PERFORMANCE AND EMISSION OF SWIRL BURNER WITH DIFFERENT SWIRL NUMBERS USING PALM, COCONUT AND JATROPHA OIL BIODIESEL

NORWAZAN BINTI ABDUL RAHIM

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2017

To my beloved son

AFFAN FARIS

ACKNOWLEDGEMENT

Firstly, no doubt to say “Syukur Alhamdulilah to Allah” for His guidance and makes my dream come true. I also would like to express my thanks to my supervisor, Professor Dr. Mohammad Nazri Mohd Jaafar. I am extremely grateful for his support, guidance and patience throughout my PhD course to be completed. I am very much appreciated to his ideas and encouragement.

The award of advanced study SLAB/SLAI scholarship from the Malaysia Ministry of Higher Education is very much appreciated. That is very helpful for me to continue my journey as PhD candidate. Many thanks go to all my colleagues in the Gas Turbine Combustion Research Group (GTCRG) laboratory including Amin, Ismail, Syazwana, Nizam, and Dr. Hazir from Sudan University who have assisted me with lab equipments and my test rig development for experimental work. I am also indebted to the technicians from the combustion laboratory for their kind assistance directly or indirectly.

A big thankful for Dr. Jolius Gimbun from Universiti Teknikal Malaysia Pahang that assisted and leading me to learn about the ANSYS Fluent software successfully. Also thankful to Prof. Dr. Tirto from Institut Teknologi Bandung, Indonesia because giving me a pleasure opportunity to study and learning about the biodiesel’s production completely on his laboratory. Appreciated to his assistant, Yanti who taught and assisted me well. I would also like to thank Prof. Umi Kalsom from Faculty of Science, UTM for her permission to use their laboratory on some physical properties testing.

I would like to thank all my friends for their moral, encouragement and emotional support throughout my Phd life’s experience. Finally, my sincere thanks go to my husband, Adam Firdaus and my son, Affan Faris for their patience, encouragement, invaluable supports during my long and arduous journey. Thank you for being my backbone in order to complete my PhD. To my beloved parents, Emak and Ayah who gave me full attentions, thank you very much. To all my family members, thank you for your kindness to understand me along this period.

ABSTRACT

Biodiesel is used as an alternative invaluable fuel in reducing the effect of global warming, greenhouse-gas emissions, and severe climate changes. It is also considered as promising global green energy that can replace fossil fuel, which causes severe pollution to the environment. Biodiesel blend fuel can mitigate pollution towards greener emission in many heavy combustion industries, however, the appropriate axial swirler in burner needs to be identified. The aim of this research is to determine the most suitable percentages of biodiesel fuel blends to be combined with the swirler vane angle in the liquid fuel burner. Therefore, experimental works were conducted in this study by using swirl burner. Three different biodiesel fuel feedstocks of palm, coconut, and jatropha oils were chosen and produced through the transesterification method according to ASTM and EN Standards. The isothermal studies were also conducted via Computational Fluid Dynamics analysis to examine the characteristics of swirl number of axial swirler used in the burner. Experimental results showed that high swirl number yielded the highest center toroidal recirculation zone which could help air and fuel mixing prior to ignition and leads to complete combustion. This test also indicated that, a high swirl number reduces carbon monoxide, sulfur dioxide and unburned hydrocarbon emissions for diesel and jatropha oil biodiesel (JOB) fuels significantly. The different types of neat biodiesel fuel and their blends; B10, B15, B20, and B25 were tested and compared with diesel fuel performances in terms of lean, stoichiometric, and rich mixtures. The biodiesel fuel blends also exhibited better emissions of nitrogen oxides, carbon monoxide, sulfur dioxide and unburned hydrocarbon with high S_N effect in certain mixtures depending on the types of biodiesel feedstock and blend percentage. In overall, JOB also produced better carbon monoxide emissions in any blend percentages with a maximum reduction of 60% with JOB B25. Meanwhile, COB B25 and COB B10 blends were found able to reduce sulfur dioxide and unburned hydrocarbon emissions by 35% and 33%, respectively, relative to diesel fuel. JOB B25 is the most appropriate biodiesel blend because it is a type of non-edible oil and does not compete with human food consumption. In conclusion, biodiesel fuel blends with high S_N is a viable alternative for swirl burner applications that effectively reduce greenhouse gases, adverse climate changes and more greener environmental.

ABSTRAK

Biodiesel digunakan sebagai bahan api alternatif yang sangat berharga bagi mengatasi masalah pemanasan global, kesan rumah hijau dan peningkatan suhu bumi yang mendadak. Ia juga dianggap sebagai sumber tenaga global untuk menggantikan bahan api komersial yang menjadi penyumbang kepada pencemaran yang sangat serius terhadap alam sekitar. Bahan api biodiesel campuran boleh mengurangkan pencemaran ke arah pelepasan lebih hijau di dalam kebanyakan industri pembakaran berat, walaubagaimanapun, pemusar paksi yang sesuai di dalam pembakar perlu dikenalpasti. Matlamat kajian ini adalah untuk menentukan peratusan bahan api biodiesel campuran yang paling sesuai untuk digabungkan dengan sudut pemusar paksi di dalam pembakar bahan api cecair. Tiga bahan api mentah yang berbeza termasuk minyak kelapa sawit, kelapa dan jatropha telah dipilih dan dihasilkan melalui kaedah transesterifikasi mengikut piawaian ASTM dan EN. Kajian isoterma telah dilaksanakan melalui analisis Pengkomputeran Dinamik Bendalir untuk memeriksa ciri-ciri nombor pusar bagi pemusar paksi yang digunakan di dalam pembakar. Keputusan ujikaji menunjukkan bahawa nombor pemusar yang tinggi menghasilkan zon berpusar tengah toroidal yang tinggi yang mana boleh membantu percampuran udara dan bahan api sebelum penyalaan serta mendorong ke arah pembakaran lengkap. Ujikaji ini juga menunjukkan bahawa, nombor pusar tinggi dapat mengurangkan pelepasan karbon monoksida, sulfur dioksida dan karbon tidak terbakar bagi minyak diesel dan biodiesel jatropha (JOB). Tiga jenis bahan api biodiesel tulen dan campurannya; B10, B15, B20 dan B25 telah diuji dan dibandingkan dengan prestasi minyak diesel dari segi keadaan kecairan, stoikiometrik dan kepekatan. Bahan api biodiesel campuran juga didapati menunjukkan pelepasan nitrogen oksida, karbon monoksida, sulfur dioksida dan karbon tidak terbakar yang lebih baik dengan kesan S_N yang tinggi dengan pencampuran tertentu bergantung kepada jenis bahan api biodiesel tertentu dan peratusan campuran. Secara keseluruhannya, JOB juga menghasilkan pelepasan karbon monoksida lebih baik dalam mana-mana peratus campuran dengan pengurangan maksimum sebanyak 60% yang dihasilkan oleh JOB B25. Sementara itu, campuran COB B25 dan COB B10 didapati boleh mengurangkan pelepasan sulfur dioksida dan karbon tidak terbakar dengan kadar pengurangan sebanyak 35% dan 33% masing-masing. JOB B25 merupakan bahan api biodiesel campuran yang paling sesuai kerana ia adalah sumber yang tidak boleh dimakan dan tidak menjejaskan keperluan makanan manusia. Kesimpulannya, minyak biodiesel campuran dengan S_N yang tinggi adalah alternatif yang berdaya maju untuk aplikasi di dalam pembakar bahan api cecair bagi mengurangkan kesan rumah hijau, perubahan iklim yang mendadak dan persekitaran lebih hijau secara berkesan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

% v/v	-	Percentage of volume to volume
% w/w	-	Percentage of weight to weight
Al_2O_3	-	Aluminium oxide
ASTM	-	American Society for Testing and Materials
AV	-	Acid value
AV_f	-	Final acid value
AV_i	-	Initial acid value
B	-	Blend
BTU	-	British thermal unit
CAD	-	Computer aided design
CaO	-	Calcium oxide
CFD	-	Computer fluid dynamics
CFPP	-	Cold filter plugging point
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
COB	-	Coconut oil biodiesel
CP	-	Cloud point
CRZ	-	Corner recirculation zone
CTRZ	-	Center toroidal recirculation zone
D	-	Diameter
D_c	-	Diameter of combustor
EN	-	European Standard
ERZ	-	External recirculation zone
EU	-	European Union
FAME	-	Fatty acid methyl ester
FFA	-	Free fatty acid
GC	-	Gas composition

G_x	-	Axial flux of the axial momentum
G_θ	-	Axial flux of the tangential momentum
H_2O	-	Water
H_2SO_4	-	Sulfuric acid
HC	-	Hydrocarbon
HCl	-	Hydrochloric acid
IRZ	-	Internal recirculation zone
JOB	-	Jatropha oil biodiesel
JOME	-	Jatropha oil methyl ester
K	-	Kelvin
KNO_3	-	Potassium nitrate
KOH	-	Potassium hydroxide
L_c	-	Length of combustor
LES	-	Large eddy simulation
MJ/kg	-	Mega joules per kilograms
MOME	-	Moringa oil methyl ester
MPOB	-	Malaysian Palm oil Board
Mw	-	Molecule weight
N	-	Normality
N_2O	-	Nitrous oxide
N_2O_5	-	Dinitrogen pentoxide
NaOH	-	Sodium hydroxide
NO	-	Nitric oxide
NO_3	-	Nitrate
NO_x	-	Nitrogen oxide
O_2	-	Oxygen
ORZ	-	Outer recirculation zone
PM	-	Particulate matter
POB	-	Palm oil biodiesel
POME	-	Palm oil methyl ester
PP	-	Pour point
ppm	-	Part per millions
R	-	Outer radius of annular
RANS	-	Reynolds Average-Navier Stokes

RBD	-	Refined blend diesel
RNG	-	Renormalized Group
RSM	-	Reynolds stress model
r_i	-	Inner radius
r_0	-	Outer radius
S_N	-	Swirl number
SO_2	-	Sulfur dioxide
SST	-	Shear transport
U_0	-	Input velocity
UHC	-	Unburned hydrocarbon
USDA	-	United State Department of Agriculture
V	-	Volume
W	-	Weight
x	-	Length
η	-	Efficiency
ρ	-	Density
υ	-	Viscosity
ϕ	-	Equivalence ratio
θ	-	Swirl angle

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Globally, alternative fuels are considered a form of sustainable energy towards the green technology by which internal combustion engine or gas turbine combustion operated. These engines are widely used in many industries including transportation, heavy industries and the electrical power plant industry because of its many advantages such as higher efficiency and lower fuel consumption. All types of engine are using diesel fuel as a main medium to operate it. Diesel fuel has been used and produced high gaseous pollutions into environment. Due to high volumes consuming with diesel fuel in many applications, the depletion of viable fossil fuel is fast increasing. Thus, biodiesel fuel production is being studied more and more as a solution to these issues, in reference to respective country policies.

In order to improve pollution and emissions reduction, the quality of the combustion performance must be taken into consideration [1]. This can be done using a variety of methods such as improving the air intake system, using appropriate fuels, etc. New technologies involving biodiesel fuel are now being discovered, either in the gas turbine or diesel engine industries, in order to achieve better performance and to reduce pollutant emissions towards a greener environmental. Rudolp Diesel introduced the first diesel engine to use peanut oil, which is considered to be biodiesel fuel [2]. Biodiesel is one of the versatile renewable energies that has significant advantages such as being biodegradable, sustainable, and requiring low cost energy resources. It is also environmentally clean and non-toxic [3-5]. Throughout the years, research and development on biodiesel fuels from many resources have been continuously conducted to obtain optimum yield and advancement in biodiesel production.

Biodiesel is used as an alternative fuel that can be blended with diesel fuel or used directly inside the engine. Biodiesel is a general term covering a number of ester-based oxygenated fuel produced from fatty acid triglycerides contained in either plant oils or animal fats or plant oil waste (i.e. used cooking oil). There are two types of plant oil feedstocks: edible and non-edible. One of the reason plant oil is more attractive than petroleum is because it contains no or less sulfur [6, 7]. Plant oils produced from different plants give different levels and mixes of fatty acid content. The fatty acids of oils are divided into two types either saturated or unsaturated.

Many types of biodiesel from various feedstocks have been researched and applied in different kinds of applications. Biodiesel feedstocks can be produced from edible oils such as soybean, sunflower, palm, coconut, corn, canola, olive, rapeseed, etc. [8-11]. However, non-edible oils are more often used for conversion into biodiesel fuels because their production does not reduce the available plant oils for human use and food consumption [12, 13] These include oils from jatropha, karanja, polanga, mahua, castor, and rubber plants. Non-edible oils are more practical for producing biodiesel fuel because this type of oil does not compete with human food consumption and is considered waste. In this study, various feedstocks, from edible or non-edible oils, i.e including palm, coconut, and jatropha oils were selected for the production of biodiesel fuel. Then, a comparative study of the combustion performance of all biodiesel fuels was conducted with diesel fuel as the benchmark.

