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Microalgae Oil as Bio-lubricant- A Review

[1]Monika P, [1]Adarsh K V,[1]Harish K,[1]N Sai Vinay, [2]Niranjan Hiremath
[1] Students, School of Mechanical Engineering, REVA University, Bengaluru, India
[2]Associate Professor, School of Mechanical Engineering, REVA University, Bengaluru, India

Abstract—In the current world environmental pollution is a major concern which is mostly affected by usage of wide variety of petroleum-based products which increases global warming. As a result, more environmentally friendly products are required especially in automotive field. In this concern we are producing a bio-lubricant which is eco-friendly and bio-degradable for industrial applications. There are many vegetable bio-oil extracts from neem, palm, jatropha etc., in current market but we chose Alga bio-oil due to its availability and environmentally friendly properties as a renewable resource. In this study, we extracted lipids from algae and converted that into glycerol by Transesterification process and further tested oil properties for viscosity and FFA percentage. Final obtained oil is tested for different lubricant properties. Experiments were conducted using four-ball tribometer. The results were compared with those of 20W50 mineral oil.

Index Terms—Absolute Viscosity, Bio-fuel, Density, Free Fatty Acids, Fire Point, Flash Point, Glycerol, Kinematic Viscosity, Micro-algae, Schizochytrium, Titration, Transesterification.

1 Introduction

For any machine which has moving or rotating parts needs lubrication. Lubrication is very much important for smooth functioning of machine components and to avoid the wear and tear in the machine. Like other reasons for failure of a machine, improper lubrication also plays a vital role. Lubrication can be done in many ways like using bearing between rotation parts and also by using lubricants like oils. Lubrication is the process of using material to reduce friction and wear between any two mating surfaces, and the material used is called a lubricant. A lubricant act as a protective layer which allows the two mating surfaces to be separated, thus reducing the friction. The applied load is carried by a pressure generated within fluid and frictional resistance to motion is from shearing of the viscous fluid.

Generally lubricant oil is mixture of 90% of base oil which is mostly petroleum product and 10% of additives. Enormous use of petroleum-based oils created ill effects on environment due to inappropriate usage leading to ground water contamination, air pollution, soil contamination and also affection on agricultural lands thus food contamination. To overcome these situations, various alternatives for petroleum-based oils are being explored which include synthetic lubricants and vegetable oil-based lubricants and other fossil fuel oils. Substituting mineral oils by other oils is advantageous as they are biodegradable, nontoxic. Considering the population of today many of these alternatives might extinct meanwhile resulting in inappropriate distribution of resources among the population. To overcome this issue looking into natural, bio-degradable and renewable resource should be the main objective.

Microalgae are a promising feedstock for the production of bio-fuels. Various bio-oils can be produced based on the chemical composition of the algal biomass feedstock. They include biodiesel, bio-ethanol, bio-butanol, bio-methane, jet fuel, bio-hydrogen, and thermochemical conversion products such as bio-oil, bio-crude and Syngas. A method for manufacturing an algal oil based bio-lubricant includes selecting a base algae strain with a fatty acid profile that includes oleic acid, introducing the base algae strain to a flue gas recycling system, introducing a lipid trigger to the flue gas recycling system to enhance the lipid production efficiency of the algae, harvesting the algae, extracting an algal oil from the algae that is more than 40% oleic acid, and converting the algal oil into bio-lubricant using chemical modification and/or the incorporation of stabilizing additives.

2 Literature Survey

Ching-Lung Chen et, al [2015]: Aimed to develop a novel micro-algal biodiesel producing method, consisting of an open system of microwave disruption, partial dewatering oil extraction, and transesterification without the pre-removal of the co-solvent, using Chlamydomonas sp. Direct transesterification with the disrupted wet microalgae was also conducted. [1]

Hamed KazemiShariat et, al [2019]: Aimed at reviewing, thermo-chemical conversion of microalgae into bio-crude oil through pyrolysis and hydrothermal liquefaction technologies. Subsequently, possible solutions to overcome the constraints to achieve the sustainable conversion of microalgae biomass are discussed in detail. The drawbacks of biocrude oil as a transportation fuel and the technologies required for its upgrading are highlighted. [2]

