ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/355161013

Utilisation of exhaust gas from a CI engine for improving microalgae growth

Article *in* Maejo International Journal of Energy and Environmental Communication · January 2019

DOI: 10.54279/mijeec.v1i1.244894

CITATIONS
8

READS
59

5 authors, including:


Bunushree Behera
Thapar Institute of Engineering and Technology
33 PUBLICATIONS **778** CITATIONS

SEE PROFILE


Sabareesh Murugan
KU Leuven
16 PUBLICATIONS **115** CITATIONS

SEE PROFILE

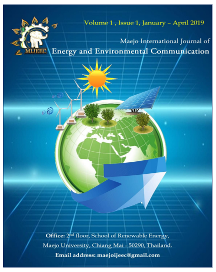

Balasubramanian Paramasivan
National Institute of Technology Rourkela
151 PUBLICATIONS **3,520** CITATIONS

SEE PROFILE

All content following this page was uploaded by Balasubramanian Paramasivan on 29 November 2022.

The user has requested enhancement of the downloaded file.

Maejo International Journal of
Energy and Environmental Communication



ARTICLE

Utilisation of exhaust gas from a CI engine for improving microalgae growth

Bunushree Behera[1], Nirmal Mallick[2], Garima Bal[2], Murugan S[2], Balasubramanian P[1,*]

[1] Agricultural and Environmental Biotechnology Group, Department of Biotechnology and Medical Engineering, NIT Rourkela, 769008, India.
[2] Internal Combustion Engine Laboratory, Department of Mechanical Engineering, NIT Rourkela, 769008, India.

*Corresponding author, *E-mail address*: biobala@nitrkl.ac.in

ARTICLE INFOR

Received 02nd November 2018

Accepted 05th January 2019

Keywords:
Diesel engine
Injection pressure
Injection timing
Heat Exchanger
Algae

ABSTRACT

Increased global warming due to the vehicular and industrial emissions has led to the development novel carbon sequestration technologies. In this investigation, exhaust gas from an internal combustion (IC) engine was used to grow microalgae. For this purpose, a twin cylinder, four stroke, water cooled direct injection (DI) developing power of 7.36 kW at a constant speed of 1500 rpm was used. The test engine was fuelled with diesel and operated at four different injection pressures, and subsequently with five different injection timings. The optimum injection pressure and injection timings were determined based on the results obtained from the performance and emission parameters of the test engine, resulting maximum carbon dioxide (CO_2) exhaust of 3% v/v. A shell and tube heat exchanger was developed and designed to cool the exhaust gas of the engine. Then, the cooled exhaust gas was supplied to an algae reactor for growing microalgae. The algae growth before and after CO_2 supply was determined and the results indicated higher growth rate in the algal media supplemented with CO_2 compared to the control without CO_2 addition. Such studies would aid in reducing the cost of algal cultivation and would further mitigate the greenhouse gas emissions (GHG).

1. Introduction

Microalgae are recognized as one of the promising sources of bioenergy with the advantages of being capable of growing on non-arable lands and waste resources. Another attractive advantage of microalgae involves the capacity to sequester large amount of CO_2 from the atmosphere. The carbon fixed into biomass can be processed as biofuel/biodiesel (Behera et al., 2018).

The mode of nutrition utilized by microalgae can be either autotrophic, heterotrophic and mixotrophic mode depending on the source of nutrients (Rangabhashiyam et al., 2017; Behera et al., 2019a). Heterotrophic mode is a promising way of growth where the microalgae utilize the externally supplied CO_2 as the major source of nutrients; accumulating more carbon into the biomass resulting in a higher productivity. Many researchers have carried out research works utilizing the waste resources as a source of carbon to cultivate microalgae under heterotrophic mode (Lizzul et al., 2014; Cuellar-Bermudez et al., 2015). The conversion of CO_2 into the lipid, carbohydrates, proteins and other metabolites is regarded as one of the most favourable methods for CO_2 fixation from the exhaust gases of different power plants.