Biodiesel can be produced via various methods such as transesterification, dilution, pyrolysis, and micro-emulsion [14]. Transesterification is the most popular method because it is considered the most economical and easiest method. In addition, this method produces good quality and yield of biodiesel [15]. In the transesterification method, which involves alcohol reaction with oil, the presence of a catalyst is needed. The transesterification process is considered as a straightforward reaction requiring a molar ratio of alcohol reagent and catalyst reaction [16]. In one study, crude jatropha oil with high free fatty acid (FFA) was treated with an acid catalyst, sulphuric acid (H_2SO_4), in the initial stage of the pre-treatment esterification process resulting in a FFA of 14% that was subsequently reduced to less than 1%. Then, the transesterification process with methanol and potassium hydroxide (KOH) was continued for 24 mins of reaction time to produce a biodiesel yield of 99% [17]. Catalysts can be categorized as homogeneous or heterogenous catalysts. Homogeneous catalysts include acid, basic (alkaline), and enzyme catalysts. However, basic catalysts such as sodium hydroxide (NaOH) or KOH are the most commonly used in the transesterification process. In one research, transesterification using a homogeneous catalyst, NaOH, significantly accelerated the reaction of rapeseed oil biodiesel conversion compared to all four different heterogeneous catalysts [18]. Shahbazi *et al.* [19] found that the yield of transesterification reaction with KOH as a catalyst was higher than the one carried out using NaOH. Calcium oxide (CaO) is one of the heterogeneous catalysts that can be recycled and reused. The CaO catalyst obtained in the transesterification method exhibited high yields of biodiesel production of over 90% [20]. Ito *et al.* [21] found that waste cooking oil (WCO) showed an improvement of −5°C in the pseudo-cold filter plugging point when produced by pyrolysis compared to being produced via the transesterification method.

Some studies of biodiesel fuel combustion show that emission products can be reduced and potentially contribute towards environmental improvement. Furthermore, blended biodiesel with petroleum oils have different physical properties such as higher viscosity and cetane number, and lower heating values compared to conventional fossil fuels, which translates to a high potential in emissions reduction. These different fuel properties can be influenced by fuel and air mixing and also combustion characteristics, especially when the biodiesel is applied either in gas turbines or diesel engines. Besides being renewable, these blended fuels have also been proven to reduce emissions involving carbon monoxide (CO), unburned hydrocarbons (UHCs), oxides of sulphur (SO_x), and particulate matter (PM); the net reduction in carbon dioxide (CO_2) accompanied by an increase in nitrogen oxide (NO_x) was observed in the use of biofuels in automotive and aviation applications [22, 23]. Gan and Ng [24] found that the combustion of palm biodiesel B10 and B20 fuel blends produced higher NO_x and lower CO emissions compared to the diesel No. 2 combustion in a non-pressurised burner. However, the combustion of biodiesel and diesel in a large-scale laboratory furnace showed that the biodiesel produced slightly similar amounts of CO emission but lower NO_x emissions. Both emission gaseous were reduced and increased due to the increase in excess air level up, respectively.

Currently, the biodiesel combustion studies are widely investigated in the internal combustion engine and gas turbine engine. The emissions from biodiesel combustion are well predicted in different speed of engine, load and effect on brake fuel consumption in case of internal combustion engine [references]. Meanwhile, gas turbine engine or furnace application is evaluated on the blend percentage of biodiesel in diesel fuel to reduce the emissions formation during combustion [references]. In furnace or burner application, there has lacking on the swirling flow via biodiesel blends combustion that will effect on their emission performances. As mentioned in many studies, the swirler is one of the technologies used in a combustion chamber or burner in order to enhance flame stability and to produce recirculation flow in the combustion process [25].

Most researches reported the relationship between the swirling flow and the combustion process conducted with gaseous fuels such as methane, propane, etc. [26]. The effect of swirling flow has commonly been identified to improve flow reversal, enhance flame stability, achieve better and fast mixing of fuel and oxidizer, and promote vortex breakdown [27, 28]. Hashemi *et al.* [29] studied diffusion flames using hydrogen and hydrogen-hydrocarbon fuels. The study used a numerical realizable k-ε model and experimental methods, showing that increasing air turbulence intensity resulted in a decrease in NO concentration in the flame zone and at the combustor outlet. Nowadays, the combustion performance and emission using diesel and biodiesel fuels in diesel engines have been widely explored [30-34]. However, the application of biodiesel and their blends in burners has not been widely studied. Many experimental studies on the combustion behavior of liquid fuels such as diesel or Jet A-1 in a tubular combustor have been reported for predicting the distribution temperature and various species concentration of emissions in the combustor [35, 36]. In this study, the effect of using various biodiesels from different feedstock and blend percentages on the gaseous emission level was evaluated and their combustion performances defined by high swirling flow in a liquid fuel burner. The combustion performance was evaluated from the emission formation of NO_x, CO, CO_2, SO_2, and UHC.

1.2 Problem Statement

Currently, the biodiesel combustion performances are widely investigated in the internal combustion engine. The emissions from biodiesel combustion are well predicted in different speed of engine, load and effect on brake fuel consumption [9, 34, 37-41]. There are also studies on different types of feedstock of biodiesel on the internal combustion engines [9, 34, 42-44]. However, the studies on biodiesel combustion using burner are rarely investigated. There are few cases on biodiesel fuel have been studied in burner application such as cottonseed oil biodiesel combustion in Riello burner [45], effect on emissions of palm oil biodiesel in non-pressurized combustion chamber [3], NO emissions from six different biodiesels fuel on burner [46] and combustion of palm oil biodiesel via high temperature air (673K) in gas turbine engine [11]. In reacting flows, the interaction between the physical and chemical reaction is highly significant in causing a vortex breakdown that induces flow recirculation [47]. The characteristics of combustion of biodiesel and its blend inside a swirl-stabilized burner have not been properly understood yet. There is no comparison study on the palm oil biodiesel with other biodiesel types and their blend that burned in a liquid swirl burner.

One of the technologies that can be used in a combustion chamber or burner is by attaching a swirler inside the chamber to support the air-flow stability towards producing the recirculation zone. The swirler is also commonly used to increase the flame stability and hence to produce lower emissions formation. It is important to note that the effects of the swirler attached inside the burner during combustion of biodiesel and its fuel blends have not been widely investigated as yet. In order to obtain better emissions from biodiesel combustion, flame stability and good recirculation flow are needed, which calls for the swirler attachment. As a consequence, the suitable swirler vane angles by swirl number, S_N need to be carried out. Thus, the viable swirler suit to diesel and biodiesel fuels combustion in swirl burner can be determined. Therefore, the four different swirlers were then simulated via Computational Fluid Dynamics (CFD) as to their suitability for attachment with the burner to produce lower and better emissions to the environment.

The influence of important parameters during combustion such as exhaust temperature at the end of the system and the value of emission products with different axial swirler angles has been widely studied. However, there has been a lack of research on the influence of vane angles on liquid fuel, especially on various neat biodiesel and also biodiesel blends fuel combustion on swirl burner. This study focuses on liquid fuel combustion with an attached axial swirler to evaluate three different feedstocks of biodiesel, namely from jatropha, palm, and coconut oils and their blends against diesel fuel. Diesel fuel is used as a benchmark and compared with the biodiesel fuel blends in this study. From this study, the potential use of different feedstocks of biodiesel fuel and their blends using a liquid fuel burner with an axial swirler can be determined and assessed to study the reduction of emissions formation.

1.3 Research Objectives

The main goal of this research study is to determine the most suitable biodiesel fuel blends percentages in order to suit the suitable swirler attach to the liquid fuel burner. In order to achieve the main goal, the following objectives have been identified:

1. To determine the suitable swirl number, S_N, inside the liquid fuel burner via isothermal studies in numerical analysis and experimental studies of combustion for both plant oil biodiesel fuel blend and diesel fuel combustion.
2. To define the suitable percentages of acid catalyst of sulfuric acid on esterification process of jatropha oil biodiesel production via established transesterification method according to ASTM and EN standards.
3. To evaluate palm, coconut and jatropha oils neat biodiesel and their blends and to compare their performances to that of diesel fuel via their gaseous emissions using a swirl burner.

1.4 Scopes of study

This study focuses on the emission formation, which is taken as the combustion performance of a liquid fuel burner, to determine suitable swirler vane angles represent as swirl number for each biodiesel fuel used. The present work also carried out a numerical simulation for isothermal swirling flows inside the liquid fuel burner. Initially, the velocity profiles in central recirculation zones during the isothermal condition have been widely studied using numerical methods, namely ANSYS Fluent, which is a CFD package software. These properties were evaluated in order to define the mixing flow in recirculation zone. Four different axial swirler vane angles in the liquid fuel burner used are limited from 30º to 60º were evaluated and represented as four different swirl numbers, S_N of 0.436, 0.630, 0.895 and 1.300.

Biodiesel or methyl esters of various feedstocks including palm, coconut and jatropha oils were tested and characterized to confirm that the biodiesel fuels produced in the laboratory are according to ASTM or EN standards. These three types of feedstock were selected in the study based on the availability of palm oil in Malaysia as the second largest producer in the world and coconut oil also as the main cooking oil in Indonesia due to the largest in Asia as importer. Both oils are considered as food products that produced by plant oil and need to be produced continuously to the consumers. However, when the biodiesel fuel suppliers considered to consume both types of oil, the demands of oils are increasing drastically. Thus, many researches start to observe other alternative to replace the edible oil with non-edible oil such as jatropha, polanga, karanja, rubber oils and etc. In order to support this study, both edible and non-edible oils including palm, coconut and jatropha oils need to be considered to evaluate their combustion performance such as emissions characteristic in the swirl burner. All the biodiesel fuels are being produced in the laboratory due to unavailability in the market.

Initially, the methyl esters were tested in regard to the acid value of each feedstock, so as to identify the most suitable method to be used. Once the acid value is known and recorded, the esterification process step is defined for optimum yield production. In this study, two different pre-treatment steps were used involving acid-catalysed and alkaline-catalysed processes using methanol with presence of H_2SO_4 and KOH.

Other parameters of biodiesel combustion that affect the reduction of emission products such as NO_x, CO, CO_2, SO_2, and UHC were identified using different biodiesel fuel feedstocks in a liquid fuel burner with attached the suitable swirler. In this study, the diesel fuel is used as a baseline and the biodiesel fuel blends are compared in terms of gaseous emissions via experimental works. There are included the neat biodiesel combustion and the effect of S_N on biodiesel combustion. A major concern related to the reduction of emission products is addressed in order to achieve better performance towards a greener environment.

1.5 Thesis Outline

This thesis contains six chapters. Chapter 1 presents the introduction and highlights the problem statement of this study. It also contains the objectives and scope of the study followed by the thesis outline. Two methods are used in this study include experimental work and numerical simulation to evaluate the diesel and bidioesel fuel blends in a liquid fuel burner, which will be described in detail in the next chapter.

Chapter 2 reviews the literature from other researches involving numerical and experimental studies. In the numerical analysis, many researchers have employed simulation methods using CFD solvers, ANSYS Fluent with different models of RANS, swirler application, and turbulent swirling flow characterization. In this study, the apprioprate swirl angle was identified in order to achieve better performance for the liquid fuel burner. Furthermore, various feedstocks were used to produce biodiesel fuel via the transesterification method with the presence of a catalyst. The biodiesel fuel blend emission products were evaluated using combustion testing as part of the experimental works of this study.

Chapter 3 explains the numerical simulation method and experimental works used in this research. First, a description of the numerical simulation method involving the design of the liquid fuel burner, swirler used, and suitable model applied are presented. The numerical method in this research is based on Reynolds-Averaged Navier Stokes (RANS). Implementation of the RANS model is explained in detail for different types of RANS models such as standard k-ε and further discussed in the next chapter. In addition, the major framework for experimental works are described about biodiesel from the beginning of the biodiesel production processes; characterization of fuel properties; and up to the combustion rig set up including collection of emissions data throughout the flue gases from the gas analyzer.

The results obtained from the numerical simulation of the non-reacting flow are presented in Chapter 4. These are analysed and discussed in different subsections accordingly. Earlier in the chapter, the steps of the numerical study with inlet mass flow rate on the axial swirler to determine the effect of swirling flow are presented. Then, the isothermal studies are conducted with different RANS models, S_N, and R_e.

The combustion performance of the biodiesel fuel and diesel based on different parameters are presented in Chapter 5. In this chapter, a few paramaters are varied to determine the combustion performance of the two types of fuel. In this case, a liquid fuel burner was used. The parameters include effect of S_N on diesel and biodiesel blends, various neat biodiesels, and different blend percentages on various feedstock.

Finally, the conclusions are summarized in Chapter 6, together with the recommendations for future work regarding the development of biodiesel fuel production and suggestions for the design of a new liquid fuel combustor.

REFERENCES

1. Park, S. H., Kim, H. J., and Lee, C. S., Numerical Investigation of Combustion and Exhaust Emissions Characteristics Based on Experimental Spray and Atomization Characteristics in a Compression Ignition Diesel Engine. *Energy & Fuels*, 2010. 24(4): 2429-2438.

