COMBUSTION STABILITY ANALYSIS USING VEGETABLE OIL IN MICRO GAS TURBINE COMBUSTION CHAMBER

By:

MOHD ZUHAIRI BIN NORDIN

(Matrix no: 128948)

Supervisor:

Dr. Khaled Ali Mohammad Al-Attab

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Thesis submitted in fulfilment of the requirements
for the degree of
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DECLARATION

I hereby declare that this thesis is composed by myself, that the work contained herein is my own investigations, except where otherwhise stated. Other sources are acknowledged by giving explicit references. In addition, this thesis has not previously been accepeted in substance for any degree and is not being concurently in candidature for any degree.

Sign:……………………………………………….(MOHD ZUHAIRI BIN NORDIN)

Date:……………………………………………….

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LIST OF SYMBOLS

$\dot{m}$	Mass flow rate
ρ	Density
℃	Degree Celsius
$\dot{v}$	Volume flow rate
C_p	Specific heat capacity

LIST OF ABBREVIATIONS

MGT	Micro Gas Turbine
CO	Carbon Monoxide
SFC	Specific Fuel Consumption
TIT	Turbine Inlet Temperature
TOT	Turbine Outlet Temperature
COT	Compressor Outlet Temperature
HV	Heating value

ABSTRAK

Turbin gas mikro adalah penjana tenaga yang dibangunkan daripada sistem turbin gas. Secara konvensional, turbin gas mikro berfungsi dengan menggunakan diesel dan gas petroleum cecair . Di kawasan pedalaman bahan bakar diesel sukar diperoleh dan sangat mahal. Untuk menjamin persekitaran yang bersih dan mampan, penggunaan bahan api yang boleh diperbaharui di dalam turbin gas mikro menjadi permintaan. Oleh itu, biofuel sedang dikaji kesesuaian untuk menggantikan diesel dalam turbin gas mikro.

Tujuan projek ini ialah untuk mereka bentuk dan membuat kaca sampingan di ruang pembakaran turbin gas mikro. Dengan mempunyai kaca sisi di samping ruang pembakaran, kestabilan pembakaran pelbagai biofuel boleh dianalisis secara fizikal dan dibandingkan dengan pembakaran diesel sebagai penanda aras. Oleh itu, biofuel terbaik boleh dicadangkan untuk menggantikan diesel di dalam turbin gas mikro dari segi prestasi dan kestabilan pembakaran. Prestasi turbin gas mikro memfokuskan pada output kuasa, penggunaan bahan bakar khusus dan pelepasan karbon monoksida (CO).

Turbin gas mikro diuji pada 3 tekanan yang berbeza dan suhu keluar pemampat, suhu masuk dan keluar turbin, kadar aliran udara dan kadar aliran bahan api dicatatkan. Perbincangan ini termasuk prestasi dan analisis kestabilan turbin gas mikro dengan menggunakan parameter yang berbeza iaitu tekanan turbin gas mikro.

ABSTRACT

A micro gas turbine (MGT) is a power generator which is develop from gas turbine system. Conventionally, the MGT is running by using diesel and LPG. In rural area diesel fuel is difficult to get and very expensive. To secure a sustainable and poluution free environment, utilization of renewble fuels in micro gas turbine become a demand. Because of that, biofuel is being studied in term of it compatibility to replace diesel in micro gas turbine.

The purpose of this project is to design and fabricate a side glass on the MGT combustion chamber. By having a side glass on the combustion chamber, combustion stability of various biofuels can be analyse physically and compared with combustion of diesel as benchmark. So, the best biofuel can be proposed to replace diesel in MGT in term of it performance and stability of combustion. The performance of the MGT is focussing on the power output, specific fuel consumption and emission of carbon monoxide (CO).

The MGT is run at 3 different pressure and the temperature of compressor outlet, temperature of the turbine inlet and outlet, air flow rate and fuel flow are recorded. The discussion include the performance and stability analysis of the MGT with different input parameter which is the MGT pressure.