Jan Lorenzen1 et, al [2017]: Showed that microalgae are capable of producing up to 70% w/w triglycerides with respect to their dry cell weight. Since microalgae utilize the greenhouse gas CO_2, they can be cultivated on marginal lands and grow up to ten times faster than terrestrial plants, the generation of algae oils is a promising option for the development of sustainable bio processes, that are of interest for the chemical lubricant, cosmetic and food industry. [3]

Shoshana (Malis) Arad et, al [2006]: The rheological properties of the sulfated polysaccharide of the red microalga Porphyridium sp., a heteropolymerwith a molecular weight of 3-5 x106Da, indicated that this material might be an excellent candidate for lubricationapplications: the viscosity of the polysaccharide isstable over a range of temperatures, pH values, and salinities. In this study, various rheological and lubricant properties of the polysaccharide were evaluated in comparison with thoseof a widely used biolubricant, hyaluronic acid. The viscosity of the Porphyridium sp. polysaccharide remained essentiallyunchanged in a temperature range of 25-70 °C. In tribology tests on a ball-on-flat ceramic pair, the values for thefriction coefficient and wear rate for the pair lubricated with polysaccharide were remarkably lower than those forhyaluronic acid, especially at high loads. In a test on a steel ring/ultrahigh-molecular-weight polyethylene (UHMWPE)block pair, the wear tracks on the surface of the UHMWPE were more pronounced for hyaluronic acid than for thepolysaccharide. Atomic force microscopy showed that the polysaccharide was effectively adsorbed onto mica surfaces, forming ultrathin coating layers in the nanometer range. As isrequired for biolubricant applications, the polysaccharidewas not degraded by hyaluronidase. The stability of the Porphyridium sp. polysaccharide to heat and to hyaluronidasecombined with its ability to reduce friction and wear indicate its potential as an advantageous biolubricant.[4]

Meng Chen et, al [2010]: Production of biofuel from algae isdependent on the microalgal biomass production rate and lipid content. Both biomass production and lipid accumulation arelimited by several factors, of which nutrientsplay a key role. In this research, the marine microalgae Dunaliellatertiolectawas used as a model organismand a profile of its nutritional requirements was determined. Inorganic phosphate PO4-3 andtrace elements: cobalt (CO2+), iron (Fe3+), molybdenum (MO2+) and manganese (Mn2+) were identified as requiredfor algae optimum growth. Inorganic nitrogen in the form of nitrate NO3- instead of ammonium (NH4+) was required for maximal biomass production. Lipids accumulated under nitrogen starvation growthcondition and this was time-dependent. Results of this research can be applied to maximize productionof microalgal lipids in optimally designed photobioreactors.[5]

Ronald Halim et, al [2012]: The rapid increase of CO2 concentration in the atmosphere combined with depleted supplies of fossil fuelshas led to an increased commercial interest in renewable fuels. Due to their high biomass productivity, rapid lipid accumulation, and ability to survive in saline water, microalgae have been identified as promisingfeedstocks for industrial-scale production of carbon-neutral biodiesel. This study examines the principlesinvolved in lipid extraction from microalgal cells, acrucial downstream processing step in the productionof microalgal biodiesel. We analyze the different technological options currently available for laboratoryscalemicroalgal lipid extraction, with a primary focus on the prospect of organic solvent and supercriticalfluid extraction. The study also provides an assessment of recent breakthroughs in this rapidly developingfieldand reports on the suitability of microalgal lipid compositions for biodiesel conversion. [6]

I.V. Babich et, al [2011]: The pyrolytic conversion of chlorella algae to liquid fuel precursor in presence of a catalyst (Na2CO3) has been studied. Thermal decomposition studies of the algae samples wereperformed using TGA coupled with MS. Liquid oil samples were collected from pyrolysisexperiments in a fixed-bed reactor and characterized for water content and heating value.The oil composition was analyzed by GC-MS. Pretreatment of chlorella with Na2CO3influences the primary conversion of chlorella by shifting the decomposition tempera-tureto a lower value. In the presence of Na2CO3, gas yield increased and liquid yield decreasedwhen compared with non-catalytic pyrolysis at the same temperatures. However, pyrolysisoil from catalytic runs carries higher heating value and lower acidity. Lower content ofacids in the bio-oil, higher aromatics, combined with higher heating value show promisefor production of high-quality bio-oil from algae via catalytic pyrolysis, resulting in energyrecovery in bio-oil of 40%.[7]

