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Potentiality of Fish Wastes in Generating Biodiesel –a review

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Abstract
Biodiesel is a cost-effective alternative to fossil fuels. It is renewable, biodegradable and on combustion produces less carbon-di-oxide and other air pollutants. Transesterification reactions of organic oils give rise to biodiesel and glycerol is obtained in this process as a valuable byproduct. Globally India is the 2nd largest producer in aquaculture. In India West Bengal is the second largest producer state of fishes only after Andhra Pradesh. More than 50% of dry tissue weight could be obtained as fish oil from regular fish wastes. Yield of biodiesel extracted from fish oils may be more than 85%. Potentiality of producing biodiesel from fish wastes appears to be quite high in India. However, converting of fish wastes into valuable and reusable products is not carried out at present and the fish wastes remained of no use. Government of India has issued National Policy on Biofuels – 2018 that did not consider fish wastes as a potent resource. Proper plan to harness the potential of the oil rich, cost free fish waste resources towards production of valuable and environment friendly biodiesel, through incorporation in the national policy is observed necessary.

Key words: Fish Wastes, Potentiality**,** Biodiesel,

1. Introduction

Biodiesel is an animal or vegetable oil-based diesel fuel that burns without the emission of much soot, carbon oxide and particulate matter. (Oliveira *et al.*,2013). It consists of long chain mono-alkyl esters and is formed by transesterification of vegetable oil or animal fat. In this process, the animal or vegetable oil is changed into biodiesel when one mole of triglyceride reacts with three moles of alcohol (methanol) to produce a mole of glycerol and three moles of mono-alkyl esters. (Maria *et al*.2009). Biodiesel like petro-diesel is made of hydrocarbon chains but contain less sulphur or aromatic compounds, (He *et al.* 2009). It is an alternative fuel that is obtained from renewable resources that burns in diesel engines with less environmental pollutants.

The practice of biodiesel in Europe from 2007 to 2010 signified a portion of more than 80% of the transportation biofuel consumption, and 30.26% of the total road transportation fuels consumption in 2010. (Serrano et al., 2012). The production and use of biofuels on a wide scale is done because of the high level of atmospheric pollution caused by the extreme use of fossil fuels leading to the greenhouse effect.

2. Materials and Methods

This is a review work based on the study of secondary data obtained from recent research communications published in recognised research journals.

Characteristics of Biodiesel

Biodiesel has been preferred as one of the key substitute fuels because of its superior characteristics and advantages. It is renewable, biodegradable, has around 11% oxygen by weight and contains little or no sulphur and aromatic compounds. (Crutzen et al., 2008; CPCB, 2002). In addition, biodiesel has a low emission outline and are environment friendly. Biodiesel as automotive fuel has similar properties to petro-diesel and as such can be directly used in existing diesel engines with no or minor modifications. It can be used alone (B100) or mixed in any ratio with petrodiesel. The most common blend is B20, a mix of 20% biodiesel with 80% petroleum diesel. (CPCB, 2002).

Lubricity is especially important for rotary/distributor type fuel injection pumps in which parts are lubricated by the fuel itself and not by the engine oil. Biodiesel show better lubricating properties thereby reducing engine wear and extend the life of fuel injection systems. Toxocity and other effects of biodiesel were also found to be insignificant. (CPCB, 2002).

Emission Characteristics of Biodiesel

Biodiesel is the only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the United States Environmental Protection Agency (USEPA). The use of biodiesel in a conventional diesel engine results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter. Emissions of nitrogen dioxides are also reduced. Biodiesel decreases the solid carbon fraction of particulate matter (since the oxygen in the fuel enables more complete combustion to CO2), eliminates the sulphur fraction (as there is no sulphur in the fuel), while the soluble or hydrogen fraction stays the same or is increased. (CPCB, 2002). Biodiesel gives a distinct emission benefit almost for all pollutants when compared to conventional diesel fuel.