CHAPTER 1

INTRODUCTION

1.1 Introduction

A gas turbine is an internal combustion engine which converts the chemical energy of natural gas or other liquid fuels to mechanical energy for driving a generator that produces electrical energy. The gas turbine heats a mixture of air and fuel at a very high temperature, causing the turbine blades to spin at high speed and generate electricity. There are three main components in a gas turbine which comprise a compressor, a combustor and a power turbine. The gas turbine is suitable as the high-power engine such as engine for airplane. Micro gas turbines have the same basic operating principle as open cycle gas turbines (Brayton open cycle). In this cycle, the air is compressed by the compressor, going through the combustion chamber, where it receives energy from the fuel and thus raises in temperature. Leaving the combustion chamber, the high temperature working fluid is directed to the turbine, where it is expanded by supplying power to the compressor and for the electric generator or other equipment available[1]. Micro-gas turbine (MGT) usually produces between 25 and 500 kW of electrical power, it has minimal maintenance and operational cost, high power density and low emission. An important factor that attracts researchers to develop MGT's especially for renewable energy fuel types is that it can be operated with various kinds of fuels [1]. Micro-gas turbine being focused by researchers in term of generation of re-newable energy[2].

The micro gas turbine has been developed from the gas turbine system which offers some advantages over other small-scale power generation system. Micro gas turbines are small-scale independent and reliable distributed generation systems that offer potential for saving energy and reducing carbon monoxide emissions[3]. Micro gas turbines are a promising technology for distributed power generation because of their compact size, low emissions, minimal maintenance, low noise, high reliability and multi-fuel capability[2]. Micro gas turbine engines that produce extremely low emissions have the prospect to be used for hybrid vehicles, continuous power generation and distributed power source[2]. For most of the simple cycle micro gas turbines, where no heat recovery from the exhaust for preheating of the combustion gas or known as recuperated, are single stage, single shaft and low-pressure gas turbine[4]. Due to their rather low electrical efficiency of 30%, Micro Gas Turbine MGT mostly used in co-, tri- or polygeneration applications. In these applications, where there is a specific need for heat and the remaining heat in the exhaust gases can be used efficiently, the MGT achieve very high total efficiencies which about 80%, making them profitable. MGT also are considered as a valuable option as primary energy converter by many researchers to integrating energy networks with a clear power and heat demand. Recuperation typically doubles the electrical efficiency of the unit whilst reducing the amount of recoverable heat from the combustion chamber, however, this may not be desirable depending on the application[1]. A simple micro gas turbine compresses the incoming air, then passes through the recuperator where heat is gained before entering the combustor, hence, the hot high-pressure gas or fuel is exhausted through the turbine which extracts energy and uses to drive the compressor and shaft-mounted alternator. The alternator is a high-speed device producing a high-frequency output which is converted to the desired mains frequency and voltage in the power conditioner[1].

The main benefit of using micro gas turbine is the application of biomass or biofuels can be utilized for low greenhouse gasses emission. Biomass such as agricultural and urban wastes is an important type of renewable energy fuel sources especially in Malaysia with agriculture as her main economy [5]. Biofuel is a type of fuel that obtainable from biological material and can be existed in the form of solid, liquid or gas. Unlike fossil fuel which is derived from fossils of biological material, biofuels are more environmentally friendly and renewable. Normally, biofuel can be derived from agricultural crop, food waste and other by-product from industry. Biofuel is considered greener and cleaner than conventional fossil fuel due to the balance of the emission and consumption of greenhouse gas in the growth of the plantation. Besides, there are some crucial advantages over the usage of biofuels in energy generation in term of environment, socio-economic and technology concerns. A further advantage of the use of biofuels is the possibility to use various technologies that allow small scale production, according to the spirit of decentralization and medium scale plants[6]. Nevertheless, some typical problems arise with the application of the biofuels on micro gas turbines, including, possible contamination of the lubricating oil with the biofuel, formation of deposits in the injector, implementation of high-frequency injector for achieving fast ignition in the combustion chamber and much more[7, 8]. Hence, the difference composition of diesel and biofuel blends should be further research to test the performance of the micro gas turbine.

Recently, substantial attention is given to the micro gas turbine and biofuel due to their capability and potential applications on the energy regeneration with environment-friendly. The fuel properties and engine performances have been studied since few years back and available in the literature[7-9]. The micro gas turbine running on diesel has been proven to be effective in lots of research and study, in fact, offering several advantages compared to other ignition engines[7-9].