Several microalgae species like *Chlorella* sp., *Scenedesmus* sp., *Nannochloropsis* sp. and *Botryococcus* sp. represent significant capacity to trap the flue gases. The growth of microalgae in the presence of CO_2 from the flue gas is comparable to that of the growth rate of microalgae cultured in the presence of an external carbon source (Jacob et al., 2015; daSilva et al., 2016). Jhiang et al. (2013) reported that *S. dimorphus* is capable of tolerating very high concentration of CO_2 ranging from 2-20%, along with SO (100-200 ppm) and NO (150-500 ppm). Numerous studies suggest the purging of flue gases into an algae reactor can improve the overall yield, oil productivity and CO_2 sequestration (Cheah et al., 2015; Aly and Balasubramanian, 2016; 2017; Ou-Yang et al., 2018; Behera et al., 2019b,c).

Malek et al. (2015) studied the modelling and optimization of CO_2 supply and waste heat recovery integrated with the open pond photobioreactors, and projected that the process economics of the entire cultivation can be reduced significantly by employing waste CO_2 exhaust injection scenarios compared to the pure CO_2 injection modes. It is reported that, the low level of SO and NO, do not inhibit the microalgae growth rate and most species are well tolerant towards substantial level of SO and NO (Chiu et al., 2011; Kao et al., 2014). Further, maintaining an optimal pH can further negate the effects of acidic oxides. Crude utilisation requires injection of the exhaust gases involves cooling it down below its dew point (137 ^{0}F) using corrosion resistant heat exchanger as the gases like CO_2, NO and SO may combine with water making the media acidic. Chiu et al., (2011) reported that, the CO_2 uptake and utilization rate by microalgae depends on several environmental factors like pH, temperature, presence of heavy metals in addition to the microalgae species under study. De Godos et al. (2014) have stated that the maintenance of optimum pH and the flow rate of exhaust gas influence the maximal biomass yield.

Even though the studies by Chiu et al. (2011); De Godos et al. (2014) and Aslam et al. (2017) have reported the growth of microalgae using industrial flue gases and boilers, none of the study have reported the growth of microalgae using the exhaust gas of an IC engine, which could reduce the atmospheric pollution and global warming via CO_2 bio-mitigation.

Thus, the main objectives of this investigation are to (i) determine the maximum CO_2 emitted from a twin cylinder diesel engine operated with different injection pressure and injection timing, and (ii) study the algal growth when CO_2 is injected from engine exhaust operated with a maximum CO_2 condition.

2. Methodology

In this study, a twin cylinder, 4 stroke, water cooled direct fuel injection engine was used for providing CO_2 for algae growth. The specifications of the test engine are given in Table 1. The schematic layout of the test engine used in this study is shown in Figure 1. The engine was fuelled with diesel and run at different load conditions when it was subjected to different injection pressures and subsequently at different injection timings.

Nomenclature and Abbreviation

BSFC	Brake specific fuel consumption
BP	Brake power
IC	Internal combustion
DI	Direct injection
B_{TH}	Brake thermal efficiency

The optimum injection pressure and timing were determined based on the engine performance and emission parameters. Then, the exhaust gas was cooled in a shell and tube heat exchanger to study the growth of algae in the reactor. For applying engine load, an eddy current dynamometer was coupled to the test engine. The cooling method employed was water jacketed cooling in which the cooling water was allowed to flow through the jacket provided around the engine cylinder.

The engine was equipped with individual pump and nozzle system, with separated pumps. An AVL 444 five gas analyzer system was used to measure the HC, CO, CO_2, NO and O_2 from the engine exhaust. Since this study was focused on utilizing the CO_2 for growing algae, only the values of CO_2 and NO were measured at different operating conditions. An algae tank (tubular photobioreactor) made up of acrylic was connected to the engine exhaust with a suitable hose pipe. The tank diameter and height were 150 mm and 630 mm respectively. The total volume and the working volume of the tank were 10 L and 6.5 L respectively.

