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Possibilities for conversion of microalgae oil into aviation fuel: A review

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ABSTRACT

The aviation sector relies on petroleum jet fuel because it is the most efficient energy carrier. Due to environmental and economic concerns a strong demand for alternative fuels is emerging. There is a need for diversification of energy sources from natural resources. These resources must be environmentally friendly and costs effective. Environmental impacts of fossil fuels on global warming and climate change are being a major concern today. Furthermore, the fluctuations of oil prices and need for sustainable fuel supply are the strong drivers for the economies of fuel users. In the aviation sector, Jet fuel from microalgae is one of the alternatives receiving considerable attention; it offers the potential to diversify energy sources. Microalgae species can produce lipids; they do not require high use of land, do not need freshwater, can grow in marine water or wastewater, grow faster in very short period of time, the produced oil is not a threat to food security. Similarly, the effect of climate change and global warming due to the generation of greenhouse gases (GHG) from petroleum jet fuel can be considerably reduced due to low carbon footprint generated by algae based fuels. Therefore, algae based aviation fuels can be considered as an alternative to produce an efficient fuel compared to conventional fuels. Conversely, the key challenge is: many algae species have lower lipid content. Harvesting and drying processes are costly as well as upstream processes to convert microalgae oil into Jet fuel. Although algae biofuels are still small players in the aviation industry, there is a potential for the future. This review analyses some routes to be explored or already explored, their strengths and weaknesses, the current trends and possible conceptual approaches to get aviation fuel from microalgae oil.

1. Introduction

Global reserves of petroleum oil have decreased significantly during the last decades; a probable energy crisis could severely affect the world in the near future. Environmental and economic concerns are pressurizing the aviation industry to an extent of strongly influencing the industry growth. Despite the implementation of many international treaties aiming for the promotion of environmental sustainability, the aviation industry is requested to work toward the reduction of its environmental impacts. It can only be achieved by developing new technologies or by upgrading the current ones. Therefore, this will successfully promote the concept or idea of green aviation. An average of 705 Mt of CO_2 has been generated in 2013 from airlines operations; it is almost 2–3% of global anthropogenic CO_2 emissions [1]. Predictions show that this figure will increase between 1000 and 3100 Mt by 2050. The aviation industry has given itself a target to reach a carbon neutral growth status by 2020 [1]. It is achievable through the pillars of innovation with main focus on operations, air traffic management, environmental protection, safety and fuel processing technology and sustainability. Focusing on the last one, renewable energy from biofuels may constitute an acceptable alternative and possibly a reliable option in case the energy crisis deepens in the near future. However, production costs for bio- Jet fuels are relatively higher compared to those for conventional Jet fuels. Consequently, the selling price may become exorbitant. Higher production costs are attributed to factors such as relative immaturity of the technology, small number of active producers; producers of biofuels are focusing more on novel end products because of low funding in the biofuel markets. Also, the costs of raw materials may be another cause of higher production costs for biofuels. It is reported that 80% of the operating costs is made up of raw materials costs regarding biofuel/ biodiesel production [2]. Therefore, it is necessary to look for suitable and alternative raw materials or crops capable of producing non-edible oil at low costs to produce biofuels than using edible vegetable oil for biofuel production.

Microalgae species such as nannochloropsis sp, tetraselmis sp, Chlamydomonas sp, Synechococcus sp. and many others can be an acceptable alternatives compared to the edible oil used domestically because they do not constitute a threat to food security. They are

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photosynthetic cells growing at very high rates in an aquatic environment. Also, they are considered as emerging alternatives for biofuel production because their composition reveals a remarkable presence of fatty acids and lipids. Fatty acids and lipids are the main sources of energy for biofuels. Similarly, According to Rodolfi (2009) [3], they have attracted great attention in the biofuel market because of their high capacity to accumulate abundant amounts of triacylglycerols (TAG). These species are mainly used in the production of biofuels such as biodiesel, bio-hydrogen and bio-Jet fuel. Bio-Jet fuel from algae is gaining more interest and might become a very important deal with global implications in the near future. Firstly, there is a great focus on aviation biofuels to reduce the impact of climate change and global warming. This will also assist in reducing the operating costs in the aviation industry. Secondly, the petroleum or conventional Jet fuel prices and their volatility have a severe impact on the business of airlines: because of fuel price fluctuations there are rippling repercussions to economies of many airlines as well as many countries. Furthermore, there is a big market for Jet fuel which is currently being served partially and the demand has kept its increasing trend due to the need which is growing yearly. The world consumption of Jet fuel has almost tripled in 30 years; from 1,837,000 barrels/per day in 1980, to 5,220,000 barrels per day in 2010. About 30% of the world consumption was used in the United States (1,398,130 barrels per day in 2012) [4]. These data are used for information regarding the trends but new data should be more informative.

