Reducing CO_2 Emission using Microalgae

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***Abstract*- Global warming's effects can be seen worldwide, and many experts believe it's only going to get worse as CO2 emissions continue to rise. Global warming is caused by the emission of greenhouse gases. 72% of the totally emitted greenhouse gases is carbon dioxide (CO2), 18% Methane and 9% Nitrous oxide (NOx). Carbon dioxide emissions therefore are the most important cause of global warming. CO2 forms the largest component in flue gas. With fossil fuels currently meeting over 80% of global energy carbon capture and storage (CCS) is vital in meeting greenhouse gas reduction targets.Microalgae's ability to photosynthesis and grow rapidly has resulted in the possibility of using them for CO2 bio-fixation. A number of studies have been carried out to determine the ability of microalgae to withstand the high CO2 concentrations present in flue gas, as well as the potentially toxic accompanying SOx and NOx gases. Thus, a lot of work has been carried out to isolate microalgal strains that are especially suitable for this application. Most of the research on algae bio-fixation has been concerned with carbon fixation strategy, photobioreactor design,conversion technology from microalgal biomass to bioenergy, and economic evaluations of microalgal energy In this respect, a number of relevant topics are addressed: the nature of microalgae (e.g., species and composition); CO2 capture via microalgae; the techniques for microalgal cultivation, harvesting and pretreatment; and the techniques for lipid extraction and in addition biofuel production.**

Keywords: Microalgae; Extraction; CO_2 capture; Algae Emissions

I. INTRODUCTION

Fossil fuels, which are recognized as unsustainable sources of energy, are continuously consumed and decreased with increasing fuel demands. Microalgae have great potential as renewable fuel sources because they possess rapid growth rate and the ability to store high-quality lipids and carbohydrates inside their cells for biofuel production. Microalgae can be cultivated on opened or closed systems and require nutrients and CO_2 that may be supplied from wastewater and fossil fuel combustion. In addition, CO_2 capture via photosynthesis to directly fix carbon into microalgae has also attracted the attention of researchers. The conversion of CO_2 into chemical and fuel (energy) products without pollution via this approach is a promising way to not only reduce CO_2 emissions but also generate more economic value.To replace fossil fuels, various biomass feedstocks, including both terrestrial plants and aquatic algae, have been discovered to generate renewable fuels. Aquatic microalgae are ideal for producing liquid fuels because their rapid growth, high biomass yields, product variety and simple harvest from ponds or closed bioreactor systems allow them to be potentially consumed as sustainable environmentally friendly carbon-neutral fuel sources. This article reviews the literature on microalgae that were cultivated using captured CO_2, technologies related to the production of biofuels from microalgae and the idea of the commercialization of microalgae-based biofuels to demonstrate the potential of microalgae. In this respect, a number of relevant topics are addressed: the nature of microalgae (e.g., species and composition); CO_2 capture via microalgae; the techniques for microalgae cultivation, harvesting and pretreatment; and the techniques for lipid extraction and biofuel production.