2. Dhamodaran, G., Krishnan, R., Pochareddy, Y. K., Pyarelal, H. M., and Sivasubramanian, H., Ganeshram, A. K., A comparative study of combustion, emission, and performance characteristics of rice-bran-, neem-, and cottonseed-oil biodiesels with varying degree of unsaturation. *Fuel*, 2017. 187: 296-305.

3. Ng, H. K. and Gan, S., Combustion performance and exhaust emissions from the non-pressurised combustion of palm oil biodiesel blends. *Applied Thermal Engineering*, 2010. 30(16): 2476-2484.

4. Ibrahim, A., Performance and combustion characteristics of a diesel engine fuelled by butanol–biodiesel–diesel blends. *Applied Thermal Engineering*, 2016. 103: 651-659.

5. Issariyakul, T. and Dalai, A. K., Biodiesel from vegetable oils. *Renewable and Sustainable Energy Reviews*, 2014. 31: 446-471.

6. Kurji, H., *et al.*, Combustion characteristics of biodiesel saturated with pyrolysis oil for power generation in gas turbines. *Renewable Energy*, 2016. 99: 443-451.

7. Jindal, S., Nandwana, B. P., Rathore, N. S., and Vashistha, V., Experimental investigation of the effect of compression ratio and injection

pressure in a direct injection diesel engine running on Jatropha methyl ester. *Applied Thermal Engineering*, 2010. 30(5): 442-448.

8. Gopinath, A., Puhan, S., and Nagarajan, G., Effect of unsaturated fatty acid esters of biodiesel fuels on combustion, performance and emission characteristics of a DI diesel engine. *International Journal of Energy and Environment*, 2010. 1(3): 411-430.

9. Abedin, M. J., Masjuki, H. H., Kalam, M. A., Sanjid, A., Rahman, S. M. A., and Fattah, I. M. R., Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine. *Industrial Crops and Products*, 2014. 59: 96-104.

10. Atabani, A. E., *et al.*, Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renewable and Sustainable Energy Reviews*, 2013. 18: 211-245.

11. Hashimoto, N., Ozawa, Y., Mori, N., Yuri, I., and Hisamatsu, T., Fundamental combustion characteristics of palm methyl ester (PME) as alternative fuel for gas turbines. *Fuel*, 2008. 87(15-16): 3373-3378.

12. Mardhiah, H. H., Ong, H. C., Masjuki, H. H., Lim, S., and Lee, H. V., A review on latest developments and future prospects of heterogeneous catalyst in biodiesel production from non-edible oils. *Renewable and Sustainable Energy Reviews*, 2017. 67: 1225-1236.

13. Yang, J., He, Q. S., Corscadden, K., and Caldwell, C., Improvement on oxidation and storage stability of biodiesel derived from an emerging feedstock camelina. *Fuel Processing Technology*, 2017. 157: 90-98.

14. Atadashi, I. M., Aroua, M. K., Abdul Aziz, A. R., and Sulaiman, N. M. N., Production of biodiesel using high free fatty acid feedstocks. *Renewable and Sustainable Energy Reviews*, 2012. 16(5): 3275-3285.

15. Rajaeifar, M. A., Akram, A., Ghobadian, B., Rafiee, S., Heijungs, R., and Tabatabaei, M., Environmental impact assessment of olive pomace oil

biodiesel production and consumption: A comparative lifecycle assessment. *Energy*, 2016. 106: 87-102.

16. Achten, W. M. J., *et al.*, Jatropha bio-diesel production and use. *Biomass and Bioenergy*, 2008. 32(12): 1063-1084.

17. Tiwari, A. K., Kumar, A., and Raheman, H., Biodiesel production from jatropha oil (Jatropha curcas) with high free fatty acids: An optimized process. *Biomass and Bioenergy*, 2007. 31(8): 569-575.

18. Georgogianni, K. G., Katsoulidis, A. K., Pomonis, P. J., Manos, G., and Kontominas, M. G., Transesterification of rapeseed oil for the production of biodiesel using homogeneous and heterogeneous catalysis. *Fuel Processing Technology*, 2009. 90(7-8): 1016-1022.

19. Shahbazi, M. R., Khoshandam, B., Nasiri, M., and Ghazvini, M., Biodiesel production via alkali-catalyzed transesterification of Malaysian RBD palm oil – Characterization, kinetics model. *Journal of the Taiwan Institute of Chemical Engineers*, 2012. 43(4): 504-510.

20. Maneerung, T., Kawi, S., and Wang, C.-H., Biomass gasification bottom ash as a source of CaO catalyst for biodiesel production via transesterification of palm oil. *Energy Conversion and Management*, 2015. 92: 234-243.

21. Ito, T., Sakurai, Y., Kakuta, Y., Sugano, M., and Hirano, K., Biodiesel production from waste animal fats using pyrolysis method. *Fuel Processing Technology*, 2012. 94(1): 47-52.

22. Altun, Ş., Bulut, H., and Öner, C., The comparison of engine performance and exhaust emission characteristics of sesame oil–diesel fuel mixture with diesel fuel in a direct injection diesel engine. *Renewable Energy*, 2008. 33(8): 1791-1795.

23. Mueller, C. J., Boehman, A. L., and Martin, G. C., An Experimental Investigation of the Origin of Increased NOx Emissions When Fueling a

Heavy-Duty Compression-Ignition Engine with Soy Biodiesel. *SAE PTechnical Paper Series 2009-01-1792*, 2009.

24. Gan, S. and Ng, H. K., Effects of antioxidant additives on pollutant formation from the combustion of palm oil methyl ester blends with diesel in a non-pressurised burner. *Energy Conversion and Management*, 2010. 51(7): 1536-1546.

25. Mastorakos, E., Ignition of turbulent non-premixed flames. *Progress in Energy and Combustion Science*, 2009. 35(1): 57-97.

26. Briones, A., Som, S., and Aggarwal, S., Effect of multistage combustion on NOx emissions in methane–air flames. *Combustion and Flame*, 2007. 149(4): 448-462.

27. N. Syred and Beer, J. M., Combustion in Swirling flow: A Review. *Combustion and Flame*, 1974. 23: 143-201.

28. Kalt, P. A. M., Al-Abdeli, Y. M., Masri, A. R., and Barlow, R. S., Swirling Turbulent Non-Premixed Flames of Methane Flow Fluid and Compositional Structure. *Proceedings of the Combustion Institute, Volume*, 2002. 29: 1913–1919.

29. Hashemi, S. A., Fattahi, A., Sheikhzadeh, G. A., and Mehrabian, M. A., Investigation of the effect of air turbulence intensity on NOx emission in non-premixed hydrogen and hydrogen-hydrocarbon composite fuel combustion. *International Journal of Hydrogen Energy*, 2011. 36(16): 10159-10168.

30. He, B.-Q., Advances in emission characteristics of diesel engines using different biodiesel fuels. *Renewable and Sustainable Energy Reviews*, 2016. 60: 570-586.

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

32. Sharon, H., Karuppasamy, K., Soban Kumar, D. R., and Sundaresan, A., A test on DI diesel engine fueled with methyl esters of used palm oil. *Renewable Energy*, 2012. 47: 160-166.

33. Chauhan, B. S., Kumar, N., and Cho, H. M., A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends. *Energy*, 2012. 37(1): 616-622.

34. Ong, H. C., Masjuki, H. H., Mahlia, T. M. I., Silitonga, A. S., Chong, W. T., and Yusaf, T., Engine performance and emissions using Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel in a CI diesel engine. *Energy*, 2014. 69: 427-445.

35. Khalil, A. E. E. and Gupta, A. K., Distributed swirl combustion for gas turbine application. *Applied Energy*, 2011. 88(12): 4898-4907.

36. Wong, O., Design and Development of an Apparatus to Study Aviation Jet Fuel Thermal Stability. *Institute of Aerospace Studies, University of Toronto*, 2010.

37. Mofijur, M., Masjuki, H. H., Kalam, M. A., Atabani, A. E., and I.M. Rizwanul Fattah, H. M. M., Comparative evaluation of performance and emission characteristics of Moringa oleifera and Palm oil based biodiesel in a diesel engine. *Industrial Crops and Products*, 2014. 53: 78-84.

38. Habibullah, M., Masjuki, H. H., Kalam, M. A., Rizwanul Fattah, I. M., Ashraful, A. M., and Mobarak, H. M., Biodiesel production and performance evaluation of coconut, palm and their combined blend with diesel in a single-cylinder diesel engine. *Energy Conversion and Management*, 2014. 87: 250-257.

39. El-Kasaby, M. and Nemit-allah, M. A., Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel. *Alexandria Engineering Journal*, 2013. 52(2): 141-149.

40. Roy, M. M., Alawi, M., and Wang, W., Effects of Canola Biodiesel on a DI Diesel Engine Performance and Emissions. *International Journal of Mechanical & Mechatronics Engineering*, 2013. 13(2): 46-53.

41. Can, Ö., Öztürk, E., Solmaz, H., Aksoy, F., Çinar, C., and Yücesu, H. S., Combined effects of soybean biodiesel fuel addition and EGR application on the combustion and exhaust emissions in a diesel engine. *Applied Thermal Engineering*, 2016. 95: 115-124.

42. Banapurmath, N. R., Tewari, P. G., and Hosmath, R. S., Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters. *Renewable Energy*, 2008. 33(9): 1982-1988.

43. Tan, Y. H., Abdullah, M. O., Nolasco-Hipolito, C., Zauzi, N. S. A., and Abdullah, G. W., Engine performance and emissions characteristics of a diesel engine fueled with diesel-biodiesel-bioethanol emulsions. *Energy Conversion and Management*, 2017. 132: 54-64.

44. Liaquat, A. M., *et al.*, Effect of Coconut Biodiesel Blended Fuels on Engine Performance and Emission Characteristics. *Procedia Engineering*, 2013. 56: 583-590.

45. Daho, T., *et al.*, Combustion of vegetable oils under optimized conditions of atomization and granulometry in a modified fuel oil burner. *Fuel*, 2014. 118: 329-334.

46. Bazooyar, B., Hashemabadi, S. H., and Shariati, A., NO X formation of biodiesel in utility power plant boilers; Part B. Comparison of NO between biodiesel and petrodiesel. *Fuel*, 2016. 182: 323-332.

47. Al-Abdeli, Y. M. and Masri, A. R., Recirculation and flowfield regimes of unconfined non-reacting swirling flows. *Experimental Thermal and Fluid Science*, 2003. 27(5): 655-665.

48. Gupta, A. K., Gas turbine combustion prospects and challenges. *Energy Convers. Mgmt*, 1997. 38(10-13): 1311-1311.

49. Chong, C. T. and Hochgreb, S., Flow Field of a Model Gas Turbine Swirl Burner. *Advanced Materials Research*, 2012. 622-623: 1119-1124.

50. Grech, N., Koupper, C., Zachos, P. K., Pachidis, V., and Singh, R., Considerations on the Numerical Modeling and Performance of Axial Swirlers Under Relight Conditions. *Journal of Engineering for Gas Turbines and Power*, 2012. 134(11): 1115051-8.

51. Beltagui, S. A., Kenbar, A. M. A., and Maccallum, N. R. L., Comparison of Measured Isothermal and Combusting Confined Swirling Flows Peripheral Fuel Injection. *Experimental Thermal and Fluid Science*, 1993. 6: 147-156.

52. Majidi, R. and So, R. M. C., Swirl effects on variable-density jet mixing in confined flows. *Int. J. Heat and Fluid Flow*, 1987. 9(4): 366-372.

53. Kim, M.-K., Yoon, J., Park, S., Lee, M.-C., and Youngbin, Y., Effects of unstable flame structure and recirculation zones in a swirl-stabilized dump combustor. *Applied Thermal Engineering*, 2013. 58(1-2): 125-135.

54. Khanafer, K. and Aithal, S. M., Fluid-dynamic and NOx computation in swirl burners. *International Journal of Heat and Mass Transfer*, 2011. 54(23-24): 5030-5038.

55. Lahane, S. and Subramanian, K. A., Impact of nozzle holes configuration on fuel spray, wall impingement and NOx emission of a diesel engine for biodiesel–diesel blend (B20). *Applied Thermal Engineering*, 2014. 64(1-2): 307-314.

56. Yusoff, M. H. M., Abdullah, A. Z., Sultana, S., and Ahmad, M., Prospects and current status of B5 biodiesel implementation in Malaysia. *Energy Policy*, 2013. 62: 456-462.

57. Foo, K. Y., A vision on the opportunities, policies and coping strategies for the energy security and green energy development in Malaysia. *Renewable and Sustainable Energy Reviews*, 2015. 51: 1477-1498.

58. Jayed, M. H., Masjuki, H. H., Kalam, M. A., Mahlia, T. M. I., Husnawan, M., and Liaquat, A. M., Prospects of dedicated biodiesel engine vehicles in Malaysia and Indonesia. *Renewable and Sustainable Energy Reviews*, 2011. 15(1): 220-235.

59. Apostolakou, A. A., Kookos, I. K., Marazioti, C., and Angelopoulos, K. C., Techno-economic analysis of a biodiesel production process from vegetable oils. *Fuel Processing Technology*, 2009. 90(7-8): 1023-1031.