The exhaust gas after utilization in the reactor was released to the atmosphere. The algal reactor contained a native mixed culture of microalgae isolated from a small water pond called the Naga pond of NIT Rourkela. It was grown in the control media having urea (1 g L^{-1}) without CO_2 and the test media with urea (0.1g L^{-1}) supplemented with the engine exhaust having the maximum CO_2, when the engine was operated at the optimum injection pressure and timing.

The growth rate in terms of biomass content and the cell count were assessed. The pH profile of the media was also evaluated over a time period 14 days. The results obtained were compared with that of the control media (without exhaust gas addition).

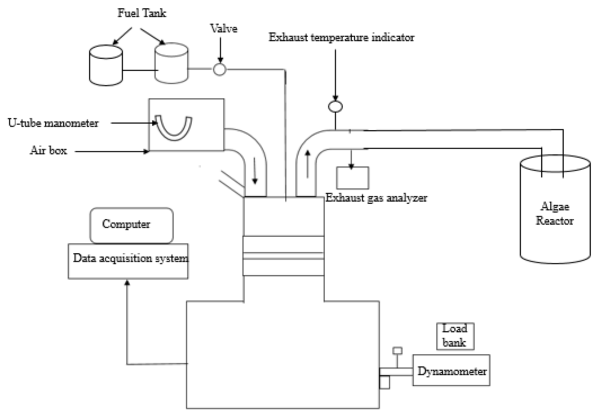


Figure 1. Schematic layout of the test engine

Table 1. Specification of the IC engine used for study

No. of cylinders	Vertical twin cylinder
Starting type	Hand start
Bore *stroke (in mm)	87.5*110
Compression ratio	17.5:1
Cooling	Water cooled
Dynamometer	Eddy current dynamometer
Power	10 hp
N	1500 rpm
Fly wheel radius	175mm
Type of fuel injection	Direct injection

3. Methodology

3.1 Experimental

3.1.1 Brake specific fuel combustion

Figure 2 depicts the variation of brake specific fuel consumption (BSFC) with the brake power (BP) when the engine was operated at different injection pressures. It can be observed from the figure that the BSFC increases with the increase in brake power. This may be due to the amount of fuel consumed to produce the same power in the entire load spectrum. The BSFC decreases with the increase in injection pressure to 215 bar.

Increasing the fuel injection pressure increases the penetration length and spray cone angle increases, so that at optimum pressure, fuel air mixing and spray atomization will be improved.

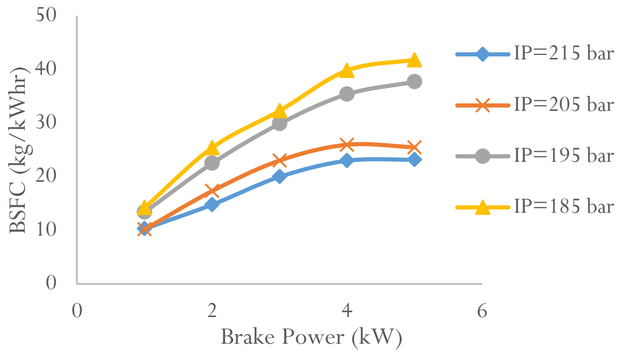


Figure 2. Variation of brake specific fuel consumption with brake power at different injection pressure

3.1.2 Brake thermal efficiency

Figure 3 shows the variation of brake thermal efficiency (B_{TH}) with brake power (BP) when the engine was operated with diesel at different injection pressures. B_{TH} increases with the increase in BP due to the reduced heat loss with the increase in power and the increase in load. In the entire engine operation, the efficiency is low at lower injection pressure which is due to poor atomization and mixture formation. With the increase in injection pressure, the B_{TH} increases in the entire load spectrum. This may be due to the reduction in the viscosity, improved atomization and better combustion. The maximum efficiency for all fuels tested is obtained at 215 bar injection pressure which is due to fine spray formed during injection and improved atomization, which reduces the physical delay period resulting in better combustion of fuel air mixture.