The advantages of the using of micro gas turbine running on biofuels gains interest especially in rural area due to the effortless availability[9].

One of critical issue in development of MGT is the design of combustion chamber based on temperature homo-genetic and CO emission. Low outlet temperature and CO emissions are some issues that need for further design and development to the MGT combustor. Flame sustain-ability over a range of operating mass flows and air-fuel (AF) ratios in a high-power density micro combustion were investigated[10, 11]. By using a stainless-steel based combustor, a high and uniform temperature distribution along the wall of the micro-combustor has being achieved[12, 13]. To improve thermal performances of MGT, another micro-axial stainless-steel based combustor was developed[14, 15].

There are several challenges that need to be overcome regarding the design of micro gas turbines. First, scaling is a common technique to define larger or smaller geometries with similar characteristics. But, a simple scaling of a high-performance large gas turbine is not the right way to go for a good micro gas turbine design. One of the main reasons is the big change of the Reynolds number, as well as the heat transfer between the hot and cold components, which is not negligible[16].

Furthermore, the major mechanical problem of the MGT is the high rotational speed that is needed to obtain the enthalpy and pressure. Rather than geometrical constraints are concerned, material and manufacturing technique selection is crucial to lowering the cost of the production since micro gas turbines need to compete with heavier but cheaper batteries in many cases (i.e. for UAV applications). Another major issue in micro gas turbines is the decrease of compressor and turbine efficiency with decreasing dimensions.

1.2 Project background

The aim of this project is to study the combustion stability analysis using vegetable oil in the micro gas turbine combustion chamber. Firstly, the existing combustion chamber needs to modify by putting side glass of any suitable materials. This because we want to analyst the flame of the combustion as one of the techniques to study the combustion chamber. The side glass must be from material that can withstand high temperature because combustion inside the combustion chamber could reach 2000 K. After done the modification, the combustion of the biofuels and diesel can be done. The existing fuels today are mostly extracted from fossil fuels which is not renewable. The problem arises with the common believe that the world oil reserve to be decline and the negatively impact on the environment.

Nevertheless, the implementation biofuel is believed to be more environmentally friendly and the most crucial part is the renewable of biofuel. Unlike fossil fuel, biofuel is easily obtained from biological material such as agricultural and urban wastes which is a vital fuel source for a country like Malaysia with agriculture as the main economy [7,8]. Nonetheless, the main concern on the biofuel is the possibility of the contamination deposit in the injector and combustion chamber since biofuel are basically a lower quality renewable fuels which related to the unfavourable physical and chemical characteristics, for instance, high viscosity and corrosive [5]. In addition, liquid biofuels suffer in general from the higher viscosity that is directly associated with injection and atomization deficiencies, lower heating value and higher ash content that greatly affect combustion stability [9]. The application of the biofuels on micro gas turbine is favorable for the benefits to the economy and environment. However, the performance of the micro gas turbine running on biofuel is still lack of information. Hence, the performance of the micro gas turbine running on biofuels must study further on the optimization of energy conversion and efficiency. The combustion of diesel will be the benchmark to be compared with other biofuels.

The emission from those combustions also need to take into consideration as we want to reduce pollution to the environment. For this reason, control strategies to improve air quality in local areas need to include control measures that are mandated and implemented on a state, region-wide or national basis, in combination with local control measures. In general, regulations established by the national government tend to have the widest application, which can minimize boundary and economic competition issues. If the emission from the MGT over the limit, some modification needs to be done to the Micro Gas Turbine (MGT).

1.3 Problem statement

Biofuels are the future interest in renewable green fuels. The biofuel that gain interest for research in the project is the vegetable oil and diesel blending. The main concern of the usage of biofuels over other fossil fuels is the higher viscosity, the lower heating value and other properties which will affect the combustion and performance on emission effect of the micro gas turbine. However, there are still lack of informations of the performance of existing single stage micro gas turbine running on liquid biofuels, hence, the experimental analysis is required to clarify the performance characteristic of the micro gas turbine running with the diesel, vegetable oil and the mixing of the biofuels.