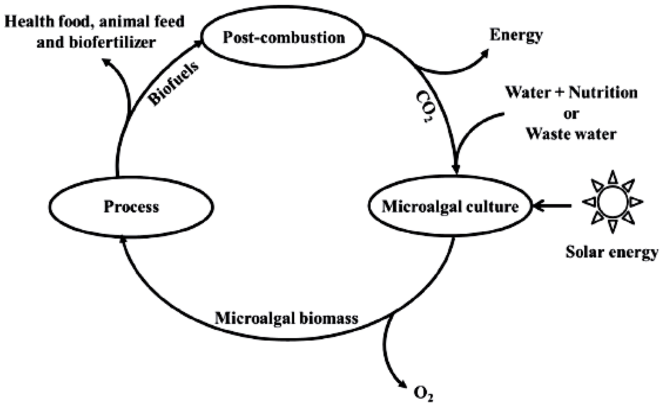

Fig. 1 An integration of microalgae cultivation with CO2 utilization

II. MICROALGAE

Certain species of microalgae offer the possibility of sustainable, low GHG (greenhouse gas) emissions. Some of their perceived advantages of microalgae are that they grow rapidly, yield significantly more biofuel per hectare than oil plants, can sequester excess carbon dioxide as hydrocarbons, produce a fuel that contains no sulphur with low toxicity that is highly biodegradable, does not compete significantly with food, fibre or other uses and does not involve destruction of natural habitats. Microalgae contain lipids and fatty acids as membrane components, storage products, metabolites and sources of energy. When grown under standard, nutrient-replete conditions, they show large differences in percentages of the key macronutrients: by dry weight, typically 25 to 40% of protein, 5 to 30% of carbohydrate and 10 to 30% of lipids/oils. Species containing considerably higher oil content have been found and more than a dozen algal species have been mentioned as possible candidates for producing biodiesel. Microalgae, which many geologists believe produced most fossil fuels in the first place, need light, nutrients and warmth to grow. This occurs naturally on larger scales in bogs, marshes and swamps, salt marshes and salt lakes. Smaller-scale sources include wastewater treatment ponds, animal waste and other liquid wastes. When algal growth conditions exist, the steps involved in producing biodiesel from the algae are shown below. Microalgae are diverse, pervasive, productive and less competitive with other plants as a source of food for human consumption. Though microalgae are aquacultured widely to produce various high-value foods, nutraceuticals and chemicals, the methods adopted have not yet been shown to be economically and ecologically viable for the production of biodiesel in quantities large enough to replace fossil fuels.

A. Photosynthesis

Photosynthesis has existed and shaped the environment on earth for more than 3.5 billion years, providing the foundation for all aerobic forms of life. Using the following reaction, plants and photosynthetic microorganisms (including microalgae and cyanobacteria) convert carbon dioxide into organic compounds with the aid of light energy, and release molecular oxygen, as follows:
6CO2 + 6H2O light energy C6H12O6 + 6O2
Photosynthesis is a physicochemical process and consists of two steps:

1. light dependent reaction, which only takes place in the presence of light, and
2. light independent reaction, which takes place under both the absence and presence of light.

The first step is catabolic, which involves the release of energy. This energy is stored in organic form in the second step. Proper cycling of these two steps is important for fixing carbon. Excess exposure to light and oxygen rich environments may lead to photo inhibition, which reduces the efficiency of the photosynthetic process. When photo inhibition occurs, CO2 may actually be released into the environment.

B. Species

Most microalgal species isolated from natural streams, lakes or oceans have been pre-adapted for the living environment through artificial domestication. They have been successfully used for fixation of atmospheric CO_2. However, unlike atmospheric air, which has low CO_2 content (about 0.038% volume concentration v/v), post-combustion flue gas typically contains 4–14% or more v/v CO_2 concentration and possibly toxic compounds (SOx, NOx and trace elements) in a high flow rate, high temperature (80-120°C or above) stream.
Microalgae and cyanobacteria species commonly used for CO_2 mitigation include Botryococcus braunii, Chlorella vulgaris, Chlorella kessleri, Chlorella sp., Chlorocuccum littorale, Chlamydomonas reinhardtii, Scenedesmus obliquus, Scenedesmus sp., M. minutum, Tetraselmis sp., and Spirulina sp. A few Chlorella and cyanobacteria species could grow well and achieve a high CO_2 fixation (500–1800 mg/L/d) with a relatively high tolerance for temperature and CO_2 concentration.

III. CULTIVATION TECHNIQUES

A wide range of microalgae cultivation techniques has been reported in the literature (Wang et al., 2008; Suali and Sarbatly, 2012; Bahadar and Khan, 2013; Zhao and Su, 2014). There are many types of microalgae cultivation techniques depending on (1) the investment cost, (2) the desired products, (3) the source of nutrients and (4) CO2 capture. The cultivation systems are categorized into open and closed systems. The open systems are outdoor facilities consisting of ponds, lagoons, deep channels, shallow circulating units and others. In contrast, the closed systems are vessels or tubes with walls that are made of transparent materials and that are located in outdoors under sunlight irradiation or artificial irradiation (Razzak et al., 2013).

