Green technologies for air pollution treatment by microalgae in tubular photobioreactor

T T Minh¹, N H Tien²³, L V Giang¹, H H Loc⁴, V T D Hien³ and T Tran¹²³,*

¹Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology (HCMUT), VNU-HCM, Ho Chi Minh City, 70000, Vietnam.
²Institute of Environmental Sciences, Nguyen Tat Thanh University, Ho Chi Minh City, 70000, Vietnam.
³Faculty of Food and Environmental Engineering, Nguyen Tat Thanh University, Ho Chi Minh City, 70000, Vietnam.
⁴Water and Engineering Management, Asian Institute of Technology, Pathum Thani 12120, Thailand.

*E-mail: thanhtran2710@gmail.com

Abstract. Air pollution in general and motorcycle exhaust, in particular, is a big problem attracting a lot of attention from people and researchers worldwide because of the significant impacts it has on humans and the environment. The issue of air pollution is growing, and the impact is more evident than ever. Carbon dioxide represents a series of problems that we face daily but have not yet been effectively solved. Currently, microalgae are known to photosynthesize and use free CO₂, bicarbonate ions as a source of nutrients to grow. Microalgae are developed under appropriate environmental conditions, which will bring admirable CO₂ treatment efficiency and obtain biomass for other applications. The study approach was an inexpensive and natural air purification solution by microalgae, which is designed as a tubular photobioreactor. The study was conducted by evaluating the ability of Chlorella Vulgaris to grow and absorb CO₂ emissions in the newly established system with exhaust gas supplied from a mini motorcycle engine. The results showed that microalgae grew stably in the tubular photobioreactor system with a biomass concentration of 6×10⁶ cells/ml after 42 days of the experiment. Simultaneously with the stable growth of microalgae, the CO₂ emission concentration was reduced with 26.59% absorption efficiency after 11 days of the experiment. Finally, establishing the tubular photobioreactor technology system has yielded impressive initial results in cultivating stable growing microalgae combined with CO₂ emission treatment.

1. Introduction
Currently, under the continuous development of people, the demand for production and consumption is increasing day by day. Rapid growth but not reasonable control causes a lot of waste to be released into the environment, including the air environment [1]. Referring to the atmosphere environment, the phenomenon of global warming, caused by the increase in the concentration of greenhouse gases in the atmosphere, is of great concern and is receiving more and more attention due to the significant impacts that it causes to humans and animals. CO₂ represents the greenhouse gas that we face every day, but there are not many solutions to it.

CO₂ emissions come from burning fossil fuels, land-use changes, mainly deforestation, and other industrial processes such as oil refineries, cement and lime production, thermal plants, coal power (13–
15% CO₂ by volume) and natural gas power plants (8–10%) [1]. The burning of fossil fuels is the largest source of CO₂ emissions (68%) into the atmosphere causing climate change [2]. Some studies estimated that humans contribute CO₂ to the atmosphere about 9 Gigatons (Gt) per year. About 7.6 Gt of this is from fossil fuels and 1.4 Gt from land-use change. Natural processes absorb up to 55% of this carbon. Up to 4 Gt, the remainder is deposited in the atmosphere each year [3], contributing significantly to global warming and climate change, heavily affecting the environment and resources. According to a 2019 report of the Intergovernmental Panel on Climate Change (IPCC), between 2030 and 2052, the world is likely to warm up to 1.5°C [4] if human emissions continue to increase at a standard rate, this requires a serious effort to develop new technologies to reduce emissions in general and CO₂ in particular. Many studies also show that the increase in CO₂ concentration from human activities in industrialization and transportation is the leading cause of increasing global warming rate and climate change due to these two sectors mostly using fossil fuels [5]. With such a high concentration of developed CO₂ sources, many approaches have been opened to manage the level of CO₂ released into the atmosphere. The first is the result of increased energy conversion efficiency, the second is the use of low-carbon or no-carbon energy sources, and one of the most well-studied approaches is carbon sequestration. with state-of-the-art carbon capture and storage (CCS) technology with up to 90% CO₂ removal rate [6]. However, it is estimated that the cost of implementing CCS technology is quite high and it is only economically feasible in the future when the technology is modernized, which makes CCS deployment at large scale. unlikely in the near future. Therefore, the capture and use of CO₂ emissions as an energy source are important strategies for the sustainable development of many countries around the world.

