American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-03, pp-330-338
www.ajer.org

Research Paper Open Access

Microalgae: An Alternative Source of Renewable Energy

A. Z. A. Saifullah, Md. Abdul Karim, Aznijar Ahmad-Yazid

Department of Mechanical Engineering, IUBAT – International University of Business Agriculture and Technology, Dhaka 1230, Bangladesh
Department of Mechanical Engineering, IUBAT – International University of Business Agriculture and Technology, Dhaka 1230, Bangladesh
Department of Engineering Design and Manufacture, University of Malaya 50603 Kuala Lumpur, Malaysia

Abstract:- This paper presents an overview on the potentiality of microalgae with particular emphasis as a sustainable renewable energy source for biodiesel. One of the most important dilemmas of the modern world is to supply maximal amount of energy with minimal environmental impact. The total energy demand of our planet is increasing with population growth whereas the fossil fuel reserves are dwindling swiftly. Biodiesel produced from biomass is widely considered to be one of the most sustainable alternatives to fossil fuels and a viable means for energy security and environmental and economic sustainability. But as a large area of arable land is required to cultivate biodiesel producing terrestrial plants, it may lead towards food scarcity and deforestation. Microalgae have a number of characteristics that allow the production concepts of biodiesel which are significantly more sustainable than their alternatives. Microalgae possess high biomass productivity, oils with high lipid content, fast growth rates, possibility of utilizing marginal and infertile land, capable of growing in salt water and waste streams, and capable of utilizing solar light and CO_2 gas as nutrients.

Keywords: – *Biodiesel, Energy security, Environment friendly, Microalgae, Sustainability*

I. INTRODUCTION

The global energy demand is expanding with rapid population growth. Almost 1.4 billion people of our planet face daily shortage of energy [1]. Estimate shows that the world would require 50% more energy in 2030 than it does today [2]. Adversely, the fossil fuel reserves are being exhausted day by day [3]. Fossil fuel meets about 80% of the world's energy demand [4]. The basic sources of this energy are wood, coal, petroleum oil and natural gas [5-10]. As these sources of energy are limited and cannot be reused, our planet is going to face energy scarcity. In addition, the emission produced by the combustion of fossil fuels also contributes to air pollution and global warming [11-14]. The combustion of fossil fuels is a major source of air contaminants including CO_x and SO_x [15-19]. Carbon dioxide contributes to greenhouse effect [20-23]. Sulfur dioxide leads to acid rain by forming sulfuric acid which changes the normal pH of soil [5, 22]. It can be assumed that the global consumption of energy will raise and lead to more environmental smash up [16]. The concern about rapid depletion of fossil fuels, energy security and climate change are forcing governments, scientist and researchers to explore alternative sources of energy. Presently many options are being studied and implemented including solar energy, hydroelectricity, geothermal energy, wind energy, ocean energy and biofuels [24, 25]. Only the transportation sector accounts for almost 30% of the world's energy consumption most of which is in the form of liquid fuels [26]. When energy consumption for transportation comes into consideration and as two thirds of global energy consumption is derived from petroleum based liquid fuels, more attention should be given on the renewable energy sources of liquid fuels, which is biomass derived liquid fuels or biofuels [27,28]. Biofuels can play a vital role in mitigating energy crisis and environmental pollution [29, 30]. The most common biofuels are ethanol produced from sugar and starch crops, and biodiesel produced from vegetable oils and animal fats [31, 32].

The objective of this study is to reveal microalgae as an alternative renewable energy source for producing biodiesel. Microalgae has been discussed in a broad broad-spectrum showing that microalgae is a sustainable renewable energy source for biodiesel as other biomass sources of biodiesel need arable agricultural lands and sophisticated expensive technologies for their production on commercial basis.

II. BIODIESEL

Biodiesel is a non-toxic renewable energy source. It consists of monoalkyl esters of long chain fatty acids [33]. It is derived from vegetable oils and animal fats via transesterification reaction. The animal or vegetable oils are converted into biodiesel when one mole of triglyceride reacts with three moles of alcohol (such as methanol or ethanol) to produce a mole of glycerol and three moles of monoalkyl esters (biodiesel) [5]. Methanol is the most commonly used alcohol in the commercial production of biodiesel because of its low price [4, 34]. Biodiesel is usually blended with petroleum based diesel though it also can be used in pure form with some modifications of engines [35, 36]. Blends are indicated by the abbreviation B_{XX}, where XX is the percentage of biodiesel in the mixture.

2.1 Sources of Biodiesel

Biodiesel can be produced from both edible and non-edible sources of oil such as soybean oil [37-39], rapeseed [40,41], palm oil, maize[42], mahua[43], canola, coconut, corn oil [44], cotton seed [45], sunflower [44], fish oil, peanut, mustard oil, tobacco seed oil, jojoba oil, olive oil [46], pungam seed oil, linseed, groundnut oil, tall oil, fried oil, beef tallow, chicken fat, lard oil, animal fat, soapnut, Jatropha [47], pongamia, argemone, castor [46], karanja oil [48], algae, etc.