A. Open System

There are various types of ponds, including unstirred, raceway and circular ponds. Unstirred ponds are the most economical due to their simple management and construction. Commercial unstirred ponds are built in natural water ponds of less than half a meter in depth. Unstirred ponds are commercially used for some microalgae species, such as Dunaliella salina (Borowitzka and Borowitzka, 1990). However, this type of pond is very limited in its applications, given that microalgae are not able to grow under frequently poor growth conditions and competitive growth with contaminating protozoa, bacteria and viruses. Raceway ponds (or stirred paddle wheel open ponds) are the most famous open system in current use. Raceway ponds are usually shallow, between 15 and 25 cm in depth. These ponds are normally constructed as either a single channel or groups of channels that are built by connecting individual raceway ponds. The productivity of the biomass

Fig 2. Open System (1) unstirred pond, (2) raceway pond, (3) circular pond

In the raceway pond is 60–100 mg dry weight/L/day Raceway ponds are mostly used for the commercial culturing of four species of microalgae The circulation of the cultivation media in the raceway pond is induced by paddle. The optimal circulation velocity is required for water flow without the deposition of sedimentation or the aggregation of cells. Circular ponds (central pivot) (Fig. 2) are the oldest large-scale algae-cultivation open ponds. The depth of these ponds is approximately 25–30 cm. Microalgae are usually grown in concrete circular ponds of up to 45 m in diameter with agitation by rotating paddles. A 20-to-30- cm-thick layer of inorganic nutrient solution with algae is exposed to sunlight and CO2 bubble under the continuous movement of paddle wheels.

1). Limitations of open system

(1) poor light consumption by cells, (2) evaporative losses, (3) diffusion limitation of CO2 from the atmosphere, (4) large land area requirement and (5) easy contamination by unwanted algae, mold, and bacteria. These limitations can be overcome using translucent plastic covers or greenhouses over the open ponds. However, this proposal cannot solve the contamination issues; in addition, the high capital cost, maintenance and overheating make open ponds that are covered by translucent plastics impractical due to the large land area of the pond.

B. Close System

Photobioreactors are a type of closed pond system that are used for microalgae cultivation, as they can reduce contamination risk from unwanted algae, mold, and bacteria; control temperature; minimize water evaporation; and remove carbon dioxide losses. However, it should be noted that although photobioreactors significantly reduce the growth of competitive algal weeds, they cannot completely eliminate the growth of contaminants. Tubular photobioreactors (Fig.3) are made with transparent materials and are placed in outdoor facilities under sunlight irradiation. Gas exchange vessels to supply CO2, air and nutrients and to remove O2 are connected to the main reactor.For the design of these cultivation vessels, a large surface area per unit volume is required to maximize the exposure of microalgae to sunlight. The tube sizes are generally less than 10 cm in diameter to maintain sunlight permeability. In a typical tubular microalgae cultivation system, the medium is circulated through the tubes, where it is exposed to sunlight for photosynthesis. However, tubular photobioreactors are still studied on the laboratory scale but are not practical. In some photobioreactors, the tubes are a coiled spiral, forming helical-tubular photobioreactors. These types of reactors are suitable for the cultivation of microalgal species in the presence of sunlight. An artificial light sometime replaces natural light to enhance microalgae growth. However, the use of artificial light adds to the investment costs, leading to the helical-tubular photobioreactors only being adequate for the manufacture of high-value added products