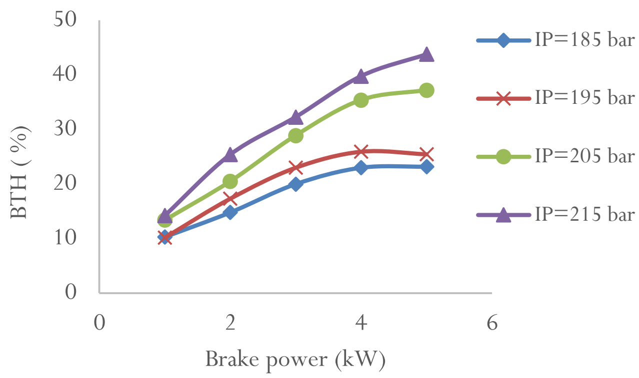


Figure 3. Variation of brake thermal efficiency with brake power at different injection pressure

3.1.3 Nitric oxide (NO) emission

Figure 4 depicts the variation of nitric oxide emission with BP, when engine was operated at different injection pressures. NO emission is resulted from the oxidation of atmospheric nitrogen at high temperature inside the combustion chamber of an engine. NO emission increases with the increase in BP, for the entire load spectrum. With the increase in load, the temperature of combustion chamber increases, and since the NO formation is strongly temperature dependent, the emissions are found to gradually increase.

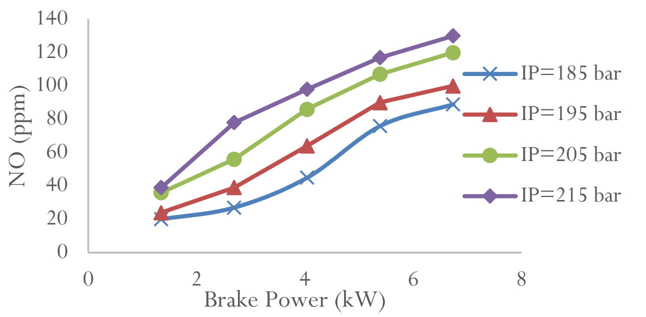


Figure 4. Variation of NO emission with brake power at different injection pressure

3.1.4 Carbon dioxide (CO_2) emission

Figure 5 depicts the CO_2 emission with the variation in BP when the engine is operated at different injection pressures. CO_2 and H_2O are the products of combustion that will appear in the exhaust under an ideal combustion process. The emission of CO_2 is therefore, a measure of combustion efficiency of the system. It is desirable to have high CO_2 and less HC emissions under any operating condition. It is found that with the increase in injection pressure, there is an increase in CO_2 emission, over the entire load spectrum which may be attributed to efficient mixing of air fuel mixture and good diffusion flame combustion.

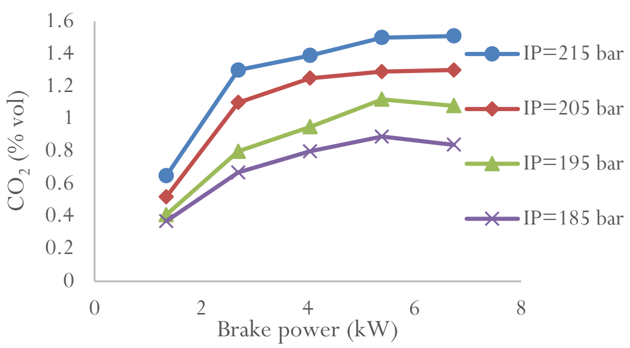


Figure 5. Variation of CO_2 emission with brake power at different injection pressure

3.2 Injection timing

3.2.1 Brake thermal efficiency

Figure 6 depicts the variation of B_{TH} with BP when the engine was operated at different injection timings. Advanced injection timing leads to better mixing, which results in better combustion leading to maximum B_{TH} at that timing, in the entire load spectrum. However, for the diesel operation the rated injection timing is in the optimum value. The advancement or retardation from the optimum value of injection timing resulted in early combustion during advanced injection timing and late combustion during retarded injection timing thus affecting the brake thermal efficiency.