2.2 Creditability of biodiesel

Biodiesel has the potentiality to strengthen our energy security. It is an environmentally friendly energy source [49]. It is non-toxic and highly biodegradable [50-55]. The combustion of biodiesel emits less CO_x, SO_x, hydrocarbons, aromatic hydrocarbons, alkenes, aldehydes, ketones and particulate matter [56]. Biodiesel feedstock plants absorb CO_2 through photosynthesis, which is more than it discharges by the combustion process. Therefore, it can maintain ecological balance more effectively compared to petroleum diesel. Table 1 shows average emission impacts of biodiesel blends compared to petroleum diesel [57, 58].

Table 1. Average emission impacts of biodiesel blends compared to petroleum diesel

Biodiesel Blends	B20	B40	B60	B80	B100
Unburned hydrocarbons	-20%	-35%	-49%	-59%	-67%
Carbon Monoxide	-12%	-22%	-32%	-40%	-48%
Particulate Matter	-12%	-22%	-32%	-40%	-47%
NO_X	+2%	+4%	+6%	+8%	+10%

The production of biodiesel has the potentiality to generate new employment opportunity for developing country. Moreover, biodiesel has some technical advantages. Biodiesel gives more clean combustion than petroleum diesel. It possesses high cetane number. The cetane number is a measurement of the combustion quality of diesel fuel during compression ignition. So the flammability of biodiesel is better than that of diesel oil. Biodiesel can be transported safely due to its high flash point. Biodiesel acts as a better lubricant and detergent than petroleum diesel. Table 2 shows comparison of different properties of diesel and biodiesel [59, 60].

Table 2. Comparison of different properties of diesel and biodiesel

Fuel	Density at 15° C g/cm^3	Viscosity at 40°C mm^2/s	Sulfur, %	Carbon, %	Hydrogen, %	Oxygen, %	Flash point	Cetane Number	Lower calorific value MJ/kg
Diesel	0.834	2.83	0.034	86.2	13.8	—	62	47	42.59
Biodiesel	0.8834	4.47	< 0.005	76.1	11.8	12.1	178	56	37.243

The production and use of biodiesel involve multiple input and output to make a full assessment [61]. Nothing is wasted in the process of biodiesel production. Usually sodium hydroxide or potassium hydroxide is used as catalyst for biodiesel production. 4% alcohol can be extracted from the product and reused. 9% glycerin is produced which can be used as raw material for toiletries industry. Table 3 shows reactants and products of transesterification reaction of biodiesel production [61].

Table 3. Reactants and products of transesterification reaction of biodiesel production [61]

Input(Reactants)	Output(Products)
1. Oil 87%	1. Methyl ester (Biodiesel) 86%
2. Alcohol 12%	2. Glycerin 9%
3. Catalyst 1%	3. Alcohol 4%
	4. Fertilizer 1%

2.3 Limitations of biodiesel

As arable lands are used for biodiesel production, it may lead to food scarcity. It also may cause deforestation because of the excessive demand of land for biodiesel production. The water demand for some biodiesel crops could put unsustainable pressure on local water resources. Using fertilizer for biodiesel production can have harmful effects on environment. The combustion of biodiesel increases nitrogen oxides emissions which creates smog and acid rain [62-68]. Biodiesel is less energy efficient than petroleum diesel. The content of a gallon of biodiesel is 11% less than the energy content of petro diesel. Biodiesel has higher viscosity than petro diesel [69, 70]. The viscosity of biodiesel is about 11-17 times greater than that of diesel fuel which leads to problem in pumping, atomization in the injector and combustion [71]. Biodiesel causes excessive engine wear. Biodiesel is corrosive against copper and brass [71].

2.4 Three generations of biodiesel feedstock

- First generation (Biodiesel produced from soybeans, coconut, sunflower, rapeseed, palm oil, etc.)
- Second generation (Biodiesel produced from jatropha, mahua, cassava, miscanthus, jojoba oil, salmon oil, tobacco seed, straw, etc.)
- Third generation (Biodiesel produced from microalgae)

The first generation Biofuels can assure the energy security and healthy environment. But the production of first generation Biofuels needs arable agricultural lands. Consequently, it may impact on global food security. As a large portion of land is required for global total fuel demand, it also may cause of deforestation. The second generation Biofuels is produced from non-edible components. It is intended to produce from woody part of non-edible plants that do not compete with food production. However, converting the woody biomass into fermentable sugars requires sophisticated and expensive technologies for commercial production. Therefore second generation Biofuels cannot be produced economically in large scale [72]. They also need arable lands which may cause food scarcity and deforestation. Biodiesel produced from microalgae is considered as the third generation of Biofuels. Microalgae can be a sustainable renewable energy source for biodiesel to overcome the limitations of first and second generation Biofuels [72].

