COMPARISON OF BIOFUELS IN JET ENGINE COMBUSTION CHARACTERISTIC USING COMPUTATIONAL FLUID DYNAMICS

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by

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LIST OF SYMBOLS

D	Body Diameter
$\frac{\Delta P_L}{q_{ref}}$	Liner Pressure Drop Factor
PF	Pattern Factor
A_L	Liner Area
L	Total Length
A_{in}	Inlet Area
A_{out}	Outlet Area
n_B	Number of Swirler Blades
D_{in}	Inner Diameter
k_{eff}	Effective Conductivity
$\vec{J}_j$	Diffusion Flux of Species j
j	Species
S_h	Heat of Chemical Reaction

LIST OF ABBREVATIONS

ANZ	Air New Zealand
ARC	Agricultural Research Center
ASTM	American Society for Testing and Materials International
CAD	Computer-Aided Design
CAL	Continental Airlines
CFD	Computational Fluid Dynamics
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVCC	Constant-Volume Combustion Chamber
DCN	Derived Cetane Number
EINOx	Emission Index Nitrogen Oxide
EPA	Environmental Protection Agency
FAME	Fatty Acid Methyl Esters
FEA	Finite Element Analysis
FT	Fischer-Tropsh
GHG	Green House Gas
HC	Hydrocarbon
HEFA	Hydroprocessed Esters and Fatty Acids
HEFA-SPK	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene
HRJ	Hydrotreated Renewable Jet
IATA	International Air Transport Association

JAL	Japan Airlines
LESS	Low Emission Stirred Swirl
MiniJETRig	Miniature Jet Engine Test Rig
NO	Nitric Oxide
NOx	Nitrogen Oxide
PDPA	Phase Doppler Particle Analyzer
RFS	Renewable Fuel Standard
SO	Sulphur Monoxide
SPK	Synthetic Paraffinic Kerosene
TRCC	Toroidal Re-entrant Combustion Chamber
UCOs	Used Cooking Oils
UHC	Unburnt HydroCarbons
WAFs	Wasted Animal Fats
WHO	World Health Organisation

PERBANDINGAN ANTARA BAHAN API BIO TERHADAP CIRI-CIRI PEMBAKARAN ENJIN JET MENGGUNAKAN PERKOMPUTERAN DINAMIK BENDALIR

ABSTRAK

Pengurangan sumber dan pencemaran alam sekitar yang disebabkan oleh industri penerbangan telah menjadi isu yang teruk yang menyebabkan peningkatan kesan rumah hijau. Penggunaan bahan api bio telah menjadi pilihan untuk mengurangkan masalah yang berkaitan dengan sumber daya yang tidak dapat diperbaharui. Walau bagaimanapun, bahan api bio tidak mudah diperoleh dan kerja eksperimental untuk mengkaji prestasi bahan api bio juga mahal. Oleh itu, simulasi perkomputeran dinamik bendalir (CFD) adalah cara yang mudah untuk mengkaji ciri-ciri pembakaran bahan api bio. Kajian ini menunjukkan simulasi berkomputasi yang mengenai ciri pembakaran pelbagai bahan bakar alternatif dalam geometri ruang pembakaran yang sebenar. Bahan api bio yang digunakan dalam kajian ini adalah jenis bahan api biodiesel, alga dan asid lemak dihidrat (HEFA) yang didapat dari Camelina. Sementara itu, Jet-A digunakan sebagai bahan bakar dasar. Sifat bahan bakar dan ciri pembakaran akan diselidiki dan dianalisis. Hasil analisa akan ditunjukkan dalam profil suhu dan tekanan serta pembentukan oksida nitrat dan jelaga yang dihasilkan dari ruang pembakaran. Hasil analisa menunjukkan bahan api HEFA adalah bahan api bio yang paling disyorkan di antara keempat-empat bahan api yang diuji kerana didapati bahawa bahan api ini terbakar dengan suhu 37.6% lebih rendah; tekanan 15.2% lebih rendah; pelepasan oksida nitrat lebih 89.5% rendah dan pelepasan jelaga 8.1% lebih rendah berbanding dengan bahan bakar dasar. Dengan itu, bahan api HEFA yang dipilih terbakar dengan tenaga yang tinggi dan bahan pencemar yang rendah.

COMPARISON OF BIOFUELS IN JET ENGINE COMBUSTION CHARACTERISTIC USING COMPUTATIONAL FLUID DYNAMICS

ABSTRACT

Rapid decreasing of resources and environmental pollution caused by aviation industries have become a severe issue which leads to increases in the greenhouse effect. The use of biofuel becomes an option to alleviate issues related to unrenewable resources. However, the biofuel is not easy to obtain and experimental work to study biofuels' performances will be costly. Therefore, computational fluid dynamics (CFD) simulation is a feasible way to study on the biofuel combustion characteristics. This study presents a computational simulation on the biofuel combustion characteristics of various alternative fuels on a real combustion chamber geometry. The biofuels used in this study are biodiesel derived from Sorghum, algae extracted from Spirulina platensis and hydrotreated ester fatty acid types of fuel (HEFA) made from Camelina. Meanwhile, Jet-A is used as a baseline fuel. The fuel properties and combustion characteristics are being investigated and analysed. The results are presented in terms of temperature and pressure profiles in addition to the formation of NOx and soot generated from the combustion chamber. Results obtained show that HEFA fuel is the most recommended biofuel among all four tested fuels as it is being found that it burns with 37.6% lower temperature; 15.2% lower pressure; 89.5% lower NOx emission and 8.1% lower soot emission compared with the baseline fuel. In other words, HEFA fuel burns with relatively high energy and low pollutants.