1.4 Objective

The project is aimed:

1. To modify the combustion chamber of micro gas turbine (MGT) to allow visual inspection of flame during combustion process.
2. To characterize the combustion and stability analysis of the micro gas turbine (MGT) with diesel as the benchmark.
3. To analyses the combustion and stability analysis of the micro gas turbine (MGT) with difference ratio of vegetable oil with diesel blending and 100% of vegetable oil.

1.5 Scope of work

The stability analysis of micro gas turbine is mainly focussing on combustion, temperature profile and emission. The performance of 100% diesel will be the benchmark of the whole experiment. The blending of vegetable oil with diesel will be premixed with different ratios from B10 up to B100. With the different ratio of vegetable oil and diesel blending, the stability analysis will be compared to the micro gas turbine running on 100% diesel which act as the benchmark. B100 which is vegetable oil is preheated to overcome its high viscosity at different temperature levels.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, publish papers related to performance of MGT and combustion chamber of the MGT are used as references for this project. This current project more focusing on the stability of the combustion inside the combustion chamber by using diesel as the benchmark of the stability analysis.

2.2 Literature review

In a study by Enagi et al. [3], the design of a combustion chamber and the performance of MST was investigated. In designing the single state MST which currently used in this project they faced some challenges such as emission control, chamber materials temperature limitations and flame stability.

From this study, the design and development of the combustion chamber for MST was performed by SolidWorks and Ansys-Fluent simulation software. To determine the optimum flame holder chamber geometries special transport and non-premixed combustion model were used. From their study, they find out that the best chamber geometry was 50 mm flame holder diameter, 60 cm chamber height, having 4 holes of 6, 8 and 10 mm with dead zone between the combustion zone and dilution zone. The experimental test for the performance characteristic of MST was done by using liquefied petroleum gas (LPG) fuel resulted in stable combustion with CO emission below 100 ppm and turbine inlet temperature below 900 °C. However, the design consideration of the MST in this study only based on two-stage turbines. From this study, it just tests the performance of the liquefied petroleum gas (LPG) and a bit discussion about the stability of combustion. So, it quite different from my study which needs to analyses the stability of the combustion using vegetable oil in the combustion chamber.

Another study by De Robbio et al. [17], this study was focus on the potential of the micro gas turbine combustor when operated under unconventional fuel supplied. This study mainly aimed on the combustion analysis of natural gas mixtures which focussed on flame stability and flashback in premixed flames. Then, the results from this study are examined to make comparison of combustion stability and efficiency and pollutant production with high hydrogen / natural gas ratios. The author used 3D ANSYS-FLUENT solver to analyst the reacting flow. In this study, the author used MGT capstone C30 to analyses the combustion of hydrogen-natural gas. The combustor of the MGT was designed by supplier included the CAD geometry that available in this paper. The combustor is divided into 3 parts which are external liner, internal core and the injector and The CFD analysis was performed with the ANSYS-FLUENT solver. From this study, the author concluded that Also the addition of an amount of H2 does not improve combustion efficiency. This study also a bit different from my study which does not discuss about combustion stability of vegetable oil and diesel.

The performances of bioliquid run in MGT have been studied by Chiaramonti, Rizzo et al. [8]. In this study, several alternative biofuels like biodiesel, pure vegetable oil and bio oil from fast pyrolysis have been testing in MGT and then the performances of the alternative's biofuels are compared with MGT that run with diesel. The MGT used is Garrett GTP 30-67 is modified to allow testing with desired biofuels. The testing of the fuels is run in 3 phases with is (phase 1) vegetable oil and biodiesel and characterized with diesel fuel, then (phase 2) a series of tests will be conducted with vegetable oil and biodiesel, and (phase 3) major modifications will be implemented to allow operation with pyrolysis oil and pyrolysis oil/biodiesel emulsions at 95/5%. Besides the performances of the biofuels, exhaust emissions of the MGT also compared between the biofuels and diesel. The result from this study was focused to serve as a basis standard for modifying the micro gas turbine to be operated with biofuels from fast pyrolysis. Data collected from this study such as Fuel injection pressure (bar), temperature (°C), (on the same point) and flowrate (l/h); Compressor delivery pressure [bar], and temperature (°C), Turbine discharge temperature (°C), Exhaust gas dry composition in terms of CO2, O2, NO, NOx and CO (%vol).