III. MICROALGAE

Microalgae are prokaryotic or eukaryotic photosynthetic microorganisms. Naturally they can grow rapidly in fresh or salt water due to their unicellular or simple multi-cellular structure. Because of their simple cellular structure, they are very efficient converters of solar energy. As the cells of microalgae grow in aqueous suspension, they have efficient access of water, CO_2 and other nutrients [73]. Microalgae are one of the oldest living organisms in our planet. Microalgae have more than 300000 species. Several species of them have oil content up to 80% of their dry body weight. Table 4 shows lipid contents of different microalgal species [74, 80].

Table 4. Lipid contents of different microalgal species

Microalgae species	Lipid content (% dry weight)
Botryococcus braunii	25-75
Chlorella	18-57
Chlorella emersonii	25-63
Chlorella sp.	10-48
Dunaliella sp.	18-67
Dunaliella tertiolecta	18-71
Nannochloris sp.	20-56
Nannochloropsis sp.	12-53
Neochloris oleoabundans	29-65
Phaeodactylum tricornutum	18-57
Scenedesmus obliquus	11-55
Schizochytrium sp.	50-77

Many researches proved that microalgae have many advantages for biodiesel production in comparison with other conventional feedstock. Microalgae can be either autotrophic or heterotrophic. Autotrophs use inorganic compounds as a source of carbon. Autotrophs can be photoautotrophic, using light as a source of energy, or chemoautotrophic, oxidizing inorganic compounds for energy. Heterotrophs use organic compounds for growth. Heterotrophs can be photoheterotrophs, using light as a source of energy, or chemoheterotrophs, oxidizing organic compounds for energy [73]. Figure 1 shows different stages of production of microalgal biodiesel.

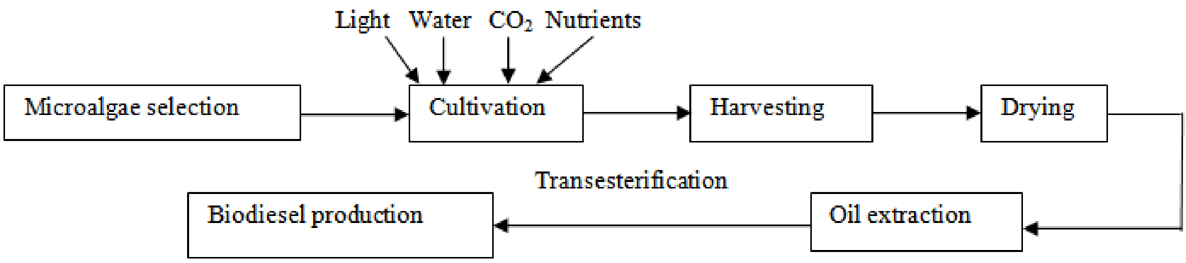

Figure 1. Different stages of production of microalgal biodiesel

3.1 Microalgal biodiesel creditability

Microalgae can be considered as a sustainable energy source of next generation biofuels [81]. Microalgae are capable of producing oil all year long. Oil productivity of microalgae is greater compared to conventional crops [82]. The oil content of microalgae is in the range of 20-50% which is greater than other competitors. Microalgae produce 15-300 times more oil for biodiesel production than traditional crops on an area basis. Biodiesel production from algal lipid is non toxic and highly biodegradable. Microalgae can grow in high rates which can be 50 times more than that of switchgrass, which is the fastest growing terrestrial crop [83]. They can complete an entire growth cycle in every few days via photosynthesis that converts sun energy into chemical energy. Microalgae have higher photon conversion efficiency; it is approximately 3-8% against 0.5% for terrestrial plants. Microalgae do not compete for land with food crops [84, 85]. They grow in fresh water, seawater, waste water or non-arable lands [86-88]. Therefore, they have minimal environmental effect such as deforestation. So microalgae are an alternative fuel feedstock that could avoid fuel versus food conflict [89]. The cultivation of microalgae needs less water than other energy oil crops. Table 5 shows comparison of different sources of biodiesel [90-100].

Table 5. Comparison of different sources of biodiesel

Biodiesel source	Oil yield (Liter oil/ha)	Land use (m^2/GJ)	Energy (GJ/ha)	Water required (m^3/GJ)
Soybean	446	689	15	383
Rapeseed	1190	258	39	383
Palm oil	5906	52	192	75
Sunflower	951	323	31	61
Jatropha	1896	162	62	396
Microalgae	24355-136886	2-13	793-4457	<379

