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Carbon dioxide capture from combustion gases in residential building by microalgae cultivation

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ABSTRACT

Introduction: Global warming and the need to reduce greenhouse gas emissions from various emission sectors are not hidden from anyone. The aim of this study was to determine Carbon dioxide (CO_2)capture from combustion gases of methane for cultivation of microalgae spirulina platensis.

Materials and methods: Microalgae culture medium was added in two photobioreactor. Air and combustion gas was injected into control and test reactors respectively. Artificial light with 10 Klux intensity was used and operated in continuous and intermittent (14 h ON and 8 h OFF) modes. Inlet concentration of carbon dioxide in to the test photobiorector was set in the range of 2000 to 6000 ppm and was measured in the inlet and outlet of photo-bioreactor by ND-IR CO_2 analyzer.

Results: In the control photo-bioreactor, the average removal of CO_2 from the air was 42%. In the test reactor with an inlet CO_2 concentration of 4100 ppm, the average removal of CO_2 from the combustion gas was 23%. After 9 days of cultivation, the amount of carbon dioxide stabilized by microalgae was 0.528 and 1.14 g/L (dry weight) in the control and experimental photo-bioreactors respectively. The CO_2 bio-fixation rate was in the range of 2.2% and 4.0% at different runs. After 9.0 days of cultivation concentration of microalgae was 0.25 and 1.0 g/L in the control and test reactors respectively. Algae productivity with intermittent light was 35% less than continuous light exposure.

Conclusion: It is possible to use CO_2 capture from combustion gases of commercial heater for cultivation of microalgae spirulina.

Introduction

The increase of Greenhouse Gases (GHGs) emissions has led to global warming and climate change. Concentration of Carbon dioxide (CO_2)in atmosphere has increased from the preindustrial level of 280 ppm to 418 ppm in 2022 [1] and even 421 ppm in some regional atmosphere [2] and increase

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in the average temperature of 1°C above the preindustrial level, and if this trend continues, it is projected to rise 1.5 °C by 2050 [3]. Human activities including fossil fuels combustion in various sectors such as transportation, power generation, industries, residential, commercial, and agricultural, along with deforestation, land use change, and solid waste burning are the main reasons for increased CO_2 concentrations in the atmosphere [4, 5]. In addition to solutions such as using renewable energy resource, recycling materials, and changing lifestyles, methods for decrease CO_2 concentration in atmosphere are categorized into two main categories. The first category is CO_2 Capture and Storage (CCS) from flue gases of major point sources such as power plants, cement factory, and so on. The second category is CO_2 Removal (CDR) methods including Bio-Energy with Carbon Capture and Storage (BECCS), Direct Air Capture (DAC) by physicochemical or biological methods, bio char production, enhanced weathering, and ocean fertilization [6, 7]. Among the different methods, CO_2 capture by microalgae cultivation is a promising technology. Microalgae cultivation is generally carried out in outdoor ponds and also in controlled photo-bioreactors. In a photo-bioreactor, CO_2 is captured during photosynthesis, microalgae grow and biomass is produced [8]. One type of microalgae that has attracted much attention is Spirulina platensis. It is a genus of cyanobacteria (blue-green algae) that can grow in both fresh and salt water. Each 100 g of dried spirulina contains 23.9 g carbohydrate, 7.72 g fat, 57.47g of 18 types of proteins, 15 types of vitamins, and eight types of minerals. Spirulina is used in different countries in cosmetics, medication, aquaculture, and animal and poultry farms. This ingredient is widely used as a supplement for certain foods. The optimum growth condition is alkaline condition and temperatures above 25°C [9]. One of the major CO_2 emission sources is residential sector. Natural gas and kerosene are used for heating and hot water production of buildings in many countries and considerable direct emissions of CO_2 are from heating in buildings [10].