Advantages of Biodiesel

a) It is a renewable source of energy. The process leaves a residue of methyl esters and glycerine residue, which can be used for production of soap and other products.

b) Experts are of the opinion that diesel engines require little modification while running on biodiesels and the energy produced is 90% of what the conventional version can offer. Carbon dioxide emissions from the combustion of biodiesel are 60% less than conventional diesel.
c) The use of biodiesel is not hazardous to the environment.
d) Biodiesel is culture oriented, non-poisonous, biodegradable and a renewable fuel.
e) It has a high cetane number, a lower carbon monoxide emission, low sulphur, low volatility and presence of oxygen atoms in the fuel molecule. (Aljaafari et al.2022).

Preparation of Biodiesel

There are several methods to produce biodiesel; transesterification is one of those used ways to produce biodiesel (Lisboa et al., 2014).

Fatty acid methyl esters (FAME), the biodiesel, are a type of fatty acid ester that is derived by transesterification of fats with methanol.

The process takes place in steps. The first step is to mix the alcohol (methanol) for reaction with the catalyst that is typically a strong base such as NaOH or KOH. Once the catalyst is prepared, the triglyceride will react with methanol, excess methanol is used to ensure complete reaction. The alcohol/catalyst then reacts with the fatty acid of plant or animal fat, so that the transesterification reaction takes place. (Clifford.2022).The three attached carbons with hydrogen react with OH- ions and form glycerol, while the CH_3 group reacts with the free fatty acid to form the fatty acid methyl ester and glycerol. (Figure-1).The fatty acid methyl ester is the biodiesel.

With 100 lbs of fat and 16-20 lbs of alcohol and 1 lb of catalyst, the reaction produced 100 lbs of biodiesel and 10 lbs of glycerol. The reaction typically took place at between 40-65°C. (Clifford, 2022). Both the glycerol and biodiesel need to have alcohol removed and recycled in the process. Water is added to both the biodiesel and glycerol to remove unwanted side products, particularly glycerol, that may remain in the biodiesel. (Clifford.2022)

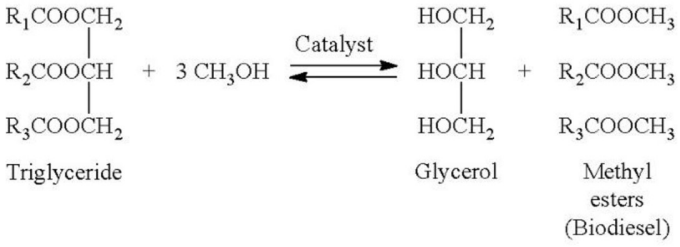

Fig. 1. Chemical changes in biodiesel production. Source: Nahian et al. 2016

Source of Biofuels

The potential sources for biodiesel production can be vegetable oil, animal oil, waste oil, waste derived from plants and animals, also agricultural residues and municipal wastes (Balat, M., 2008).The recent studies carried out for the production of biodiesel are from vegetable oil, spent oil and industrial oil.
Biofuels can also be obtained from organic wastes including vegetable wastes (Abromovic and Klofutar,1998; Rukunudin et al.,1998; Son et al.,2010) animal wastes (Lebedevas et al.,2006; Adebanjo et al.,2005) including fish wastes (Preto et al., 2008), micro-algae (Benemann,2013), seaweeds and plants such as *Jatropha* sp. (Kywe and Oo,2009).

The extraction of biofuel from plant materials such as vegetable wastes and plants is not practical. Planting and cultivation assets are unfavorable (Abromovic and Klofutar,1998) obtaining biofuel from waste materials yields oil which can then be processed to yield biodiesel, but its physical and chemical characteristics do not match that of the currently used fuel and are not acceptable to current engines. (Abromovic and Klofutar,1998). When oil is obtained from an edible source this is a waste of food; a main disadvantage in producing fuel from vegetable oil (Ken,1987; Yuvaraj et al.,2016).