Production of biodiesel from microalgae can fix CO_2 [101-103]. Roughly 1kg of algae biodiesel fixes 1.83 kg of CO_2. Microalgae cultivation has a higher CO_2 mitigation rate between 50.1 ± 6.5% on cloudy days and 82.3 ± 12.5% on sunny days for different algal species [104]. Some of the microalgae species are very efficient in capturing of CO_2 from high CO_2 streams such as flue gases. The CO_2 content in flue gases is usually 5-15%. The cultivation of Chlorella sp. in 55 m^2 culture area photo bioreactor mitigates 10-50% of CO_2 from flue gas (CO_2 content 6-8% by volume) [104]. Therefore, microalgae have the ability of decarbonization of flue gases. The cultivation of microalgae can utilize nitrogen and phosphorus as nutrients from waste water sources. So microalgae can give the additional benefit of wastewater bioremediation. Moreover, microalgal biodiesel can reduce the emission of NO_x. Microalgae produce valuable co-products or byproducts such as H_2, ethanol, biopolymers, proteins, cosmetic products, carbohydrates, fertilizer, animal feed, biomass residue etc. [105]. Microalgae cultivation does not require fertilizer, herbicides and pesticides. The heating value of Microalgal biodiesel is more than that of other terrestrial plants. The high heating value of biodiesel derived from rapeseed or soybean is 37 MJ/kg, while biodiesel derived from microalgae is 41 MJ/kg [106]. Table 6 shows properties of petroleum based diesel and microalgal biodiesel [107].

Table 6. Properties of petroleum based diesel and microalgal biodiesel

Energy source	Density (at 15°C) Kg / m^3	Kinematic viscosity (at 40°C) mm^2 / s
Diesel	836	3.03
Microalgal biodiesel	919	33.06

3.2 Limitations of microalgal biodiesel

Microalgae have low biomass concentration due to the limit of light penetration of algal cells. Therefore the cost of Microalgal biodiesel production is relatively higher compared to other feedstock. The drying process of harvested microalgae would be an energy consuming process due to the large water content. The heating value of Microalgal biodiesel is lower than that of petroleum based diesel fuel [108].

IV. CONCLUSION

Microalgal biodiesel is potentially alternative sustainable green energy. It is possible to produce microalgal biodiesel to satisfy the fast growing energy demand within the restraints of land and water resources. Microalgal farming can be coupled with flue gas CO_2 mitigation and wastewater treatment. Microalgae can produce a large variety of novel byproducts. Microalgae biodiesel is not yet economically viable enough to replace petroleum based fuels or compete with other renewable energy technologies such as wind, solar, geothermal and other forms of Bioenergy. Despite their high potential both in terms of productivity and sustainability, most algae based biofuel concepts still require significant investment to become commercially viable.

REFERENCES

[1] N. M. Komerath, P. P. Komerath, Terrestrial Micro Renewable Energy Applications of Space Technology, *Physics Procedia, 20,* 2011, 255-269.

[2] Yahaya Muhammad Sani, Wan Mohd Ashri Wan Daud, A.R. Abdul Aziz, Solid acid-catalyzed biodiesel production from Microalgal oil-The dual advantage, *Journal of Environmental Chemical Engineering,1,* 2013, 113-121.

[3] Saifuddin Nomanbhay, Refal Hussain, Md. Mujibur Rahman, Kumaran Palanisamy, Review Paper Integration of Biodiesel and Bioethanol Processes: Conversion of Low Cost Waste Glycerol to Bioethanol, *Advances in Natural and Applied Sciences, 6,* 2012, 802-818.

[4] Daming Huang, Haining Zhou, Lin Lin, Biodiesel: an Alternative to Conventional Fuel, *Energy Porcedia, 16,* 2012, 1874-1885.

[5] Demshemino S. Innocent, O'Donnell P. Sylvester, Muhammad F. Yahaya, Isioma Nwadike, and Linus N. okora, Comparative Analysis of biodiesel and petroleum Diesel, *International journal of Education and Research, 1(*8), 2013.

[6] Nivea De Lima Da Silva, Julian A. G. Garnica, Cesar B. Batistella, Maria Regina Wolf Maciel, Use of experimental design to investigate biodiesel production by multiple-stage Ultra-Shear reactor, *Bioresource Technology, 102,* 2011, 2672-2677.

[7] Surendhiran D. and Vijay M, Microalgal Biodiesel – A Comprehensive Review on the Potential and Alternative Biofuel, *Research Journal of Chemical Sciences, 2(11),* 2012, 71-81.

[8] Bajhaiya A.K., Mandotra S.K., Suseela M.R., Toppa K. and Ranade S., Algal Biodiesel: the next generation biofuel for India: Review Article, *Asian J. Exp.Biol.Sci., 1,* 2010, 728-739.

[9] Subramaniam R., Dufreche S., Zappi M. and Bajpai R., Microbal lipids from renewable resources: production and characterization, *J. Ind. Microbial Biotechnol., 37,* 2010, 1271-1287.

[10] David Painter, Are biofuels the future or a folly? : A review, *New Zealand Journal of Forestry, 53,* 2009.

[11] Zhou A., Thomson E., The Developments Of Biofuels in Asia, *Applied Energy, 86,* 2009, 11-20.

[12] Prabhakar, S. V. R. K., Elder M., Biofuels and resource use efficiency in developing Asia: Back to basics, *Applied Energy, 86,* 2009, 30-36.

[13] Agrawal A. K., Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, *Progress in Energy and Combustion Science, 33,* 2007, 233-271.

[14] CheHafizan, Noor Zainon Zainura, Biofuel: Advantages and disadvantages based on life cycle assessment (LCA) perspective, *Journal of Environmental Research and Development, 7,* 2013.