1) Advantages and limitations-Close System

The advantages of these units include (1) high mass transfer, (2) good mixing with low shear stress, (3) low energy consumption, (4) relatively easy operation under sterile conditions, (5) good for the immobilization of algae on moving particles and (6) less photo inhibition and oxidation. However, the limitations of these units include (1) high manufacturing and maintenance costs, (2) smaller irradiation per unit surface area, (3) more sophisticated construction materials, (4) higher shear stress on microalgal cultivations, and (5) larger number of units needed to construct a commercial plant

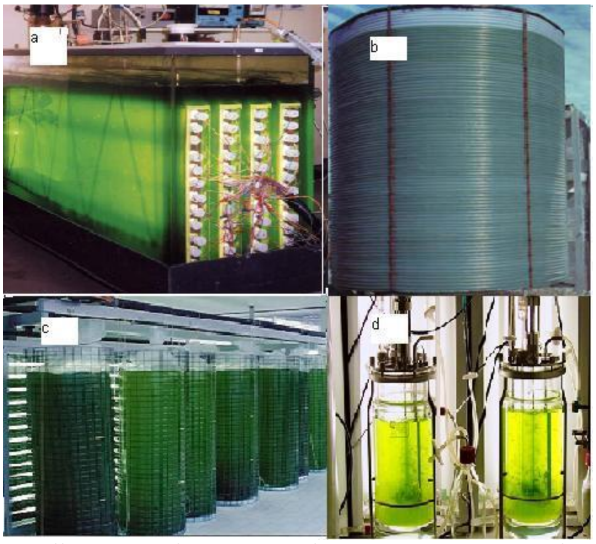

Fig 3. Different types of closed system for culturing microalgae: (a) flat plat photo bioreactor; (b) Biocoil 1000 L tubular photo bioreactor; (c) bag culture; and (d) air lifted tubular bioreactor.

IV. EXPERIMENTAL PROCEDURE

A. Material

1) Stainless steel column

A typical stain less steel is JIS SUS304. The benefits of stainless steel is that it has high strength, great heat-resistance, and it resists staining e.g. rust. Due to its high resistance to heat it makes an ideal material for mechanical parts that are subjected to heating such as a heater of a Sterling engine. Also, due to the materials resistance to rusting, it is ideal for use where it is exposed to water. Other examples of its use is in drive shafts where both strength and corrosion resistance is needed. Stainless Steel tends to be a bit sticky in respect to cutting and machining and as it is a relatively hard material it tends to shorten the life of the cutting tools being used. Such cutting tools need to be sharpened often particularly in prolonged cutting operations. Stainless Steel can usually be identified by its glossy silver color.

2) PVC for pipes

Rigid PVC is used primarily for water pipe and pipe fittings. It is occasionally used for electrical enclosures too. Rigid PVC offers similar properties to ABS at a slightly reduced cost. However, the appearance of PVC cannot come close to ABS. In its plastic phase, PVC is corrosive to molds and molding machines. In its solid phase, PVC is non corrosive.
Tensile Strength: 10,000-12,000 psi
Flexural Modulus: 350,000-600,000 psi

Impact Strength: 0.8-1.4 ft-lb/in notched izod
Maximum Temp.: 170 F short duration 120 F long term
Dimensions: Length = 2.5 meters (total)
Diameter = 1.5 centimeter

3) Cyclic Olefin Copolymer for container

Cyclic Olefin Copolymer (COC) is an amorphous polymer made by several polymer manufacturers. COC is a relatively new class of polymers as compared to commodities such as polypropylene and polyethylene. This newer material is used in a wide variety of applications including packaging films, lenses, vials, displays, and medical devices.