To secure sustainability, the use of renewable fuels in gas turbine become global demand. In a study by Enagi et al. [3], the reason why the utilization of renewable fuels in gas turbines has been increase because it is sustainable and free from pollution. Global warming also the main reason why now day people want to use renewable fuels in their daily life. In this study, they convert biomass into biofuels using different energy conversion technologies. They used biomass because of it storable, programmable and suitable to many energy needs. Based on the result obtain, it shown that the used of palm methyl ester (PME) showed combustion characteristics like those of diesel fuel in term NO emission. But Combustion performance of biodiesel and diesel/vegetable oil and animal showed slightly higher in CO emissions. Although this study quite different from my study, but the main idea can be applied to my study which is compare the emission of different types of biofuels with diesel. In this study also, some ways have been testing to reduce NO emission. So, this idea can be used to MGT in terms to reduce NO emission.

Emission of MGT being study a lot to reduce pollution toward the environment. A test bench has therefore been designed and developed for the specific case. The test bench was initially operated with the reference diesel oil to determine a baseline condition for comparison with bioliquids. Compared to diesel, biodiesel, vegetable oil and biodiesel/vegetable oil mixtures showed higher levels of CO in the exhaust under the same fuel feeding conditions[18]. From another study, the result shows that diesel fuels tend to generate the highest temperatures, natural gas the lowest and biodiesel lies in-between. The variability of the composition of gas oils can substantially change flame temperature, while biodiesel fuels are less sensitive to composition variations[19]. The results show that diesel fuels tend to generate the highest temperatures, natural gas the lowest and biodiesel lies in-between. The variability of the composition of gasoils can substantially change flame temperature, while biodiesel fuels are less sensitive to composition variations[19]. However, the study on emissions of MGT operates with vegetable oil need further study in term of combustion stability.

Other than modification the combustion chamber of MGT, the current project focus on the combustion stability using vegetable oil in the combustion chamber. The stability of combustion is characterizing by observing the flame structure by temperature field of the chamber inner flow. The analysis was done with numerical simulations. There are several challenges need to overcome in achieving stability of the combustion such as design are related to wall cooling, flame stability and emissions control[20]. from the study by Guenther C, the flame inside the combustion chamber is stabilized by a combination of swirling air and the formation of recirculation zones. In this study, only combustion of natural gas was examined. It quite different from my study which need to compared combustion stability of vegetable oils with the combustion stability of diesel. But, the methods and objective of this study can do as reference in completing my study. In another study by De

Robbio et al. [17], different models of the reacting flow in the combustor of a C30 type Micro Gas Turbine result in different combustion analysis in term of chemical equilibrium. With respect to the already studied eddy dissipation concept, the PPC models indicate incomplete combustion of CH4, which is the species with a higher concentration in the natural gas. So, from the study by De Robbio et al. we conclude that the design of the combustion chamber effect the combustion analysis of the MGT.

CHAPTER 3

METHODOLOGY

3.1 Overview

In the study of stability analysis using vegetable oil in micro gas turbine combustion chamber, it includes both modification and experimental work. Firstly the combustion chamber is modified by putting side glass to see the combustion inside the combustion chamber. Then, the temperature profile, flow rate and emission result are getting from the experimental. While for the power, SFC, equivalent ratio and efficiency are being calculated. The results are plot in graphs and the stability of combustion is further analyse.