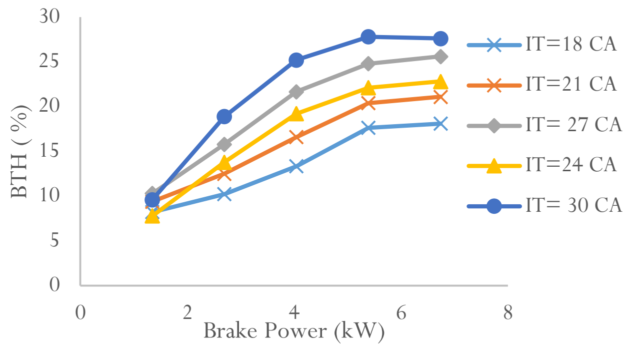


Figure 6. Variation of brake thermal efficiency with brake power at different injection timing

3.2.2 Brake specific fuel consumption

Figure 7 shows the variation in BSFC with the BP when the engine is working at different injection timings. It is apparent from the figure that, as the injection timing is advanced, there is a decrease in BSFC whereas with the decrease in injection timing there is an increase in BSFC.

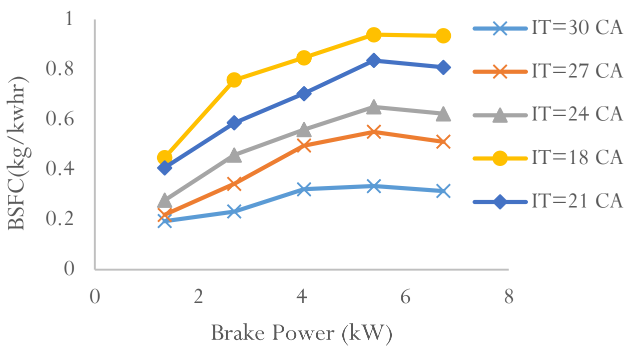


Figure 7. Variation of brake specific fuel consumption with brake power at different injection timing

This may be due to the fact that, at advanced injection timing fuel air mixing is improved due to longer ignition delay resulting in an efficient combustion. By retarding the injection

This journal is © School of Renewable Energy, Maejo University 2019

timing the efficiency of the engine decreases because the maximum pressure obtained in the cylinder is shifted away.

3.2.3 Nitric oxide (NO) emission

Figure 8 shows the variation of NO emission with the BP when the engine was operated at different injection timings. It can be observed that with the advancing injection timing there is a gradual increase in NO emission in the entire engine operation. At advanced injection timing, there is an efficient combustion of fuel so there is a rise in temperature of the combustion chamber.

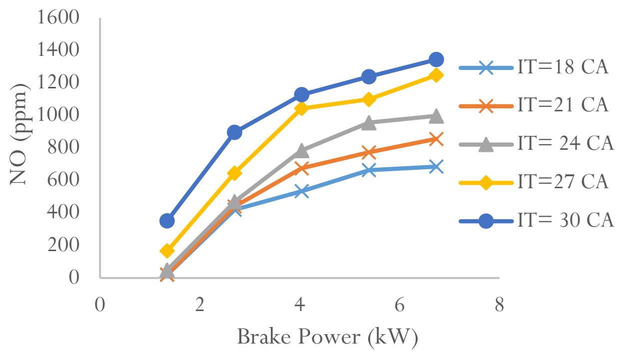


Figure 8. Variation of NO emission with brake power at different injection timing

Since the NO formation depends upon cylinder temperature and oxygen available for combustion, there is a rise in NO emission. Similarly, at retarded injection timing there is inefficient burning due to shifting of fuel injected resulting in less combustion chamber temperature; hence there less NO emissions.

