at various $CO_2$ content of inlet feed gas, (b) 5% $CO_2$

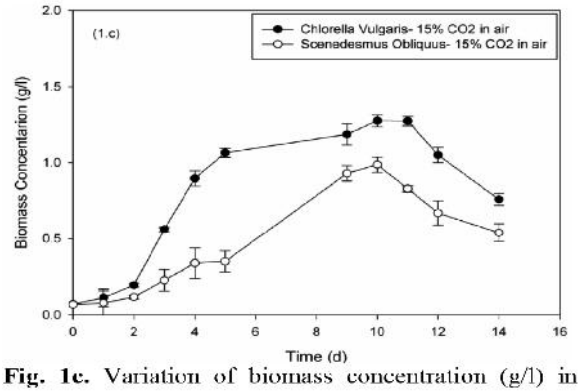


**Fig. 1c.** Variation of biomass concentration (g/l) in batch cultivation of *C. vulgaris* (●) and *S. obliquus* (○) at various $CO_2$ content of inlet feed gas, (c) 15% $CO_2$

increased $CO_2$ fixation while carbon dioxide concentration increases from 0.04% to 5%, and represents a reduction in $CO_2$ fixation as it increases from 5% to 15%.

*Effect of $NO_x$ and $SO_x$ towards growth rate*

As a model of flue gas of power plant acidic gaseous ($NO_x$ and $SO_x$) was added to a 15% $CO_2$ stream and was used in this experiment. Figure 2a shows biomass concentration when the mixture of 100 ppm $NO_x$ and 15% $CO_2$ was injected to the medium during the cultivation. Higher biomass concentration of 1.27g/l for *C. vulgaris* compared with 0.76g/l for *Scenedesmus obliquus* was obtained. *Chlorella* vulgaris represents higher specific growth rate, 0.2 $day^{-1}$, and higher maximum productivity, 0.35g/l/d, followed by 0.16$d^{-1}$ and 0.19g/l/d for *Scenedesmus obliquus* when mixture of 100 ppm $NO_x$ and 15% $CO_2$ was injected to culture medium. *C. vulgaris* stands for higher maximum carbon dioxide biofixation, 0.65g/l/d, followed by 0.36g/l/d for *S. obliquus*.

As shown in Figure 2b when the mixture of 60 ppm $SO_x$ and 15% $CO_2$ was added to culture medium, microalgae growth was more inhibited than in the presence of 100 ppm $NO_x$. similar to Figure 1a maximum biomass concentration obtained for *C. vulgaris* was higher than S. *obliquus* as corresponding values was 1.18 g/l for *C.vulgaris* followed by 0.76 g/l for *S. obliquus*. However, S. *obliquus* indicates higher specific growth rate and higher maximum productivity (0.19 $d^{-1}$ and 0.12 g/l/d for *S. obliquus*, 0.14 $d^{-1}$ and 0.11 g/l/d for *C. vulgaris*, respectively).

As shown in Figure 3 continuous feeding of supplemental $CO_2$ resulted in almost steady pH levels and by addition of $NO_x$ or $SO_x$ to cul-

ture medium this trends shifted to the lower pH levels. Although, by pH reduction in cultivation medium, the growth of *C. vulgaris* was inhibited but *S. obliquus* shows better tolerance towards lower pH.

## Discussion

$CO_2$ biofixation As tabulated in Table 2, $CO_2$ fixation rate of *C. vulgaris* decreased by adding the acidic gaseous pollutants however S. *obliquus* shows increase in $RCO_2$ when $NO_x$ and $SO_x$ was added to culture medium.

**Table 1.** Maximum biomass concentration, maximum specific growth rate and maximum biomass productivity for different microalgae species in different cultural condition.

| *Microalgae species* | *Maximum biomass concentration (g/lit)* | | | *Maximum specific growth rate, $\mu_{max}$ (1/day)*[a] | | | Maximum biomass productivity , $P_{max}$ (g/L/d) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.04% $CO_2$ | 5% $CO_2$ | 15% $CO_2$ | 0.04% $CO_2$ | 5% $CO_2$ | 15% $CO_2$ | 0.04% $CO_2$ | 5% $CO_2$ | 15% $CO_2$ |
| *C. vulgaris* | 1.84 | 2.587 | 1.41 | 0.374 | 0.44 | 0.46 | 0.408 | 0.39 | 0.37 |
| *S. obliquus* | 0.57 | 0.78 | 1.036 | 0.353 | 0.34 | 0.28 | 0.165 | 0.28 | 0.16 |

