Biomass Production Using Geothermal Flue Gas

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Biomass Production Using Geothermal Flue Gas
at the Blue Lagoon, Iceland

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ABSTRACT

This paper reports on the use of carbon dioxide (CO₂) rich flue gas, from a geothermal power plant, to cultivate microalgae for high-value skin care products. Microalgae growth rate was monitored under previously optimized growing conditions, using CO₂ of two different sources as feedstock. This paper describes the techniques used to collect geogas from a geothermal power plant and its applications for high-value biomass production. A comparison to commercially available CO₂ gas (ISAGA, Reykjavík, Iceland) suggests that geothermal flue gas (geogas) is fully competitive as a feedstock for microalgae cultivation. This technique provides a method to manage CO₂ emission from geothermal power plants and a more economical and environmentally friendly method for microalgae cultivation.

Keywords: geothermal, flue gas, biomass production, microalgae

1. INTRODUCTION

The Blue Lagoon is a geothermal aquifier that was gradually formed from the effluents of HS Orka, a nearby geothermal power plant, almost four decades ago (Fig. 1). It has since then developed its own geothermal ecosystem characterized by microalgae, minerals and silica. The geothermal seawater of the lagoon is composed of approximately two-thirds seawater and one-third fresh water and is very high in silica content. A unique microalgae species (Cyanobacterium aponinum), has been isolated from the Blue Lagoon ecosystem, and is cultivated in large-scale photobioreactor at the Blue Lagoon R&D Center (Fig.2) (Petursdottir and Kristjansson, 1997; Petursdottir et al., 2009). This unique microalgae species has been reported to provide protection against extrinsic skin ageing warrants (Grether-Beck 2007) and is currently used as an active ingredient in the skin care products of Blue Lagoon ltd.

Figure 1. The Blue Lagoon was formed by effluents of a nearby geothermal power plant.
2. MATERIALS AND METHODS

2.1 Laboratory studies

Microalgae was cultured in a laboratory-scaled photobioreactor, using CO₂ rich gas of two different sources; a) commercial CO₂ gas (ISAGA, Reykjavík) and b) geothermal flue gas (HS Orka, Grindavik). The culturing liquid consisted of geothermal brine enriched with 0.67 g/L (4%) of Cell Hi-WP nutrition (Varicon Aqua-Solutions Ltd., UK). Optimal growth parameters were previously determined as pH 7.5, temperature 45°C and 2.5 % salinity (Indra et al., 2010).

2.2 Microalgae monitoring and harvest

The cell density was monitored on a daily basis by means of spectrophotometer, where light absorbance at 620 nm was measured. The linear relationship between absorption and microalgae concentration is based on the Beer–Lambert law (Equation 1)

\[ A = \alpha \lambda \cdot b \cdot c \]  

Where A is the measured absorbance, \( \alpha \lambda \) is a wavelength-dependent absorptivity coefficient, b is the path length, and c is the analyzed concentration. Additionally, microalgae growth was monitored with dry weight measurements where a certain volume of microalgae culture was measured and its dry content weighed. Microalgae that was collected for chemical analysis was harvested by means of a centrifugal separator (GEA, Westfalia, Germany) and dried for 24 hours using a freeze dryer (Alpha Christ, SciQuip, United Kingdom).

3. GEOTHERMAL GAS SUPPLY

3.1 Use of commercial and geothermal CO₂ in microalgae cultivation

Carbon dioxide (CO₂) is one of the fundamental parameters in algae cultivation, along with nutrition and light for photosynthesis. HS Orka power plant produces 75 MW of electrical energy and uses 240°C hot steam, from drilling holes to a depth of 2000 m, to turn turbines to produce electricity. The steam, however, contains about 1-2% of geogas that cannot be used for electricity generation and is therefore discarded into the atmosphere. The annual output of geogas from HS Orka is over 60,000 ton of CO₂ and over 700 ton of H₂S. The geogas from HS Orka power plant has an unusually high content of CO₂ (~97%) compared to other geothermal power plants in Iceland (~75%) and a relatively low sulfur content (~2% wt.) mainly in the form of H₂S (www.hsorka.is). In comparison, the geogas from Hellisheiði Power Station in South of Iceland...
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contains about 25% H₂S, but H₂S is a well known corrosion agent. A high maintenance cost of machinery is often an unwelcome side effect in such an environment.