3.2 Activity chart

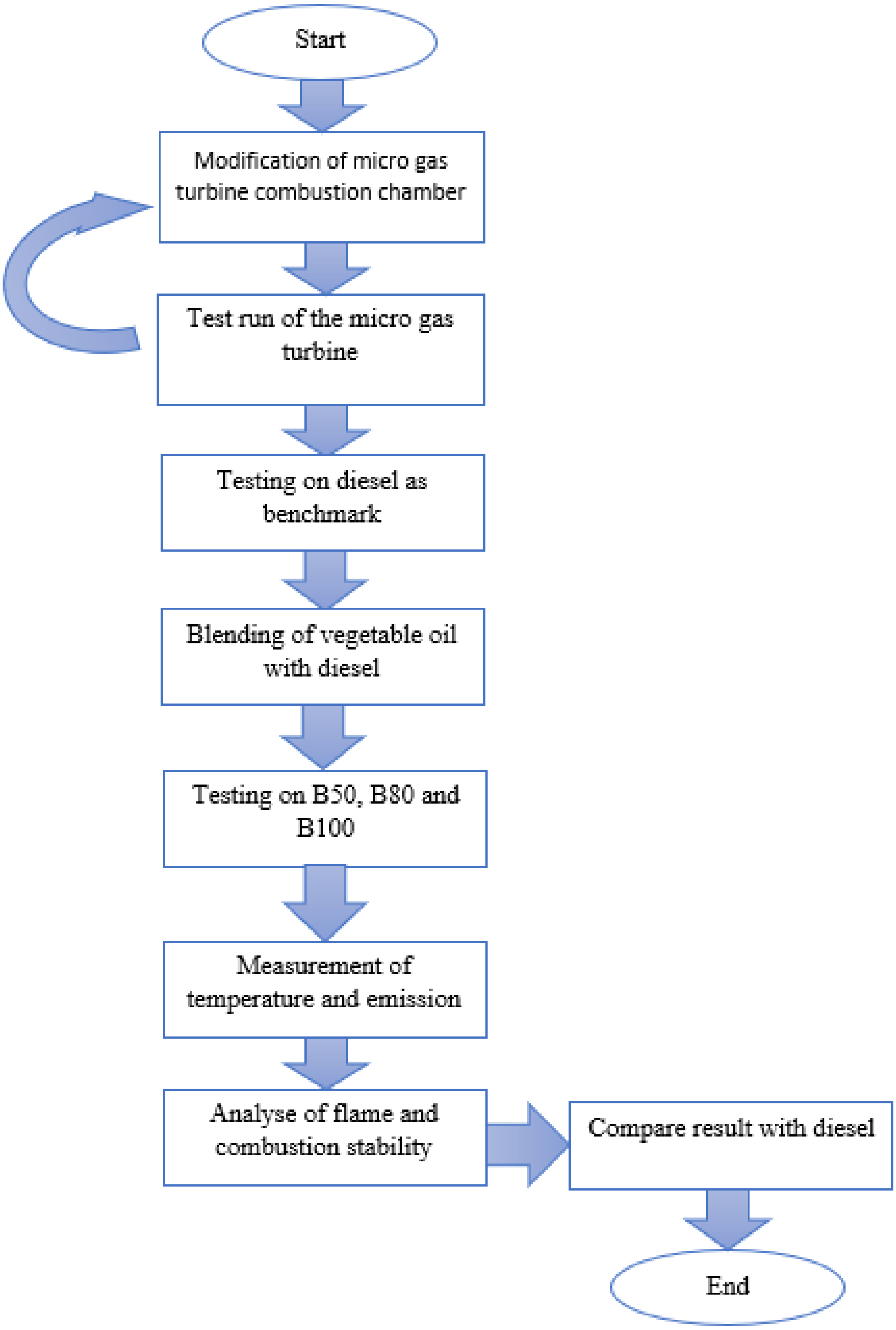

Figure 3.1: Activity flow chart for the project

3.3 Methodology activity

Firstly, combustion chamber of the Micro Gas Turbine that available in Biomass Lab is modified. The front side of the combustion chamber is cut off and side glass is mounted on the wall. The purpose of the side glass is to make sure that the combustion inside the flame tube can be visually analysed. The frame of the side glass is fully welding and around the assembly between the cover and frame is covered with high-temperature cement to make sure that there is no pressure drop inside the combustion chamber which may reduce the performace of the micro gas turbine. Furthermore, the side glass that being used is a special tempered glass that can withstand temperature up to 300 ^{o}C.

Figure 3.2: Modified combustion chmaber with side glass

Then, leakage at the water injection piping and blockage inside LPG injector pipe are fixed. All these minor problems are very important to be fixed to make sure that the MGT can run smoothly at its highest efficiency.