Microalgae are known photosynthetic organisms, converting CO₂ from the exhaust gas to grow into biomass [7] and indirectly reduce CO₂ emissions. At the same time, with the ability to absorb ammonium, nitrate and phosphate available in many wastewaters [8], microalgae can produce biomass as a promising biofuel like petroleum. Still, when used, it emits less harmful substances such as CO, hydrocarbons and SO₃ [9]. It can be said that bioabsorption of CO₂ by microalgae is considered as a potential strategy to reduce not only CO₂ emissions but also generate lipid-rich microalgae biomass as a renewable energy source [10]. Besides, microalgae technology has a much higher growth rate and yield than pine forests and other aquatic plants [8]. Moreover, not only absorb CO₂, but also many other emissions such as hydrocarbons, VOCs, SOx, and NOx are interested in researchers worldwide.

Photobioreactor technology is a bioreactor system that uses a light source to culture phototrophic microorganisms. In the artificial medium of the photobioreactor system, specific conditions are carefully controlled for the respective species. Thus, the photobioreactor system allows for much higher growth rates and purity levels than anywhere else in nature or similar natural habitats, while increasing system control is always stable. According to many studies, biomass grown in photosystems can be applied in wastewater treatment and CO₂ emissions by considering them a source of nutrients for the environment. A tubular photobioreactor is one of the most common forms of photobioreactor [11]. As a system made of transparent glass or a long plastic such as acrylic, polypropylene or polyvinyl chloride with a small inner diameter to increase light penetration, this form of photoreactivity has achieved great success in producing microalgae. The system has an extensive lighting surface area, so the biomass yield is good. As well as better air residence time so more dissolved, CO₂ can be supplied [12]. Besides, this system is also relatively cheap to build and suitable for outdoor microalgae culture where there is a large surface area of light and thus will produce good biomass yield.

Therefore, based on the superb characteristics of microalgae and tubular photobioreactor technology, this study aims to establish a simple algae culture system to treat CO₂ emissions and the construction cost and low-cost operation. From that, evaluate the potential of a model of using algae to treat emissions from vehicles, especially motorcycles. Thereby, the research will help scientists and managers have a more comprehensive view, make strategic decisions for socio-economic development and especially the environment more effectively in the future.
2. Materials and research methods

2.1. Research Materials

2.1.1. Microalgae research application.

The algae *Chlorella Vulgaris* used in the experiment was provided from the Environmental Technology Laboratory - Institute of Environmental Science - Nguyen Tat Thanh University, Ho Chi Minh City.

*Chlorella Vulgaris* culture medium used is KUN medium with the nutritional ingredients shown in Table 1. After the microalgae are propagated enough, about $10^6$ cells will be included in the model to perform the experiments.

### Table 1. Nutrient composition of KUN medium used in the experiment

| Nutritional ingredients | Unit |
|-------------------------|------|
| **Basic nutrition**     |      |
| KNO₃                    | 101.1g/L |
| NaH₂PO₄                 | 62.1g/L |
| CaCl₂·2H₂O              | 1.47g/L |
| Na₂HPO₄·2H₂O            | 8.9g/L  |
| MgSO₄                   | 24.65g/L |
| FeEDTA                  | 0.695g/L |
| **Micronutrients**      |      |
| H₃BO₃                   | 0.061g/L |
| ZnSO₄·7H₂O              | 0.278g/L |
| (NH₄)₆Mo₇O₂₄·4H₂O       | 0.01235g/L |
| MnCl₂·4H₂O              | 0.169g/L |
| CuSO₄·5H₂O              | 0.024g/L |

2.1.2. Inlet gas source.

The two-stroke 50cc mini motorcycle engine is the source of emissions with the parameters shown in Table 2. The fuel supplied to the engine is a mixture of gasoline and viscous mixture with a ratio of 50:1. Gasoline is RON95 gasoline distilled from fossil fuels rich in carbon and hydrocarbons, so when burned, it produces a lot of CO₂ and CO - gases that are very harmful to the environment. Lubricants are aromatic two-stroke gasoline-mixed oils INDO PETRO SUPER 5000 2T.