[15] Quaye E. C., Energy Demands in the 21st century: The Role of Biofuels in a developing country, *Renewable Energy, 9,* 1996, 1029-1032.

[16] Basha S.A., Gopal K.R., Jebaraj S., A review on biodiesel production, combustion, emission and performance, *Renewable and Sustainable Energy Reviews, 13,* 2009, 1628-1634.

[17] Teresa M. Mata, Antonio A. Martins, Nidia. S. Caetano, Microalgal for biodiesel production and other applications: A review, *Renewable and Sustainable energy Reviews, 14*, 2010, 217-232.

[18] A. B. M. Sharif Hossain, Aishah Salleh, Biodiesel fuel production from algae as renewable energy, *American Journal of Biochemistry and Biotechnology, 4,* 2008, 250-254.

[19] Vishwanath Patil, Khanh-Quang Tran, Hans Ragnar Giselrød, Towards Sustainable Production of Biofuels from Microalgae, *International Journal of Molecular Sciences, 9,* 2008, 1188-1195.

[20] Amela Ajanovic, Biofuels versus food production: Does biofuels production increase food prices?, *Energy*, 2010, 1-7.

[21] S. N. Naik, Vaibhav V. Goud, Prasant K. Rout, Ajay K. Dalai, Production of first and second generation biofuels: A comprehensive review, *Renewable and Sustainable Energy Reviews, 14,* 2010, 578-597.

[22] R. Prakash, R. K. Shing, S. Murugan, Comparison of performance and emission parameters of a diesel engine fueled biodiesel and wood pyrolysis oil emulsions, *International Energy Journal, 13*, 2012, 123-132.

[23] Bruce Gardner, Wallace Tyner, Explorations in biofuels economics, policy, and history: Introduction to the special issue, *Journal of Agricultural and Food Industrial Organization, 5*, 2007.

[24] Gilbert R, Perl A., Transport revolutions: moving people and freight without oil, *Earthscan*, 2008.

[25] Dewulf J, Van Langenhove H., Renewables-based technology: sustainability assessment, Jhon Wiley & Sons, Ltd., 2006

[26] Parvatker A. G., Biodiesel from microalgae – A sustainability analysis using life cycle assessment, *International Journal of Chemical and Physical Sciences, 2*, 2013.

[27] Hagg A. L., Algae Bloom Again, *Nature, 447*, 2007, 520-521.

[28] Schneider D., Grow your Own? : Would the Wide Spread Adoption of Biomass-Derived Transportation Fuels Really Help the Environment, *American scientist, 94,* 2006, 408-409.

[29] Guanhua Huang, Feng Chen, Dong Wei, Xuewu Zhang, Gu Chen, Biodiesel production from microalgal biotechnology, Applied Energy, 87, 2010, 38-46.

[30] S. Kiran Kumar, Performance and Emission Analysis of Diesel Engine Using Fish Oil and Biodiesel Blends with Isobutanol as an Additive, *American Journal of Engineering Research, 2,* 2013, 322-329.

[31] Divya Bajpai, V. K. Tyagi, Biodiesel: Source, production, consumption, properties and its benefits, *Journal of Oleo Science, 55*, 2006, 487-502.

[32] Annisa Bhikuning, Engine Performance and Oil Analysis of Biodiesel from Bulk Oil, *Asian Transactions on Engineering, 1,* 2011.

[33] M. U. Kaisan, G. Y. Pam, D. M. Kulla, Physico–Chemical Properties of Bio–diesel from Wild Grape Seeds Oil and Petro–diesel Blends, *American Journal of Engineering Research, 2*, 2013, 291-297.

[34] Ramadhas A.H., Jayaraj S., Muraleedharan C., Biodiesel production from high FFA rubber seed oil, *Fuel, 84,* 2005, 335-340.

[35] Apostolakou A.A., Kookos I.K., Marazioti C., Angelopoulos K.C., Techno-economic Analysis of a biodiesel Production process from Vegetable oils, *Fuel Processing Technology, 90,* 2009, 1023-1031.

[36] Pedrojevic Z.J., The production of biodiesel from waste frying oils: A comparison of different purification steps, *Fuel, 87,* 2008, 3522-3528.

[37] Lepuerta M., Armas O., Fernandez J.R., Effect of Biodiesel Fuels on diesel Engine emissions, *Progress in Energy and Combustion Science, 34,* 2008, 198-223.

[38] A.L. Ahmad, N.H. Mat Yasin, C.J.C. Derek, J.K. Lim, Microalgae as a sustainable energy source for biodiesel production: A review, *Renewable and Sustainable Energy Reviews, 15,* 2011, 584-593.

[39] Celikten I., Koca A., Arslan MA., Comparison of performance and emissions of diesel fuel, rapeseed and soybean oil mythyl esters injected at different pressures, *Renew Energy*, *35,* 2010, 814-820.

[40] Zankruti Patel, Krishnamurthy R., Biodiesel: Source Materials and Future Prospects, *International Journal of Geology, Earth and Enviromental Sciences, 3(2),* 2013, 10-20.