S. Natarajan et, al [2017]: In this research, work is focused on the performance and emission characteristics of the CI engine fuelled withalgae oil diesel blend B20 with variable injection timing. Algaebased bio-diesel is receiving increased attentionin the recent yearsbecause of its low emission characteristics. Algae oil methyl ester isobtained from microalgae. The oil has been converted into biodiesel with the help of transesterification process. The experiment isconducted both by advancing and retarding the injection timing withvarious load conditions. The retardedinjection timing of 21°bTDCand 19°bTDC is selected for this study. For advanced injection timing 25°bTDCand 27°bTDC is adopted. The experimental results reveal that the brake thermal efficiency (BTE) increased by5.70% inthe advanced injection timing of 270bTDC with a massive reductionof CO by 81.25% and HCemission is reduced by 30 %. The smokeintensity is reduced by 26.39% at high load conditions. The retardation test showed significant decrease in NOx by 28% at high loadcondition. The exhaust gas temperature is alsoreduced by 7.8% byadvancing the injection timing at high load condition. [8]

Kaige Wang et, al [2014]: In this study, pyrolysis of microalgal remnants was investigated for recovery ofenergy and nutrients. Chlorella vulgaris (C. vulgaris) biomass was first solvent-extracted forlipid recovery then the remnants were used as the feedstock forfast pyrolysis experimentsusing a fluidized bed reactor at 500oC. Yields of bio-oil, biochar and gas were 53, 31, and10wt%, respectively. Bio-oil from C.vulgaris remnants was a complex mixture of aromaticsand straight-chain hydrocarbons, amides, amines, carboxylic acids, phenols and othercompounds with molecular weights ranging from 70Da to 1200Da. Structure and surfacetopography of the biochar was analyzed.The high inorganic content (potassium, phosphorous, and nitrogen) of the biochar suggests it may be suitable to provide nutrients for crop production. The bio-oil and biochar represented 57 and 36% of the energy conent of the microalgae remnant feedstock respectively. [9]

Kaige Wang et, al [2014]: Wereport an economically- and environmentally-promising microalgae biorefinerypathway, which usescatalytic pyrolysis with HZSM-5 catalyst to convert whole microalgaeinto aromatic hydrocarbons. This process produces valuable petrochemicals and ammonia, the latter of which can be recycled as afertilizer for microalgae cultivation. We tested samples of lipid-leangreen microalgae, Chlorella vulgaris, at various reaction temperturesand catalyst loads. We also tested samples of lignocellulosic biomass, red oak, forcomparison. Our results demonstrated thatcatalytic pyrolysis of microalgae produces betteraromatic yields andbetter aromatic distributions catalytic pyrolysis of red oak. Themaximum carbon yield of aromatics from microalgae was 24%, whilethat from red oak was16.7%. Moreover, catalytic pyrolysis of microalgae produced more monocyclic aromaticsthan were producedby catalytic pyrolysis of lignocellulosic biomass. Microalgae presentmany advantages as a feedstock for bio fuel. [10]

PeigaoDuanet, al [2010]: We determined the influence of a Pt/C catalyst, high-pressure H2, and pH on the upgrading of a crudealgal bio-oil in supercritical water (SCW). The SCW treatment led to a product oil with a higher heatingvalue (-42 MJ/kg) and lower acid number than the crude bio-oil. The product oil was also lower in O andN and essentially free of sulfur. Including the Pt/C catalyst in the reactor led to freely flowing liquidproduct oil with a high abundance of hydrocarbons. Overall, many of the properties of the upgradedoil obtained from catalytic treatment in SCW are similar to those of hydrocarbon fuels derived from fossilfuel resources. Thus, this work shows that the crude bio-oil from hydrothermal liquefaction of a microalgacan be effectively upgraded in supercritical water in the presence of a Pt/C catalyst. [11]

