UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF SOLAR-POWERED BIODIESEL REACTOR FOR KUWAIT SHEEP TALLOW

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By

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Biodiesel is one of the recent green fuel production in the world, where it can be produced from several raw materials such as straight vegetable oils, animal fats, tallow and waste cooking oils etc, and blended with diesel. Properties of biodiesel are different compared to the fossil diesel in terms of production methods and emission levels released after the combustion in internal combustion engine. Kuwait consumes a huge amount of energy which is almost 8% to meet the increasing demand for electricity and water. Also, the use of electricity in the production of biodiesel adversely increases energy use and cost of production. While Kuwait is receiving the amount of irradiation from 2050 KWh/m^2 to 2100 KWh/m^2. Besides that, to the best of our knowledge there are no previous studies applied solar powered in producing biodiesel in Kuwait. The present study is concerned with the evaluation of the potential of using solar energy to produce biodiesel from sheep fat waste as a raw material due to its less cost, more efficient and renewable method. An experimental test rig was set up for a single cylinder diesel engine in the laboratory, where the solar system was used to assist the production process of biodiesel from tallow waste. The biodiesel is then blended with diesel at different volume percentages, such as graded as B20, B50, B75 and B100 respectively. The performance of the biodiesel was also investigated on a single-cylinder four-stroke diesel engine. The exhaust gases such as oxygen, carbon monoxide, carbon dioxide, nitric oxide and nitric dioxide where also analyzed. A solar system was designed and applied effectively to power the reactor for biodiesel production system. The designed solar system was consisted of solar cells, solar panels, two sources of electricity (12-volt DC and 240-volt AC power supply), adapter and 8-batteries. An optimum decrease values of nitric oxide level was observed at the load of 51%, 68%, 85% and 93% during the operation at blend of biodiesel B20, B50, B75, B100, respectively. Nitric dioxide was decreased at the load of 51%, 68% and 85% during the operation using of B20, B50, and B75. Optimum sfc was achieved at B20, B50, B75 during high loads of 85% and 93%. It can be concluded that sheep

tallow biodiesel shows a promising result in terms of fuel consumption and environmental emissions of greenhouse gases.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN REAKTOR BERKUASA SOLAR BAGI PENGELUARAN BAHAN API BIODIESEL DARIPADA LEMAK KAMBING BIRI-BIRI KUWAIT

Oleh

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Biodiesel merupakan antara bahan api ‘hijau’ yang terkini dihasilkan di seluruh dunia, di mana ia boleh dihasilkan daripada pelbagai bahan seperti minyak sayuran, lemak haiwan, lemak terproses, sisa minyak masak dan sebagainya. Biodiesel adalah berbeza berbanding diesel yang diperbuat daripada fosil seperti kaedah pengeluaran dan tahap pencemaran yang dilepaskan oleh enjin pembakaran dalaman. Negara Kuwait menggunakan jumlah tenaga yang amat tinggi iaitu sebanyak 8 peratus untuk memenuhi permintaan yang meningkat bagi kegunaan elektrik dan air. Selain daripada itu, penggunaan elektrik dalam pembuatan biodiesel juga menyebabkan peningkatan kepada jumlah tenaga yang digunakan dan kos pengeluaran. Kuwait juga menerima akibat daripada proses penyinaran berjumlah dari 2050 kWh/m^2 sehingga 2100 kWh/m^2. Selain itu, dengan pengetahuan yang terbaik, tidak ada kajian terdahulu yang menggunakan tenaga solar dalam menghasilkan biodiesel di Kuwait. Kajian ini mengambil kira penilaian terhadap penggunaan tenaga solar yang berpotensi untuk menghasilkan biodiesel daripada sisa lemak haiwan sebagai bahan pembuatan disebabkan kos yang kurang, kaedah yang lebih cekap dan boleh diperbaharui. Sebuah rig ujian dihasilkan untuk eksperimentasi di dalam makmal menggunakan enjin diesel satu silinder, di mana sistem solar digunakan bagi membantu pengeluaran biodiesel daripada lemak kambing biri-biri. Biodiesel kemudiannya dicampur dengan minyak diesel berdasarkan jumlah peratusan isipadu berdasarkan gred seperti B20, B50, B75 dan B100. Prestasi minyak biodiesel yang dihasilkan juga disiasat menggunakan sebuah enjin diesel satu silinder empat lejang. Gas-gas ekzos yang dihasilkan seperti oksigen, karbon monoksida, karbon dioksida, nitrik oksida dan nitrik dioksida juga dianalisis. Sebuah sistem solar direka dan digunakan secara efektif dalam memberikan kuasa kepada reaktor untuk sistem pengeluaran biodiesel. Sistem solar yang telah direka mempunyai beberapa ciri-ciri yang terdiri daripada sel solar, panel solar dan dua sumber tenaga elektrik (12-voltan arus terus dan 250-voltan arus ulang alik), penyesuai dan lapan bateri. Pengurangan yang optimum terhadap paras nitrik oksida