60. Panigrahy, S. and Mishra, S. C., Analysis of combustion of liquefied petroleum gas in a porous radiant burner. *International Journal of Heat and Mass Transfer*, 2016. 95: 488-498.

61. González-Espinosa, A., Lozano, A., García, J. A., Barreras, F., and Lincheta, E., Design modification of the air diffuser in the burners of a fuel oil power plant. Part II: Interaction with the liquid spray. *Fuel*, 2014. 124: 141-150.

62. Ti, S., *et al.*, Numerical simulation of the combustion characteristics and NOx emission of a swirl burner: Influence of the structure of the burner outlet. *Applied Thermal Engineering*, 2016. 104: 565-576.

63. Ling, Z., Zhou, H., and Ren, T., Effect of the flue gas recirculation supply location on the heavy oil combustion and NOx emission characteristics within a pilot furnace fired by a swirl burner. *Energy*, 2015. 91: 110-116.

64. Al-Abdelia, Y. M. and Masri, A. R., Review of laboratory swirl burners and experiments for model validation. *Experimental Thermal and Fluid Science*, 2015. 69: 178-196.

65. Shuguang Ti, Z. C., Zhengqi Li, Xiqian Zhang, Hao Zhang, Gaopeng Zou, Lingyan Zeng, Qunyi Zhu, Effects of the outer secondary air cone length on the combustion characteristics and NOx emissions of the swirl burner in a 0.5 MW pilot-scale facility during air-staged combustion. *Applied Thermal Engineering*, 2015. 86: 318-325.

66. Reddy, V. M., Biswas, P., Garg, P., and Kumar, S., Combustion characteristics of biodiesel fuel in high recirculation conditions. *Fuel Processing Technology*, 2014. 118: 310-317.

67. ANSYS, ANSYS Fluent Theory Guide. 2013.

68. Claypole, T. C. and Syred, N., The Effect of Swirl Burner Aerodynamics on NOx Formation. *Eighteenth Symposium (International) on Combustion*, 1981: 81-89.

69. Zhang, M., Fu, Z., Lin, Y., and Li, J., CFD Study of NOx Emissions in a Model Commercial Aircraft Engine Combustor. *Chinese Journal of Aeronautics*, 2012. 25(6): 854-863.

70. Deur, J., Kundu, K., and Nguyen, H., Applied analytical combustion/emissions research at the NASA Lewis Research Center - A progress report. 1992.

71. Westbrook, C. K. and Dryer, F. L., Chemical Kinetics and Modeling of Combustion Processes. *Eighteenth Symposium (International) on Combustion*, 1981.

72. Zanforlin, S., Reitz, R. D., and Gentili, R., Studying the Roles of Kinetics and Turbulence in the Simulation of Diesel Combustion by Means of an Extended Characteristic-Time-Model. *SAE Technical Paper Series 1999-01-1177*, 1999.

73. Magnussen, B. F. and Hjertager, B. H., On Mathematical Modeling of Turbulent Combustion with Special Emphasis on Soot Formation and Combustion. *Symposium (International) on Combustion*, 1977. 16(1): 719-729.

74. Kaario, O., Larmi, M., and Tanner, F., Comparing Single-Step and Multi-Step Chemistry Using the Laminar and Turbulent Characteristic Time Combustion Model in Two Diesel Engines. *SAE Technical Paper Series 2002-01-1749*, 2002.

75. Bazooyar, B., Ghorbani, A., and Shariati, A., Combustion performance and emissions of petrodiesel and biodiesels based on various vegetable oils in a semi industrial boiler. *Fuel*, 2011. 90(10): 3078-3092.

76. Chinnamma, M., *et al.*, Production of coconut methyl ester (CME) and glycerol from coconut (Cocos nucifera) oil and the functional feasibility of CME as biofuel in diesel engine. *Fuel*, 2015. 140: 4-9.

77. Chong, C. T., Ng, J.-H., Ahmad, S., and Rajoo, S., Oxygenated palm biodiesel: Ignition, combustion and emissions quantification in a light-duty diesel engine. *Energy Conversion and Management*, 2015. 101: 317-325.

78. Tashtoush, G., Al-Widyan, M. I., and Al-Shyoukh, A. O., Combustion performance and emissions of ethyl ester of a waste vegetable oil in a water-cooled furnace. *Applied Thermal Engineering*, 2003. 23: 285–293.

79. Ghorbani, A., Bazooyar, B., Shariati, A., Jokar, S. M., Ajami, H., and Naderi, A., A comparative study of combustion performance and emission of biodiesel blends and diesel in an experimental boiler. *Applied Energy*, 2011. 88(12): 4725-4732.

80. Rakopoulos, C. D., Antonopoulos, K. A., Rakopoulos, D. C., Hountalas, D. T., and Giakoumis, E. G., Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins. *Energy Conversion and Management*, 2006. 47(18-19): 3272-3287.

81. Rehman, A., Phalke, D. R., and Pandey, R., Alternative fuel for gas turbine: Esterified jatropha oil–diesel blend. *Renewable Energy*, 2011. 36(10): 2635-2640.

82. Sahoo, P. K., Das, L. M., Babu, M. K. G., and Naik, S. N., Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. *Fuel*, 2007. 86(3): 448-454.

83. Sequera, D., Agrawal, A. K., Spear, S. K., and Daly, D. T., Combustion Performance of Liquid Biofuels in a Swirl-Stabilized Burner. *Journal of Engineering for Gas Turbines and Power*, 2008. 130(3): 032810.

84. Ejilah, I. R., A.A., A., Adisa, A. B., and Ejila, A., The effect of diesel fuel-Jatropha curcas oil methyl ester blend on the performance of a variable speed compression ignition engine. *Australian Journal of Agricultural Engineering*, 2010. 1(3): 80-83.

85. How, H. G., Masjuki, H. H., Kalam, M. A., and Teoh, Y. H., An investigation of the engine performance, emissions and combustion characteristics of coconut biodiesel in a high-pressure common-rail diesel engine. *Energy*, 2014. 69: 749-759.

86. Nagi, J., Ahmed, S. K., and Nagi, F., Palm Biodiesel an Alternative Green Renewable Energy for the Energy Demands of the Future. *ICCBT*, 2008. 7: 79-94.

87. Roy, M. M., Wang, W., and Alawi, M., Performance and emissions of a diesel engine fueled by biodiesel–diesel, biodiesel–diesel-additive and kerosene–biodiesel blends. *Energy Conversion and Management*, 2014. 84: 164-173.

88. Varatharajan, K. and Cheralathan, M., Influence of fuel properties and composition on NOx emissions from biodiesel powered diesel engines: A review. *Renewable and Sustainable Energy Reviews*, 2012. 16(6): 3702-3710.

89. Rahman, M. M., Hassan, M. H., Kalam, M. A., Atabani, A. E., Memon, L. A., and Rahman, S. M. A., Performance and emission analysis of Jatropha curcas and Moringa oleifera methyl ester fuel blends in a multi-cylinder diesel engine. *Journal of Cleaner Production*, 2014. 65: 304-310.

90. Mofijur, M., Masjuki, H. H., Kalam, M. A., and Atabani, A. E., Evaluation of biodiesel blending, engine performance and emissions characteristics of

Jatropha curcas methyl ester- Malaysian perspective. *Energy*, 2013. 55: 879-887.

91. Iqbal, M. A., Varman, M., Hassan, M. H., Kalam, M. A., Hossain, S., and Sayeed, I., Tailoring fuel properties using jatropha, palm and coconut biodiesel to improve CI engine performance and emission characteristics. *Journal of Cleaner Production*, 2015. 101: 262-270.

92. Pereira, C., Wang, G., and Costa, M., Combustion of biodiesel in a large-scale laboratory furnace. *Energy*, 2014. 74: 950-955.

93. Lefebvre, A. H. and Ballal, D. R., Gas Turbine Combustion Alternative Fuels and Emissions. 2010.

94. Korres, D. M., Karonis, D., Lois, E., Linck, M. B., and Gupta, A. K., Aviation fuel JP-5 and biodiesel on a diesel engine. *Fuel*, 2008. 87(1): 70-78.

95. R.E, J., Gas Turbine Engine Emissions Problems, Progress and Future. *Energy Combust Sci.*, 1978. 4: 73-113.

96. Tadano, Y. S., *et al.*, Gaseous emissions from a heavy-duty engine equipped with SCR aftertreatment system and fuelled with diesel and biodiesel: assessment of pollutant dispersion and health risk. *Sci Total Environ*, 2014. 500-501: 64-71.

97. Chiaramonti, D., Rizzo, A. M., Spadi, A., Prussi, M., Riccio, G., and Martelli, F., Exhaust emissions from liquid fuel micro gas turbine fed with diesel oil, biodiesel and vegetable oil. *Applied Energy*, 2013. 101: 349-356.

98. Bolszo, C. D. and McDonell, V. G., Emissions optimization of a biodiesel fired gas turbine. *Proceedings of the Combustion Institute*, 2009. 32(2): 2949-2956.

99. Boyce, M. P., Gas Turbine Engineering Handbook. 2012.

100. Yoon, S. H., Park, S. H., Suh, H. K., and Lee, C. S., Effect of Biodiesel-Ethanol Blended Fuel Spray Characteristics on the Reduction of Exhaust Emissions in a Common-Rail Diesel Engine. *Journal of Energy Resources Technology*, 2010. 132(4): 042201.

101. Hoekman, S. K. and Robbins, C., Review of the effects of biodiesel on NOx emissions. *Fuel Processing Technology*, 2012. 96: 237-249.

102. McCarthy, P., Rasul, M. G., and Moazzem, S., Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different bio-diesels. *Fuel*, 2011. 90(6): 2147-2157.

103. Macor, A. and Pavanello, P., Performance and emissions of biodiesel in a boiler for residential heating. *Energy*, 2009. 34(12): 2025-2032.

104. Omidvarborna, H., Kumar, A., and Kim, D.-S., NOx emissions from low-temperature combustion of biodiesel made of various feedstocks and blends. *Fuel Processing Technology*, 2015. 140: 113-118.

105. Corsini, A., Marchegiani, A., Rispoli, F., Sciulli, F., and Venturini, P., Vegetable Oils as Fuels in Diesel Engine. Engine Performance and Emissions. *Energy Procedia*, 2015. 81: 942-949.

106. Peterson, C. L. and Reece, D. L., Emissions Testing with Blends of Esters of Rapeseed Oil Fuel With and Without a Catalytic Converter. *SAE PTechnical Paper Series 961114*, 1996.

107. Altaie, M. A. H., *et al.*, Performance and exhaust emission characteristics of direct-injection diesel engine fueled with enriched biodiesel. *Energy Conversion and Management*, 2015. 106: 365-372.

108. Buyukkaya, E., Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. *Fuel*, 2010. 89(10): 3099-3105.

109. Chattopadhyay, S. and Sen, R., Fuel properties, engine performance and environmental benefits of biodiesel produced by a green process. *Applied Energy*, 2013. 105: 319-326.

110. McCormick, R. L., Graboski, M. S., Alleman, T. L., Herring, A. M., and Tyso, K. S., Impact of Biodiesel Source Material and Chemical Structure on Emissions of Criteria Pollutants from a Heavy-Duty Engine. *Environ. Sci. Technol.*, 2001. 35: 1742-1747.

111. Lapuerta, M., Armas, O., and Rodriguezfernandez, J., Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science*, 2008. 34(2): 198-223.

112. Protection, U. S. E. and Agency, A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. *EPA*, 2002.

113. Ng, H. K., Gan, S., Ng, J.-H., and Pang, K. M., Simulation of biodiesel combustion in a light-duty diesel engine using integrated compact biodiesel–diesel reaction mechanism. *Applied Energy*, 2013. 102: 1275-1287.

114. Canakci, M., Erdil, A., and Arcaklioğlu, E., Performance and exhaust emissions of a biodiesel engine. *Applied Energy*, 2006. 83(6): 594-605.

115. Ghai, S., Das, L. M., and Babu, M. K. G., Emissions and performance study with sunflower methyl ester as diesel fuel engine. *ARPN Journal of Engineering and Applied Sciences*, 2008. 3(5): 75-80.

116. Palash, S. M., Kalam, M. A., Masjuki, H. H., Masum, B. M., Rizwanul Fattah, I. M., and Mofijur, M., Impacts of biodiesel combustion on NOx emissions and their reduction approaches. *Renewable and Sustainable Energy Reviews*, 2013. 23: 473-490.

117. Miller, J. A. and Bowman, C. T., Mechanism and modeling of nitrogen chemistry in combustion. *Progress in Energy and Combustion Science*, 1989. 15: 287-338.

118. Cormick, R. L. M., Williams, A., Ireland, J., Brimhall, M., and Hayes, R. R., Effects of biodiesel blends on vehicle emissions. *NREL* 2006.

119. Sharma, N. Y. and Som, S. K., Influence of fuel volatility and spray parameters on combustion characteristics and NOx emission in a gas turbine combustor. *Applied Thermal Engineering*, 2004. 24(5-6): 885-903.