Totally, 40% of energy consumption is in building sector. Moreover, building sector contributes about 30 percent of total annual greenhouse gas emissions, which is expected to double in the next 20 years [11]. According to Iran's third national communication to UNFCCC, CO_2 emission by residential building subsector in 2000 and 2010 was 69 and 107 million tons respectively , and it is expected to be 152 million tons in 2020 [12]. National Iranian oil products distribution company reported that annual consumption of kerosene and natural gas in the residential-commercial sector was 3400 million L and 2 billion m^3 respectively in 2018 [13] . The CO_2 biofixation by microalgae cultivation is a promising, eco-friendly, and cost-effective technique to reduce CO_2 emission. Numerous studies have been conducted to cultivate different microalgae by using CO_2 [14]. Several studies have been conducted for microalgae cultivation by CO_2 capture from industrial flue gas [15-17]. Capture of CO_2 from power plant desulfured flue gas [18], CO_2 capture from flue gas of steel plant by cultivation of Chlorella sp [19], Cultivation of Chlorella , Synechocystis and Tetraselmis in photo-bioreactor by industrial combustion gases of methane [20], using flue gas of a coal-fired power plant for microalgae cultivation and biofuel production [21], utilization of biogas as CO_2 provider for Spirulina platensis cultivation [22], using flue gas of industrial heater to growth of Euglena grasilis [23]

and microalgae production from kerosene combustion [24] have been examined for microalgae cultivation using industrial flue gases.

In all of the above-mentioned studies, high concentrations of CO_2 have been examined. Industrial flue gas has high concentrations of CO_2 (4-14% v/v or more) along with toxic gases such as SO_2, NO_x, and heavy metals with high temperatures [25, 26]. High concentrations of CO_2 inhibit the growth of microalgae [27]. Sulfur dioxide (SO_2) in flue gas in excess of 100 ppm inhibits algae growth [28]. Moreover, the presence of Nitrogen Oxides (NO_x) gases in excess of 300 ppm has a negative effect on the growth of algae [29]. Due to the high volumes of industrial flue gases and presence of toxic gases, industrial flue gas needs pre-treatment in order to grow algae, which increases the cost [30].

In a review article, the use of microalgae photo bioreactors in the architecture and facades as well as types of PBR for integration with buildings and their technical requirements were described [31]. An article outlining the types of intelligent buildings, refers to a building in the Hamburg- Germany with a facade made of PBR used for microalgae cultivation [32].

According to literature review, there is no study on using residential combustion gases for microalgae cultivation, the aim of this study was to capture carbon dioxide from house chimney gases for cultivation of microalgae spirulina.

Materials and methods

Spirulina platensis seed culture was obtained from caspian institute of ecology and fisheries in Sari, Iran. In order to prepare stock microalgae, 50.0 mL of seed culture was inoculated into 5.0 L of Zarrouk culture medium in a glass vessel. Composition of modified (carbon free) Zarrouk medium was: $NaNO_3$ 2.5g/L, NaCl 1.0g/L, K_2SO_4 1.0 g/L, K_2HPO_4 0.5g/L , $MgSO_4.7H_2O$ 0.2g/L, $FeSO_4$ 0.01g/L, $CaCl_2.2H_2O$ 0.08g/L, EDTA 0.08g/L and pH=9.5 by adding NaOH 1.0N [25]. Aeration of growth medium was performed by an aquarium air pump. Four white fluorescent lamps (each 20W) were used for light illumination of culture medium. Modified Zarrouk medium containing above mentioned composition without $NaHCO_3$ (or carbon free) was used for microalgae cultivation in our experiments. 50 mL of stock microalgae was inoculated in photo-bioreactor containing 3.0 L of modified zarrouk medium. Microalgae spirulina was grown in the air aerated stock culture vessel containing modified Zarrouk medium. Spirulina cultivation was performed by air injection in two neutral and alkaline medium separately. Initial pH of the growth medium was adjusted to 9.5 by adding a few milliliter of NaOH 1.0N [26]. Concentration of algal biomass at the beginning of each test run was 20 mg/L. In order to determine algal biomass concentration, light absorbance of microalgae medium was measured at 689 nm by spectrophotometer (HACK, DR2800). Carbon percentage in spirulina biomass was measured by the CHNS analyzer (Perkin-Elmer,2400,USA).