[41] Armen B. Avagyan, New Design & Build Biological System through the Use of Microalgae Addressed to Sustainable Development, *Journal of Environmental Protection, 1,* 2010, 183-200.

[42] Tahani S. Gendy, Seham A. El-Temtamy, Commercialization potential aspects of microalgae for biofuel production: An overview, *Egyptian Journal of Petroleum, 22,* 2013, 43-51.

[43] Sudheer Nandi, Performance of C. I. Engine by Using Biodiesel – Mahua Oil, *American Journal of Engineering Research, 2*, 2013, 22-47.

[44] Abu Yousuf, Mozammel Hoque, M. Asraful Jahan, Domenico Pirozzi, Technology and Engineering of Biodiesel Production: a Comparative Study between Microalgae and Other Non-Photosynthetic Oleaginous Microbes, *International Review of Chemical Engineering, 4(6),* 2012.

[45] Shashi Kumar Jain, Sunil Kumar, Alok Chaube, Technical Sustainability of Biodiesel and Its Blends with Diesel in C.I. Engines: A Review, *International Journal of Chemical Engineering and Applications, 2(2),* 2011.

[46] Bello Y. Makama, Bankefa Temitope, Nwaeburu Clifford, Linus N. Okoro, Synthesis and Calorific Value of Biodiesel by Methanolysis of Castor and Olive Oils in Admixture, *Australian Journal of Basic and Applied Sciences, 5(11),* 2011, 874-878.

[47] K. Sudhakar, M. Rajesh, M. Premalatha, Carbon mitigation potential of Jatropha Biodiesel in Indian context, *Energy Procedia, 14*, 2012, 1421-1426.

[48] S. Jaichandar1, K. Annamalai, The Status of Biodiesel as an Alternative Fuel for Diesel Engine – An Overview, *Journal of Sustainable Energy and Environment, 2*, 2011, 71-75.

[49] C.G. Tsanaktsidis, S.G. Christidis, G.T. Tzilantonis, Study about Effect of Processed Biodiesel in Physiochemical Properties of Mixtures with Diesel Fuel in order to Increase Their Antifouling Action, *International Journal of Environmental Science and Development, 1,* 2010.

[50] Parag Sexena, sayali Jawale, Milind H Joshipura, A review on prediction of properties of biodiesel and blends of biodiesel, Procedia Engineering, 51, 2013, 395-402.

[51] M. R. Jakeria, M. A. Fazal, A. S. M. A. Haseeb, Influence of different factors on the stability of biodiesel: A review, Renewable and Sustainable Energy Reviews, 30, 2014, 154-163.

[52] Fangrui Ma, Milford A. Hanna, Biodiesel production: A review, *Bioresource Technology, 70,* 1999, 1-15

[53] Hossain A. B. M. S., Nasrulhaq Boyce A., Salleh A., Chandran S., Biodiesel production from waste soybean oil biomass as renewable energy and environmental recycled process, *African Journal of Biotechnology, 9*, 2010, 4233-4240.

[54] A. P. Sathiyagnanam, Member, Iaeng, C. G. Saravanan, Experimental Studies on the Combustion Characteristics and Performance of A Direct Injection Engine Fueled with Biodiesel/Diesel Blends with SCR, *Proceedings of the World Congress on Engineering, 3*, 2011.

[55] Xiaohu Fan, Rachel Burton, Recent Development of Biodiesel Feedstocks and the Applications of Glycerol: A Review, *The Open Fuels and Energy Science Journal, 2,* 2009, 100-109.

[56] L. G. Anderson, Effects of Biodiesel Fuels Use on Vehicle Emissions, *Journal of Sustainable Energy and Environment, 3*, 2012, 35-47.

[57] A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, *United States Environmental Protection Agency*, 2002.

[58] Idusuyi N. Ajide O. O. Abu R., Biodiesel as an Alternative Energy Resource in Southwest Nigeria, *International Journal of Science and Technology, 2,* 2012.

[59] Dongsheng Wen, H. Jiang, Kai Zhang, Supercritical fluids technology for clean biofuel production, *Progress in Natural science, 19,* 2009, 273-284.

[60] M. Sakunthala, V. Sridevi, K. Vijay Kumar, K. Rani, Biodiesel – Renewable Fuel, Environmental Implications and Its Handling, *Journal of Chemical, Biological and Physical Sciences, 3,* 2013, 1564-1571.

[61] Adriana Downie, David Lau, Annette Cowie, Paul Munroe, Approches to greenhouse gas accounting methods for biomass carbon, *Biomass and Bioenergy, 60,* 2014, 18-31.

[62] Xiaoyan Shi, Xiaobing Pang, Yujing Mu, Hong He, Shijin Shuai, Jianxin Wang, Hu Chen, Rulong Li, Emission reduction potential of using ethanol-biodiesel-diesel fuel blend on a heavy-duty diesel engine, *Atmospheric Environment, 40*, 2006, 2567-2574

[63] Jinlin Xue, Tony E. Grift, Alan C. Hansen, Effect of biodiesel on engine performances and emissions, *Renewable and Sustainable Energy Reviews, 15,* 2011, 1098-1116.