CHAPTER 1

INTRODUCTION

1.1 GENERAL INFORMATION

The rapid growth of the aviation industry is causing an increase in the greenhouse gas emitted into the atmosphere. In 2010, carbon dioxide (CO_2) emissions from international aviation amounted to 448 megatons, with forecasts of increased emissions ranging from 682 megatons to 755 megatons by 2020, and as high as 2700 megatons by 2050 if no action is taken [1, 2]. In 2015, the amount of carbon dioxide in the atmosphere from aviation was 780 million tons [3]. The total fuel consumption of global aviation is about 5 million barrels per day, which is equal to 5.8% of total fuel consumption in the world [4]. The jet fuel demand is estimated to grow by 38% from 2008 to 2025 with a mean growth rate of 1.9% per year [4]. Based on the Statistical Review of World Energy in 2016, there would be only about 115 years of coal production, and roughly 50 years of both oil and natural gas remaining [5].

Following the high consumption of fossil fuel, the production of nitrogen oxides (NOx) and soot emissions have been committed to photochemical smog and greenhouse gas (GHG) generation and this will be causing the reduction of the protective ozone layer in the stratosphere [6-8]. NOx gases are generated from the reaction of nitrogen gas and oxygen gas in the air during the burning process, especially at high temperatures. A significant amount of NOx is formed as the flame temperatures reach 2800°F (~1538°C) [7, 9, 10]. NOx has a lifetime of 1–2 weeks in the upper troposphere and lower stratosphere, at the same time it just has a lifetime of a few hours in the boundary layer [7, 10]. NOx generated at high attitude impacts mainly on the respiratory system causing inflammation occurred in the airways. Prolonged exposure to NOx causing decreasing the lung function of the human body and increasing the risk of having sickness in respiratory systems might as well increasing the reaction to various allergens. NOx also playing important roles in the formation of fine particles at ground-level ozone, which will associate with adverse health effects [7, 11, 12]. Thus, lower emission of NOx is required to ensure a healthy life [13, 14]. Soot is an undesirable product from hydrocarbon (HC) combustion and the emission of soot resulting from combustion process needs to be reduced to the maximum it could achieved [15], [16]. Nevertheless, there are circumstances where soot production is considered, for example, when the heat released from the combustion process needs to transfer to feedwater effectively [15]. However, soot emitted into the atmosphere have caused health problems to human as well as the environment. The diameter of soot particles is less than 100 nm. These particles would travel deep into the lungs, or might as well into the alveoli, and the particles even small enough to go through the cells and get into blood circulatory systems. This particle is able to be translocated to other organs in the human body, for instance, the heart, and the brain; as a result inducing severe health concerns like cardiovascular diseases in humans [17], [18], [19]. As for that reason, researchers have done extensive studies in replacing geological processed fuel with renewable resources. Biofuel is one of the common renewable resources that be able to slow down the rapid reduction of fossil fuel and more environmentally friendly as it can alleviate greenhouse gases emission [20-23].

The use of biofuels in aircraft can cut carbon particle emissions by 70% and also decrease the formation of contrails, which are adversely impacting the atmosphere [8, 14]. By 2017, The International Air Transport Association (IATA) has established the target of 10% use of biofuels which is consistent with the goal of the industry's carbon footprint with a reduction of up to 80% in the years ahead [14]. The use of biofuel has been implemented in the aerospace industry in stages. For example, in France, Airbus has become the first airplane manufacturer that provided the option of transporting their new jet by using blended sustainable jet fuel to its customers since the first delivery in May 2016 [6].

The main concern of the biofuel production from renewable resources is with relatively low GHG’s life cycle and sustainability at an economical price compared with other resources [22]. However, biofuel is able to issue both near-term and long-term solutions to the conventional aviation industries and the military aircraft with the lower environmental impacts compared with fossil-based fuels [24]. To have a clear picture in studying biofuels’ characteristics, it is important to comprehend the types and differences between biofuels. The main factors that decided the types of biofuels are the raw materials and the extraction processing. The three types of biofuels chosen are being investigated through these two perspectives.

Various type of biofuels has been developed. Biodiesel is possible in replacing petroleum-based diesel fuel. Renewable resources such as used oils, animal fats and oils derived from plants can be used to produce biodiesel [25-27]. Biodiesel consists of mono-alkyl esters of long-chain fatty acids. Most of the biodiesel productions are done by using edible oil, non-edible oil, and animal fats by acid or by base catalysed transesterification with ethanol or methanol [28-31]. Recently, edible oil is becoming one of the main resources in biodiesel manufacturing [32]. Nevertheless, there are plenty of intentions for not using edible oils as feedstocks in the manufacturing of biodiesel. Consuming edible oils in biodiesel manufacturing has big impacts on the global imbalance of market demand and food supply. This happens due to the high prices of feedstock, the depletion of food sources and the growth of commercial plant capacity. Thus, the most suitable way to solve this issue is to shift the use of edible resources to non-edible resources, that won't affect human nutrition and can be grown in the barren lands [33]. In the production of biodiesel, the active compounds in biodiesel are known as fatty acid methyl esters (FAME), that which are transferred from triglycerides into FAME in the reaction known as transesterification [34]. The most common process of producing biodiesel is shown in Figure 1.1.