[a] $\mu = \ln (X_f/X_i)/T$

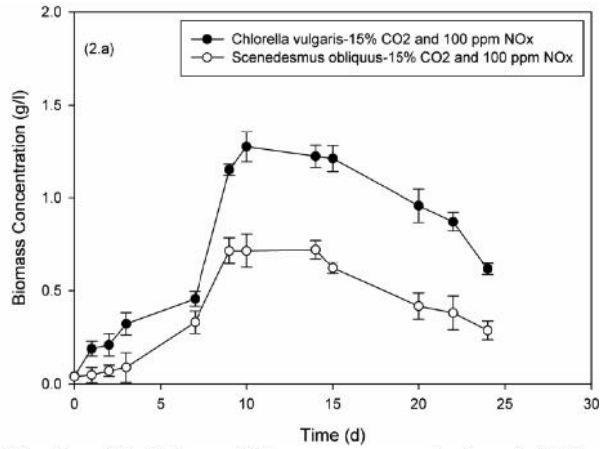


**Fig. 2a.** Variation of biomass concentration (g/l) in batch cultivation of *C. vulgaris* (●) and *S. obliquus* (○)

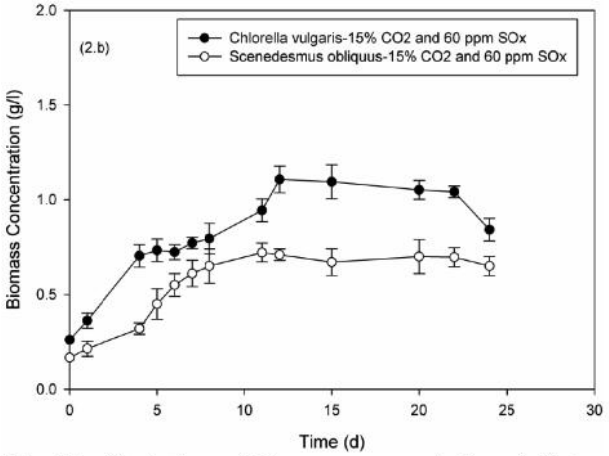


**Fig. 2b.** Variation of biomass concentration (g/l) in batch cultivation of *Chlorella vulgaris* (●) and *Scenedesmus obliquus* (○) at 15% $CO_2$ and (b) 60 ppm $SO_x$of inlet feed gas

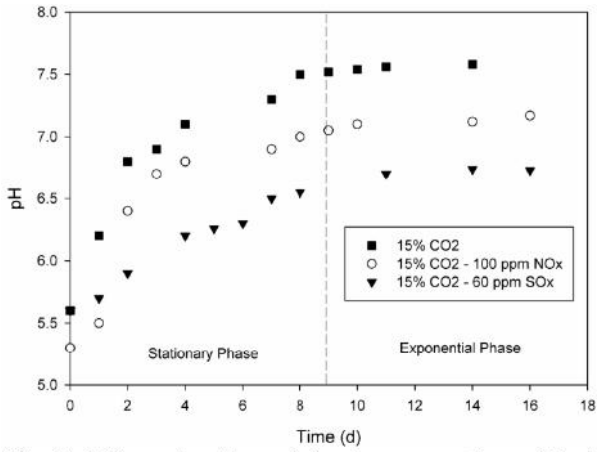


**Fig. 3.** Effect of pollutant injection on medium pH of *Chlorella vulgaris* in 15% inlet $CO_2$ content

**Table 2.** Maximum $CO_2$ bio-fixation rate (gC/lit/day) in various inlet feed gas content

| | 0.04% $CO_2$ | 5% $CO_2$ | 15% $CO_2$ | 15% $CO_2$, 100ppm $NO_x$ | 15% $CO_2$, 60ppm $SO_x$ |
|---|---|---|---|---|---|
| C. vulgaris | 0.768 | 0.73 | 0.69 | 0.65 | 0.21 |
| S. Obliquus | 0.311 | 0.53 | 0.212 | 0.36 | 0.24 |

These results indicate the resistance of S. *obliquus* toward injection of gaseous pollutants and its tendency to grow in the medium with lower pH.

In BG11 culture medium, biofixation of $CO_2$ by *C. vulgaris* is higher than *S. obliquus*. Although, in the presence of 100 pm $NO_x$ and 60 ppm $SO_x$ in a gas stream containing 15% $CO_2$, as a model of flue gas of power plant, growth rate of *C. vulgaris* was decreased but *S. obliquus* shows higher resistance and inclination towards injection of gaseous pollutants. In conclusion, Due to high biomass productivity, maximum $CO_2$ fixation rate and maximum growth rate, *C. vulgaris* is the best option for producing parallel to industries with high pollutants emission and an appropriate choice for sustainable energy production and carbon dioxide fixation.

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