[64] Jon Van Gerpen, Biodiesel processing and production, *Fuel Processing Technology, 86,* 2005, 1097-1107.

[65] Ambarish Datta, Bijan Kumar Mandal, Biodiesel production and its emission and performance: A review, *International Journal of Engineering & Scientific Research, 3*, 2012.

[66] Gaurav Dwivedi, Siddharth Jain, M. P. Sharma, Diesel engine performance and emission analysis using biodiesel from various oil sources – Review, *Journal of Material and Environmental Science, 4,* 2013, 434-447.

[67] S. Oberweis, T. T. Al-Shemmeri, Effect of biodiesel blending on emissions and efficiency in a stationary diesel engine, International Conference on Renewable Energies and Power Quality, 2010.

[68] James W. Richardson, Joe L. Outlaw, Marc Allison, The Economics of Microalgae Oil, *AgBioForum, 13(2),* 2010, 119-130.

[69] Mustafa E. Tat, Jon H. Van Gerpen, The Kinematic Viscosity of Biodiesel and Its Blends with Diesel Fuel, *Journal of the American Oil Chemists' Society, 76(12),* 1999.

[70] Pooja Ghodasara, Mayur Ghodasara, Experimental Studies on Emission and Performance Characteristics in Diesel Engine Using Bio–Diesel Blends and EGR (Exhaust Gas Recirculation), *International Journal of Emerging Technology and Advanced Engineering, 2(2),* 2012.

[71] M. Mofijur, H. H. Masjuki, M. A. Kalam, A.E. Atabani, M. Shahabuddin, *Effect of biodiesel from various feedstocks on combustion characteristics, engine durability and materials compatibility: A review, Renewable and Sustainable Energy Reviews, 28,* 2013, 441-455.
[72] Firoz Alam, Abijit Date, Roesfiansjah Rasjidin, Saleh Mobin, Hazim Moria, Abdul Baqui, Biofuel from algae- Is it a viable alternative?, *Procedia Engineering 49*, 2012, 221-227.
[73] Giuliano Dragone, Bruno Fernandes, Antonio A. Vicente, Jose A. Teixeira, Third generation biofuels from microalgae, Institute for Biotechnology and Bioengineering, Centre of Biological Engineering, University of Minho, Portugal.
[74] Suphi S. Oncel, Microalgae for a macroenergy world, *Renewable and Sustainable Energy Reviews, 26,* 2013, 241-264.
[75] S. Karthikeyan, A critical review: Microalgae as a renewable source for biodiesel production, International *Journal of Engineering Research & Technology, 1,* 2012.
[76] Yusuf Chisti, Biodiesel from microalgae, *Biotechnology Advances, 25,* 2007, 294-306.
[77] Liam Brennan, Philip Owende, Biofuels from microalgae – A review of technologies for production, processing, and extraction of biofuels and co-products, *Renewable and Sustainable Energy Reviews,* 2009.
[78] Xiaodan Wu, Rongsheng Ruan, Zhenyi Du, Yuhuan Liu, Current status and prospects of biodiesel production from microalgae, *Energies, 5,* 2012, 2667-2682.
[79] Luisa Gouveia, Ana Cristina Oliveira, Microalgae as a raw material for biofuels production, *Journal of Industrial Microbiology and Biotechnology, 36,* 2009, 269-274.
[80] Ramasamy Sakthivel, Sanniyasi Elumalai, M. Mohommad Arif, Microalgae lipid research, past, present: A critical review for biodiesel production, in the future, *Journal of Experimental Sciences, 2,* 2011, 29-49.
[81] P. Hyka, S. Lickova, P. Pribyl, K. Melzoch, K. Kovar, Flow cytometry for the development of biotechnological processes with microalgae, *Biotechnology Advances, 31,* 2013, 02-16.
[82] Rudras Baliga, Susan E. Powers, Sustainable Algae Biodiesel Production in Cold Climates, *International Journal of Chemical Engineering,* Volume 2010.
[83] Patrick E. Wiley, J. Elliott Campbell, Brandi Mckuin, Production of Biodiesel and Biogas from Algae: A Review of Process Train Options, *Water Environment Research, 83,* 2011, 326-338.
[84] Kalpesh K. Sharma, Holger Schuhmann, Peer M. Schenk, High Lipid Induction in Microalgae for Biodiesel Production, *Energies, 5,* 2012, 1532-1553.
[85] Janusz Jakóbiec, Mariusz Wądrzyk, Microalgae as a Potential Source for Biodiesel Production, *Agricultural Engineering, 6(124),* 2010.
[86] N. Abdel-Raouf, A. A. Al-Homaidan, I. B. M. Ibraheem, Microalgae and Wastewater Treatment, *Saudi Journal of Biological Sciences, 19,* 2012, 257-275.
[87] Andrzej Lewicki, Jacek Dach, Damian Janczak, Wojciech Czekala, The experimental photoreactor for microalgae production, *Procedia Technology, 8,* 2013, 622-627.
[88] Raphael Slade, Ausilio Bauen, Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects, *Biomass and Bioenergy, 53,* 2013, 29-38.
[89] Wanchat Sawaengsak, Thapat Silalertruksa, Athikom Bangviwat, Shabbir H. Gheewala, Life cycle cost of biodiesel production from microalgae in Thailand, *Energy for Sustainable Development, 18,* 2014, 67-74.
[90] J.E. Andrade, A. Perez, P.J. Sebastian, D. Eapen, A review of bio-diesel production processes, *Biomass and Bioenergy, 35,* 2011, 1008-1020.
[91] A. E. Atabani, A. S. Silitonga, Irfan Anjum Badruddin, T. M. I. Mahlia, H. H. Masjuki, S. Mekhilef, A comprehensive review on biodiesel as an alternative energy resource and its characteristics, *Renewable and Sustainable Energy Reviews, 16,* 2012, 2070-2093.
[92] S. Kent Hoekman, Amber Broch, Curtis Robbins, Eric Ceniceros, Mani Natarajan, Review of biodiesel composition, properties, and specifications, *Renewable and Sustainable Energy Reviews, 16,* 2012, 143-169.
[93] Aninidita Karmakar, Subrata Karmakar, Souti Mukherjee, Properties of various plants and animals feedstocks for biodiesel production, *Bioresource Technology, 101,* 2010, 7201-7210.
[94] Anita Kirrolia, Narsi R. Bishnoi, Rajesh Singh, Microalgae as a boon for sustainable energy production and its future research & development aspects, *Renewable and Sustainable Energy Reviews, 20,* 2013, 642-656.
[95] Shalini Rajvanshi, Mahendra Pal Sharma, Microalgae : A Potential Source of Biodiesel, *Journal of Sustainable Bioenergy Systems, 2,* 2012, 49-59.
[96] Xiaodong Deng, Yajun Li, Xiaowen Fie, Microalgae: A Promising Feedstock for Biodiesel, African Journal of Microbiology Research, 3, 2009, 1008-1014.