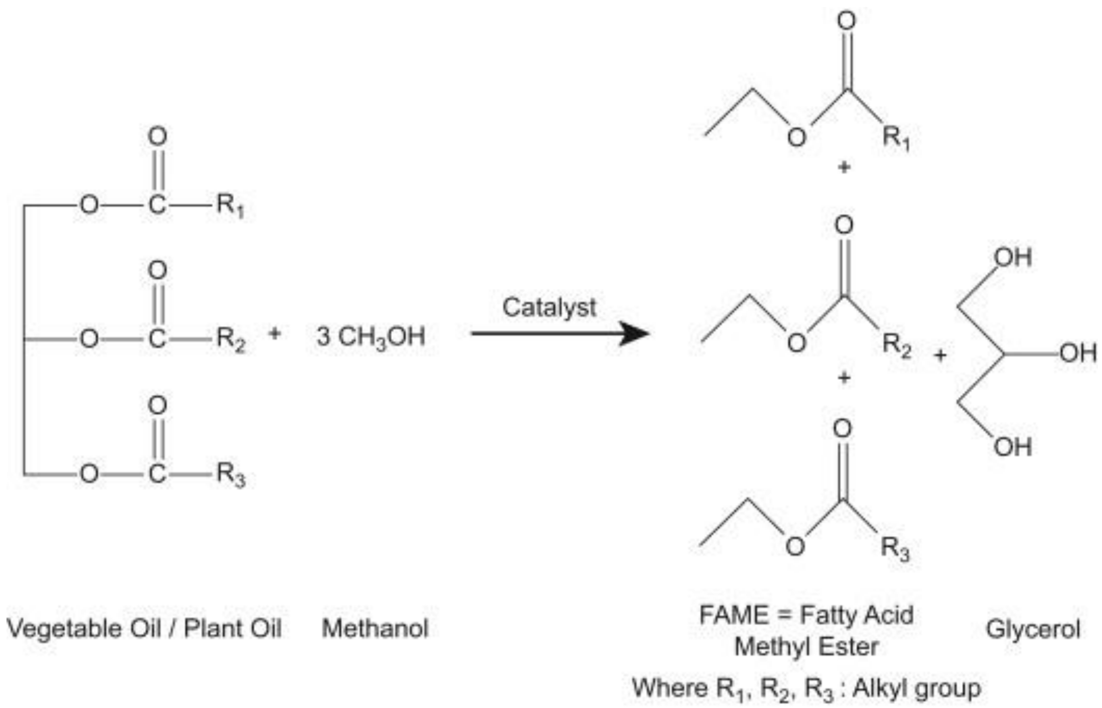

Figure 1.1 Process of Producing Biodiesel [25]

Biodiesel has physical properties that similar to the conventional diesel and it is also non-toxic and biodegradable. The application of different concentrations of biodiesel with Jet A-1 kerosene fuel has been implemented in jet engines such as MPM-20 [3]. However, the majority of the tested works are being carried out in the internal combustion engines or diesel engines [35]. In this research, the biodiesel fuel with being tested in the running of simulation through ANSYS to investigate the flow characteristics and combustion characteristics.

The second biofuel chosen in this study is the algae fuel, and the study of algae fuel is started with reviewing the process of algae fuel production. The production of biofuel from algae is shown in Figure 1.2. The fuel is produced using a process called transesterification. In this process, an alcohol and an ester compound are mixed and produced a different type of alcohol and a different type of ester [21, 36]. This process allows the oil extracted from the algae to be converted into biofuel through a specific chemical reaction [37, 38]. Additionally, the fuel can also be developed from a process called fermentation [39]. In this process, algae are cultivated in closed containers and fed with sugar to speed up their growth. This method eliminates all margin of error since all the environmental factors are under-controlled [40]. However, the growth of algae requires a carbon source which raises an issue for the system as it will result in producing CO_2 gases. Therefore, for the purpose of reducing carbon footprint, the waste carbon sources are being chosen in the production of algae fuel, glycerol from biodiesel transesterification as an approach to obtain a growth profile similar to glucose [36].

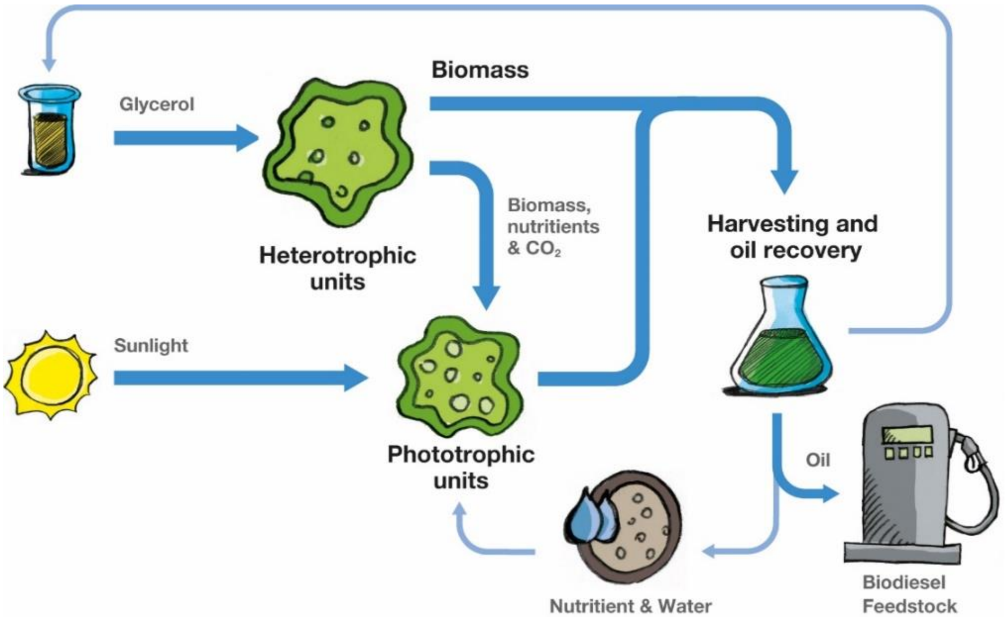

Figure 1.2 Process of Producing Algae Fuel [36]