### Table 2. Specifications of mini 50 cc motorcycle engine

| No | Parameter            | Unit                  | Note                     |
|----|----------------------|-----------------------|--------------------------|
| 1  | Size                 | 25 × 22 × 14 cm       | length × width × height  |
| 2  | Weight               | 3.2 kg                |                          |
| 3  | Vehicle capacity     | 1.3 Horse power; 1000 W |                        |
| 4  | Number of rounds     | 0 - 10000             | Adjust via throttle      |
| 5  | Loads                | 250 kg                |                          |
| 6  | Burning material     | Gasoline mixed with viscous |                |
| 7  | Velocity             | 45-50 km/h            |                          |

The characteristics of the exhaust gas composition of the mini engine after the combustion process are described in Table 3. The entire input exhaust gas source will be directed to the source box to stabilize and use aeration for algae culture experiments. Attention should be paid to the CO₂ composition in the exhaust gas with a concentration of about 1700 - 1900 ppm.
Table 3. Characteristic of input exhaust gas composition

| No | Criteria       | Unit | Value  | Analytical Equipment       | Note                                      |
|----|----------------|------|--------|----------------------------|------------------------------------------|
| 1  | CO₂            | ppm  | 1700-1900 | IMR - EX610-CO2             | Sensor connected to the computer         |
| 2  | Temperature    | °C   | 33     | DM502-03                   |                                          |
| 3  | Humidity       | %    | 98     | EXTECH VFM200              |                                          |
| 4  | TVOC           | mg/m³| 1,888  |                            |                                          |
| 5  | HCHO           | mg/m³| 0,205  |                            |                                          |
| 6  | PM 2.5         | µg/m³| >999   | DM502-03                   | Reach maximum equipment value            |
| 7  | PM 10          | µg/m³| >999   |                            | Reach maximum equipment value            |

With the scale of the tubular photobioreactor model implemented in the laboratory, experiments were conducted to aerate exhaust gases from the engine with 30 minutes/day and a flow rate of 5 L/min, with three repetitions.

2.2. *Tubular photobioreactor equipment models and evaluation of CO₂ removal efficiency*

The experimental model is designed with a volume of 30 litres (see Figure 1 with the structure of 10 transparent mica plastic tubes (1) with dimensions of 60×2×500 mm divided into five floors. Each floor has two parallel pipes. There are two mica pipes 60×2×1000 mm (2), one recirculating mica tube 60×2×1000 mm (3), the inlet is also the air outlet (4), the recirculation valve (5), the gas flowmeter (6), aerator (7), pipe joints, 800×1000 mm box-shaped iron frame for easy transport of the model. Exhaust gas is supplied from the source box (8) through the aerator (7). It is regulated gas flow by a gas flowmeter (6); algae were harvested and tested at the sampling and harvesting gate (10).

Exhaust gas supplied from the mini engine through the power box to stabilize the concentration and lower the temperature will then be directed into the model from the top by an aerator. Due to the pressure, the incoming exhaust gas will create a central gas column equal to the height of the tube (1000 mm). From here, the gas follows the model pipe and exits (red gas stream). Under the push from the gas, the algae-containing water environment also moves along (the blue liquid is shown). When it is close to the air outlet, the water will recirculate and start again until the gas supply stops. When performing exhaust gas aeration, also open two light bulbs to provide light energy for microalgae.

The tubular photobioreactor model includes an 800×400×1000mm box-shaped frame to accommodate the piping system and is fitted with wheels for easy transport. The plumbing system is made of transparent mica plastic pipes with a diameter of 60mm, especially the pipes and valves are made of plastic with a total pipe length of 12.5m, and a design volume of 30L in which the adequate volume is used is 26L.
Figure 1. Structure of tubular photobioreactor system for microalgae culture

The Algae culture system is adjusted base on relevant environmental factors for the growth of *Chlorella Vulgaris* algae. The light is provided with LED bulbs; the light intensity is about 4590 lux with a 24:0 light-dark cycle. The culture environment temperature is 26°C, and pH=6.8 - 7.2. Continuous air supply with an airflow velocity of 0.0295 m/s and flow rate of 0.083 L/s

Because the model has a retention time, it is necessary to withdraw the algae biomass daily and add new nutrient water. The extracted algae solution will conduct concentration analysis using two red blood cell counting and photometric measurements. Two experiments evaluate microalgae growth under Kun media with natural gas conditions and exhaust gas from mini engines. Besides assessing the development of microalgae daily, we also assess CO₂ absorption efficiency by using sensors that continuously measure system input and output emissions with 30 minutes/day and a frequency of 10 seconds for each measurement (total 180 emissions data). The study can compare and analyze the concentration of the input and output exhaust gases of the model.