The photo-bioreactor used in this study was fabricated by plexiglass with total volume of 5.6 L containing 3.0 L of growth medium. In order to supply combustion gases, commercial gas heater was used. Combustion gases of methane (the sole carbon source for microalgae cultivation) were injected into photo-bioreactor after passing through a condenser to remove water vapor (Fig. 1). Air was injected in control photo-bioreactor.

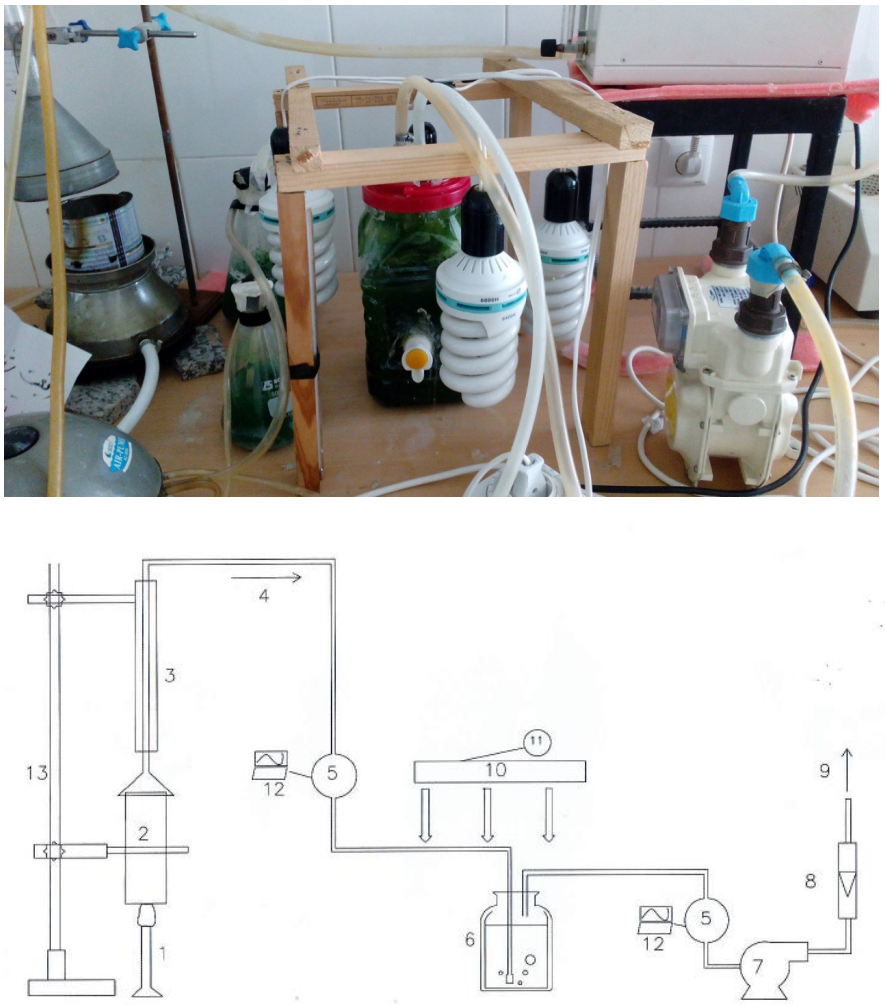

Fig. 1. Schematic and photo of experimental setup - 1:gas heater 2:funnel 3:condenser; 4:connection tube; 5: CO_2 analyzer; 6:photo-bioreactor; 7:air suction pump; 8:rotameter; 9:out let pipe; 10:fluorescent lamp; 11: timer; 12:computer; 13:holder stand