3.2.4 Carbon dioxide (CO_2) emission

Figure 9 depicts the variation in the CO_2 emissions with BP, when the engine is operated at different injection timings. Increase in injection timing results in a lower CO_2 emission over the entire load spectrum. The highest CO_2 concentration in the exhaust is recorded at retarded injection timings. Standard injection timing at both speeds offered a net reduction in CO_2 emission compared to the results obtained when running on diesel fuel.

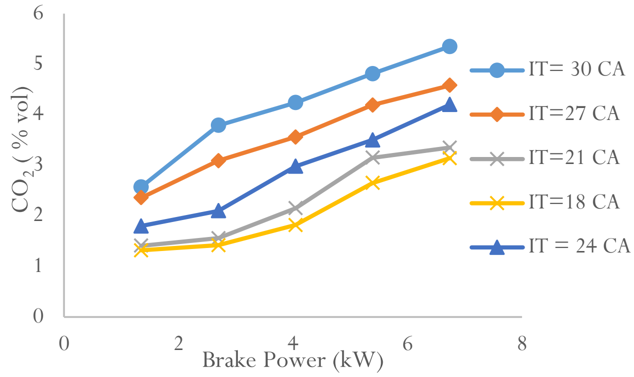


Figure 9. Variation of carbon dioxide emission with brake power at different injection timing

3.3 Algae growth

The profile of microalgal growth in terms of the biomass content and cell count, with respect to time are plotted in Figure 10. The growth rate of microalgae increases with the supplementation of media with the exhaust emission. The biomass productivity of microalgae with CO_2 from engine exhaust was found to be about 0.075 g L^{-1} d^{-1} whereas the biomass productivity in the control was 0.036 g L^{-1} d^{-1}. The specific growth rate in the case of the media supplemented with CO_2 is found to be 0.19 d^{-1} compared to 0.13 d^{-1} in case of the control.

The biomass content and the microalgal cell count are found to be almost doubled in the case of the media supplied with CO_2, as evident from the gap in the profile for both the conditions. This implies that the microalgae adapted and grew well utilizing the CO_2 from the engine exhaust; thus facilitating carbon capture and conversion into biomass. The higher microalgal biomass content and cell count obtained might be attributed to the presence of NO which serves as the additional source of nitrogen. Researchers like Chiu et al. (2011) and Aslam et al. (2017) have reported the increase in the growth rate of microalgae as well as the biomass productivity with the use of flue gas from the industries.

This journal is © School of Renewable Energy, Maejo University 2019

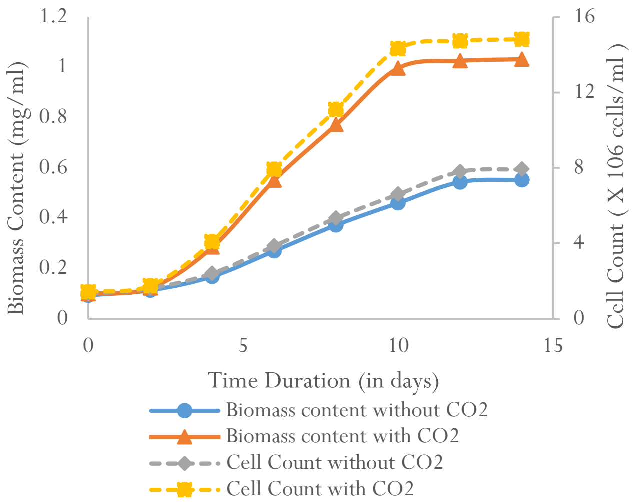


Figure 10. Variation of microalgal biomass content (on dry wt. basis) and cell count over time with and without CO_2 from engine exhaust

Figure 11 shows the pH profile of microalgae over a time period of 14 days in the media with CO_2 and without CO_2. It is apparent that, when the CO_2 is purged from the engine exhaust into the reactor, immediately after aeration for a period of 30 mins, the pH declines to 5.5-6 due to the dissolution of CO_2 and NO. However, with the increase in utilization of dissolved CO_2, and gradual increase in microalgal biomass concentration, the pH of the media increases significantly compared to the control, as evident from the gap in Figure 11. Maintaining an optimum pH can help to achieve the desired yield (Malek et al., 2015). The pH of the media remains at 7.5-8.5 thus providing optimal algal growth on supplementation with engine exhaust.