Properties: The optical properties of COC are exceptional, and in many ways very similar to glass. COC materials offer exceptional transparency, low birefringence, high Abe number and high heat resistance. The moisture insensitivity of COC is often an advantage over competing materials such as polycarbonate and acrylics. The high flow of COC enables higher aspect ratio (large yet thin) optical component fabrication than other optical polymers. High ultraviolet transmission is a hallmark of COC materials, with optimized grades the leading polymer alternatives to quartz glass in analytical and diagnostic applications. Some properties will vary due to monomer content. These include glass Transition temperature, viscosity, and stiffness. The glass transition temperature of these polymers can exceed 200°C. COC resins are commonly supplied in pellet form and are suited to standard polymer processing techniques such as single and twin screw extrusion, injection molding, injection blow molding and stretch blow molding (ISBM), compression molding, extrusion coating, biaxial orientation, thermoforming and many others. COC is noted for high dimensional stability with little change seen after processing.COC and COP are generally attacked by non-polar solvents, such as toluene. COC shows good chemical resistance and barrier to other solvents, such as alcohols, and is very resistant to attack from acids and bases. Electronic properties of COC are in some respects similar to fluoro polymers, most notably a similarly low dissipation factor or tan delta, and low permittivity. It is a very good insulator.

4) Dimensions of components

Racks and Columns:
Length of column = 75 centimeter
Length of rack = 75 centimeter
Width =1cm
Plastic Container:
Diameter of container = 10centimetre
Height of container = 25 centimeters
Volume = $2*10^{-3}$ m^3
PVC pipes:
Length =2.5 meters (total)
Diameter = 1.5 centimeter

B. Design Considerations and Experimental Procedure

Diameter of suppressor: 1.5 cm
Length of pipe: 2.5 m
Size of the container: Height = 25 cm and Diameter = 10 cm and Volume= 2 liter

Length ofrack: 75 cm
Length of the column: 75 cm

$$\text{Bending Stress} = \frac{2wl*b/2}{9b4/12}$$

$$= \frac{4wl}{3*b3}$$

$$b3 = \frac{(f.o.s)\ 4wl}{3*(B.S)}$$

f.o.s = Factor of safety=2.5

- Bending Stress of stainless steel is 340 N/mm2
- So, b = 4 mm

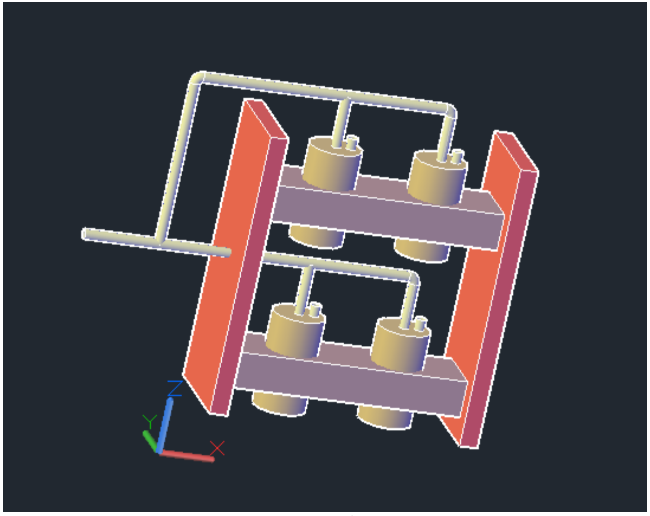

Fig 4. 3D CAD model of the experimental setup

1) Working

Exhaust flue gases from the silencer is made to pass to the container through the inlet port containing algae solution. The solution of algae absorbs CO_2 from the exhaust gases by the process of photosynthesis. CO_2 acts as a catalyst which multiplies the reaction of algae. The remaining exhaust gas escapes out from the outlet port.

2) Effect of Temperature

Temperature effects on the growth of algae.

In this experiment exhaust gases were passed through the algae in 4 different containers. at different temperatures i.e. 20, 25, 30, 35 (°C) respectively. After 1st day algae from the 1st container was removed, dehydrated and the mass of the dry algae obtained was measured. This experiment was similarly carried out for next 5 days from container 2 (temp20), container 3(temp 25), container 4(temp30), container 5 (temp 35) respectively. The measured mass of the dry algae was plotted in graph against Time (days).