Biodiesel Initiatives in India

India has great potential for production of bio-fuels like bio-ethanol and biodiesel from non-edible oil seeds. From about 100 varieties of oil seeds, only 10-12 varieties have been tapped so far. The annual estimated potential is about 20 million tons per annum. Wild crops cultivated in the wasteland also form a source of biodiesel production in India and according to the Economic Survey of Government of India, out of the cultivated land area, about 175 million hectares are classified as waste and degraded land. Thus, given a demand-based market, India can tap its potential and produce biodiesel in a large scale. (Sahu *et al*.2008)

Production of biodiesel unlike petrodiesel, is relatively a less cumbersome process and therefore large-scale production can be undertaken with a short lead time. (CPCB, 2002).

Prospects of Biodiesel from Fish Wastes

One possible source of biofuel is the fish wastes. Fish wastes, rich in fatty acids can be used as the raw material to produce biodiesel through transesterification reaction. Fish based biodiesel provided a significant reduction in carbon monoxide (CO) and hydrocarbon (HC) emissions under engine loads of 15 (Nm) and required no engine modification. The viscosity of the generated biodiesel was within the range of international standards. The biodiesel has a low base number and show a lower specific fuel consumption compared to the conventional diesel. It therefore appeared that biodiesel obtained from waste fish oil may be considered as a potential

source of commercial biodiesel. The pisciculture industry is an activity of great economic importance in India. (Mohammed and Amru, 2017)

In the global position India is the 3rd largest producer in fisheries, contributing to 8.0% of global fish production following a lengthy coastline of 8,118 kilometres. Total fish production was 162.48 lakh tonnes of which 41.27 lakh tonnes was marine and 121.21 lakh tonnes inland, during 2021-22. In India Andhara Pradesh made maximum fish production (48.13 lakh tonnes) followed by West Bengal (18.43 lakh tonnes) (Handbook 2022).

The fish market and fish handling industry produce enormous quantities of unwanted fish wastes, nearly 1/3rd part such as head, viscera, tail, skin, liver, eyes, fins etc. which is considered as wastes. The marine fish oil extracted from discarded parts of marine fishes is recognised as rich, cheap & possible source of biodiesel (Patil et al., 2013).

More than 50 different types of fish & shellfish products are being exported to 75 countries around the world. Fish & fish products have presently emerged as the largest group in agricultural exports from India, with 13.77 lakh tonnes in terms of quantity & rupees more than 45 thousand crores in value. (NFDB 2019).

India is the second leading manufacturer of freshwater fish in the globe. The Indian major carps, namely catla, rohu and mrigal were the main freshwater fish in India donating 70-75% of total freshwater fish production, followed by silver carp, grass carp, common carp and catfishes (Ayyappan, 2014). The Indian major carps, rohu (*Labeo rohita*) is one of the highly traded fish species in the Indian fish markets, which leads to production of enormous quantities of fish wastes as left-overs. (Ayyappan, 2014; Swapna et al.,2010). The overall waste generated from rohu fish in India was projected to be roughly around 0.9 million tons per annum. Most of these wastes is generated, particularly from the visceral mass & it contains about 25% to 35% lipids (w/w of wet mass) (Swapna et al.,2010)

As a result, fish oil from rohu fish handling wastes may offer a plentiful, low-priced, steady, renewable and an unconventional raw material to produce biodiesel in India. Thus, production of biodiesel from rohu processing waste oil would be a great advantage for the fish industry sectors & domestic fish markets also in decreasing the disposal cost and application of biodiesel as a substitute for conventional diesel fuel thus reducing the energy crisis and environmental pollutants (Tanaji et al., 2017).