Producing algae Jet fuel will require a comprehensive identification of the potential technical, economic and environmental challenges. Once these challenges are clearly identified and solved properly, there is a possibility to make bio-Jet fuel from algae “a drop in” fuel which will strictly comply the aviation fuel standards. The objective of this review is to highlight, analyse and suggest some possibilities/ processes or routes that will lead to Jet fuel from microalgae oil. This study focuses on downstream processes, the feasibility, their strengths and weaknesses. It is important to stress on the fact that various routes for algae Jet fuel production are technically possible but not costs effective and commercially viable to compete with conventional Jet fuel. The economic studies and historical developments are not part of this article as they can be part of another detailed and specific study in the future.

2. Common points between petroleum crude oil and algae crude bio-oil

Algae bio-crude oil extracted from species such as Nannochloropsis sp, Schizochytrium sp, Botryococcus braunii and many other species may have many similarities with petroleum crude oil in terms of hydrocarbons content and molecular structure [5]. The majority of petroleum crude oil originates from algae in marine environment or ancient algae deposit [6]. Petroleum crude oil consists largely of liquid hydrocarbons because it is mainly made up of carbon and hydrogen. On average 85% w/w of oil is carbon, 10–14% of oil is hydrogen, oxygen accounts for 1–2% and sulphur represents up to 4% of the oil total weight [7]. Petroleum crude oil originates from a compound named Kerogen; this compound is created in marine environment by sedimentary rocks from a series of biochemical and/or chemical reactions called diagenesis and catagenesis [8]. It is transformed into crude oil under specific conditions of pressure and temperature. It is largely composed with algae, biodegraded organic compounds, plankton, bacteria and plant material. Various forms of Kerogen have different amounts of hydrogen relative to carbon and oxygen [8]. Qualitatively, algae crude bio-oil have a similar molecules compared to petroleum crude oil, however, there are some differences quantitatively [5]. This is based on the fact that petroleum crude oil is derived from Kerogen and algae is part of Kerogen as mentioned before. However, algae crude bio-oil may differ slightly from petroleum crude oil depending on species features: the type and nature of species, as well as the species lipids content. Therefore, one of the main focuses of algae biotechnology is the development of biofuels making use of microalgae as the main raw material.

3. Compliance and current drivers for alternative jet fuels

The biggest challenge for algae biofuel producers is to make a Jet fuel which is totally compliant to stringent regulations as it is the case with conventional Jet fuel. Compliance is mainly focusing on physico-chemical properties or parameters such as cold flow property, energy density, energy content, kinetic viscosity, freezing point, concentration of aromatics, material compatibility, safety properties, flash point and thermal stability. The concept of compliance must also at the time be centred on combustion and kinetic aspects such as ignition and extinction characteristics, chemical kinetics, lubricity flame speed and flammability limits. Table 1 provides an overview of some requirements based on physico-chemical characteristics, the operational purpose as well as the specifications. Furthermore, compliance implies that Jet fuel composition must display specific physico-chemical characteristics that are critical for the fuel to perform efficiently. These features must strongly correlate with the composition of Jet fuel knowing that the composition depends mainly on the raw crude oil, the type of refining process used and additives to improve the quality of Jet fuel. Generally, conventional Jet fuel composition is made up roughly of 20% paraffin, 40% isoparaffin, 20% naphthenes and 20% aromatics [9]. However additions are made to the Jet fuel in order for it to comply with environmental aspects and the expected performance. This data is given for information only and reports only on the main components of jet fuel. These components play a crucial role in the effectiveness of the fuel during operation. For instance, the heat density per unit mass of the fuel is greatly improved when the ratio hydrogen-to-carbon from isoparaffins and paraffins is high; another fact is that naphthenes assist

Table 1
Summary of important jet fuel properties (derived from [11]).

Parameters	Purpose
High energy density	Impacts on the aircraft range
Low freezing point	Influences pumping capacity of the fuel at lower temperature
High thermal stability	Clogging or fouling of fuel system and nozzles occur generally due to Coke and gum deposits during combustion. It prevents the chemical decomposition of the fuel.
Viscosity	Influences the ability of the fuel nozzles to spray fuel and the capacity of the engine to restart at higher altitudes.
Combustion features	To minimise the formation of particulates in combustor and in exhaust
Adequate lubricity	Affects the ability of the jet fuel to lubricate fuelling system and engine controls
Material compatibility	The Jet Fuel interacts with metals and many others materials, it necessary to ensure an effective compatibility with materials in contact with jet fuel.
Safety	Avoidance of explosions during handling of the jet fuel and during its storage into containers
High specific energy	Decreases take-off weight and helps to improve the efficient of the fuel
High flash point	Allow the fuel ignition for safe operation
Aromatic compounds	Must be sufficient because it allows acceptable seal swell to prevent leaks in the fuel system.