M. A. Mohammad Mirzaie et, al [2016]: As a new interest for biodegradable non-hazardousbiolubricant from renewable resources, microalgae lipid issuggested as a new feedstock by introducing the microalgaebasedlubricants. Chlorella vulgaris was successfully grownin a cheap substrate-based mixotrophic medium. The kineticodeling of microalgae growth, lipid production, and substrateconsumption was carried out in optimum conditions ofbiomass productivity and lipid production to enhancemicroalgae lipid for biolubricant production. Designedmodels have good compatibility with more than 95 % confidencelevel when compared to the cultivation system. Validation of the models with additional experiments confirmedthe accuracy of the models to predict new conditions. The highest biomass concentration of C. vulgaris was2.9 g L-1 with a lipid content of 30 % of dry weight. Themodel proposed for lipid production indicated that the lipidwas produced simultaneous with growth. Microalgae lipidhad sufficient lubricating property showing that thismicroalgal lipid could be used as potential feedstock forbiolubricant production. [12]

Jan Lorenzen et, al [2010]: Microalgae are capable of producing up to 70% w/w triglycerides with respect to their dry cell weight. Since microalgae utilize the greenhouse gas CO2, they can be cultivated on marginal lands and grow up to ten times faster than terrestrial plants, the generation of algae oils is a promising option for the develop ment of sustainable bioprocesses, that are of interest for the chemicallubricant, cosmetic and food industry. For the first time we havecarried out the optimization of supercritical carbondioxide (SCCO2) mediated lipid extraction from biomass of the microalgae Scenedesmus obliquus and Scenedesmus obtusiusculus under industrially relevant conditions. All experiments were carried out in an industrialpilot plant setting, according to current ATEX directives, with batchsizes up to 1.3 kg. Different combinations of pressure (7-80 MPa), temperature (20-200 °C) and CO2 to biomass ratio (20-200) havebeen tested on the dried biomass. The most efficient conditions werefound to be 12 MPa pressure, a temperature of 20°C and a CO2 tobiomass ratio of 100, resulting in a high extraction efficiency of up to92%. Since the optimized CO2 extraction still yields a crude triglyceride product that contains various algae derived contaminants, suchas chlorophyll and carotenoids, a very effective and scalable purification procedure, based on cost efficient bentonite based adsorbers, was devised. In addition to the sequential extraction and purificationprocedure, we present a consolidated online-bleaching procedure foralgae derived oils that is realized within the supercritical CO2 extraction plant.[13]

MordhayAvron et, al [1978]: A process for the production of glycerol and proteinous substances of nutritive value which comprises cultivating algae of the Dunaliella species in a nutrient medium containing the mineral requirements of growth of the algae, said nutrient medium having a sodium chloride content of at least 1.5M, the cultivation being effected while an adequate supply of carbon dioxide is provided and continued until a maximum concentration of algae is obtained, and continuing the cultivation of the algae in a nutrient medium having a content of sodium chlo ride of at least 3M, cultivating the algae in this second nutrient medium until a high glycerol content is established, harvesting the algae, recovering from same the glycerol, and recovering the residue having a high pro tein content. [14]

BILL J. CHEN and C. H. CHI [1981]: This article proposes and develops a process for large-scale production of glycerol by means of a halophilic alga. The process is shown to be economically and technically feasible. Although the proposed process is extremely capital intensive, the total production cost is competitive with existing glycerol processes. In addition, the overall energy requires- ment is much lower than that of the petrochemical process. This proposed process provides an alternative route for glycerol production that is minimally dependent on fossil fuels and is, therefore, less sensitive to crude oil availability and price. The primary raw material, carbon dioxide from stack gas, is an inexpensive and renewable resource. Maximal utilization of solar energy is made not only in the glycerol synthesis steps but also in the product recovery system. Significant improvement in the process economics can be realized through further development of large-scale cultivation technology, and biomass distribution and collection machinery. Due to the labor-intensive nature of the proposed algal process, it is particularly suitable for less developed nations with limited fossil fuel resources and lower labor costs. [15]

Zhanyou Chi et, al [2007]: Crude glycerol is the primary byproduct in the biodiesel industry, which is too costly to be purified into to higher quality products used in the health and cosmetics industries. This work investigated the potential of using the crude glycerol to produce docosahexaenoic acid (DHA, 22:6 n-3) through fermentation of the microalga Schizochytriumlimacinum. The results showed that crude glycerol supported alga growth and DHA production, with75-100g/Lconcentrationbeingtheoptimalrange.Amongothermediumandenvironmentalfactorsinfluencing DHAproduction, temperature, trace metal (PI) solution concentration, ammonium acetate, and NH4Cl had significant effects ($P < 0.1$). Their optimal values were determined 30 mL/L of PI, 0.04 g/L of NH4Cl, 1.0 g/L of ammonium acetate, and 19.2 °C. A highest DHAyield of 4.91 g/L with 22.1 g/L cell dry weight was obtained. The results suggested that biodiesel-derived crude glycerol is a promising feedstock for production of DHA from heterotrophic algal culture. [16]