120. Cheikh Mansour, A. B., Abdelkader Aris, Françoise Gaillard Gas–Diesel (dual-fuel) modeling in diesel engine environment. *Int. J. Therm. Sci*, 2001. 40: 409–424.

121. Woo, M., Choi, B. C., and Ghoniem, A. F., Experimental and numerical studies on NOx emission characteristics in laminar non-premixed jet flames of ammonia-containing methane fuel with oxygen/nitrogen oxidizer. *Energy*, 2016. 114: 961-972.

122. Gonzalez-Juez, E. D., Kerstein, A. R., Ranjan, R., and Menon, S., Advances and challenges in modeling high-speed turbulent combustion in propulsion systems. *Progress in Energy and Combustion Science*, 2017. 60: 26-67.

123. Bohon, M. D. and Roberts, W. L., NOx emissions from high swirl turbulent spray flames with highly oxygenated fuels. *Proceedings of the Combustion Institute*, 2013. 34(1): 1705-1712.

124. Ridluan, A., Eiamsa-ard, S., and Promvonge, P., Numerical simulation of 3D turbulent isothermal flow in a vortex combustor. *International Communications in Heat and Mass Transfer*, 2007. 34(7): 860-869.

125. Litvinov, I. V., Shtork, S. I., Kuibin, P. A., Alekseenko, S. V., and Hanjalic, K., Experimental study and analytical reconstruction of precessing vortex in a tangential swirler. *International Journal of Heat and Fluid Flow*, 2013. 42: 251-264.

126. Sloan, D. G., Smith, P. J., and Smoot, L. D., Modeling of Swirl in Turbulent Flow Systems. *Progress in Energy and Combustion Science*, 1986. 20: 163-250.

127. Eldrainy, Y. A., Saqr, K. M., Aly, H. S., and Jaafar, M. N. M., CFD insight of the flow dynamics in a novel swirler for gas turbine combustors. *International Communications in Heat and Mass Transfer*, 2009. 36(9): 936-941.

128. Yegian, D. T. and Cheng, R. K., Development of a Vane-Swirler for Use in a Low NOx Weak Swirl Burner. *American Flame Research Committee 1996 International Symposium*, 1996.

129. Jaafar, M. N. M., Jusoff, K., Osman, M. S., and Ishak, M. S. A., Combustor Aerodynamics Using Radial Swirler. *International Journal of the Physical Sciences*, 2011. 6(13): 3091-3098.

130. Derksen, J. J., Simulations of confined turbulent vortex flow. *Computers & Fluids*, 2005. 34(3): 301-318.

131. Yehia A. Eldrainy, M. N. M. J., Tholudin Mat Lazim, Numerical investigation of the flow inside primary zone of tubular combustor model. *Jurnal Mekanikal*, 2008. 26: 162 - 176.

132. Dombard, J., Poinsot, T., Mourea, V., Savary, N., Staffelbach, G., and Bodoc, V., Experimental and numerical study of influence of small geometrical modifications on the dynamics of swirling flows. *Proceedings of the Summer Program*, 2012.

133. Yoon, J., Kim, M.-K., Hwang, J., Lee, J., and Yoon, Y., Effect of fuel–air mixture velocity on combustion instability of a model gas turbine combustor. *Applied Thermal Engineering*, 2013. 54(1): 92-101.

134. Palm, R., Grundmann, S., Weismüller, M., Šarić, S., Jakirlić, S., and Tropea, C., Experimental characterization and modelling of inflow conditions for a gas turbine swirl combustor. *International Journal of Heat and Fluid Flow*, 2006. 27(5): 924-936.

135. García-Villalba, M., Fröhlich, J., and Rodi, W., Numerical Simulations of Isothermal Flow in a Swirl Burner. *Journal of Engineering for Gas Turbines and Power*, 2007. 129(2): 377.

136. Han, D., Ickes, A. M., Bohac, S. V., Huang, Z., and Assanis, D. N., HC and CO emissions of premixed low-temperature combustion fueled by blends of diesel and gasoline. *Fuel*, 2012. 99: 13-19.

137. Mathur, M. L. and Maccallum, N. R. L., Swirling air jets issuing from vane swirlers Part 1: Free jets. *Journal of the Institute of Fuel*, 1967: 214-225.

138. Lilley, D., Swirling flows in typical combustor geometries. *AAIA 23rd Aerospace Sciences Meeting*, 1985.

139. Lilley, D. G., Prediction of Inert Turbulent Swirl Flows. *AIAA Journal*, 1973. 11(7): 955-960.

140. Lilley, D. G., Modeling of combustor swirl flows. *Acta Astronautica*, 1974. 1: 1129-114.

141. Lilley, D. G., Swirl Flows in Combustion: A Review. *AIAA Journal*, 1977. 15(8): 1063-1078.

142. Orbay, R. C., Nogenmyr, K. J., Klingmann, J., and Bai, X. S., Swirling turbulent flows in a combustion chamber with and without heat release. *Fuel*, 2013. 104: 133-146.

143. Pollard, A., Ozem, H. L. M., and Grandmaison, E. W., Turbulent, swirling flow over an axisymmetric, constant radius surface. *Experimental Thermal and Fluid Science*, 2005. 29(4): 493-509.

144. Murphy, S., Delfos, R., Pourquié, M. J. B. M., Olujić, Ž., Jansens, P. J., and Nieuwstadt, F. T. M., Prediction of strongly swirling flow within an axial hydrocyclone using two commercial CFD codes. *Chemical Engineering Science*, 2007. 62(6): 1619-1635.

145. Thundil Karuppa Raj, R. and Ganesan, V., Study on the effect of various parameters on flow development behind vane swirlers. *International Journal of Thermal Sciences*, 2008. 47(9): 1204-1225.

146. Raj, R. T. K. and Ganesan, V., Experimental study of recirculating flows induced by vane swirler. *Indian Journal of Engineering & Materials Sciences*, 2009. 16: 14-22.

147. Tagaki, T. and Okamoto, T., Characteristics of Combustion and Pollutant Formation in Swirling Flames. *Combustion and Flame*, 1981. 43: 69-79.

148. Yılmaz, İ., Effect of Swirl Number on Combustion Characteristics in a Natural Gas Diffusion Flame. *Journal of Energy Resources Technology*, 2013. 135(4): 1-8.

149. Shah, B. K., Dhakiya, A. K., and Mohite, A. S., Experimental study on the effect of various parameters of recirculating flows induced by vane swirler. *International Journal of Engineering Research and Development*, 2012. 3(4): 40-46.

150. Matsubayashi, T., Katono, K., Hayashi, K., and Tomiyama, A., Effects of swirler shape on swirling annular flow in a gas–liquid separator. *Nuclear Engineering and Design*, 2012. 249: 63–70.

151. Lee, C. W. and Moon, S. Y., An experimental investigation of the effects of turbulence generators attached to an axial swirler nozzle on mixing and combustion. *Aerospace Science and Technology*, 2002. 6: 517-520.

152. Magnussen, B. F., The eddy dissipation concept a bridge between science and technology. *ECCOMAS Thematic Conference on Computational Combustion, Lisbon, June 21-24, 2005*, 2005.

153. Launder, B. E. and Spalding, D. B., The Numerical Computation of Turbulent Flows. *Computer Methods in Applied Mechanics and Engineering*, 1974. 3: 269-289

154. Jones, W. P. and Launder, B. E., The prediction of laminarisation wirh a two-equation model of turbulence. *Int. J. Heat Mass Transfer*, 1972. 15: 301-314.

155. Benim, A. C., Escudier, M. P., Nahavandi, A., Nickson, A. K., Syed, K. J., and Joos, F., Experimental and numerical investigation of isothermal flow in an idealized swirl combustor. *International Journal of Numerical Methods for Heat & Fluid Flow*, 2010. 20(3): 348-370.

156. Shamami, K. K. and Birouk, M., Assessment of the Performances of RANS Models for Simulating Swirling Flows in a Can Combustor. *The Open Aerospace Engineering Journal*, 2008. 1: 8-27.

157. Ohtsuka, M., Numerical analysis of swirling non-reacting and reacting flows by Reynolds stress differential method. *Int. J. Heat Mass Transfer*, 1995. 38(2): 331-337.

158. German, A. and Mahmud, T., Modelling of non-premixed swirl burner flows using a Reynolds-stress turbulence closure. *Fuel*, 2005. 84(5): 583-594.

159. Li, Z., Kharoua, N., Redjem, H., and Khezzar, L., RANS and LES Simulation of a Swirling Flow in a Combustion Chamber with Different Swirl Intensities. *Proceedings of CHT-12. ICHMT International Symposium on Advances in Computational Heat Transfer*, 2012.

160. Koutmos, P. and McGuirk, J., Isothermal modeling of gas turbine combustors - Computational study. *Journal of Propulsion and Power*, 1991. 7(6): 1064-1071.

161. Xia, J. L., Smith, B. L., Benim, A. C., Schmild, J., and Yadigaroglu, G., Effect of Inlet and Outlet Boundary Conditions on Swirling Flows. *Computers & Fluids*, 1997. 26(8): 811-823.

162. Dong, M. and Lilley, D., Inlet velocity profile effects on turbulent swirling flow predictions. *31st Aerospace Sciences Meeting and Exhibit*, 1993.

163. Sturgess, G., Syed, S., and McManus, K., Importance of inlet boundary conditions for numerical simulation of combustor flows. *American Institute of Aeronautics and Astronautics*, 1983.

164. Merlo, N., *et al.*, Combustion characteristics of methane–oxygen enhanced air turbulent non-premixed swirling flames. *Experimental Thermal and Fluid Science*, 2014. 56: 53-60.

165. John F. Widmann, S. Rao Charagundla, and Presser, C., Aerodynamic study of a vane cascade_swirl. *Chemical Engineering Science*, 2000. 55: 5311-5320.

166. Thet Mon Soe and Khaing, S. Y., Comparison of Turbulence Models for Computational Fluid Dynamics Simulation of Wind Flow on Cluster of Buildings in Mandalay. *International Journal of Scientific and Research Publications*, 2017. 7(8): 337-350.

167. A.J. Hoekstra, J.J. Derksen, and Akker, H. E. A. V. D., An experimental and numerical study of turbulent swirling flow in gas cyclones. *Chemical Engineering Science*, 1999. 54: 2055-2065.

168. Guillas, S., Glover, N., and Malki-Epshtein, L., Bayesian calibration of the constants of the k-ε turbulence model for a CFD model of street canyon flow. *Computer Methods in Applied Mechanics and Engineering*, 2014. 279: 536-553.

169. Toshio Kobayashi and Yoda, M., Modified k–e model for turbulent swirling flow in a straight pipe. *JSME Int. J*, 1987. 30(259): 66-71.

170. R. D. Brum and Samuclsen, G. S., Two-component laser anemometry measurements of non-reacting and reacting complex flows in a swirl-stabilized model combustor. *Experiments in Fluids*, 1987. 5: 95-102.

171. Diego del Olmo D´ıaz and Hinz, D. F., Performance of eddy-viscosity turbulence models for predicting swirling pipe-flow- Simulations and laser-Doppler velocimetry. 2015.

172. Escue, A. and Cui, J., Comparison of turbulence models in simulating swirling pipe flows. *Applied Mathematical Modelling*, 2010. 34(10): 2840-2849.

173. Tsan-Hsing Shih, Jiang Zhu, William Liou, Kuo-Huey Chen, Nan-Suey Liu, and Lumley, J. L., Modeling of turbulent swirling flows. 1997.

174. Y. Bartosiewicz, Zine Aidoun, P. Desevaux, and Mercadier, Y., CFD-Experiments Integration in the Evaluation of Six Turbulence Models for Supersonic Ejectors Modeling.

175. Marzouk, O. A. and Huckaby, E. D., Simulation of a Swirling Gas-Particle Flow Using Different k-epsilon Models and Particle-Parcel Relationships. *Engineering Letters*, 2010. 18(1).

176. AbdelGayed, H. and Abdelghaffar, W., Main flow characteristics in a lean premixed swirl stabilized gas turbine combustor – Numerical computations. *American Journal of Scientific and Industrial Research*, 2013. 4(1): 123-136.

177. Xia, J. L., Yadigaroglu, G., Liu, Y. S., Schmidli, J., and Smit, B. L., Numerical and experimental study of swirling flow in a model combustor. *International Journal of Heat and Mass Transfer*, 1998. 41(11): 1485-1491.

178. Datta, A. and Som, S. K., Combustion and emission characteristics in a gas turbine combustor at di◎fferent pressure and swirl conditions. *Applied Thermal Engineering*, 1999. 19: 949-967.

179. Yakhot, V. and Orszag, S. A., Renormalization Group and Local Order in Strong Turbulence. *Nuclear Physics*, 1987.

180. Shih, T.-H., Liou, W. W., Shabbir, A., Yang, Z., and Zhu, J., A New k-t Eddy Viscosity Model for High-Reynolds Number Turbulent Flows. *Computers Fluids*, 1995. 24(3): 227-238.