After the modification is done, vegetable oil and diesel are mixed by using electric stirrer for 1 hour to form B50 which mean 50% vegetable and 50% diesel of blending. Then, the MGT is startup by using LPG gas to warming up the combustion chamber until 600 ^{o}C. The experiment continued by using diesel as the benchmark to be compared with B50 B80 and B100. These experiments are run at two different flow rate which is 0.1 bar and 0.2 bar controlled by the compressor pressure. Data collected from these expriments are temperature of combustion chamber,temperature of compressor outlet, temperature of turbine outlet, flow rate of the air and fuel, the emission of carbon monoxide and lastly pictures of the combustion flame. From the results, calculation can be made to obtain the power of the MGT, the efficiency of the MGT, equivalent ratio and SFC.

Figure 3.3: Micro Gas Turbine (MGT) that available in biomass lab

3.4 Equipment and instrumentation

Measuring equipment used in this combustion stability analysis such as scanning thermometer, CO analyser, stopwatch, hot wire anemometer and Lab Digital Overhead Stirrer and The digi scanning thermometer which is a data logger that can store the temperature at various time interval. The data can be transferred to the computer to be analysed. Temperature that being recorded using the data logger such as compressor outlet temperature and turbine inlet and outlet temperature,. Data logger that being used as shown in the figure below:

Figure 3.4: Digi scanning thermometer

Testo 310 CO analyser is a device used to measure the CO emission from the MGT. The analyser is put at the outlet of heat recovery unit and the reading of CO emission is taken for different type of fuel used in the MGT. stopwatch is used to measure the flow rate of fuel used in the MGT while hot anemometer used to check the flow rate of air intake at different combinations of fuel and pressure. Lastly, Digital Overhead stirrer is used to stir biofuel solutions. This stirrer has a digital screen that display the speed of the spindle that can be adjusted manually.

Figure 3.5: Testo 310 CO analyser

Figure 3.6: Digital Overhead stirrer

3.5 Experimental procedure

3.5.1 Preparation of biofuel

For the preparation of biofuel which is B50, B80 and B100, diesel is mixed with vegetable oil and then stirred using Lab Digital Overhead Stirrer for about 1 hour. The speed of the stirrer changed depend on the type of biofuel to make sure the solution completely dissolves. The higher percentage of palm oil in the solution, the higher the speed of the stirrer will be.

3.5.2 Preparation of the MGT

Before any fuel can be injected into the combustion chamber, all equipments need to be set up properly and make sure the MGT is in good condition. These should be done to make sure that the MGT can run at its highest efficiency and to obtain accurate result from the experiment. The setup includes properly plug in the thermocouple into the digi scanning thermometer, turn on the water cooler and setup the Testo 310 CO analyser at the heat recovery unit. Lastly, check any leakage at the MGT that may reduce the performance of the MGT and it may cause injury if has any damage or leakage.

3.5.3 Warming up the combustion chamber

In this experiment, MGT is started with liquefied petroleum gas for warming up the combustion chamber before fuel is injected into the combustion chamber. The MGT is running with 0.1 bar LPG for 10 minutes until the temperature achieve 600 ^{o}C. Then, the compressor pressure is adjusted so that the pressure of LPG increase to 0.2 bar and the let the MGT running for another 10 minutes.

3.5.4 MGT running with diesel as benchmark

After the combustion chamber is warmed up, diesel fuel injected into the combustion chamber through the injector. The pressure of diesel is controlled by the inverter and at about 17 hz the pressure of the diesel is 0.1 bar. At the same time, LPG gas is slowly closed until only diesel burn inside the combustion chamber. The MGT is cooled down by stopped the diesel injection and open the LPG source at low pressure. After the MGT is cooled, the steps before is repeated and frequency of the inverter is increased so that the pressure becomes 0.2 bar. At every pressure, the compressor outlet temperature, turbine inlet and outlet temperature, emission of CO, flow rate of air intake and flow rate of diesel injection are recorded. These experimets are repeated 2 times and average of the data are calculated. Picture of the combustion flame also are been taken at every pressure of fuel that being used to anlyse the combustion stability.