3. Results and discussion
3.1. Evaluation of growth and adaptability of *Chlorella Vulgaris* in tubular photobioreactor system
3.1.1. Adaptation process in normal conditions
The growth of the microbial population was studied by analyzing the growth curve in microbial culture by the method of culture in a closed system. The results in Figure 2 show that the microalgae grow quite stably from the first day to the 20th day in the system and reach a concentration of 3×10⁶ cells/ml on the 20th day. Algae mass into the system, the concentration of algae biomass increased quite slowly from 450,000 cells/ml to 1.4×10⁶ cells/ml after ten days of adaptation. The reason is that at this stage, the algae have not yet adapted well to the new environment, so the biomass concentration usually increases quite slowly. From the 10th to the 20th day, enter the log phase or the exponential phase. During this period, algae have adapted and started to grow, dividing cells at a fast rate from 1.4×10⁶ to 3×10⁶ cells/ml, increasing by 1.6×10⁶ cells/ml in 10 days. The average growth rate daily is 160,000 cells/ml, there is not much change during this period, and the cells divide steadily. From day 20-25, during this period, the algal mass continues to increase rapidly, possibly due to the continuous supply and supply of nutrients. After 26 days of culture, the concentration of algae biomass reached 4.5×10⁶ cells/ml.
3.1.2. The adaptation and development of biomass in the exhaust gas supply environment

After growing at Kun media for 26 days, the microalgae was well adapted and developed in the system reaching 4.5×10^6 cells/ml. The following experiment aims to evaluate the growth of microalgae with exhaust gas from the mini engine at 30 minutes/day.

Figure 3 shows that the growth of microalgae in the system when the exhaust gas from the mini engine is aerated is stable. When the concentration of algae biomass reached 4.5×10^6 cells/ml in KUN medium, it then continued to grow and reached 5×10^6 cells/ml. After the next 11 days, the algal concentration reached 6×10^6 cells/ml. The average growth rate is about 100,000 cells/ml.day. During this period, the concentration of algae biomass increased but not significantly, possibly because the number of new cells was relatively balanced with the number of cells that died. The cells may be stopped dividing and still kept metabolically active ingredients. It can be seen that in the new environmental condition of exhaust gas from mini-engines, microalgae can also grow stably in the tubular photobioreactor system and tend to increase. The data proves that this strain of *Chlorella Vulgaris* can ultimately live in a mini-engine (motorcycle) exhaust gas environment. Components in the exhaust gas such as CO₂, HCHO, VOCs have been used by microalgae as an additional source of nutrients, helping microalgae to grow, create biomass.

Figure 3. Biomass growth of *Chlorella Vulgaris* in tubular photobioreactor systems with input exhaust gas

Figure 2. Algae biomass under culture conditions in a tubular photobioreactor with KUN medium
3.2. Evaluation of the CO2 removal efficiency of the tubular photobioreactor system

The results in Figure 4 show that the ability of *Chlorella Vulgaris* to absorb CO2 after 11 days is quite good. The CO2 inlet concentration was reduced on the first day of testing (1391 ppm output vs 1796 ppm input) with an efficiency of 22.55%. Microalgae are now in the process of adapting to new conditions. The average performance reached 23.72% in the first five days, 6.32% lower than the following five days (30.04%). It can be explained because the algae begin to adapt and use the carbon source for cell synthesis, and it can be seen that the concentration of algae biomass also increases. During the 11-day experimental period, the average treatment efficiency was 26.59%, and the highest was 35.90% (average input was 1800 ppm and average output was 1325 ppm after exhaust gas pass through the system).