Light exposure with the intensity of 10 Klux was in intermittent (14 h on / 10 h off) and continuous mode [26]. Flow rate of combustion gas into the photo-bioreactor was set at 1.5 L/min. In order to prevent the heating of the culture medium, due to the small size of the photobioreactor, part of the flue gas was separated and injected into the medium. The initial concentration of carbon dioxide was in the range of 2000 to 6000 ppm and measured in the inlet and outlet of photo-bioreactor by ND-IR CO_2 analyzer. Daily sampling of culture medium was performed to measure optical density and mass of microalgae. Plot of algal biomass concentration (g/L) versus optical density was used as calibration curve. Duration of each test run was 9.0 days and each daily sample from pho-bioreactor was filtered by using GF/A filter and biomass of microalgae was measured by analytic balance (0.0001g) after 12 h drying at 80°C. The maximum microalgae productivity was calculated using Eq. 1.

$$P_{max} = X_t\text{-}X_0 / t_x\text{-}t_0 \quad (1)$$

Where P_{max}, is the maximum algae production (g/L.d) during cultivation period (t_x-t_0), X_t is

concentration (g/L of algae in the final day and X_0 is initial concentration (g/L) of microalgae. The stabilized CO_2 in the bioreactor is derived from Eq. 2.

$$F = (X_t - X_0)\ M \times V \times \left(\frac{44}{12}\right) \quad (2)$$

Where F is stabilized CO_2 (g), X_t is algae concentration (g/L) at t (d), X_0 is algae concentration at inoculation (t_0), M is a fraction of carbon in algae determined by CHNS analyzer (g/g of algae), V is volume of culture medium (L). The percentage of carbon stabilized in algae was calculated by dividing the amount of carbon in algae by the total carbon injected into the reactor (27).

Results and discussion

Effect of pH on the growth of microalgae in control photo-bioreactor which was operated by injecting air containing 600 ppm of carbon dioxide, is shown in Figure 2.When the pH of the culture medium was increased from 7 to 9, the concentration of algal biomass increased daily and reached to 0.48 g/L after 9 days. The initial pH of the culture medium was 9.5 and gradually reached to 8.5 at the end of experiment (9th days). Due to the formation of bicarbonate, the pH of culture medium was always higher than 8 and the alkaline conditions was suitable for microalgae growth. A study showed that there was a direct relationship between algae production and pH [28] .