[97] Baljeet Singh Saharan, Deepansh Sharma, Rajender Sahu, Ozlem Sahin, Alan Warren, Towards Algal Biofuel Production: A Concept of Green Bio Energy Development, *Innovative Romanian Food Biotechnology, 12,* 2013.
[98] Md.Imran Kais, Farsad Imtiaz Chowdhury, Kazy Fayeen Shahriar, Biodiesel from Microalgae as a solution of third world energy crisis, Bioenergy Technology, World Renewable Energy Congress 2011.
[99] Peer M. Schenk, Skye R. Thomas-Hall, Evan Stephens, Ute C. Marx, Jan H. Mussgnug, Clemens Posten & Olaf Kruse, Ben Hankamer, Second Generation Biofuels: High Efficiency Microalgae for Biodiesel Production, *Bioenergy Research, 1,* 2008, 20-43.
[100] Sushant S. Satputaley, Chetan Chawane, N. V. Deshpande, A Critical Review of Biofuels from Algae for Sustainable Development, *International Journal of Computer Applications,* National Conference on Innovative Paradigms in Engineering & Technology 2012.
[101] Lingling Wang, Bingtao Zhao, Yixin Zhang, Prediction of energy microalgae production under flue gas using response surface methodology, *Energy Procedia*, *16*, 2012, 1066-1071.
[102] Razif Harun, Manjinder Singh, Gareth M. Forde, Michael K. Danquah, Bioprocess engineering of microalgae to produce a variety of consumer products, *Renewable and Sustainable Energy Reviews, 14,* 2010, 1037-1047.
[103] M. S. Ghayal, M. T. Pandya, Microalgae biomass: a renewable source of energy, *Energy Procedia, 32,* 2013, 242-250.
[104] Yanqun Li, Mark Horsman, Nan Wu, Christopher Q. Lan, Nathalie Dubois-Calero, Biofuels from Microalgae, American Chemical Society and American Institute of Chemical Engineers, 2008.
[105] Emma Suali, Rosalam Sarbatly, Conversion of microalgae to biofuel, *Renewable and Sustainable Energy Reviews*, *16*, 2012, 4316-4362.
[106] Matthew N Campbell, Biodiesel: Algae as a Renewable Source for Liquid Fuel, *Guelph Engineering Journal*, *1*, 2008, 2-7.
[107] Yi-Hung Chen, Bo-Yu Huang, Tsung-Han Chiang, Ting-Cheng Tang, Fuel properties of microalgae (Chlorella protothecoides) oil biodiesel and its blends with petroleum diesel, *Fuel*, *94*, 2012, 270-273.
[108] GuanHua Huang, Feng Chen, Dong Wei, Xuewu Zhang, Gu Chen, Biodiesel production by microalgal biotechnology, *Applied Energy, 87,* 2010, 38-46.