Possibilities of fish wastes as source of bio-fuels

Potentialities of fish wastes in generation of biodiesel largely depend on the lipid load in fish wastes. Oil in fish also depend on the type of species, their feeding habits, climatic condition, age, sex, maturity etc. (Çelik et al.,2005; Haliloğlu et al.,2004; Ratkowsky et al.,1996; Saito et al.,1999). Jayasinghe et al., 2013, extracted 10% and 3% oils by weight from the discarded viscera of Tilapia and Mackerel fishes respectively. Tilapia wastes therefore appeared to be more rewarding in production of biodiesel. Yield of extraction is dependent on fish species and parts

used for extraction. Processing scraps of *Merluccius merluccius, Merluccius paradoxus* can yield around 10 g of oil/100 g of dry tissue materials. But the scraps of fatty fish species like salmon *Salmo salar* and orange roughy *Hoplostethus atlanticus* may provide 40g and 50g of oil respectively per 100 g dry tissue. (Rubio et al., 2012). Indian mackerel may yield as high as 52.3 g oil/100 g dry raw material (Sahena et al., 2010) whereas only about 10 g oil /100 g dry raw material from different parts of sardine (Letisse et al.,2006; Gedi et al.,2015).

However, Hamed, et al.2008, found that acid value of salmon oil is high, as such normal alkaline-catalysed transesterification could not be adopted for producing biodiesel from the salmon oil. Instead a two-step process was adopted, in which a sulphuric acid-catalysed pre-treatment was used in the first step to reduce the acid value and then alkaline catalysed transesterification was applied.

Potentialities of fish wastes as alternative energy resource

Research Scenario in India

When compared to ordinary diesel fuel, biodiesel is more efficient and the emissions such as carbon monoxide, sulphur dioxide, hydrocarbon are reduced. Comprehensive research review on biodiesels categorically confirmed that fish oil obtained from fish fat and their esters can be used as complete or partial substitute for diesel as renewable energy sources. (Parandhaman et al., 2017).

A single step transesterification process using alkaline catalyst (CH3ONa) was performed in the study of Sharma et al. 2014, which showed that waste fish oil was low in acid value and could be well-used to produce biodiesel of high (Fatty Acid Methyl Esters) FAME content. However, in the present scenario, since the fish markets are scattered all over the country, the waste parts are usually disposed of as solid waste with no proper application. Alternatively, these wastes could be channelized into local biodiesel plants as an economic feedstock for high-quality biodiesel production. (Sharma et al., 2014). Rasal et al., 2017, observed that higher brake thermal efficiency can be achieved with the use of fish oil biodiesel compared to diesel and a considerable amount of decrease in all emissions except NO_X.

Fish processing generates solid wastes that can be as high as 50-80% of the original raw material. During 2006-07, it was estimated that 3, 02,750 tons of processing and pre-processing wastes was generated. Utilization of fish wastes in India for preparation of different by products like fish meal, dry fish, fish body oil, fish ensilage, fish scales, fish calcium, pearl essence, fish glue, fish hydrolysate, fish maws and isinglass, fish collagen, surgical sutures from freshwater fish gut, gelatin, ambergris, fish sausage, chitin, glucosamine hydrochloride, carboxymethyl chitin and chitosan was discussed. However, little is reported on the utilization of fish wastes in preparation of biodiesel. (Mathew, 2009)

Franco et al., 2014 studied the brake thermal efficiency for sardine fish oil biodiesel. Emission analysis revealed that there was an increase in NO_x emission for all biodiesel blends when compared to diesel, whereas there is a significant reduction in CO_2, HC and smoke emissions. With respect to catalyst concentration, the optimum value for alkaline transesterification is 1%. Bhatti et al.2008 reported that as the catalyst concentration increases, the biodiesel production increases as well until a maximum concentration of 1%. The maximum biodiesel production is achieved using a molar ratio of 1:6 for oil: methanol (Mohammed & Amru, 2017). Carbon monoxide emissions from petro diesel are always higher than biodiesel. It could also possibly be because biodiesel itself has approximately 11% of oxygen content which will enhance the completion of its combustion. (Ramadhas et al., 2005).

In another study discarded marine and freshwater fish-waste was utilized as renewable, cost-effective sources for biodiesel production. Results showed that marine fish waste contains more lipids compare to freshwater fish waste. Microwave lipid extraction was nearly 30-50% more efficient as compare to conventional. Microwave assisted transesterification of lipid shows cleaner and greener method in terms of energy and solvent utilization with reduced time and efficient reaction rate. Analysis showed the presence of methyl ester of palmitic acid, oleic acid, stearic acid were the essential components of marine fish biodiesel. (Jaiswal et al., 2014).