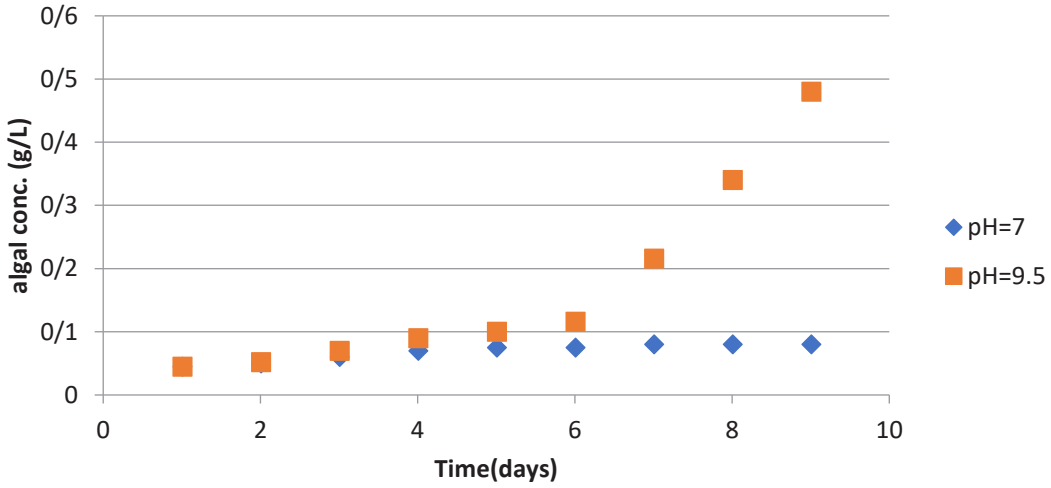

Fig. 2. Effect of pH on growth of microalgae

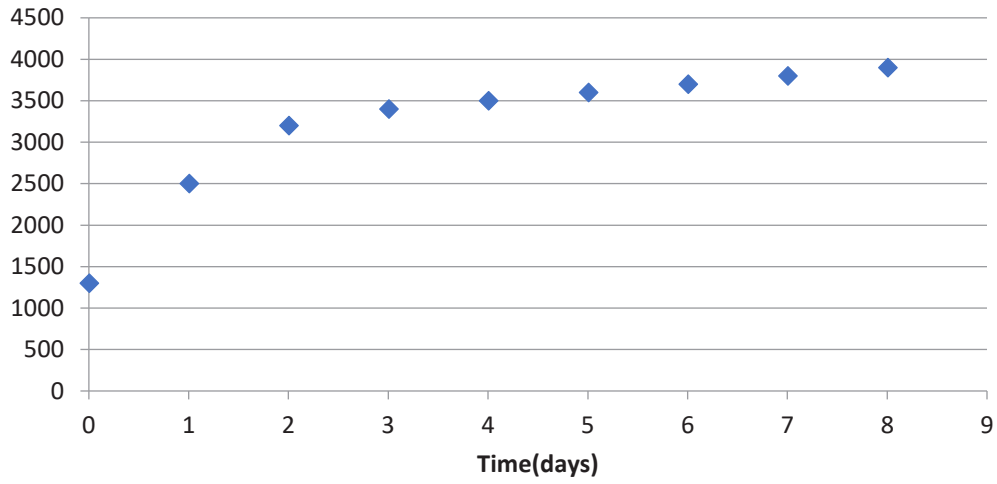

Fig. 3. Effect of contact time on concentration of CO_2 in the outlet of photo-bioreactor

Fig. 3 shows the change in CO_2 concentration in the outlet of photobioreactor with the inlet CO_2 concentration of 4000 ppm. As can be seen in the Fig. 3 , the maximum absorption of carbon dioxide occurred immediately after the injection of combustion gas in the culture medium and after 9.0 days of cultivation the outlet concentration was reached to 4000 ppm. In a study power plant flue gas was used for microalgae cultivation in a pilot plant photo-bioreactor that results showed 2,234 kg CO_2 per year was absorbed [18]. In another study flue gas of steel factory was used for CO_2 capture and microalgae cultivation in a 50.0 L photo-bioreactor and after six days, concentration of algal microalgae was increased from 0.75 to 2.87 g/L [19]. In a study algal bloom was occurred in the CO_2 concentration of 4,000 to 6,000 ppm at the fourth or fifth days using combustion gases of methane [29]. In another study, the effects of different concentration of CO_2 on growth rate of three types of microalgae was investigated, and when concentration of CO_2 was in the range of 50,000 to 60,000 ppm, growth rate of alga was low because high concentrations of CO_2 had an inhibitory effect on algal growth. In a study, by changing the concentration of CO_2 and measuring the growth rate of algae, the best CO_2 concentration for optimal growth of algae was in the range of 1,000 to 6,000 ppm [20]. In one study flue gas of coal burning power plant was used for microalgae Scenedesmus cultivation. Diluted combustion gas containing 10,000 to 40,000 ppm CO_2 was injected in Scenedesmus cultivation pond and results showed that highest growth rate of microalgae was in CO_2 concentration of 20,000 ppm [21].