181. Sicot, C., Devinant, P., Loyer, S., and Hureau, J., Rotational and turbulence effects on a wind turbine blade. Investigation of the stall mechanisms. *Journal of Wind Engineering and Industrial Aerodynamics*, 2008. 96(8-9): 1320-1331.

182. A. Kumar, S. O. O., Saul S. Namango, Kirimi H Kiriamiti, Heterogeneous Basic Catalysts For Transesterification Of Vegetable Oils- A Review. *Proceedings of the 2012 Mechanical Engineering Conference on Sustainable Research and Innovation*, 2012. 4: 59-68.

183. Andrade-Tacca, C. A., *et al.*, Reduction of FFA in jatropha curcas oil via sequential direct-ultrasonic irradiation and dosage of methanol/sulfuric acid catalyst mixture on esterification process. *Energy Conversion and Management*, 2014. 88: 1078-1085.

184. Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., and Mekhilef, S., A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews*, 2012. 16(4): 2070-2093.

185. Deng, X., Fang, Z., and Liu, Y.-h., Ultrasonic transesterification of Jatropha curcas L. oil to biodiesel by a two-step process. *Energy Conversion and Management*, 2010. 51(12): 2802-2807.

186. Salvi, B. L. and Panwar, N. L., Biodiesel resources and production technologies – A review. *Renewable and Sustainable Energy Reviews*, 2012. 16(6): 3680-3689.

187. Sharma, Y. C. and Singh, B., Development of biodiesel: Current scenario. *Renewable and Sustainable Energy Reviews*, 2009. 13(6-7): 1646-1651.

188. Johnston, M. and Holloway, T., A Global Comparison of National Biodiesel Production Potentials. *Environmental Science & Technology*, 2007. 41(23): 7967-7973.

189. Balat, M. and Balat, H., Progress in biodiesel processing. *Applied Energy*, 2010. 87(6): 1815-1835.

190. Srivastava, A. and Prasad, R., Triglycerides-based diesel fuels. *Renewable and Sustainable Energy Reviews* 2000. 4: 111-133.

191. Demirbas, A., Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Conversion and Management*, 2008. 49(8): 2106-2116.

192. Sáez-Bastante, J., Pinzi, S., Reyero, I., Priego-Capote, F., Luque de Castro, M. D., and Dorado, M. P., Biodiesel synthesis from saturated and unsaturated oils assisted by the combination of ultrasound, agitation and heating. *Fuel*, 2014. 131: 6-16.

193. Pimentel, D., Biofuels, Solar and Wind as Renewable Energy Systems. 2008.

194. Abo El-Enin, S. A., Attia, N. K., El-Ibiari, N. N., El-Diwani, G. I., and El-Khatib, K. M., In-situ transesterification of rapeseed and cost indicators for biodiesel production. *Renewable and Sustainable Energy Reviews*, 2013. 18: 471-477.

195. Li, Y., Qiu, F., Yang, D., Sun, P., and Li, X., Transesterification of soybean oil and analysis of bioproduct. *Food and Bioproducts Processing*, 2012. 90(2): 135-140.

196. Balat, M., Prospects for Worldwide Biodiesel Market Development. *Energy Sources, Part B: Economics, Planning, and Policy*, 2009. 4(1): 48-58.

197. Lim, S. and Teong, L. K., Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview. *Renewable and Sustainable Energy Reviews*, 2010. 14(3): 938-954.

198. Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., and Norhasyima, R. S., Comparison of palm oil, Jatropha curcas and Calophyllum inophyllum for biodiesel: A review. *Renewable and Sustainable Energy Reviews*, 2011. 15(8): 3501-3515.

199. Darnoko, D. and Cheryan, M., Kinetic of palm oil transesterification in a Batch Reactor. *JAOCS*, 2000. 77(12): 1263-1267.

200. Moser, B. R., Influence of extended storage on fuel properties of methyl esters prepared from canola, palm, soybean and sunflower oils. *Renewable Energy*, 2011. 36(4): 1221-1226.

201. Arbab, M. I., *et al.*, Evaluation of combustion, performance, and emissions of optimum palm–coconut blend in turbocharged and non-turbocharged conditions of a diesel engine. *Energy Conversion and Management*, 2015. 90: 111-120.

202. Rizwanul Fattah, I. M., Masjuki, H. H., Kalam, M. A., Mofijur, M., and Abedin, M. J., Effect of antioxidant on the performance and emission characteristics of a diesel engine fueled with palm biodiesel blends. *Energy Conversion and Management*, 2014. 79: 265-272.

203. Tamilselvan, P., Nallusamy, N., and Rajkumar, S., A comprehensive review on performance, combustion and emission characteristics of biodiesel fuelled diesel engines. *Renewable and Sustainable Energy Reviews*, 2017. 79: 1134-1159.

204. Gopinath, A., Puhan, S., and Nagarajan, G., Effect of biodiesel structural configuration on its ignition quality. *International Journal of Energy and Environment*, 2010. 1(2): 295-306.

205. Nakpong, P. and Wootthikanokkhan, S., High free fatty acid coconut oil as a potential feedstock for biodiesel production in Thailand. *Renewable Energy*, 2010. 35: 1682–1687.

206. Jiang, J.-J. and Tan, C.-S., Biodiesel production from coconut oil in supercritical methanol in the presence of cosolvent. *Journal of the Taiwan Institute of Chemical Engineers*, 2012. 43(1): 102-107.

207. Kalam, M. A., Husnawan, M., and Masjuki, H. H., Exhaust emission and combustion evaluation of coconut oil-powered indirect injection diesel engine. *Renewable Energy*, 2003. 28(15): 2405-2415.

208. Machacon, H. T. C., Shiga, S., Karasawa, T., and Nakamura, H., Performance and emission characteristics of a diesel engine fueled with coconut oil–diesel fuel blend. *Biomass and Bioenergy*, 2001. 20: 63–69.

209. Koh, M. Y. and Mohd. Ghazi, T. I., A review of biodiesel production from Jatropha curcas L. oil. *Renewable and Sustainable Energy Reviews*, 2011. 15(5): 2240-2251.

210. Divakara, B. N., Upadhyaya, H. D., Wani, S. P., and Gowda, C. L. L., Biology and genetic improvement of Jatropha curcas L.: A review. *Applied Energy*, 2010. 87(3): 732-742.

211. Sharma, Y. C. and Singh, B., Development of biodiesel from karanja, a tree found in rural India. *Fuel*, 2008. 87(8-9): 1740-1742.

212. Juan, J. C., Kartika, D. A., Wu, T. Y., and Hin, T. Y., Biodiesel production from Jatropha oil by catalytic and non-catalytic approaches: an overview. *Bioresour Technol*, 2011. 102(2): 452-60.

213. Liu, Y., Lu, H., Jiang, W., Li, D., Liu, S., and Liang, B., Biodiesel Production from Crude Jatropha curcas L. Oil with Trace Acid Catalyst. *Chinese Journal of Chemical Engineering*, 2012. 20(4): 740-746.

214. Borugadda, V. B. and Goud, V. V., Biodiesel production from renewable feedstocks: Status and opportunities. *Renewable and Sustainable Energy Reviews*, 2012. 16(7): 4763-4784.

215. Bojan, S. G. and Durairaj, S. K., Producing Biodiesel from High Free Fatty Acid Jatropha Curcas Oil by A Two Step Method- An Indian Case Study. *Journal of Sustainable Energy & Environment* 2012. 3 63-66.

216. Kalam, M. A., Ahamed, J. U., and Masjuki, H. H., Land availability of Jatropha production in Malaysia. *Renewable and Sustainable Energy Reviews*, 2012. 16(6): 3999-4007.

217. Corro, G., Tellez, N., Ayala, E., and Marinez-Ayala, A., Two-step biodiesel production from Jatropha curcas crude oil using SiO2·HF solid catalyst for FFA esterification step. *Fuel*, 2010. 89(10): 2815-2821.

218. Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., and Chong, W. T., Biodiesel Conversion from High FFA Crude Jatropha Curcas, Calophyllum Inophyllum and Ceiba Pentandra Oil. *Energy Procedia*, 2014. 61: 480-483.

219. Sahoo, P. K. and Das, L. M., Process optimization for biodiesel production from Jatropha, Karanja and Polanga oils. *Fuel*, 2009. 88(9): 1588-1594.

220. Nabi, M. N., Rahman, M. M., and Akhter, M. S., Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. *Applied Thermal Engineering*, 2009. 29(11-12): 2265-2270.

221. Panwar, N. L., Shrirame, H. Y., Rathore, N. S., Jindal, S., and Kurchania, A. K., Performance evaluation of a diesel engine fueled with methyl ester of castor seed oil. *Applied Thermal Engineering*, 2010. 30(2-3): 245-249.

222. Prasad, C. S. N., Reddy, K. V. K., Kumar, B. S. P., Ramjee, E., Hebbel, O. D., and Nivendgi, M. C., Performance and emission characteristics of a diesel engine with castor oil. *Indian Journal of Science and Technology*, 2009. 2(10): 25-31.

223. Bateni, H., Karimi, K., Zamani, A., and Benakashani, F., Castor plant for biodiesel, biogas, and ethanol production with a biorefinery processing perspective. *Applied Energy*, 2014. 136: 14-22.

224. Sánchez, N., Sánchez, R., Encinar, J. M., González, J. F., and Martínez, G., Complete analysis of castor oil methanolysis to obtain biodiesel. *Fuel*, 2015. 147: 95-99.

225. Ramezani, K., Rowshanzamir, S., and Eikani, M. H., Castor oil transesterification reaction: A kinetic study and optimization of parameters. *Energy*, 2010. 35(10): 4142-4148.

226. Abdul-Manan, A. F. N., Baharuddin, A., and Chang, L. W., A detailed survey of the palm and biodiesel industry landscape in Malaysia. *Energy*, 2014. 76: 931-941.

227. Castro Gonzáles, N. F., International experiences with the cultivation of Jatropha curcas for biodiesel production. *Energy*, 2016. 112: 1245-1258.

228. Mahmudul, H. M., Hagos, F. Y., Mamat, R., Adam, A. A., Ishak, W. F. W., and Alenezi, R., Production, characterization and performance of biodiesel as an alternative fuel in diesel engines – A review. *Renewable and Sustainable Energy Reviews*, 2017. 72: 497-509.

229. Bhuiya, M. M. K., Rasul, M. G., Khan, M. M. K., Ashwath, N., and Azad, A. K., Prospects of 2nd generation biodiesel as a sustainable fuel—Part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. *Renewable and Sustainable Energy Reviews*, 2016. 55: 1109-1128.

230. Bhuiya, M. M. K., Rasul, M. G., Khan, M. M. K., Ashwath, N., Azad, A. K., and Hazrat, M. A., Prospects of 2nd generation biodiesel as a sustainable fuel – Part 2: Properties, performance and emission characteristics. *Renewable and Sustainable Energy Reviews*, 2016. 55: 1129-1146.

231. Hajjari, M., Tabatabaei, M., Aghbashlo, M., and Ghanavati, H., A review on the prospects of sustainable biodiesel production: A global scenario with an emphasis on waste-oil biodiesel utilization. *Renewable and Sustainable Energy Reviews*, 2017. 72: 445-464.

232. Mofijur, M., *et al.*, Prospects of biodiesel from Jatropha in Malaysia. *Renewable and Sustainable Energy Reviews*, 2012. 16(7): 5007-5020.

233. Mofijur, M., Masjuki, H. H., Kalam, M. A., Shahabuddin, M., Hazrat, M. A., and Liaquat, A. M., Palm Oil Methyl Ester and Its Emulsions Effect on Lubricant Performance and Engine Components Wear. *Energy Procedia*, 2012. 14: 1748-1753.

234. Avinash, A., Subramaniam, D., and Murugesan, A., Bio-diesel—A global scenario. *Renewable and Sustainable Energy Reviews*, 2014. 29: 517-527.

235. Sanjid, A., Masjuki, H. H., Kalam, M. A., Rahman, S. M. A., Abedin, M. J., and Palash, S. M., Production of palm and jatropha based biodiesel and investigation of palm-jatropha combined blend properties, performance, exhaust emission and noise in an unmodified diesel engine. *Journal of Cleaner Production*, 2014. 65: 295-303.

236. De Rossi, A., Vescio, R., Russo, D., and Macrì, G., Potential Use of Jatropha Curcas L. on Marginal Lands of Southern Italy. *Procedia - Social and Behavioral Sciences*, 2016. 223: 770-775.

237. Gui, M. M., Lee, K. T., and Bhatia, S., Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. *Energy*, 2008. 33(11): 1646-1653.

238. Johnston, M. and Holloway, T., A Global Comparison of National Biodiesel. 2007.

239. Azad, A. K., Rasul, M. G., Khan, M. M. K., Sharma, S. C., and Islam, R., Prospect of Moringa Seed Oil as a Sustainable Biodiesel Fuel in Australia: A Review. *Procedia Engineering*, 2015. 105: 601-606.

240. Karmakar, A., Karmakar, S., and Mukherjee, S., Properties of various plants and animals feedstocks for biodiesel production. *Bioresour Technol*, 2010. 101(19): 7201-10.