Temperature (ºC)	**20°**	**25°**	**30°**	**35°**
Weight /Day 1 (gm)	0.15	0	0	0
Weight /Day 2 (gm)	0.156	0.003	0.005	0.035
Weight /Day 3 (gm)	0.165	0.005	0.007	0.06
Weight /Day 4 (gm)	0.175	0.015	0.02	0.015
Weight /Day 5 (gm)	0.18	0.015	0.035	0.09

Table 1. Temp. Variation and algal growth

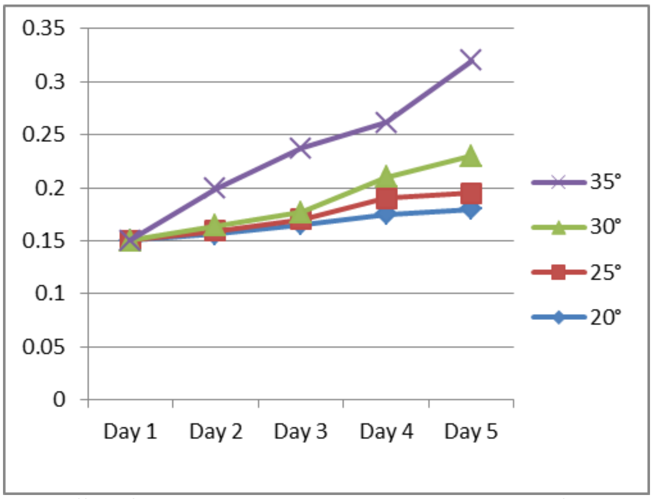

Fig 5. Effect of various temperatures on biomass concentration of Spirulina

V. CONCLUSION

The investigations carried out have established the fundamental aspects that need to be taken into account when a microalgae CO_2 sequestration system is being designed. As far as the culturing medium is concerned, Spirulina was found to grow best in supplemented distilled water. It can therefore be cultured in any water that does not contain any growth inhibitors. It was also observed that the algae multiplied exponentially over the period of time. This gives the proof that it has absorbed the carbon dioxide from the exhaust gas to carry out photosynthesis. Lot of algae was deposited. It was also found that the optimal temperature range for Spirulina cultures is 25-33°C. If temperatures are higher than 38°C, it can be lethal for a number of algal species, especially green microalgae. Temperatures that are lower than 16°C will slow down the growth of algae. Light also has an effect on the growth of algae: it must not be too strong or weak. Nutrient also plays an important role in the growth of algae .growth was considerably higher when nutrient powder was added as opposed to the growth rate when no powder was added similarly optimal pH of water for the growth of algae was around 9.

REFERANCES

[1] Worasaung Klinthong, Yi-Hung Yang, Chih-Hung Huang, Chung-Sung Ta n, Department of Chemical Engineering, National Tsing Hua University "Microalgae and Their Applications in CO2 Capture and Renewable Energy, 1680-8584 print / 2071-1409

[2] Abed, R., Dobretsov, S. and Sudesh, K. (2009). Applications of Cyanobacteria in Biotechnology. J. Appl. Microbiol. 106: 1–12.

[3] Abu-Khader, M.M. (2006). Recent Progress in CO2 Capture/Sequestration: A Review. Energy Sources Part A 28: 1261–1279.

[4] Bozzo, G.G., Colman, B. and Matsuda, Y. (2000). Active Transport of CO2 and Bicarbonate is Induced in Response to External CO2 Concentration in the Green Alga *Chlorella kessleri*. *J. Exp. Bot.* 51: 1341–1348.

[5] Chang, E.H. and Yang, S.S. (2003). Some Characteristics of Microalgae Isolated in Taiwan for Biofixation of Carbon Dioxide. *Bot. Bull. Acad. Sinica*44: 43–52.

[6] Cheng, I., Zhang, I., Chen, H. and Gao, C. (2006). Carbon Dioxide Removal from Air by Microalgae Cultured in a Membrane-photobioreactor. *Sep. Purif. Technol.* 50: 324– 329.