The first successfully flighted commercial aircraft is from Virgin Atlantic in 2008 by using the blended algae fuel. Hence, it is crucial to investigate the use of algae fuel in the aviation industry [41]. Not far from that, the cultivation between the FAME and the alkenones from the algae called Isochrysis is known as a possible jet biofuel feedstock in 2015 [42]. Therefore, algae fuel is one of the most possible biofuels to be used as aviation fuel on its own.

The last biofuel chosen in the study is the Hydro-processed Esters and Fatty Acids, which are known as HEFA. The HEFA fuel is a straight-chain paraffinic hydrocarbon that is free from aromatics, oxygen and sulphur and having a high cetane number [43]. It is another type of fuel that is produced to replace or treat as blend/drop-in fuel with conventional fuel. HEFA is manufactured from hydrotreating the natural oils such as jatropha, algae, and camelina oil. The American Society for Testing and Materials International (ASTM) has certified HEFA under the D7566 specification

[44, 45]. HEFA is produced through alkene metathesis reaction which arranging alkene fragment through carbon-carbon double bonds with the metal-based catalyst. The hydrotreating process is able to produce HEFA [43, 46]. The process of developing HEFA is shown in Figure 1.3. According to Figure 1.3, the first step of producing the fuels involves a well-established alkene metathesis reaction that produces the required precursors which most of the time in alkenes form. After that, the process involves the proprietary aromatization, cyclization, and hydrogenation of the metathesis product [46].

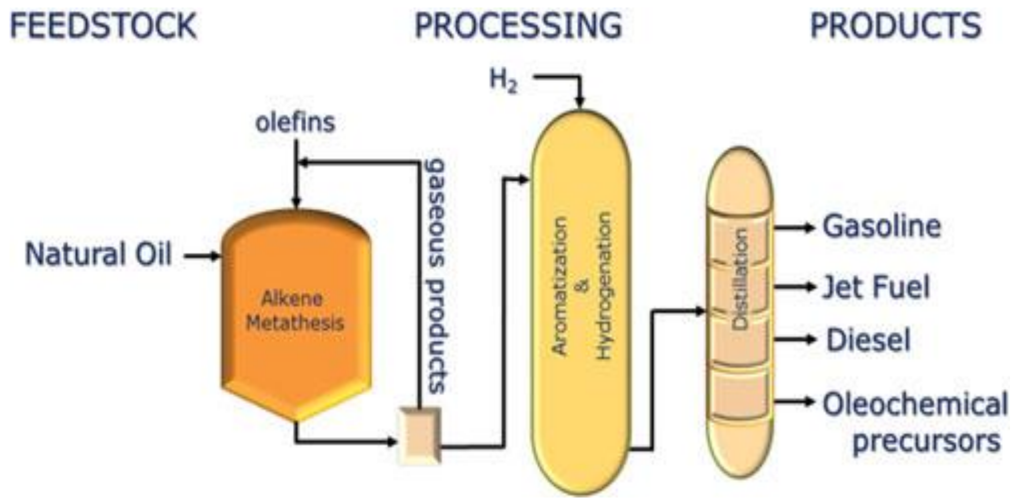

Figure 1.3 Process of Producing HEFA [46]

The Hydro-processed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK) is listed as one of the leading alternative replacements for conventional jet fuel by the CAA because of its sustainability, and it’s already been approved by Altair Engineering for use in 2011 [43]. Therefore, HEFA is one of the possible alternative biofuels to run a conventional aircraft.

1.2 RESEARCH MOTIVATION

The use of biofuel in aircraft engines has become an option to alleviate environmental problems. Therefore, a numerous study has been conducted to explore the performance of various types of biofuels in gas turbine engine either experimentally or numerically. Biofuels have not only been tested in a laboratory setting but also already elongated into real flight tests. For example, on February 24, 2008, Virgin Atlantic Airways 747-400 was the first to successfully fly their commercial flight running with 20% biofuel extracted from Brazilian Babassu nuts and coconuts, blended with 80% kerosene in one of its four engines. Later, another series of test flight are successfully conducted by other airlines such as Air New Zealand (ANZ), Continental Airlines (CAL), and Japan Airlines (JAL) which using a mixture of biofuel deriving from Jatropha, Camelina and Algae. Following these successful flights, it has proved the capability of biofuels in lessen dependency on crude oil and at the same time providing greener future aircraft.

Many factors may affect the performance and compatibility of biofuels in aircraft engines. Volatility, vapour pressure, viscosity, density, calorific value and molecular weight are some of the fuel properties that will affect combustion performance. Combustion efficiency, temperature distribution, fuel ignition is all influenced by fuel volatility. The tendency of carbon deposition in the combustion chamber is influenced by increases in the carbon/hydrogen ratio. Quality of evaporation and atomisation are all impacted by fuel’s vapour pressure, viscosity and density. At the same time, the calorific value will influence the consumption of fuel in the engine.