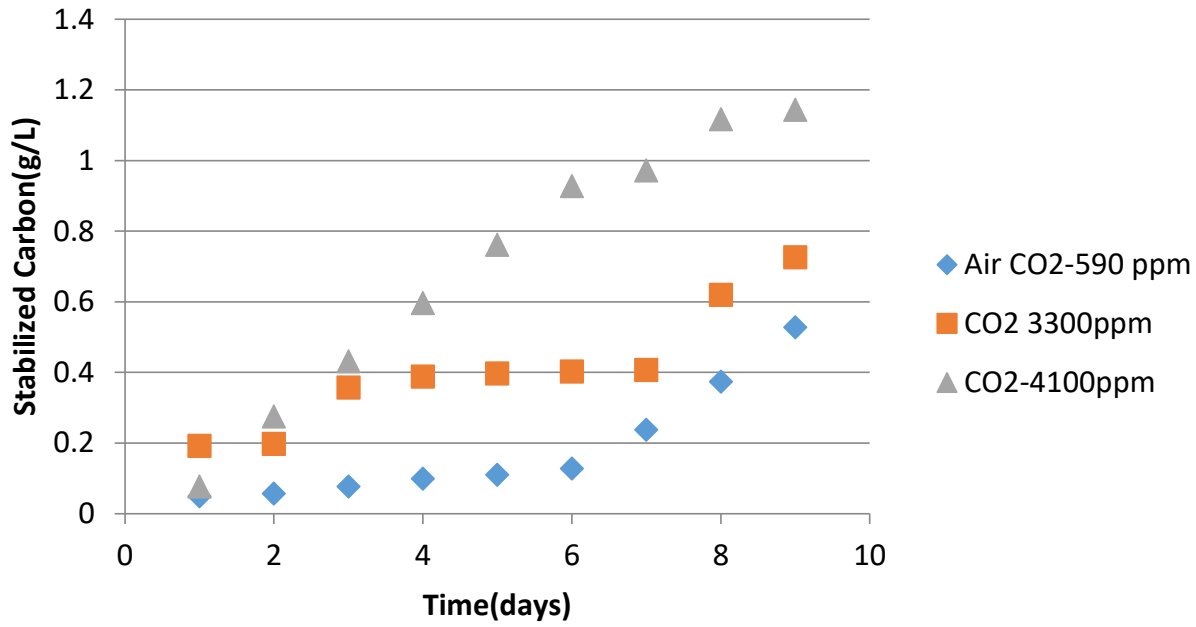

Fig. 4. Diurnal stabilized CO_2 in photo-bioreactor in different inlet concentration

Fig. 4 shows the diurnal stabilized CO_2 in control and test photo-bioreactor at different concentration of inlet CO_2. As it can be seen from Fig. 5 the stabilized CO_2 was increased by increasing the contact time and inlet CO_2 concentration. In one study biogas was supplied as CO_2 source in microalgae spirulina cultivation with the initial pH of 9.0 and the results showed that with injection of air, algal growth was continued but with injection of biogas, the microalgae concentration was decreased sharply [22]. Carbon dioxide capture from combustion gas of methane was studied by three species of microalgae by increasing concentration of CO_2 from 1,000 to 10,000 ppm, and results showed that the algal biomass was increased, however when the concentration of carbon dioxide reached above 10,000 ppm, the amount of algae production decreased [20] .In one study it was shown that increased CO_2 emissions from coal combustion up to 20,000 ppm had led to an increase in the production of Chlorella and Scenedesmus and the inhibitory effects on the growth of algae appeared at 40,000 ppm of CO_2 [21]. In another study the combustion gas was passed from an alkaline medium (lime solution) and then injected into photo-bioreactor [20]. In another similar study after 12 days of aeration, the maximum concentration of Spirulina algae reached to 1.02 g/L [30] . Simulated combustion gas containing NO_x, SO_2, and CO_2 with concentration of 60, 100 and 120,000 ppm respectively was used to produce Spirulina and the results showed that maximum algae concentration was 1.42 g/L, the algae production rate was 0.1 g/Ld, and the fixation of CO_2 was 0.14 g/Ld [25]. In another research cultivation of microalgae Euglena grasilis by using combustion gases of kerosene was studied [23]. Cultivation of Chlorella by using 20,000 ppm of CO_2 was studied and 2.6 g/L biomass was produced [30]. In the present study by using intermittent light and combustion gas of methane with CO_2 concentration of 2100 and 5500 ppm, the algal biomass was 0.66 and 1.04 g/L respectively, which is comparable reported by other researchers 1.2 g/L [21] and 1.02 g/L [30].