Anand G. Chakinala et, al [2010]: In this study, we present the gasification of microalgae (Chlorella Vulgaris) and glycerol in supercritical water (SCW) using batch (quartz capillaries) and continuous flow reactors. Preliminary tests of algae gasification were done with quartz capillaries at varying operating conditions such as temperature (400-700 °C), reaction time (1-15 min), and the addition of catalysts. The dry gas composition of uncatalyzed gasification of algae in SCW mainly comprised of CO2, CO, CH4, H2, and some C2-C3 compounds. Higher temperatures, low algae concentrations, and longer residence times favored the algae gasification efficiency (GE). The addition of catalysts to the capillaries resulted in higher yields of hydrogen and lower CO yields via enhanced water-gas shift activity. The addition of catalysts accelerated the gasification efficiency up to a maximum of 84% at 600 °C and 2 min reaction time with nickel-based catalysts. Complete gasification is achieved at higher temperatures (700 °C) and with excess amounts of (Ru/TiO2) catalyst. To elucidate part of the difficulties related to the SCWG of algae, reforming of a model compound (here glycerol) in SCW was carried out in a continuous flow reactor in the presence of additives like amino acids (L-alanine, glycine, and L-proline) and alkali salt (K2CO3) and combinations thereof. The amino acids L-alanine and glycine have a minor effect on the gasification process of glycerol, and a significant reduction of the gasification efficiency was observed in the presence of L-proline. Coke formation and colorization of the reactor effluent were more noticeable with glycerol-amino acid mixtures. In the absence of amino acids, the glycerol solution gasified without any coke formation and colorization of the reactor effluent. Again, this effect was more pronounced in the presence of L-proline. The addition of K2CO3 enhanced the glycerol gasification efficiency and increased the hydrogen yields promoting the water-gas shift reaction. [17]

John Kennedy Mwangi et, al [2015]: Microalgae can be used as a biological photocatalyst to reduce the CO2 levels in the atmosphere, with the advantage of not competing with food crops for arable land, and thus offer a potential method for limiting climate change. Microalgae have also been proposed as a sustainable fuel source. This study investigated the microalgae harvest yields, the thermogravimetric behavior of both microalgae oil and microalgae residue, the torrefaction of microalgae residue, and diesel engine tests using diesel-microalgae biodiesel blends. The mean annual harvest rate of microalgae oil in open ponds was found to be 4355 kg per 10000 m2. Compared with conventional diesel, the fuel blends - B2 (2% microalgae biodiesel + 98% conventional diesel), B2-But20 (B2 + 20% Butanol) and B2-But20-W0.5 (B2-But20 + 0.5% water) showed a reduction of 22.0%, 57.2%, and 59.5% in PM emissions, and a decrease of 17.7%, 31.4% and 40.7% in BaPeq emissions, while B2-But20 and B2-But20-W0.5 had reduced NOx emissions, of approximately 25.0% and 28.2%, respectively, but B2 showed a 2.0% increase in NOx emissions. Conversely, the addition of water and butanol fractions in diesel increases HC and CO emissions, although these can be easily removed using tailpipe catalysts and absorbers. In addition, torrefaction of microalgae residue results in solid, liquid and gas products. This study is the first of its kind to report the liquid compositions from the torrefaction of microalgae residue. The condensate liquid products contained glucose molecules like 1,4:3,6-Dianhydro-α-d-glucopyranose, and furfural, limonene, pyridine, levoglucosan, and aziridine, among others. These compounds can be utilized as microalgae value added products, and applied in specialty industries as pharmaceutical, cosmetic, or solvent raw materials. Briefly, microalgae not only offer benefits in reducing CO2 from the atmosphere or providing raw materials for biodiesel production, but microalgae residue can also be treated via torrefaction to produce biochar. Based on the results of this study, more research is recommended on the economic potential of using both solid and liquid products from microalgae torrefaction. [18]

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