241. Demirbas, A., Progress and recent trends in biodiesel fuels. *Energy Conversion and Management*, 2009. 50(1): 14-34.

242. Yilmaz, N. and Vigil, F. M., Potential use of a blend of diesel, biodiesel, alcohols and vegetable oil in compression ignition engines. *Fuel*, 2014. 124: 168-172.

243. Mekhilef, S., Siga, S., and Saidur, R., A review on palm oil biodiesel as a source of renewable fuel. *Renewable and Sustainable Energy Reviews*, 2011. 15(4): 1937-1949.

244. Maa, F. and Hanna, M. A., Biodiesel production a review. *Bioresource Technology*, 1999. 70: 1-15.

245. Qi, D. H., Chen, H., Matthews, R. D., and Bian, Y. Z., Combustion and emission characteristics of ethanol–biodiesel–water micro-emulsions used in a direct injection compression ignition engine. *Fuel*, 2010. 89: 958–964.

246. Shahid, E. M. and Jamal, Y., Production of biodiesel: A technical review. *Renewable and Sustainable Energy Reviews*, 2011. 15(9): 4732-4745.

247. Diebold, J. P. and Czernik, S., Additives To Lower and Stabilize the Viscosity of Pyrolysis Oils during Storage. *Energy & Fuels*, 1997. 11: 1081-1091.

248. Meher, L., Vidyasagar, D., and Naik, S., Technical aspects of biodiesel production by transesterification—a review. *Renewable and Sustainable Energy Reviews*, 2006. 10(3): 248-268.

249. Hameed, B. H., Lai, L. F., and Chin, L. H., Production of biodiesel from palm oil (Elaeis guineensis) using heterogeneous catalyst: An optimized process. *Fuel Processing Technology*, 2009. 90(4): 606-610.

250. Freedman, B., Pryde, E. H., and Mounts, T. L., Variables affecting the yields of fatty esters from transesterified vegetable oils. *J. Am. Oil Chem. Sot.*, 1984. 61: 1638-1643.

251. Hidayatno, A., Sutrisno, A., Zagloel, Y. M., and Purwanto, W. W., System Dynamics Sustainability Model of Palm-Oil Based Biodiesel Production Chain in Indonesia. *International Journal of Engineering & Technology*, 2011. 11(3): 1-6.

252. Berchmans, H. J. and Hirata, S., Biodiesel production from crude Jatropha curcas L. seed oil with a high content of free fatty acids. *Bioresour Technol*, 2008. 99(6): 1716-21.

253. Silitonga, A. S., Masjuki, H. H., Mahlia, T. M. I., Ong, H. C., Atabani, A. E., and Chong, W. T., A global comparative review of biodiesel production from jatropha curcas using different homogeneous acid and alkaline catalysts: Study of physical and chemical properties. *Renewable and Sustainable Energy Reviews*, 2013. 24: 514–533.

254. Vicente, G., Martinez, M., and Aracil, J., Integrated biodiesel production: a comparison of different homogeneous catalysts systems. *Bioresour Technol*, 2004. 92(3): 297-305.

255. Miao, X., Li, R., and Yao, H., Effective acid-catalyzed transesterification for biodiesel production. *Energy Conversion and Management*, 2009. 50(10): 2680-2684.

256. Canakci, M. and Gerpen, J. V., Biodiesel Production from Oils and Fats with High Free Fatty Acids. *American Society of Agricultural Engineers*, 2001. 44 (6): 1429–1436.

257. Freedman, B., Butterfield, R. O., and Pryde, E. H., Transesterification kinetics of soybean oil. *JAOCS*, 1995. 63(10): 1375-1380.

258. Encinar, J. M., González, J. F., and Rodríguez-Reinares, A., Ethanolysis of used frying oil. Biodiesel preparation and characterization. *Fuel Processing Technology*, 2007. 88(5): 513-522.

259. Diwani, G. E., Attia, N. K., and Hawash, S. I., Development and evaluation of biodiesel fuel and by-products from jatropha oil. *Int. J. Environ. Sci. Tech.*, 2009. 6(2): 219-224.

260. Alamu, O. J., Waheed, M. A., Jekayinfa, S. O., and Akintola, T. A., Optimal Transesterification Duration for Biodiesel Production from Nigerian. *Agricultural Engineering International: the CIGR Ejournal*, 2007. 7(18).

261. Thiruvengadaravi, K. V., Nandagopal, J., Baskaralingam, P., Sathya Selva Bala, V., and Sivanesan, S., Acid-catalyzed esterification of karanja (Pongamia pinnata) oil with high free fatty acids for biodiesel production. *Fuel*, 2012. 98: 1-4.

262. Zhu, H., *et al.*, Preparation of Biodiesel Catalyzed by Solid Super Base of Calcium Oxide and Its Refining Process. *Chinese Journal of Catalysis*, 2006. 27(5): 391-396.

263. Thanh, L. T., Okitsu, K., Boi, L. V., and Maeda, Y., Catalytic Technologies for Biodiesel Fuel Production and Utilization of Glycerol: A Review. *Catalysts*, 2012. 2(4): 191-222.

264. Hossain, A. B. M. S. and Mazen, M. A., Effects of catalyst types and concentrations on biodiesel production from waste soybean oil biomass as renewable energy and environmental recycling process. *Australian Journal of Crop Science*, 2010. 4(7): 550-555.

265. Rahayu, S. S. and Mindaryani, A., Optimization of Biodiesel Washing by Water Extraction. *Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA*, 2007.

266. Naik, M., Meher, L., Naik, S., and Das, L., Production of biodiesel from high free fatty acid Karanja (Pongamia pinnata) oil. *Biomass and Bioenergy*, 2008. 32(4): 354-357.

267. Lu, H., Liu, Y., Zhou, H., Yang, Y., Chen, M., and Liang, B., Production of biodiesel from Jatropha curcas L. oil. *Computers & Chemical Engineering*, 2009. 33(5): 1091-1096.

268. Baroutian, S., Aroua, M. K., Raman, A. A. A., and Sulaiman, N. M. N., Potassium hydroxide catalyst supported on palm shell activated carbon for transesterification of palm oil. *Fuel Processing Technology*, 2010. 91(11): 1378-1385.

269. Ong, H. C., Silitonga, A. S., Masjuki, H. H., Mahlia, T. M. I., Chong, W. T., and Boosroh, M. H., Production and comparative fuel properties of

biodiesel from non-edible oils: Jatropha curcas, Sterculia foetida and Ceiba pentandra. *Energy Conversion and Management*, 2013. 73: 245-255.

270. Bharathiraja, B., *et al.*, Biodiesel production using chemical and biological methods – A review of process, catalyst, acyl acceptor, source and process variables. *Renewable and Sustainable Energy Reviews*, 2014. 38: 368-382.

271. Kumar, N., Varun, and Chauhan, S. R., Performance and emission characteristics of biodiesel from different origins: A review. *Renewable and Sustainable Energy Reviews*, 2013. 21: 633-658.

272. Sarathy, S. M., Gaïl, S., Syed, S. A., Thomson, M. J., and Dagaut, P., A comparison of saturated and unsaturated C4 fatty acid methyl esters in an opposed flow diffusion flame and a jet stirred reactor. *Proceedings of the Combustion Institute*, 2007. 31(1): 1015-1022.

273. Silitonga, A. S., Atabani, A. E., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., and Mekhilef, S., A review on prospect of Jatropha curcas for biodiesel in Indonesia. *Renewable and Sustainable Energy Reviews*, 2011. 15(8): 3733-3756.

274. Benjumea, P., Agudelo, J., and Agudelo, A., Basic properties of palm oil biodiesel–diesel blends. *Fuel*, 2008. 87(10-11): 2069-2075.

275. Jain, S. and Sharma, M. P., Kinetics of acid base catalyzed transesterification of Jatropha curcas oil. *Bioresour Technol*, 2010. 101(20): 7701-6.

276. Chen, Y.-H., *et al.*, Property modification of jatropha oil biodiesel by blending with other biodiesels or adding antioxidants. *Energy*, 2011. 36(7): 4415-4421.

277. Sánchez, M., Bergamin, F., Peña, E., Martínez, M., and Aracil, J., A comparative study of the production of esters from Jatropha oil using different short-chain alcohols: Optimization and characterization. *Fuel*, 2015. 143: 183-188.

278. Yaakob, Z., Narayanan, B. N., Padikkaparambil, S., Unni K, S., and Akbar P, M., A review on the oxidation stability of biodiesel. *Renewable and Sustainable Energy Reviews*, 2014. 35: 136-153.

279. Mofijur, M., *et al.*, Properties and use of Moringa oleifera biodiesel and diesel fuel blends in a multi-cylinder diesel engine. *Energy Conversion and Management*, 2014. 82: 169–176.

280. Zhu, L., Xiao, Y., Cheung, C. S., Guan, C., and Huang, Z., Combustion, gaseous and particulate emission of a diesel engine fueled with n-pentanol (C5 alcohol) blended with waste cooking oil biodiesel. *Applied Thermal Engineering*, 2016. 102: 73-79.

281. Senthur Prabu, S., Asokan, M. A., Roy, R., Francis, S., and Sreelekh, M. K., Performance, combustion and emission characteristics of diesel engine fuelled with waste cooking oil bio-diesel/diesel blends with additives. *Energy*, 2017. 122: 638-648.

282. X. Wu, G. Iaccarino, F. Ham, and Moin, P., Simulation of the incompressible flow through a jet engine fuel nozzle rig. *Center for Turbulence Research*
Annual Research Briefs 2006, 2006.

283. García-Villalba, M., Fröhlich, J., and Rodi, W., Identification and analysis of coherent structures in the near field of a turbulent unconfined annular swirling jet using large eddy simulation. *Physics of Fluids*, 2006. 18(5): 055103.

284. Aransiola, E. F., Ojumu, T. V., Oyekola, O. O., Madzimbamuto, T. F., and Ikhu-Omoregbe, D. I. O., A review of current technology for biodiesel production: State of the art. *Biomass and Bioenergy*, 2014. 61: 276-297.

285. Yilmaz, N., Effects of intake air preheat and fuel blend ratio on a diesel engine operating on biodiesel–methanol blends. *Fuel*, 2012. 94: 444-447.

286. May, C., Liang, Y., Foon, C., Ngan, M., Chenghook, C., and Basiron, Y., Key fuel properties of palm oil alkyl esters. *Fuel*, 2005.

287. Yusup, S. and Khan, M. A., Base catalyzed transesterification of acid treated vegetable oil blend for biodiesel production. *Biomass and Bioenergy*, 2010. 34(10): 1500-1504.

288. Liu, Y., *et al.*, Kinetic studies on biodiesel production using a trace acid catalyst. *Catalysis Today*, 2016. 264: 55-62.

289. Ramos, L. P., Cordeiro, C. S., Cesar-Oliveira, M. A. F., Wypych, F., and Nakagaki, S., *Chapter 16 - Applications of Heterogeneous Catalysts in the Production of Biodiesel by Esterification and Transesterification*, in *Bioenergy Research: Advances and Applications*. 2014, Elsevier: Amsterdam. p. 255-276.

290. Chai, M., Tu, Q., Lu, M., and Yang, Y. J., Esterification pretreatment of free fatty acid in biodiesel production, from laboratory to industry. *Fuel Processing Technology*, 2014. 125: 106-113.

291. Leung, D. Y. C., Wu, X., and Leung, M. K. H., A review on biodiesel production using catalyzed transesterification. *Applied Energy*, 2010. 87(4): 1083-1095.

292. Joshi, H., Moser, B. R., Toler, J., Smith, W. F., and Walker, T., Effects of blending alcohols with poultry fat methyl esters on cold flow properties. *Renewable Energy*, 2010. 35(10): 2207-2210.

293. Mofijur, M., *et al.*, Effect of Biodiesel-diesel Blending on Physico-chemical Properties of Biodiesel Produced from Moringa Oleifera. *Procedia Engineering*, 2015. 105: 665-669.

294. Knothe, G., Analyzing biodiesel: standards and other methods. *Journal of the American Oil Chemists' Society*, 2006. 83(10): 823-833.

295. Wakil, M. A., Kalam, M. A., Masjuki, H. H., Atabani, A. E., and Rizwanul Fattah, I. M., Influence of biodiesel blending on physicochemical properties and importance of mathematical model for predicting the properties of biodiesel blend. *Energy Conversion and Management*, 2015. 94: 51-67.

296. Ayetor, G. K., Sunnu, A., and Parbey, J., Effect of biodiesel production parameters on viscosity and yield of methyl esters: Jatropha curcas, Elaeis guineensis and Cocos nucifera. *Alexandria Engineering Journal*, 2015. 54(4): 1285-1290.

297. Gülüm, M. and Bilgin, A., Density, flash point and heating value variations of corn oil biodiesel–diesel fuel blends. *Fuel Processing Technology*, 2015. 134: 456-464.