diperhatikan pada bebanan sebanyak 51%, 68%, 85 dan 93 % ketika operasi mencampurkan minyak biodiesel masing-masing kepada B20, B50, B75 dan B100. Paras Nitrik oksida berkurangan pada bebanan sebanyak 51, 68 dan 85 % ketika operasi mencampurkan minyak biodiesel masing-masing kepada B20, B50, dan B75. Jumlah pengunaan minyak yang optimum dapat dicapai untuk campuran minyak B20, B50 dan B75 ketika bebanan tinggi sebanyak 85 dan 93 %. Kesimpulannya, biodiesel daripada lemak kambing biri-biri menunjukkan keputusan yang amat memberangsangkan berdasarkan jumlah penggunaan minyak dan tahap pelepasan gas rumah hijau kepada persekitaran.

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Declaration by graduate student

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LIST OF ABBREVIATIONS/NOMENCLATURES

AFW	Animal Fat Waste
Al	Aluminium
Al_2O_3	Aluminium Oxide
B100	Pure Biodiesel
B20	Diesel + Biodiesel (80:20)
B50	Diesel + Biodiesel (50:50)
B75	Diesel + Biodiesel (25:75)
BaFeOx	Barium Iron Oxide
BaMnOx	Barium Manganese Oxide
CaCeOx	Calcium Cerium Oxide
CaFeOx	Calcium Iron Oxide
CaMnOx	Calcium Manganese Oxide
CaO	Calcium oxide
CaZrOx	Calcium Zirconium Oxide
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAGs	Diacylglycerol
EM	Electromagnetic
FAAE	Fatty Acid Alkyl Esters
FFA	Free Fatty Acide
GHG	Greenhouse Gas
H_2	Hydrogen
H_2SO_4	Sulfuric Acid
HCL	Hydrochloric Acid

IR	Infrared
KOH	Potassium Hydroxide
LHV	Lower Heating Value
MAGs	Monoacylglycerols
Mg	Magnesium
MPOC	Malaysian Palm Oil Council
MWs	Microwaves
NaOH	Sodium Hydroxide
NER	Net Energy Ratio
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O_2	Oxygen
PKO	Palm Kernel Oil
SCE	Supercritical Ethanol
SFA	Saturated Fats
SO_2	Sulfur dioxide
SPS	Solar photovoltaic system
TAGs	Triacylglycerols
TMAH	Tetramethylammonium Hydroxide
TMAH	Tetramethylammonium Hydroxide
US	Ultrasound
WCO	World Customs Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Energy is a very important factor for human endeavours. It is needed for economic growth and basic human needs such as food and health (Rey, 2013; Sopian et al., 2011). In recent years, the world is faced with energy crisis due to increased population growth, increased in the consumption of energy and depletion of energy resources (Bankovic-Ilic et al., 2014; Sopian et al., 2011). According to Abbas and Othman (2012), the energy consumption of the world doubled from 256 to 505 million GJ between 1973 to 2007. This crisis has expanded with a further decline in world petroleum reserves leading to reduction in oil production. In fact, at the current rate of energy consumption, the crude oil reserves have been estimated to completely depleted in the next 44 years (McGlade, 2012). Furthermore, most of the world's energy sources are from coal, petrochemical and natural gases (Abdullah et al., 2009; Demirbas and Demirbas, 2007). These sources have been reported to be finite and will be depleted shortly due to the current rate of consumption (Budzianowski, 2016). These situations have led to the search for environmental and sustainable sources of energy.

Sustainable energy sources such as solar, biomass, geothermal, wind and hydro are renewable and readily available, and can also be obtained at affordable cost with less impact on the environment. These energy sources can adversely lead to long term sustainable development (Sopian et al., 2011; Kjärstad and Johnsson, 2009; Sopian et al., 2011). Biomass is one of the most common and important renewable sources of energy that can be obtained from wood, animal waste, plants, and municipal waste. Biomass can be directly burnt or can easily be processed into biofuels such as methane (biogas), ethanol (bioethanol) and biodiesel, of which biodiesel is the most common and affordable biofuels (Abbas and Othman, 2012; Agrawal and Singh, 2010; Budzianowski, 2016). Therefore, there is a strong need to replace fossil fuels with more sustainable and readily available renewable energy such as biodiesel.