[7] Peter K. Campbell, Tom Beer, David Batten, Transport Biofuels Stream, CSIRO Energy Transformed Flagship PB1 Xing Zhang, CCC/250, Microalgae removal of CO2 from flue gas, APRIL 2015

[8] Brauer T, Kuchta K, Wieczorek N, Pell L (2013) Cultivation of microalgae for biomass and biogas production by exploiting combustion exhaust. Slides provided by Dr Thomas Brauer, 25 pp (2013).

[9] Brennan L, Owende P (2010) Biofuels from microalgae - a review of technologies for production, processing, and extractions of biofuels and co-products. Renewable and Sustainable Energy Reviews; 14(2); 557-577 (Feb 2010).

[10] Yun, Y.S., Lee, S.B., Park, J.M., Lee, C.I. and Yang, J.W. (1997). Carbon Dioxide Fixation by Algae Cultivation Using Wastewater Nutrient. J. Chem. Technol.Biotechnol.69:51–455.

[11] Satoh, A., Kurano, N. and Miyachi, S. (2001). Inhibition of Photosynthesis by Intracellular Carbonic Anhydrase in Microalgae under Excess Concentrations of CO_2. *Photosynth.Res.*68:215–22

[12] Borowitzka, M.A. (2007). Algal Biotechnology Products and Processes Matching Science and Economics. *J. Appl. Phycol.* 4: 267–279.

[13] Carvalho, A.P., Meireles, L.A. and Malcata, F. X. (2006). Microalgal Reactors: A Review of Enclosed System Designs and Performances. *Biotechnol. Prog.* 22: 1490– 1506.

[14] Masakazu, M. and Masahiro, I. (1997). The Biological CO2 Fixation and Utilization Project by Rite (2)-screening and Breeding of Microalgae with High Capability in Fixing CO_2. *Energy Convers. Manage.* 38: 493–497.

[15] Negoro M, Shioji N, Miyamoto K, Miura Y (1992) Growth of microalgae in high CO2 gas and effects of SOx and NOx. *Applied Biochemistry and Biotechnology*; 28–29; 877–886 (Spring 1991)

[16] Oswald W J, Golueke C G (1968) Harvesting and processing of waste-grown microalgae. In *Algae, Man and Environment, Proceedings of an International Symposium.* Syracuse, NY, USA, 18-20 June 1967. Syracuse University Press, Syracuse, NY, USA, 371-390 (1968)

[17] Sung K D, Lee J S, Shin C S, Park S C (1998) Isolation of a new highly CO2 tolerant fresh water Microalgae Chlorella sp. KR-1. *Korean Journal of Chemical Engineering*; 15 (4); 449-450 (Jul 1998)

[18] Williams, P J L B; Laurens, L M (2010) Microalgae as biodiesel and biomass feedstocks: review and analysis of the biochemistry, energetics and economics. *Energy and Environmental Science*; **3**(5); 554-590 (Mar 2010).

[19] Zhao B, Su Y (2014) Process effect of microalgal-carbon dioxide fixation and biomass production: a review. *Renewable and Sustainable Energy Reviews*; 31(1); 121-132 (Jan 2014).

[20] Pires J C M, Alvim-Ferraz M C M, Martins F G, Simões M (2012) Carbon dioxide capture from flue gases using microalgae: engineering aspects and biorefinery concept. *Renewable and Sustainable Energy Reviews*; 16 (5); 3043-3053 (Jun 2012)

[21] Murakami M, Ikenouchi M (1997) The biological CO2 fixation and utilization project by rite (2) – Screening and breeding of microalgae with high capability in fixing CO2. *Energy Conversion and Management*; 38; S493-S497

[22] Molina Grima E, Belarbi E H, Acién Fernández F G, Robles Medina A, Chisti Y (2003) Recovery of microalgal biomass and metabolites: process options and economics. *Biotechnology Advances*, 20(7-8), 491-515 (Jan 2003)