Production of fish oil biodiesel by alkaline catalysis with 5:1 molar ratio of methanol to fish oil at 60°C, and transesterification was carried out by using potassium hydroxide as catalyst. The fish methyl ester recovered was 74.82 gram from 87 g of fish oil at the following standard conditions. Molar ratio of methanol to oil 5:1, Reaction time 60 min, Catalyst concentration 1%, Reaction temperature 60 °C, Settling time 2.5 hour. Various fuel properties such as pour point, cloud point, sulfur content, acid number and kinematic viscosity were determined. It was found that all the properties met the specifications of American Society for Testing and Materials (ASTM) standard. It was concluded by Girish et al., 2017, that production of biodiesel from fish waste has potential. First it will contribute to reducing environmental impacts, and it acts as a source of renewable energy to replace diesel and other petroleum products.

Residuals

Products of the transesterification reaction include not only biodiesel, but also by-products, soaps, glycerol, excess alcohol, and trace amounts of water. The principal by-product of the transesterification process is glycerol. Transesterification of vegetable oils produced 100kg of glycerol for every tonne of biodiesel manufactured. (McNeil et al. 2012) The bio-glycerine can substitute conventional fossil glycerine, helping manifold uses in the food and beverages industry, in medical and pharmaceutical applications, plastic industries and is used to yield nitro-glycerine (Meher et al., 2006; Srivastava and Prasad, 2000).

Biofuel Policy in India

In India first National Policy on Biofuels – 2018 as amended in 2022 (The gazette of India, 2018, The gazette of India, 2022) was declared in which, several measures were prescribed to produce biofuel from oil rich plant resources in different parts of India. Potential domestic raw materials for production of biodiesel fuels in the country as mentioned in the National Policy on Biofuels are, non- edible oilseeds, Used Cooking Oil (UCO), Animal tallow, Acid Oil, Algal feedstock etc. Abundant fish waste potentiality of India has not however been included in the National Policy of Biofuels.

3. Conclusion

The debate on the sustainability of biofuels is still open, and many complex issues are at stake (Tiziano,2015). These facts, however, do not hamper the relevance and significance of biofuels in the Indian context. Production of biodiesels may become a sustainable alternative to petro-diesel, through updated and new generation-based research and development in the biofuel sector. Kim et al. 2019 reported the development of an engineered bacterium *Rhodococcus opacus* that is found to have a much higher efficiency to produce, at a much higher rate, fatty acids and esters by utilizing lignocelluloses, one of the most abundant resources on the Earth, without depending of fossil fuels and vegetable or animal oils.

There is a rising anxiety for a clean and healthy environment. Current research paid attention on reducing the toxic exhaust emissions produced from burning petroleum and improving the performance of petro-diesel through blending with biodiesel.

Biodiesel is a renewable alternative fuel that can function in a diesel engine either pure or in blends with petroleum diesel. It has the potential of substituting petroleum diesel in the future or being used in blends with petroleum diesel for better performance and reduced toxic exhaust emissions. In terms of environmental assessment and renewability, biodiesel from fish wastes can contribute in reducing particulate matter emission, reduced emission of greenhouse gases and resultant decrease in air pollution.

Present study showed the high potentiality of discarded fish wastes to get converted to biodiesel. However research on the same is found to be very scanty in India. Hundreds of fish species both marine and freshwater are used for human consumptions thereby making enormous production of oil rich fish wastes in India. This renewable natural resource, obtained free of costs, should therefore be included as an efficient alternative to the vegetable oils in the National Policy on Biodiesel – 2018.

4. Conflict of interest

The authors declare no conflict of interest over research and publication of this article.

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6. Author's contribution
First author worked out the problem and prepared the manuscript under the supervision of the second author.