It can be seen with the decrease in CO2 concentration after passing through the system and the increased concentration of algae biomass during the experiment. The result proved that the microalgae used CO2 in the exhaust gas as a source of nutrients to grow. Compared with previous studies, the CO2 removal efficiency was 15 to 25%, and the CO2 fixation rate was 20 to 35 g/L.day. This treatment efficiency is highly dependent on the type of flue gas and algae strain used. The optimum efficiency of CO2 removal from coke oven, hot furnace and power plant exhaust gas by *Chlorella* sp were 25%, 40% and 50%, respectively [13]. The study of Vunjac-Novakovic used *Dunaliella* algae to absorb emissions from the power plant with a measured CO2 removal efficiency (82.3±12.5% on sunny days and 50.1±6.5% on cloudy days) [14]. In the pure CO2 conditions, the maximum biomass of *Chlorella Vulgaris* can reach 26.95×10^6 cells/ml, and the maximum CO2 removal efficiency by Airlift photobioreactor technology [15] and conventional photobioreactor [16] reaches 94% and 74%, respectively. Thus, the efficiency of CO2 removal in mini engine exhaust reaches 26.59% after 11 days is not good. However, the expansion potential for the system is still wide open. The reason why the treatment efficiency is still low compared to previous studies can be explained by the influence of other gaseous components in motorcycle engine exhaust such as dust, HCHO, and VOCs on microalgae growth. In addition, the operating parameters of the culture system, such as aeration rate, pH, light, and temperature, have not been adjusted to the optimal level. Since then, *Chlorella Vulgaris* has not been well adapted. In addition, the experimental time is still limited, so the concentration of algae inside the system is not optimal, leading to low CO2 removal efficiency.

4. Conclusion

The design model in the form of tubular photobioreactor combined with microalgae development to treat exhaust gas has shown the ability to provide a stable growth environment for the microalgae
Chlorella Vulgaris at the same time significantly reduce the pollution of the input exhaust gas. The form of a tubular photobioreactor has increased the ability of microalgae to absorb nutrients as well as convert light energy so that the microalgae grow stably to reach a biomass concentration of $4.5 \times 10^6$ cells/ml after the first 26 days of the experiment and continue to grow up to $6 \times 10^6$ cells/ml for the next 14 days. The efficiency of CO$_2$ absorption of microalgae reached 26.59% after 11 days of testing with exhaust gas. Finally, establishing a tubular photobioreactor system has yielded impressive initial results with the success of growing stable microalgae in combination with CO$_2$ emission treatment. Although the research needs to go through more stages and testing for different types of emissions, the benefits to the environment and people are very promising.

References
[1] A. Rinanti 2016 *Algae - Org. Imminent Biotechnol*
[2] Bhola V, Swalaha F, Kumar R R, Singh M and Bux F 2014 *Int. J. Environ. Sci. Technol.* 11 2103–2118
[3] Lal R 2008 *Energy Environ. Sci.* 1 86–100
[4] IPCC 2019 *One Earth* 1 (3) 374–381
[5] Arnup K 1992 *Can. Bull. Med. Hist.*, 9 159–176
[6] Herzog H 2009 *A Research Program for Promising Retrofit Technologies*
[7] Liu Z Y, Wang G C and Zhou B C 2008 *Bioresour. Technol.* 99 4717–4722.
[8] Lage S, Gojkovic Z, Funk C and Gentili F G 2018 *Energies* 11 1–30
[9] Delucchi and Emissions A L 2003 *Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels and Materials*
A Davis
[10] Ho S H, Chen C Y, Lee D J and Chang J S 2011 *Biotecnol. Adv.* 29 189–198
[11] Travieso L, Hall D O, Rao K K, F. Benitez, E. Sánchez, and R. Borja 2001 *Int. Biodeterior. Biodegrad* 47 151–155
[12] Xing Z 2015 *Microalgae removal of CO2 from flue gas* (UK: IEA Clean Coal Centre) doi: 10.13140/RG.2.2.26617.77929.
[13] Chien-Ya Kao et al. 2014 *Bioresour. Technol.* 166 485–493
[14] Vunjak-Novakovic G, Kim Y, Wu X, Berzin I and Merchuk J C 2005 *Ind. Eng. Chem. Res.* 44 6154–6163
[15] Negar A, Sadeghizadeh A and R. Rahimi 2020 *J. Environ. Chem. Eng.* 8 104022
[16] Keffer J E and Kleinheinz G T 2020 *J. Ind. Microbiol. Biotechnol* 29 275–280

Acknowledgements
Ms Vo Thi Dieu Hien is supported by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 04/2020/STS01. We also would like thank to Nguyen Tat Thanh University to support time and facilities for this study.