Carbon dioxide stabilized in two light exposure (continuous and intermittent) by using combustion gases of methane was shown in Fig. 5. As it can be seen, microalgae concentration in continuous light exposure was more than intermittent light and the difference between the two modes was statistically significant ($p<0.05$).

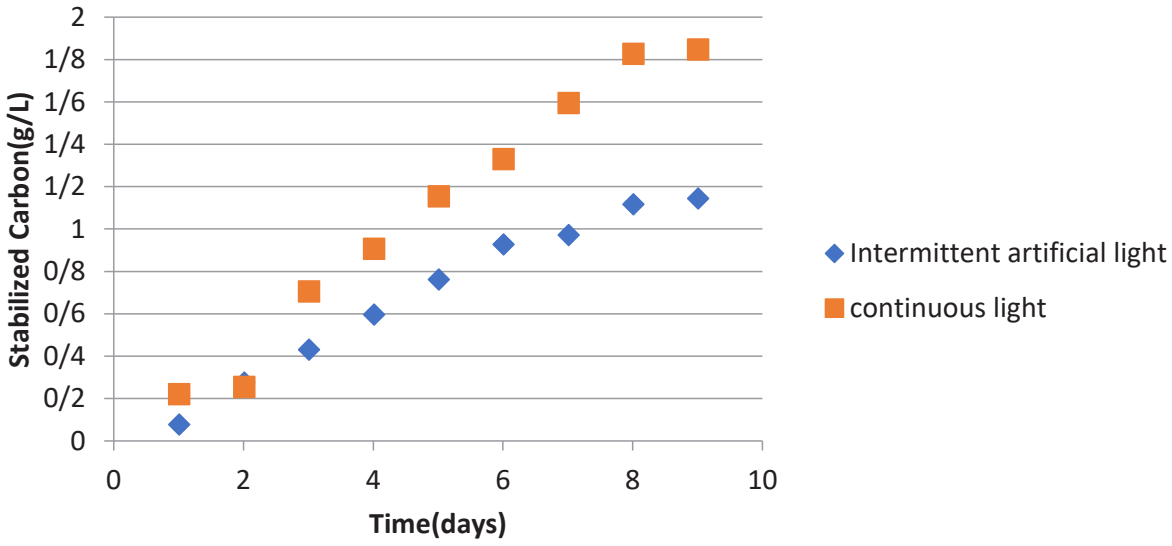

Fig. 5. Concentration of microalgae with time by using combustion gases of methane (CO_2 5500 ppm)

There is a study that shows the microalgae production in intermittent light is 25% less than continuous light [29]. In a study the growth of Clamydomonas was measured and results showed that the specific growth rate in intermittent light was 31% lower than continuous light due to consumption of biomass during respiration reaction at the dark hours [33]. Capture of CO_2 in a photo-bioreactor is carried out in two forms including absorption in culture medium and uptake by microalgae. Due to the lack of carbon source in the culture medium, photosynthesis in algae was performed only by uptake of CO_2 from combustion gas.

Conclusion

One of the important sources of greenhouse gas emission of carbon dioxide is the residential and commercial sector. Microalgae can be produced by using the combustion gases of heating devices in the buildings. In this study microalgae spirulina was produced by injection of combustion gas of methane as sole carbon source into photo-bioreactor containing the culture medium and carbon dioxide was removed from combustion gases.

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Competing interests

The authors declare that there are no competing interests.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc.) have been completely observed by the authors."

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