7. References

Abromovic H, Klofutar C.; 1998; The temperature dependence of dynamic viscosity for some vegetable oils. *Acta Chim Slov*.; 45(1):69.

Adebanjo AO, Dalai AK, Bakhshi NN.; 2005; Production of diesel like fuel and other value-added chemicals from pyrolysis of animal fat. *Energ Fuel*.19:1735–1741.

Aljaafari, A.; Fattah, I.M.R.; Jahirul, M.I.; Gu, Y.; Mahlia, T.M.I.; Islam, M.A.; Islam, M.S. Biodiesel Emissions: A State-of-the-Art Review on Health and Environmental Impacts. *Energies* 2022, 15, 6854.
https://doi.org/10.3390/en15186854

Ayyappan S.; 2014; National aquaculture sector overview, India. In: FAO, Fisheries and aquaculture department, Rome, in:
http: //www.fao.org/fishery/countrysector/naso_india/en.

Balat, M.; 2008; Global trends on the processing of biofuels, International *Journal of Green Energy*, 5, 212–238.

Benemann, J. 2013, Microalgae for Biofuels and Animal Feeds. *Energies* 6, 5869-5886. https://doi.org/10.3390/en6115869

Bhatti, H.N., Hanif, M.A. and Qasim, M.; 2008; Biodiesel production from waste tallow. *Fuel* 87(13): 2961-2966.

Çelik, M., Diler, A. and Küçükgülmez, A.; 2005; A comparison of the proximate compositions and fatty acid profiles of zander (Sander lucioperca) from two different regions and climatic conditions. *Food Chemistry*, 92, 637-641.

Clifford C. B. 2022. Alternative Fuels from Biomass Resources. in https://www.e-education.psu.edu/egee439/node/684

CPCB; 2002; Report on biodiesel as automobile fuel. in: http://www.cpcbenvis.nic.in/cpcb_newsletter/Biodiesel%20Newsletter.pdf

Crutzen, P.J., Mosier, A.R., Smith, K.A. & Winiwarter, W.; 2008; N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics* 8(2): 389-395.

Franco P. A., Shenbagavinayagamoorthi N. and Gandhi V. C. Sathish;2014; Performance and emission study of sardine fish oil biodiesel in a diesel engine, *Oxidation Communications* 37 (3), 802–816

Gedi M A, Bakar J, Maroid A A.; 2015;Optimization of supercritical carbon dioxide (CO2) extraction of sardine (SardinellalemuruBleeker) oil using response surface methodology (RSM). *Grasas Aceites*; 66 (2): 1 – 11.

Girish C. R., Mihir M. G. and Deshmukh T.; 2017; Production of Biodiesel From Fish Waste and Characterization of Produced Biodiesel. *International Journal of Civil Engineering and Technology,* 8(9); 01–06.

Haliloğlu, H. İ., Bayır, A., Sirkecioğlu, A. N., Aras, N. M. and Atamanalp, M.;2004; Comparison of fatty acid composition in some tissues of rainbow trout (*Oncorhynchus mykiss*) living in seawater and freshwater. *Food Chemistry,* 86, 55-59.

Hamed M. El-Mashada, Ruihong Zhanga, Roberto J. Avena-Bustillos;2008; A two-step process for biodiesel production from salmon oil. *Biosystems Engineering* 99, 220 – 227.

Handbook on Fisheries Statistics 2022. Department of Fisheries. Govt. of India.
He B. B., Van Gerpen J. H., Thompson J. C. 2009. Sulfur content in selected oils and fats and their corresponding methyl esters, *Applied Engineering in Agriculture*. American Society of Agricultural and Biological Engineers. Vol. 25(2): 223-226.

Jaiswal, K.K., Jha, B. and Prasath, R.A. (2014) Biodiesel Production from Discarded Fish Waste for Sustainable Clean Energy Development. *Journal of Chemical and Pharmaceutical Sciences,* 4, 113-114..