298. Hong, I. K., Lee, J. R., and Lee, S. B., Fuel properties of canola oil and lard biodiesel blends: Higher heating value, oxidative stability, and kinematic viscosity. *Journal of Industrial and Engineering Chemistry*, 2015. 22: 335-340.

299. Verma, P., Sharma, M. P., and Dwivedi, G., Evaluation and enhancement of cold flow properties of palm oil and its biodiesel. *Energy Reports*, 2016. 2: 8-13.

300. Echim, C., Maes, J., and Greyt, W. D., Improvement of cold filter plugging point of biodiesel from alternative feedstocks. *Fuel*, 2012. 93: 642-648.

301. Mofijur, M., Masjuki, H. H., Kalam, M. A., Atabani, A. E., Fattah, I. M. R., and Mobarak, H. M., Comparative evaluation of performance and emission characteristics of Moringa oleifera and Palm oil based biodiesel in a diesel engine. *Industrial Crops and Products*, 2014. 53: 78-84.

302. Qiu, F., Li, Y., Yang, D., Li, X., and Sun, P., Biodiesel production from mixed soybean oil and rapeseed oil. *Applied Energy*, 2011. 88(6): 2050-2055.

303. Corro, G., Bañuelos, F., Vidal, E., and Cebada, S., Measurements of surface acidity of solid catalysts for free fatty acids esterification in Jatropha curcas crude oil for biodiesel production. *Fuel*, 2014. 115: 625-628.

304. Ignacio R. Huerga, María Soledad Zanuttini, M. S. G., and Querini, C. A., Biodiesel production from Jatropha curcas: Integrated process optimization. *Energy Conversion and Management*, 2014. 80: 1-9.

305. Hashimoto, N., Nishida, H., and Ozawa, Y., Fundamental combustion characteristics of Jatropha oil as alternative fuel for gas turbines. *Fuel*, 2014. 126: 194-201.

306. Muthukumar, P. and Balakrishnan, S. R., CFD Analysis of recirculating flows induced by Axial Swirler. *International Journal of Engineering Research & Technology (IJERT)*, 2013. 2(6): 86-90.

307. Eiamsa-ard, S. and Promvonge, P., A Numerical Study of Gas Jets in Confined Swirling Air Flow. *Chiang Mai J. Sci.*, 2006. 33(3): 255-270.

308. Bourgouin, J.-F., Moeck, J., Durox, D., Schuller, T., and Candel, S., Sensitivity of swirling flows to small changes in the swirler geometry. *Comptes Rendus Mécanique*, 2013. 341(1-2): 211-219.

309. Jones, W. P., Lettieri, C., Marquis, A. J., and Navarro-Martinez, S., Large Eddy Simulation of the two-phase flow in an experimental swirl-stabilized burner. *International Journal of Heat and Fluid Flow*, 2012. 38: 145-158.

310. K.M. Pandey, D.H. Das, and Acharya, B., Effects of Variation of Specific Heat on Temperature in Gaseous Combustion with Fluent Software. *International Journal of Environmental Science and Development*, 2010. 1(5): 419-422.

311. Wannassi, M. and Monnoyer, F., Numerical simulation of the flow through the blades of a swirl generator. *Applied Mathematical Modelling*, 2016. 40(2): 1247-1259.

312. Rohani, B. and Saqr, K. M., Effects of hydrogen addition on the structure and pollutant emissions of a turbulent unconfined swirling flame. *International Communications in Heat and Mass Transfer*, 2012. 39(5): 681-688.

313. Merkle, K., Haessler, H., Büchner, H., and Zarzalis, N., Effect of co- and counter-swirl on the isothermal flow- and mixture-field of an airblast atomizer nozzle. *International Journal of Heat and Fluid Flow*, 2003. 24(4): 529-537.

314. Weber, R., Boysan, F., Swithenbank, J., and Roberts, P. A., Computations of Near Field Aerodynamics of Swirling Expanding Flows. *Twenty-first Symposium (International) on Combustion/The Combustion Institute*, 1986: 1435-1443.

315. Vondál, J. i. and Hájek, J. i., Swirling Flow Prediction in Model Combustor with Axial Guide Vane Swirler. *Chemical Engineering Transactions*, 2012. 29: 1069-1074.

316. Muthu Selvan, G., Muralidhara, H. S., Surya, J., and Dinesh Kanth, T. P., Computational Study of Recirculating Flows Induced by Axial Swirler. 2012.

317. Huang, R. F., Duc, L. M., and Hsu, C. M., Flow and mixing characteristics of swirling double-concentric jets influenced by a control disc at low central jet Reynolds numbers. *International Journal of Heat and Fluid Flow*, 2016. 62: 233-246.

318. Gobbato, P., Masi, M., Cappelletti, A., and Antonello, M., Effect of the Reynolds number and the basic design parameters on the isothermal flow field of low-swirl combustors. *Experimental Thermal and Fluid Science*, 2017.

319. İlbaş, M., Karyeyen, S., and Yilmaz, İ., Effect of swirl number on combustion characteristics of hydrogen-containing fuels in a combustor. *International Journal of Hydrogen Energy*, 2016. 41(17): 7185-7191.

320. Mafra, M. R., Fassani, F. L., Zanoelo, E. F., and Bizzo, W. A., Influence of swirl number and fuel equivalence ratio on NO emission in an experimental LPG-fired chamber. *Applied Thermal Engineering*, 2010. 30(8-9): 928-934.

321. Almeida, D. S. d. and Lacava, P. T., Analysis of Pollutant Emissions in Double-stage Swirl Chamber for Gas Turbine Application. *Energy Procedia*, 2015. 66: 117-120.

322. Prasad, B. V. V. S. U., Sharma, C. S., Anand, T. N. C., and Ravikrishna, R. V., High swirl-inducing piston bowls in small diesel engines for emission reduction. *Applied Energy*, 2011. 88(7): 2355-2367.

323. Lefebvre, A. H., The Role of Fuel Preparation in Low Emissions Combustion. *International Gas Turbine and Aeroengine Congress and Exposition, Houstan, Texas, 1995*, 1995.

324. Hosseini, S. E. and Wahid, M. A., Necessity of biodiesel utilization as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 2012. 16(8): 5732-5740.

325. Roy, P. and Sardar, A., SO2 Emission Control and Finding a Way Out to Produce Sulphuric Acid from Industrial SO2 Emission. *J Chem Eng Process Technology*, 2015. 6(2).

326. Kim, H.-S., Shin, M.-S., Jang, D.-S., Choi, Y.-C., and Lee, J.-G., Numerical study for the combustion characteristics of Orimulsion fuel in a small-scale combustor. *Applied Thermal Engineering*, 2005. 25(17-18): 2998-3012.

327. Bhimani, S., Alvarado, J. L., Annamalai, K., and Marsh, C., Emission characteristics of methanol-in-canola oil emulsions in a combustion chamber. *Fuel*, 2013. 113: 97–106.

328. Rokke, N. A., Hustad, J. E., and Berg, S., Pollutant Emissions From Gas Fired Turbine Engines in Offshore Practice - measurements and Scaling. *The American Society of Mehcanical Engineers*, 1993. 93-GT-170.

329. Jha, S. K., Fernando, S., and To, S. D. F., Flame temperature analysis of biodiesel blends and components. *Fuel*, 2008. 87(10-11): 1982-1988.

330. Zhu, Z., Guo, H. J., Zhou, A. P., Li, D. K., and Liu, S. H., One way to reduce the NOx Emission of biodiesels: The increase of cetane number. *International Journal of Green Energy*, 2012. 13(9): 957-962.

331. Tat, M. E., Investigation of oxides of nitrogen emissions from biodiesel-fuel. *PHD Theses and Dissertations*, 2003.

332. US, E., A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. 2002.

333. Jinlin Xue, T. E. G., Alan C. Hansen, Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews*, 2011. 15: 1098-1116.

334. Ono, M., Nakajima, M., Yoshida, K., Shoji, H., and Iijima, A., Influence of Various Biodiesel Fuels on Diesel Engine Performance. *SAE Technical Paper Series 2009-32-0100*, 2009: 7.

335. Srithar, K., Arun Balasubramanian, K., Pavendan, V., and Ashok Kumar, B., Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. *Journal of King Saud University - Engineering Sciences*, 2017. 29(1): 50-56.

336. Naumi, R. H. A. and Vishweshwara, S. C., Temperature-Viscosity Correlation for Biodiesel Blends Derived From Corn, Olive and Palm Oil. *International Journal of Multidisciplinary Sciences and Engineering*, 2015. 6(11): 21-27.

337. Kumbhare, M. and Sable, M. J., Investigation of emission & performance characteristics of waste cooking oil from diesel engine using exhaust gas recirculation. *International Journal of Multidisciplinary Research and Development*, 2015. 2(7): 604-607.

338. SenthilKumar, R. and Gopalakrishnan, V., Performance, emissions and combustion analysis of C.I engine using jatropha and mustard oil biodiesel using different injection pressure and injection timing. *International*

Journal of Science, Engineering and Technology Research (IJSETR), 2014. 3(7).

339. Graboski, M. S. and Cormick, R. L. M., Combustion of fat and vegetable oil derived fuels in diesel engines. *Prog. Energy Combust. Sci.*, 1998. 24: 125-168.

340. San José, J., Sanz-Tejedor, M. A., and Arroyo, Y., Effect of fatty acid composition in vegetable oils on combustion processes in an emulsion burner. *Fuel Processing Technology*, 2015. 130: 20-30.

341. Hoseini, S. S., Najafi, G., Ghobadian, B., Mamat, R., Sidik, N. A. C., and Azmi, W. H., The effect of combustion management on diesel engine emissions fueled with biodiesel-diesel blends. *Renewable and Sustainable Energy Reviews*, 2017. 73: 307-331.

342. Palash, S. M., Masjuki, H. H., Kalam, M. A., Atabani, A. E., Rizwanul Fattah, I. M., and Sanjid, A., Biodiesel production, characterization, diesel engine performance, and emission characteristics of methyl esters from Aphanamixis polystachya oil of Bangladesh. *Energy Conversion and Management*, 2015. 91: 149-157.

343. Komariah, L. N., Arita, S., Novia, Wirawan, S. S., and Yazid, M., Emission factors of biodiesel combustion in industrial boiler- A comparison to fossil fuel. *Journal of Renewable and Sustainable Energy*, 2013. 5: 1-8.

344. Mansourpoor, M. and Shariati, A., Analysis of Flue Gas Emissions Using a Semi-industrial Boiler Fueled by Biodiesel Produced from Two-stage Transesterification of Waste Cooking Oil. *Chem. Biochem. Eng. Q*, 2014. 28(1): 95-103.

345. Gumus, M., Sayin, C., and Canakci, M., The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fueled with biodiesel–diesel fuel blends. *Fuel*, 2012. 95: 486-494.

346. Wan Ghazali, W. N. M., Mamat, R., Masjuki, H. H., and Najafi, G., Effects of biodiesel from different feedstocks on engine performance and emissions: A review. *Renewable and Sustainable Energy Reviews*, 2015. 51: 585-602.

347. Garimella, V. N., Exhaust emissions analysis for ultra low sulfur diesel and biodiesel garbage trucks. *PHD Theses and Dissertations*, 2010: h p://utdr.utoledo.edu/theses-dissertations.

348. Teixeira, E. C., Mattuizi, C. D. P., Feltes, S., Wiegano, F., and Santana, E. R. R., Estimated atmospheric emissions from biodiesel and characterization of pollutants in the metropolitan area of Porto Alegre-RS. *Anais da Academia Brasileira de Ciência*, 2012. 84(3): 655-667.

349. Pirs, V. and Dukulis, I., Emission Reduction Potential of Using Biofuels. 2010.

350. Krzywański, J., Rajczyk, R., and Nowak, W., Model Research of Gas Emissions from Lignite and Biomass Co-combustion in a Large Scale CFB Boiler. *Chemical and Process Engineering*, 2014. 35(2): 217-231.

351. P.S, S. K. and Mahalingam, S., Effect of Injection Timing on Performance and Emission Analysis of Single Cylinder Diesel Engine Fuelled with Dual Bio-fuels. *International Journal of Advanced Mechanical Engineering*, 2014. 4(5): 487-496.

352. Xue, J., Combustion characteristics, engine performances and emissions of waste edible oil biodiesel in diesel engine. *Renewable and Sustainable Energy Reviews*, 2013. 23: 350–365.

353. Malgorzata Wilk, A. M., Monika Ku•znia, Wojciech Jerzak, The reduction of the emission of NOx in the heat-treating furnaces. *Metallugy and Foundry Engineering*, 2010. 36(1): 47-55.

354. Abedin, M. J., Masjuki, H. H., Kalam, M. A., Sanjid, A., and Ashraful, A. M., Combustion, performance, and emission characteristics of low heat

rejection engine operating on various biodiesels and vegetable oils. *Energy Conversion and Management*, 2014. 85: 173-189.

355. Atabani, A. E. and César, A. d. S., Calophyllum inophyllum L. – A prospective non-edible biodiesel feedstock. Study of biodiesel production, properties, fatty acid composition, blending and engine performance. *Renewable and Sustainable Energy Reviews*, 2014. 37: 644-655.