1.3 RESEARCH GAP

As far as the interest in biofuel is highlighted, there are clear motivations for conducting this research. The test flight of blended biofuel has already started in commercial flights in 2008. Therefore, it is essential to explore the influence of fuel properties on combustion characteristics. Although various types of biofuels have been considered to be tested for their compatibility on combustion, currently no further research work has been done, neither through experiment nor numerical, that studies the compatibility of algae fuel developed from Spirulina platensis in the combustion chamber. The World Health Organization (WHO) reported that Spirulina platensis has no risk and is a good food supplement for health because it includes bioactive components such as proteins, amino acids, minerals, vitamins, pigments, nucleic acids, carbohydrates, and lipids [47]. Besides, the maximum biofuel yield achieved by Spirulina platensis was 87.75 % at optimal reaction condition after transesterification [48]. Indeed, this motivates this present research work to be conducted, as there have been succeeded flying of the jet airplane using biofuels. Additionally, other biofuels namely biodiesel extracted from sorghum oil and HEFA developed from camelina vegetable oil will be used for evaluation. The Jet-A is considered as baseline fuel to compare with biofuels while the feedstocks chosen can be grown easily and did not compete with food demand.

The biofuels were chosen because the physical and chemical properties of those biofuels have been studied by lots of researchers. Sorghum biodiesel is chosen as this plant has a low requirement's ability to grow on marginal lands. The sorghum plant can accumulate up to 78% of the total biomass. Besides, sorghum biodiesel is compatible with aircraft engines as well [49], [28]. As The US Environmental Protection Agency (EPA) has approved the renewable fuel derived from sorghum as part of the Renewable Fuel Standard (RFS) programme in 2018 [50]. This includes the use of sorghum to produce biodiesel. Camelina chosen for HEFA fuel contains 30% to 40% oil by weight, it can be planted winter annual in most of the southern area and spring annual in the Pacific Northwest [51] . Therefore, it can be planted easily in a big amount of areas. Furthermore, the blend of camelina biofuel and Jet-A fuel already been studied as a replacement for conventional jet fuels [52].

There have been several kinds of research and successful cases on running jet aircraft by using blended biofuels. As all the certified aviation biofuel for now are blended fuels. Thus, the investigation on the possibility of flying a jet airplane on biofuel itself is the current trend. The big challenge is run an aircraft by pure biofuel only, but not blended biofuel. So, the combustion characteristics, particularly temperature and pressure profile, and formation of nitrogen oxide and soot of the selected fuels are investigated. This study also will present the factors that affect fuel properties on the combustion characteristics and the formation of gas emission will be discussed.

1.4 AIM AND OBJECTIVE

This study is conducted mainly to evaluate the compatibility of biofuels particularly algae fuel on the aircraft engine. In order to achieve this aim, few objectives have been identified, which are:

1. To investigate the combustion characteristic by evaluating the temperature and pressure profile of the fuels.
2. To evaluate the formation of NOx and soot emitted from the combustion in the combustion chamber.
3. To study the relationship between fuel properties with combustion characteristics and formation of NOx and soot.

1.5 CONTRIBUTION TO KNOWLEDGE

The main contributions of this work to knowledge comprises of the following:

1. The reconstruction of a 3D model of annular combustion chamber from the existing study.
2. The evaluation of combustion characteristics of different types of biofuels particularly algae fuel through the adaptation of a fuel's properties into CFD.
3. The prediction of nitrogen oxide (NOx) and soot formation of the selected biofuels from the combustion process.

1.6 SCOPE OF WORK

The scope of work must be decided before the research started, as a well-defined work scope can avoid easily changings requirements and let the study stay on track. To complete this study, a list of work scope is done in this section:

1. Parameter used for the annular combustion chamber is referred from the study from Mark et al. [53], the equations for important parameters are listed in Table 3.1.

2. There are some limitations to run the simulation in FLUENT, which there is a possibility of causing interpolation errors if having too few computing values [54]. Besides, biofuel properties such as boiling point and cloud point are hard to get. The properties of even the same type of biofuel can be different from different studies. Therefore, the properties of biofuels chosen are all taken from only one research. Furthermore, the time consuming for each simulation and meshing type are also issues to be solved when using numerical solutions.

3. The type of chamber chosen will be the annular combustion chamber. Annular combustion chamber is the most commonly used type of combustion chamber. It only needs 85% of the air used in the tubo-annular combustion chamber to cool down [55]. Additionally, annular combustors tend to have very uniform exit temperatures. Thus, an annular combustion chamber can perform more uniform combustion with its shorter size, lighter weight and less surface area [56].

4. The model used in this study is a 3D model with a cylindrical shape. The model is prepared by Computer-Aided Design (CAD) drawing in Solidworks. The 3D

model is then imported into a CAD software, Ansys for simulation. A 3D model is chosen for simulation in this case because it can simulate with condition near to the real condition.

1.7 THESIS LAYOUT

This thesis consists of five chapters:

Chapter One describes the introduction of this study which involves the general overview, research motivation, gap study, objectives and contribution of this research to knowledge.

Chapter Two discusses the previous studies related to combustion and spray characteristics. A table is provided at the end of this chapter that summarizes previous studies conducted either experimentally or numerically which related to the scope of this study.

Chapter Three presents the materials and methodology considered in this study. A flowchart is presented which shows a general overview of how the study is conducted. Type of fuels, combustion chamber geometry, meshing and validation of the simulation are presented.

Results and discussion are presented in Chapter Four. Combustion characteristics, such as temperature and pressure profiles obtained from the simulation, are presented. Moreover, this chapter also provides a discussion on the impact of biofuels properties on combustion characteristics and formation of NOx and soot.