Biodiesel is a renewable source of energy produced from the reaction between biomass materials (vegetable oil, animal waste oil) and alcohol often carried out in the presence of a catalyst. Biodiesel is a liquid fuel commonly known as B100 or neat biodiesel in it pure and unblended form. Biodiesel has been in existence since 1893, when Dr. Rudolf Diesel developed the first vegetable oil fuelled engine (Balat & Balat, 2010). However, the full exploration of biodiesel based on vegetable oil became of significant interest only in the 1980s, due to the increasing demand for a renewable and sustainable energy source that will also reduce greenhouse gas (GHG) emissions (Barnwal and Sharma, 2005; Janaun and Ellis, 2010; Makarow et al. 2008; Pinzi et al., 2009). Since then, biodiesel has slowly penetrated the market in Europe, especially in Germany and France, as a blend to petrol diesel (De Santi et al., 2008; Popp et al., 2014; Thuijl et al., 2003). Commercially, these blends are named as B5, B20 or B100 to represent the volume percentage of biodiesel component in the blend with diesel as 5, 20 and 100 percentage volume, respectively. Currently, many countries around the world have explored and commercially used biodiesel blends for their vehicles such as the United States, Japan, Brazil and India (Balat, 2009; Christian, 2000; Janaun and Ellis, 2010). However, most countries especially in the middle east still rely heavily on fossil fuel for its energy demand.

Countries in the middles east such as Kuwait, consumes a huge amount of energy to meet the increasing demand for electricity and water. Alotaibi (2011) reported that the energy consumption rate of the state of Kuwait is at 8% annually. The rising rate in the total energy consumption is largely driven by the increased demand from power stations and water desalination plants (Focus, 2013). There is also a rise in the use of diesel generators, especially during summer at the peak of air conditioning demand. Increased in the countries fuel production by increasing the capacity of available refineries and building of new ones have failed to meet the energy requirement of the country. Meanwhile, the electricity demand continues to grow at 5% per year. Kuwait's oil consumption is likely to continue increasing, owing to population growth and urbanization, the growth of motor car ownership, and rising living standards, all of which are tied to economic growth related to the oil industry and the rise in world oil prices. Thus, the need to urgently diversify the energy sector by adequate development of renewable energy sources as a solution to Kuwait's lingering energy problems.

1.2 Problem Statement

Biodiesel, which is a renewable and non-toxic source of energy has been demonstrated to be a suitable and adequate replacement of fossil source of energy (Furuta et al., 2004; Huong et al., 2011; Luján et al., 2009; Murillo et al., 2007; Qi et al., 2009). It also contains similar properties with diesel fuel (Enweremadu & Mbarawa, 2009; Luján et al., 2009; Song & Wei, 2016; Tat, Van Gerpen, & Wang, 2007). Several countries have seen the increased development of biodiesel as a possible alternative for fossil fuel as shown in the background of the study, there is limited study on the development of sheep tallow as a feedstock using solar energy. The use of animal fat wastes and greases have gained significant interest in recent times apart from the most common raw material (feedstock) mainly used for the production of biodiesel which is vegetable oil (Gaurav, Ng, & Rempel, 2016; Gui, Lee, & Bhatia, 2008). Commercial sheep and lamb slaughter was at 2.18 million head with the USA identifying 834 slaughtering plants under federal inspection indicating a high amount of sheep slaughtered each year (USDA, 2017). The high numbers of sheep slaughtered per year results in a problem of disposal of the sheep tallow produced (Franke-Whittle & Insam, 2013). One of the solutions of animal disposal problem is its application as a feedstock to produce biodiesel (Feddern, 2011). However, there are limited studies on the use of sheep tallow as feedstock for biodiesel production.

Furthermore, the homogeneous transesterification process has proven to produce good quality biodiesel that can meet any international fuel standard. Ma et al. (1998) used 0.3 and 0.5 wt% of NaOH and $NaOCH_3$ respectively for the transesterification of beef tallow and maximum conversion was obtained within 60 min of reaction time. Potassium hydroxide as catalyst has also been reported for biodiesel production from bovine and beef fat as feedstock (Šánek, Pecha, Kolomazník, & Bařinová, 2016). However, the literature reviewed have shown that most of the homogeneous catalysts require high fat to methanol ratio, high reaction temperature, higher pressure and in some cases, their use requires longer time and addition of co-solvents during reaction for the maximum conversion of fat to biodiesel. All these factors directly or indirectly are expected to increase the production cost of biodiesel, which is a major hurdle for the commercialization of the biodiesel. Mutreja et al. (2011) demonstrated that KOH impregnated MgO heterogenous catalysts can be effectively be used to overcome all the challenges listed above. However, more studies are required to show the efficacy of this novel homogeneous transesterification method for the production of biodiesel from animal fat waste. Therefore, in order to develop an efficient biodiesel production process at ambient conditions, the use of KOH combined with MgO catalysts becomes indispensable.