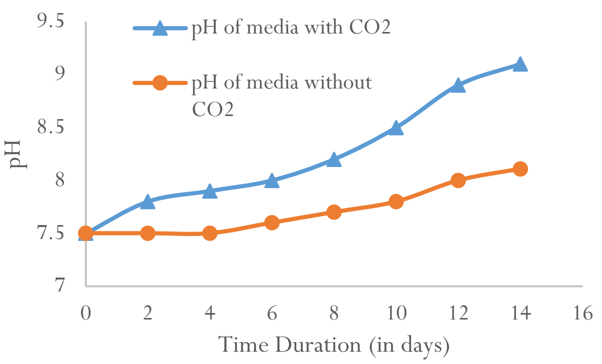


Figure 11. pH profile of microalgae aerated with the CO_2 from exhaust gas and under control condition (without CO_2)

4. Conclusion

A twin cylinder, four stroke, water cooled diesel engine developing a power of 7.36 kW at a constant speed of 1500 rpm was used in this investigation to study the effect of CO_2 obtained from the engine exhaust on the microalgal growth rate. Optimum injection pressure and injection timing were found to be 205 bar and 18 °CA respectively, which produced the maximum CO_2 emission of 3% v/v. The microalgae grew successfully with the engine exhaust emission resulting in the biomass productivity of 0.075 g L^{-1} d^{-1}. The amount of microalgal biomass accumulated as well as the cell count also increased with the addition of CO_2. The growth rate of microalgae with exhaust emissions was 31.5% higher compared to the media without emissions thus proving that the NO and other gases did not have any inhibitory effect over rather acted as a complementary nutrient source enhancing the biomass content and the cell count. The innovation of integrating microalgae based CO_2 capture for growing algae using the engine exhaust is required to bring significant advancement in CO_2 bio-mitigation aiming towards minimizing the greenhouse effects providing global warming solution.

Acknowledgements

PB and SM has initiated the concept of the project. Experiments and acquisition of data was carried out by BB, NM, GB. BB and PB have done the data analysis and interpretation. BB have drafted the manuscript. PB and SM has reviewed and finalized the manuscript. All authors are thankful to the Department of Mechanical Engineering and the Department of Biotechnology and Medical Engineering of National Institute of Technology Rourkela, Odisha, India for providing the necessary research facilities. The authors are also thankful to Ministry of Human Resources and Development of Government (MHRD) of India (GoI) for sponsoring the first author's doctoral programme.

References

Aly, N., Balasubramanian, P., 2015. Effect of photoinhibition on microalgal growth in open ponds of NIT Rourkela, India. Journal of Biochemical Technology 6, 1034-1039.

Aly, N., Balasubramanian, P., 2017. Effect of geographical coordinates on carbon dioxide sequestration potential by microalgae. International Journal of Environmental Science and Development 8, 147-152.

Behera, B., Aly, N., Balasubramanian, P., 2018. Biophysical modeling of microalgal cultivation in open ponds. Ecological Modeling 388, 61-71.

Behera, B., Acharya, A., Gargey, I.A., Aly, N., Balasubramanian, P., 2019. Bioprocess engineering principles of microalgal cultivation for sustainable biofuel production. Bioresource Technology Reports 5, 297-316.

Aslam, A., Thomas-Hall, S.R., Mughal, T.A., Schenk, P.M., 2017. Selection and adaptation of microalgae to growth in 100% unfiltered coal-fired flue gas. Bioresource Technology 233, 271-283.

Cheah, W.Y., Show, P.L., Chang, J.S., Ling, T.C., Juan, J.C., 2015. Biosequestration of atmospheric CO_2 and flue gas-containing CO_2 by microalgae. Bioresource Technology 184, 190-201.