Chapter Five summarized the present research works that have been done in this study. The discussions toward the possible works that could be done in the future is provided.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the survey of published literature in order to complete this research. The literature review in this study is focused on three main parts, which are biofuel compatibility, combustion chamber characteristics, and computational fluid dynamics.

2.1 BIOFUEL COMPATIBILITY

According to Cernan et al. [3], the difference between the chemical composition of the biofuel causing unpleasant defects in the fuel system for old transport vehicles, especially for aviation vehicles which are very sensitive to various types of defection that may influence operational safety. In this research, they have done investigated the effect of various blends for FAME biofuel and Jet A-1 kerosene with the changing of the parameter in performances and operational characteristic as well as the impact of different individual components on the aviation engine. They have concluded that the FAME biofuel and aviation kerosene blended fuel is well functioning in the aircraft turbo-compressor engine's propulsion system with some challenges that need to be solved first, as the degradation of the rubber seals in the experimental fuel system resulted in malfunction and causing fuel leakage. Thus, more studies should be made to improve the fuel properties. However, the feedstock of the FAME biofuel used in this study did not mention clearly in this paper.

Additionally, Hassan et al. [57] have done a study on the advantages and disadvantages of biofuel replacing the fossil fuels. This research stated biodiesel emits lesser emissions such as CO_2, CO, SO, but more NO_X compared to diesel. Besides, biodiesel is more pleasant to use as it can be produced easier with less time consuming. This study has also mentioned that biodiesel can let the vehicles have better performance due to its properties that having a high cetane number of over 100. Biodiesel also tends to prolong the life span of engines and lessen the need for preservation. However, the internal combustion engines that are designing for the operation of petroleum fuels are not suitable to be operated with biofuel for a long duration, because biodiesel has a corrosive nature against copper and brass. Hence, some modifications to the combustion chamber geometries can be done to solve this issue.

According to Slade et al. [58], micro-algae nowadays have received a significant interest to use as potential feedstock to produce sustainable transport fuels, which are also known as biofuels. This is because most of the micro-algae is able to make sufficient quantities of polysaccharides (sugars) and triacylglycerides (fats), which are familiar as the raw materials in the production of bioethanol and biodiesel transport fuels. In this research, the future economic viability and environmental sustainability for micro-algae manufacturing are being examined from three aspects, which are: the energy and carbon balance; environmental impacts; and production cost. To reach the finding of three aspects stated, an experiment has been done in the raceway pond system to illustrate the producing process of algal biomass at the bargain. However, there are still a lot of factors to be considered in the aspects of economic and productivity. Thus, even micro-algae can be used as aviation fuel, the cost needed to address a complete micro-algae production system is still a big challenge.

Wei et al. [59] have accomplished a review on the conversion technologies, the economic assessment, the environmental influence and the development status of renewable biojet fuels production for the aviation industry. This paper also mentioned that there are plenty of problems to solve before replacing fossil fuel with biofuels as well as the feedstock availability, economy and sustainability. This review is being done by comparing the jet fuel properties; the process of bio-jet fuels production; the minimum price for jet fuel production pathway at variance; the greenhouse gas (GHG) emission; the energy efficiency; and the water consumption of eight types of fuels. After all the comparisons have been made, the result of this research suggests that HEFA and Fischer-Tropsch (FT) synthesis is feasible as the most favorable alternatives for biojet fuels manufacturing in approach.

The investigation of Karmakar et al. [60] has been carried out on exploring the fuel properties and emission characteristics of biodiesel production through unused algae grown in India. This investigation indicates that the properties of biofuels including high density, viscosity and acid value in addition to low cloud point and pour point make it impractical for using biofuels in compression ignition (CI) engines. This is because these properties are causing severe damage to the engine parts and causing a reduction of the engine life. The mixed culture of algae used for this study is accumulated from various canals of Punjab, India. As the water level increases, the algae will decay naturally with time. Therefore, the stated algae are normally known as wastes and unutilized. This research states that all the properties of biofuels in their study are found to be within the limits of ASTM standards, hence no engine modification needed to be made. The high calorific value of biofuel represents high power. This is because the engine can be run with less fuel to reach high output power. In addition, the NOx emission of this biofuel is found out to be higher than diesel, however, the emission of other GHG, for instance, CO, CO_2 along with unburned hydrocarbon (UHC) of these biofuels are lesser than petro-diesel. Therefore, this biofuel may be an alternative to switch the fossil fuel as it needs less fuel to reach high power. However, the environmental issues should be solved before considering this biofuel.

Khan et al. [61] have discussed the feasibility of the biodiesel manufacturing from algae to control the energy crisis. This research has mentioned that the production of biofuel from the crop and food-producing plant can disturb food needs. Therefore, using algae to produce biofuel is more favorable as normally algae are having oil content ranged from 20% to 80% and this is adequate to be transfigured into various types of fuels known as algae fuel. Besides, the gene technology nowadays is fully utilized to increase the production and stability growth of algae. By increasing the genetic properties, the required biofuel amounts can be reached undoubtedly and constantly to control the fuels' inadequacy. This study concludes that the recognition of suitable species possessing pleasing characteristics and growth-wise, which required short time and further investigation on energy utilization. However, oil content that ranged from 20% to 80% is a wide range, therefore the choice of algae has to be wise to produce algae fuel.