3.5.5 MGT running with biofuel

Before biofuel is injected into the combustion chamber, the MGT is running with remaining diesel inside the tank to make sure that the biofuel will not mix with diesel which may effect the data obtained. The procedure to run the MGT with biofuel is same as runnig MGT using diesel and liquefied petroleum gas. The data that being collected for biofuel also same with data for diesel and liquefied petroleum gas which are temperature of the turbine inlet, turbine outlet, temperature of the combustion chamber, emission of CO, flow rate of air intake and flow rate of biofuel injection. This experiment started by using B50 follow by B80 and B100. For B50, the frequency of inverter is 11.5 Hz to achieve 0.1 bar of pressure while for B80 and B100 is 10 Hz and 7Hz respectively. The frequency will be increased slowly to achieve 0.2 bar and 0.3 bar of pressure. All the data that have been recorded from the experiment will be used to calculate and analyse the combustion stability analysis such as power output of the MGT, the efficiency of the MGT, SFC of fuels and the equivalent ratio the flame stability from each experiment using biofuel will be compared with flame by using diesel as fuel inside the combustion chamber.

3.6 Performance of MGT

From the data being collected power output of MGT, efficiency of MGT, SFC of fuels and equivalent ratio are calculated and the calculation as shown below.

Take diesel at 0.1 bar

Mass Flow Rate of air, $\dot{m}_{air} = \rho\dot{v}$

$$=1.16\times \mathbf{1122/3600}$$

$$=0.0361 \text{ kg/s}$$

Mass Flow Rate of Diesel, $\dot{m}_{diesel} = \rho\dot{v}$

$$= 787 \times \frac{10\times10^{-6}}{7.11}$$

$$= 0.00111 \text{ kg/s}$$

Total Mass Flow Rate, $\dot{m}_{total} = \dot{m}_{air} + \dot{m}_{diesel}$

$$= 0.0361 + 0.00111$$

$$= 0.0372 \text{kg/s}$$

Turbine Power = $Cp_{total} \times \dot{m}_{total} \times (\mathrm{TIT} - \mathrm{TOT})$

$$= 1.28 \times 0.0372 \times (951.5 - \mathbf{750.7})$$

$$= 9.561 \text{ kW --- (1)}$$

Compressor Work $= \boldsymbol{Cp_{air}} \times \boldsymbol{\dot{m}_{air}} \times (\mathbf{COT-30})$

$= 1.005 \times 0.0361 \times (63.23\text{-}30)$

= 1.205 kW

Turbine Efficiency $= \frac{\boldsymbol{compressor\ work}}{\boldsymbol{turbine\ power}} \times \mathbf{100}\%$

$= \frac{\mathbf{1.205}}{\mathbf{9.561}} \times \mathbf{100}\%$

= 12.601 % ---(2)

Diesel thermal input power , $\boldsymbol{Q_{diesel}} = \boldsymbol{\dot{m}_{diesel}} \times \mathbf{LHV}$

= 0.00111 x 45000

= 49.95 kW

Exhaust Gas thermal power, $\boldsymbol{Q_{exhaust}} = \boldsymbol{Cp_{total}} \times \boldsymbol{\dot{m}_{total}} \times (\mathbf{TOT-30})$

$= \mathbf{1.28} \times \mathbf{0.0372} \times (\mathbf{750.7-30})$

= 34.317 kW

System efficiency = $\frac{Q_{exhaust}}{Q_{diesel}} \times \mathbf{100}\%$

$= \frac{34.317}{49.95} \times \mathbf{100}\%$

= 68.702 %

Specific Fuel Consumption, SFC = $\frac{\dot{m}_{diesel} \times 3600}{Q_{exhaust}}$

= (0.00111 × 3600)/34.317

= 0.116 kg/kWh ---(3)

Actual Air Fuel Ratio, $\boldsymbol{AFR_{actual}} = \frac{\dot{m}_{air}}{\dot{m}_{diesel}}$

$= \frac{0.0361}{0.00111}$

= 32.523

Equivalence Ratio = $\frac{AFR_{stoichiometric}}{AFR_{actual}}$

$= \frac{14.7}{32.5239}$

= 0.452 ---(4)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

This section analyses and interprets the data obtained from the experiment. Temperature profile, flow rate of air and fuel, emission of CO are taken during running the MGT while turbine power, compressor power, SFC, equivalent ratio and efficiency are calculated based on the collected data. The combustion stability will be discussed based on the data collected and pictures of the combustion flame. Lastly, results from biofuel are compared with diesel as benchmark. For MGT running with B100, the data cannot be recorded as the combustion not stable and combustion only last for a short period.