Chiu, S.Y., Kao, C.Y., Huang, T.T., Lin, C.J., Ong, S.C., Chen, C.D., Chang J.S., Lin, C.S., 2011. Microalgal biomass production and on-site bioremediation of carbon dioxide, nitrogen oxide and sulfur dioxide from flue gas using *Chlorella sp*. cultures. Bioresource. Technology 102, 9135-9142.

Cuellar-Bermudez, S.P., Garcia-Perez, J.S., Rittmann, B.E., Parra-Saldivar, R., 2015. Photosynthetic bioenergy utilizing CO_2: an approach on flue gases utilization for third generation biofuels. Journal of Cleaner Production 98, 53-65.

Da Silva Vaz, B., Costa, J.A.V., de Morais, M.G., 2016. CO_2 Biofixation by the *Cyanobacterium Spirulina sp.* LEB 18 and the green alga *Chlorella fusca* LEB 111 grown using gas effluents and solid residues of thermoelectric origin. Applied Biochemistry and Biotechnology 178, 418-429.

De Godos, I., Mendoza, J.L., Acién, F.G., Molina, E., Banks, C.J., Heaven, S., Rogalla, F., 2014. Evaluation of carbon dioxide mass transfer in raceway reactors for microalgae culture using flue gases. Bioresource Technology 153, 307-314.

Jacob, A., Xia, A., Murphy, J.D., 2015. A perspective on gaseous biofuel production from micro-algae generated from CO_2 from a coal-fired power plant. Applied Energy 148, 396-402.

Jiang, Y., Zhang, W., Wang, J., Chen, Y., Shen, S., Liu, T., 2013. Utilization of simulated flue gas for cultivation of *Scenedesmus dimorphus*. Bioresource Technology 128, 359-364.

Kao, C.Y., Chen, T.Y., Chang, Y.B., Chiu, T.W., Lin, H.Y., Chen, C. D., Lin, C. S., 2014. Utilization of carbon dioxide in industrial flue gases for the cultivation of microalga *Chlorella sp.* Bioresource Technology 166, 485-493.

Lizzul, A.M., Hellier, P., Purton, S., Baganz, F., Ladommatos, N., Campos, L., 2014. Combined remediation and lipid production using *Chlorella sorokiniana* grown on wastewater and exhaust gases. Bioresource Technology 151, 12-18.

Malek, A., Zullo, L.C., Daoutidis, P., 2015. Modeling and dynamic optimization of microalgae cultivation in outdoor open ponds. Industrial & Engineering Chemistry Research 15, 3327-3337.

Ou-Yang, C., Chen, H.W., Ho, C.H., Chou, J.C., Yuan, Y.T., Ho, C.L., Chao, L.K., 2018. Value chain analysis of algal bioenergy and carbon capture integrated with a biotechnology innovation. Journal of Cleaner Production 180, 349-359.

Ramaraj, R., Tsai, D.D-W., Chen, P.H., 2015. Carbon dioxide fixation of freshwater microalgae growth on natural water medium. Ecological Engineering 75, 86-92.

Rangabhashiyam, S., Behera, B., Aly, N., Balasubramanian, P., 2017. Biodiesel from microalgae as a promising strategy for renewable bioenergy production - A review. Journal of Environmental Biotechnology Research 6, 260-269.

Tsai, D.D-W., Ramaraj, R., Chen, P.H., 2016. Carbon dioxide bio-fixation by algae of high rate pond on natural water medium. Ecological Engineering 92, 106-110.

Tsai, D.D-W., Ramaraj, R., Chen, P.H., 2017. The potential of carbon dioxide capture and sequestration with algae. Ecological Engineering 98,17-23.

Unpaprom, Y., Ramaraj, R., Whangchai, K., 2017. A newly isolated green alga, *Scenedesmus acuminatus*, from Thailand with efficient hydrogen production. Chiang Mai Journal of Science 44, 1270-1278.

This journal is © School of Renewable Energy, Maejo University 2019

View publication stats