Starck et al. [43] have studied the optimization of process yield of the HEFA production. This paper has highlighted on both FT and HEFA of SPK fuels are treated as favorable alternative replacements for conventional jet fuel. Therefore, the possibility of loosening the qualities requirements of freezing point for two types of rapeseed oil HEFA (freezing point –20°C and –47°C) have been examined. Besides, two blending strategies are being embraced to optimize the amount of these two types of HEFA fuel (HEFA1 and HEFA2) to investigate that this can incorporate into Jet-A fuel (blending ratio of 10%, 20% and 30% for HEFA1; a blending ratio of 75% for HEFA2) and Jet-B fuel (the blending ratio of 20%, 30%, 40%, 50%, 60% and 70% for HEFA1; the blending ratio of 25%, 40%, 50%, 60%, and 75% for HEFA2). This investigation has established that HEFA blended in the noteworthy amount in the conventional Jet-A fuel which HEFA1 can be accepted at the range of 30%–35%; while HEFA2 can be associated at the percentage until 59% before failing to reach its minimum total aromatics value. Nevertheless, it is worth mentioning this study is only focus on one preliminary result and no validation has been done yet.

Gawron et al. [62] have managed to carry out the evaluation on the combustion and emissions characteristics for the turbine engine fuelled with HEFA blends from various feedstocks. A specialized laboratory test rig, which is the miniature turbojet engine is applied to experiment with this study. The tested fuels used in this experiment are HEFA fuels which are extracted from the camelina oil plant and UCO respectively that blend with the conventional Jet A-1 fuel. The investigation on the performance and emissions characteristics of the miniature turbojet engine used indicates that there are dissimilarities when the miniature turbojet engine is running on neat Jet A-1 or HEFA fuels, particularly the data obtained for fuel consumption and CO emission. The fuel consumption and CO emission for HEFA fuels are lower than Jet A-1 fuel as it is having high calorific value and low density. It is worth mentioning that the NOx emissions of HEFA for both camelina and UCO blending are increased with the adding of the Jet A-1 fuel.

As stated in the research of Sundararaj et al. [63], biofuels obtained from Jatropha and Camelina feedstocks considered as one of the short-term solutions to solve the problem of the fuel crisis. Therefore, combustion and emission characteristics from biojet fuels that blended with conventional Jet A-1 fuel are being investigated in a gas turbine combustor. An experiment is being carried out in a can-type combustion chamber under two experimental circumstances. The combustion chamber capability is examined by establishing the combustion efficiency of the combustion chamber, by obtaining the temperature rises, and the emission indices (CO, NOx, UHC and soot) from the combustion chamber. The fuel properties for the blends using in this experiment are evaluated as within the prescribed limits of ASTM standards. To be concluded, it is shown that when the camelina concentration increased, the net heat of combustion is increasing and thus, increasing the NOx emissions. However, the increase in temperature causing the reduction of CO and UHC emissions. Moreover, soot emission is also decreased due to the reduction of aromatics content. Jatropha is undergoing higher net heat combustion compared to Jet A-1 and camelina due to its properties with lower viscosity and larger HC contents.

2.1.1 BIODIESEL

The biodiesel fuel chosen in this research is the biodiesel extracted from sorghum oil from the study of Ved et al. [28]. In this research, an investigation has been done on the sorghum bicolour seed oil and the methyl ester selected to evaluate the practicability to petrol diesel. The sorghum oil chosen in this experiment is grown locally in India. The sorghum oil is purchased from the local market Moga, Punjab, India. An exploration is carried out to evaluate the physical and chemical properties of sorghum oil. Thus, the alkali catalysed transesterification of sorghum oil is being done in the laboratory-scaled setup. The transesterification reaction to produce this biodiesel is required as reaction temperature need to control to keep it under the boiling point of alcohol chosen, the reaction time needs to be controlled in between 30 minutes to 2 hours so that it can complete the formation of mono alkyl ester, which is the biodiesel and glycerol. The transesterification of this biodiesel is shown in Figure 2.1 below. It is worth to mention that the acquired biodiesel is listed as one of the alternative diesel fuels in ASTM (ASTM D0975) and European organization (EN 14214) standard fuel tests. This research concludes that this biodiesel has a higher viscosity, specific gravity, flash point, pour point and cloud point; lesser density and acid value when comparison has been carried out with the petroleum diesel.

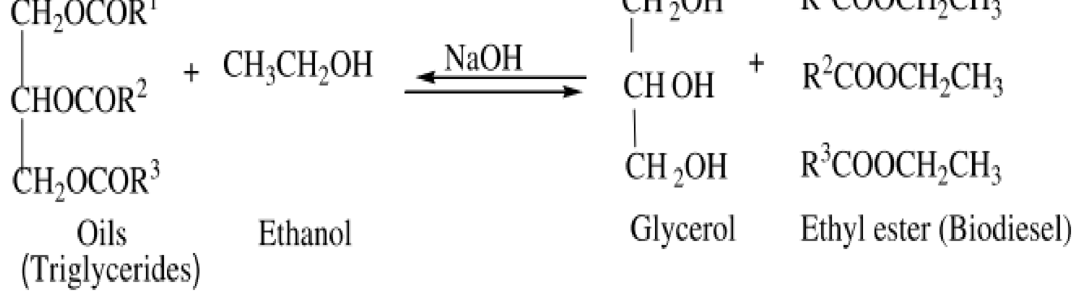

Figure 2.1 Transesterification of Biodiesel Production [28]