Jayasinghe, P., Adeoti, I. and Hawboldt, K.; 2013; A study of process optimization of extraction of oil from fish waste for use as a low-grade fuel. *Journal of the American Oil Chemists' Society,* 90, 1903 - 1915 .

Ken A.; 1987; Diesel engine performance with sun flower oil and fish oil. Journal of Senshu University-Hokkaido. *Natural Science*; 20:137–54.

Kim Hye Mi, Tong Un Chae, So Young Choi, Won Jun Kim and Sang Yup Lee; 2019; Engineering of an oleaginous bacterium for the production of fatty acids and fuels. *Nature Chemical Biology.* 15: 721–729.

Kywe TT, Oo MM.; 2009; Production of biodiesel from jatropha oil (Jatropha curcas) in pilot plant. *Proceedings of World Academy of Science, Engineering and Technology*; 38: 2070–3740.

Lebedevas S, Vaicekauskas A, & Lebedeva G, ;2006; Use of waste fats of animal and vegetable origin for the production of bio diesel fuel: quality, motor properties, and emissions of harmful components. *Energ Fuel*; 20: 2274–2280.

Letisse M, Rozieres M, Hiol A, Sergent M, Comeau L. ; 2006; Enrichment of EPA and DHA from sardine by supercritical fluid extraction without organic modifier. I. Optimization of extraction conditions. *Journal of Supercritical Fluids* ; 38(1):27−36.

Lisboa, P., Rodrigues, A.R., Martín, J.L., Simões, P., Barreiros, S. &Paiva, A. ; 2014; Economic analysis of a plant for biodiesel production from waste cooking oil via enzymatic transesterification using supercritical carbon dioxide. *The Journal of Supercritical Fluids* 85: 31-40.

María J. R., Carmen M. F., Abraham C., Lourdes R. and Ángel P., 2009, Influence of fatty acid composition of raw materials on biodiesel properties, *Bioresource Technology*, Volume 100, (1),Pages 261-268,

Mathew P.T.; 2009; Fish Waste Utilisation in India. In. *Proceedings of the National Seminar on Conservation and Sustainability of Coastal Living Resources of India, Cochin.*

McNeil J., Paul D. and Felix S., 2012, Glycerine from biodiesel: The perfect diesel fuel, *Process Safety and Environmental Protection,* 90:, (3), 180-188

Meher L.C., D.V. Sager and S.N. Naik; 2006; Technical aspects of biodiesel production by transesterification – A review. *Renewable Sustainable Energy Review* 10: 248-268.

Mohammed Saifuddin and Amru N. Boyce; 2017;Biodiesel Production from Fish (*Cyprinus carpio*) Waste and Evaluation of Engine Performance. *Sains Malaysiana* 46(10) pp. 1771–1778

Nahian, Md. R., Islam, Md. N., and Khan, S. 2016, Production of Biodiesel from Palm Oil and Performance Test with Diesel in CI Engine. International Conference on Mechanical, Industrial and Energy Engineering.

NFDB National Fisheries Development Board; 2019; http://nfdb.gov.in/about-indian-fisheries.htm

Oliveira L. E., Barboza J. C. S., Da Silva M. L. C. P.; 2013; Production of ethylic biodiesel from Tilápia visceral oil. *RE&PQJ*, Vol.1, No.11.https://doi.org/10.24084/repqj11.412

Parandhaman B., Kumar A. D., Krishna K. J., Sathish T. R., Kumar. N. Sathish; 2017; Recent Trends in Biodiesel by using Fish Fat Oil Blends with Diesel. *International Journal of Engineering Science and Computing*. 7 (4): 10043 – 10045.

Patil, A. K, Godiganur, S, Reddy, R. P.;2013;Biodiesel Fuel Production by Methanolysis of Fish Oil Derived from the Discarded Parts of Marine Fish, *International Journal of Scientific & Engineering Research;* 4; 1855-1860.

Preto F, Zhang F, Wang J.; 2008; A study on using fish oil as an alternative fuel for conventional combustors. *Fuel.*; 87:2258–68.