The geogas was collected with a 300 m long gaspipe (2” diameter) between HS Orka power plant and the Blue Lagoon R&D Center. The gas passed through a simple iron oxide (FeO) filter to decrease the concentration of H₂S, before it was pressured into a 380 L reservoir tank at 7.5-8 bars (Fig 2C). Sulfur content was measured as ~5 ppm H₂S after filtration, measured with Dräger Tubes®. Lastly, the geogas was automatically supplied to the photobioreactor, controlled with a feedback loop using pH probes and solenoid valves.

4. MICROALGAE GROWTH MONITORING

4.1. Light Absorbance and Dry Weight Measurements

Microalgae growth was measured by means of spectrophotometer and dry weight measurements. Dry weight measurements ranged from 0.68- 0.97 g/l and 0.62-1.00 for microalgae grown on geogas and commercial CO₂, respectively. Although growth rate measurements ranged a little higher for commercial CO₂, results imply that there is little or no difference in using commercial gas versus geothermal gas in cultivating the algae (see Fig. 3). Furthermore, doubling time T_d of microalgae growth, was calculated as function of time t and dry weight m (Equation. 2). Doubling time was calculated as 26.89 h and 27.81 h for commercial CO₂ and geogas, respectively. Thus, indicating that growing algae on geothermal gas does not significantly affect the growth rate of microalgae.

\[ T_d = (t_2 - t_1) \cdot \frac{\log(2)}{\log(m_2/m_1)} \]  

\[ (2) \]

Figure 3. Dry weight measurements and light absorbance at 620 nm.

4.2 Microalgae chemical analysis

Additionally to the growth measurement, the chemical composition of the microalgae was analyzed. Our main interest was if the higher concentration of sulfur in the geogas would affect the microalgae in any way such as excessive accumulation of sulfur within the microalgae. The amount of H₂S in geogas after filtration was measured as ~5 ppm. In comparison, commercially available gas (ISAGA, Iceland) contains <1 ppm total sulfur (S), thereof <0.1 ppm in form of hydrogen sulfide (H₂S). A chemical analysis was performed on three samples of microalgae: microalgae fed on commercial gas (Com-CO₂),
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Microalgae fed on geothermal gas (Geo-CO$_2$) and microalgae fed on geothermal gas that was washed three times with distilled water (Geo-CO$_2$w). The third sample was washed to make sure no traces of sulfur, which might be found in the microalgae supernatant, would be mistaken for sulfur content absorbed by the microalgae. The chemical analysis was performed with Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-EOS) by Innovation Center Iceland (see Table 1). Sulfur content was similar for all three samples and ranged from 0.466-0.496%.

Table 1: Results of a chemical analysis of microalgae performed with ICP-EOS.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sulfur S % (w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Com-CO$_2$</td>
<td>0.495</td>
</tr>
<tr>
<td>Geo-CO$_2$</td>
<td>0.466</td>
</tr>
<tr>
<td>Geo-CO$_2$w</td>
<td>0.496</td>
</tr>
</tbody>
</table>

5. DISCUSSION

The increasing concentration of carbon dioxide (CO$_2$) in the atmosphere is considered to be among the greatest problem in regards to global warming, but the annual emission of CO$_2$ has increased by 80% between 1970-2004 (IPCC, 2007). Thus, there is an increasing demand for alternative methods in managing CO$_2$ emission, such as from geothermal power plants, as well as environmentally friendly production methods.

This paper investigated the potential of using CO$_2$ rich geothermal gas for microalgae cultivation as an alternative to commercially available gas. Microalgae growth was monitored by means of spectrophotometer and dry weight measurements and our results indicate that there is no significant difference in growth in using geothermal gas or commercial CO$_2$. Furthermore, chemical analysis performed on harvested and freeze dried microalgae suggested that sulfur does not accumulate in microalgae when cultivated using geogas, although geogas contains 50 times more H$_2$S than commercial gas. Filtering the H$_2$S from the geogas is though preferable because of its unpleasant odor and corrosive effects on nearby machinery. Results in this paper are based on measurements in a lab-scaled photobioreactor. Further work will include studies on growing algae on CO$_2$, of different sources, in a large-scale photobioreactor for extended period of time to study the feasibility and sustainability for using geothermal CO$_2$ as a source of feed stock for biomass production.

Although microalgae cultivation, even for a large-scale photobioreactor, uses merely a small fraction of the annual CO$_2$ emission from power plants, this is an important addition to alternatives in managing geothermal flue gas. As demonstrated in this paper, this untapped resource of CO$_2$, can be used for producing high-value products, such as in cosmetics. Thus, turning waste into value through photosynthesis.

REFERENCES


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