2.1.2 ALGAE FUEL

In Mostafa et al. [37] investigation, the suitability of biofuel production from microalga spirulina platensis is being studied. Spirulina platensis used in this research is a plankton, filamentous, spiral-shaped, multicellular photosynthetic, blue-green microalgae. It can exist in various types of domains. In this study, the chemicals needed, which are: pure sodium hydroxide that used as alkaline catalyst, anhydrous sodium sulphate, chloroform and methanol are all acquired from Germany; while the spirulina platensis algae are got from the Microbiology Department; Soils, Water and Environment Research Institute, Agricultural Research Center (ARC), Giza, Egypt. The algae are grown and conserved in the 500mL Erlenmeyer flasks and 200mL sterilized Zarrouk liquid medium with the absence of nitrogen sources and salinity of 10g/L. The pH value is adjusted to 9 and conditions in the flask remain at 120°C for 20 minutes. The optical density of the initial inoculum is also adjusted to A_{560} 0.2, with the dry weight of 0.15g/L and chlorophyll of 8.46mg/L. The plants are incubated under the continuous shaking of the chamber at 150rpm and illumination with 2000Lux at 32 ± 2°C when immobile. Furthermore, a massive amount of spirulina platensis is grown in a 50L photobioreactor. In most cases, algae are harvested every 48 hours by centrifugation at 10,000rpm for 15 minutes and being washed by distilled water, then being dried with the use of a freeze dryer. The process of cultivation and harvest of this algae is shown below. The blends of algae fuel and petro-diesel are also being studied in this research, the obtained results show that when the algae fuel concentration in the blend increases; the viscosity, density, total acid number, initial boiling point, calorific value, flash point, cetane number and diesel index increased; while the pour point, cloud point, carbon residue and sulphur, ash and water contents decreased. Therefore, this paper concludes that this algae fuel is a valuable candidate to be used for biofuel productions it has a high growth rate and inexpensive culture medium.

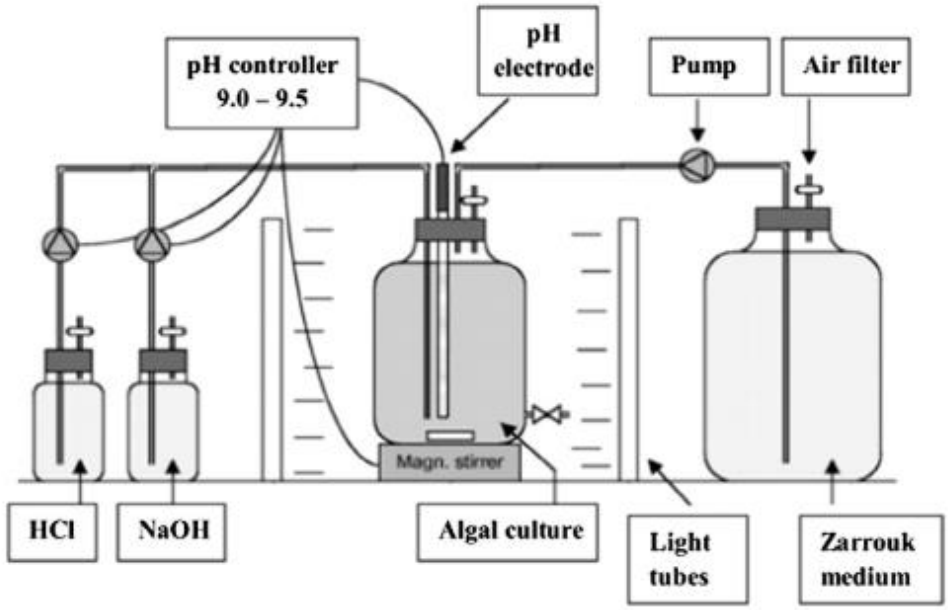

Figure 2.2 Process of Cultivation and Harvest Algae in Photobioreactor [37]

2.1.3 HEFA

According to Gawron et al. [44], the investigational accomplishment and the emission characteristics of a turbojet engine are evaluated in a miniature turbojet engine that running with the Jet A-1 fuel and HEFA which are used camelina vegetable oil as raw material. This experiment is carried out through the special-designed test rig known as Miniature Jet Engine Test Rig (MiniJETRig). This MiniJETRig is using the

GTM 140 series as the main feature, which can operate between 33,000–120,000rpm at the maximum thrust of 140N. This engine contains a single staged radial compressor driven by a single staged axial turbine and the annular combustion chamber with a set of vaporizer tubes. The tested fuels used in this experiment are the conventional Jet A-1 fuel that got from a domestic refinery and the HEFA fuel with 48% of synthetic hydrocarbons. This paper also emphasizes that the component of this HEFA production process is approved for use in engines and aircraft as it reaches the requirements of ASTM D7566-15d. The analysis for tested fuels is done in the engine operating with the speed of 39,000rpm, 70,000rpm, 88,000rpm and 112,000rpm. The result shows that the properties of HEFA fuel are having higher viscosity and heat of combustion when compared with the chosen conventional Jet A-1 fuel. At the same time, the HEFA fuel also having lower density, aromatics, and exhaust gas, which are CO, CO_2 and NOx comparing with the conventional Jet A-1 fuel.

2.2 COMBUSTION CHAMBER CHARACTERISTICS

Rodrigo et al. [64] have done a study on the computational modelling of a horizontal cyclonic combustor chamber burning biomass powder with the use of the ANSYS FLUENT software together with experimental biomass data. In their simulation, a mixture of biomass particles and the air is injected tangentially into the wall of a combustion chamber. Their results are depicted via the velocity and temperature profiles, velocity vector, and the mass fraction distribution of species as these are the main factors that affect the formation of NO_X. As conclusion, they have suggested reducing combustion chamber length to reduce the emission of NO_X. Figure 2.3 shows the schematic drawing and the meshing of the chamber used. However, in