Ramadhas, A.S., Muraleedharan, C. & Jayaraj, S. 2005; Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy* 30(12): 1789-1800.

Rasal R.,Ghaysundar M and Ashwin G.; 2017; Review on Performance and Emission characteristics of different types Fish oil biodiesel as an alternative to the conventional Diesel fuel in C.I. Engine. *International Research Journal of Engineering and Technology (IRJET)* Volume: 4(5). 405 – 410.

Ratkowsky, D. A., Olley, J., Jayasinghe, J. A. G. and Wijesundara. R. C.; 1996; A consistent correlation between monounsaturated and n-3 polyunsaturated fatty acids in flesh of fish caught at different latitudes. *ASEAN Food Journal*, 11, 43-47

Rubio-Rodriguez N, De Diego SM, Beltran S, Jaime I, Sanz MT, Rovira J.; 2012; Supercritical fluid extraction of fish oil from fish by-products: A comparison with other extraction methods. *Journal of Food Engineering*; 109: 238–248.

Rukunudin I H, White P J, Bern C J,; 1998; A modified method for determining free fatty acids from small soybean oil sample sizes. *J Am Oil Chem Soc.*; 75. (5):563–568.

Sahena F, Zaidul I S M, Jinap S, Jahurul M H A, Khatib A, Norulaini N A N. ; 2010; Extraction of fish oil from the skin of Indian mackerel using supercritical fluids. *Journal of Food Engineering*; 99:63–69.

Sahu, M., V.K.Gour, & Gupta, S. (2008). Jatropha oil: an eco-friendly sustainablebio-fuel source. *I Control Pollution,* 24.

Saito, H., Yamashiro, R., Alasalvar, C. and Konno, T.; 1999. Influence of diet on fatty acids of three subtropical fish, subfamily caesioninae (*Caesio diagramma* and *C. tile*) and family siganidae (*Siganus canaliculatus*). *Lipids*, 34, 1073 - 1082.

Serrano. L., Carreira. V., Carama. R., & Gameiro da Silva. M.; 2012; On-road performance comparison of two identical cars consuming petrodiesel and biodiesel. *Fuel Processing Technology*, 103, 125-133.

Sharma Y.C., Singh B., Madhu D., Liu Y., Yaakob Z.; 2014; Fast synthesis of high quality biodiesel from 'Waste Fish Oil' by single step transesterification. *Biofuel Research Journal* 3: 78-80.

Son S M, Kusakabe K, Guan G.; 2010; Biodiesel synthesis and properties from sunflower and waste cooking oils using CaO catalyst under reflux conditions. *J appl Sci*.; 10.(4):3191–3198.

Srivastava, A. and Prasad, R.; 2000; Triglycerides based diesel fuels. *Renewable and sustainable energy Reviews*, 4: 111-133.

Swapna H. C., A. K. Rai, N. Bhaskar, N. M. Sachindra; 2010; Lipid classes and fatty acid profile of selected Indian fresh water fishes, *J Food Sci Technol.* 47(4) 394-400.

Tanaji G. Kudre, N. Bhaskar, Patiram Z. Sakhare; 2017; Optimization and characterization of biodiesel production from rohu (*Labeo rohita*) processing waste. *Renewable Energy*: 113 (C), 1408-1418

The gazette of India, 2018, Ministry of Petroleum and Natural Gas. No.202.

The gazette of India, 2022, Ministry of Petroleum and Natural Gas. No.156

Tiziano Gomiero; 2015; Are Biofuels an Effective and Viable Energy strategy for Industrialized Societies? A Reasoned Overview of Potentials and Limits. *Sustainability*, 7: 8491-8521.

Yuvaraj D., Bharathiraja B., Rithika, J., Dhanasree, S. Ezhilarasi, V., Lavanya, A. & Praveenkumar; R. 2016. Production of biofuels from fish wastes: an overview, *Biofuels*, DOI: 10.1080/17597269.2016.1231951