In addition to the type of trasesterification catalyst, the use of electricity in the production of biodiesel adversely increases energy use and cost of production. The application of solar system to drive the chemical reactions during the process of biodiesel production can significantly reduce the electricity demand (Agee et al., 2014; Janulis, 2004; Antolin et al., 2002) and also eliminate the production of greenhouse gases such as carbon dioxide from the burning of fossil fuels. Few studies have been conducted on the use of concentrated solar energy to meet the heating energy requirements in a batch biodiesel production system (Chen et al., 2011; Cagle and Deaton, 2010; Schenk et al., 2008; Vasudevan and Briggs, 2008), however limited studies have been carried out on the application of solar energy sources for the production of biodiesel in batch systems. In fact, there is no known study on the production of biodiesel from animal fat waste as feedstock using concentrated solar energy source to power the reactor. This gap in knowledge is a serious setback for the advancement of biodiesel as a sustainable alternative to fossil fuel. Therefore, this study utilized a solar energy source of power in the production of biodiesel from animal fat waste. The results of this research can serve as a future basis for the commercialization and industrialization of biodiesel production from animal fat waste particularly in Kuwait and other Middle East countries.

1.3 Objective

This study investigated the development of a solar energy powered biodiesel production using animal fat wastes from sheep tallow. The specific objectives are:

i. To design, develop and fabricate a solar powered biodiesel production unit.
ii. To analyse and characterize the properties of biodiesel produced from sheep tallow based on reactor temperature.
iii. To determine the effect of solar energy source on the performance of biodiesel reactor.
iv. To analyse the performance of sheep fat biodiesel on diesel engine (emission levels) and compare with performance of conventional fuel.

1.4 Significance of Study

Animal fats have often been used as animal feeds, however this practice has reduced drastically due to the possibility of severe animal disease and the consequent obligation to effectively discard or recycle them (Ngo et al., 2008). Such fats can alternatively be used for biodiesel production, which constitutes no harm or danger to human and animal health.

This study has investigated the extraction of tallow from sheep. The extracted sheep fat was used as raw material for the production of biodiesel. The biodiesel production system had been designed to incorporate a solar system for powering the reactor. This makes the biodiesel production plant completely renewable. This study also produced a more efficient and user-friendly biodiesel operation process. The application of solar panel was also used to reduce the cost of production as solar is readily available.

1.5 Scope and Limitation

A four-stroke diesel engine with direct injection diesel, single cylinder was used to test the performance of the produced biodiesel in comparison with different blends (B20, B50, and B75) and was compared with conventional diesel fuels. General specification of the engine includes a capacity of 265ml and max power of 3.3 kW. The test procedure was to run the engine at 50 and 100% of engine load. The performance analysis was based only on the emission levels of exhaust temperature, NO, NO_2, CO, CO_2 and O_2. The solar system consisted of solar cells installed at the top of the laboratory roof. The solar panels were connected to the number of eight 24-volt batteries with a capacity of 80 mA, through the solar charge controller in order to control the charging process safely. The system also contains two sources of electricity the first is a 12-volt DC power supply to operate the mixing pump and the control panel, the second source is 240 volts to operate the reactor heater. For the 240-volt AC power supply, a 48-volt AC adapter was installed. The 8-batteries installed in 4 units were connected in series. Each unit contains two connected batteries, with a 48-volt parallel module in line with the converter specifications. The installed solar system was capable of securing an electric source of 1000 watts for 8 hours or 2000 watts for 4 hours. The feedstock used for the biodiesel production process is sheep tallow. The main limitation of this research work is the difficulty in accurately determining the quality of the produced biodiesel. Also, comparisons with other biodiesel production process and methods were not made. The comparative advantage of sheep tallow over other feed stock was also not determined in this study.

1.6 Thesis Layout

This thesis is organised into five chapters and each chapter is divided into several sub-sections. The background of the study, the knowledge gap, problem statement, research objectives, significance and scope of research are described in Chapter one. Chapter two gives a comprehensive review of the study based on the study objectives. A review on biodiesel production from animal fat wastes, methods of biodiesel production, alternative source of energy, and energy situation in Kuwait is presented in chapter two. Chapter three focused on methodology used in all the experiments including extraction of tallow from sheep, biodiesel production, and testing of biodiesel in an engine block. Chapter four presents the findings of the research. The results and discussions were done in such a way as to test the study objectives. Comparison with relevant literatures was also presented. Finally, the conclusions and recommendations based on the current research are presented in Chapter five.

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