CHAPTER 5

Experimental Methodology

The objective of this chapter is to explain the experimental setups and procedures. Experimental setups of this work include the gas generator system, the gas engine test rig and instrumentation. The gas generator system is divided into three major components: the gasifier, gas cleaning and cooling. The gas engine test rigs consist of a small producer gas engine, diesel engine and dynamometer. The instrumentation in the work includes a thermometer, flow meter, manometer and multi-meter. Lastly, the experimental procedures provide conditions of the experiment, gas generator system operation, small producer gas engine operation and data processing. The detail contents of the chapter are as follows.

5.1 Experimental Setup

5.1.1 Gas generator system

The producer gas used in this work was from a fixed bed downdraft gasifier run in air at atmospheric pressure and designed for charcoal and wood, shown in Figure 5.1 The gasification system consists of a gasifier, a gas cooler and a gas cleaner. The capacity of the gasifier in term of charcoal consumption was between 5-6 kg/h and could generate producer gas in a range of 25-30 Nm^3/h. Figure 5.2 (a) shows the gas cooler, the heat exchanger is installed in a 100 liter water tank. Figure 5.2 (b) shows the gas cleaner system and includes a cyclone, a water scrubber, a moisture separator, biomass filters, a fabric filter and a paper filter. The water scrubber kit was a venturi scrubber and a pack bed scrubber installed over the tar remover. The closed-loop water treatment plant uses a 335W water pump. Figure 5.3 shows a schematic diagram of the gas generator system to deliver gas to the small producer gas engine. The exit of the gasifier is a surge tank and gas flow meter leading to the engine. The producer gas composition was determined using Shimadzu GC-8A gas chromatography and the sample gas to the duration of the work (Dussadee et al, 2015). The composition of the gas feed on the test engine was of CO 30.5±2%, H_2 8.5 ± 2%, CH_4, 0.35%, CO_2 4.8±1%, O_2, 6.3±0:5%, and the balance Nitrogen. The mean calorific value of the producer gas was 4.64 MJ/Nm^3 as analyzed (Gunarathne et al, 2012). The tar and particulate matter measurements taken at the entrance of the engine with tar measurement standard (Hasler et al, 1999). Tar and particulate matter was found to be lower than 50 mg/Nm^3.

Figure 5.1 Fixed bed downdraft gasifier

(a)

(b)

Figure 5.2.Gas generator system

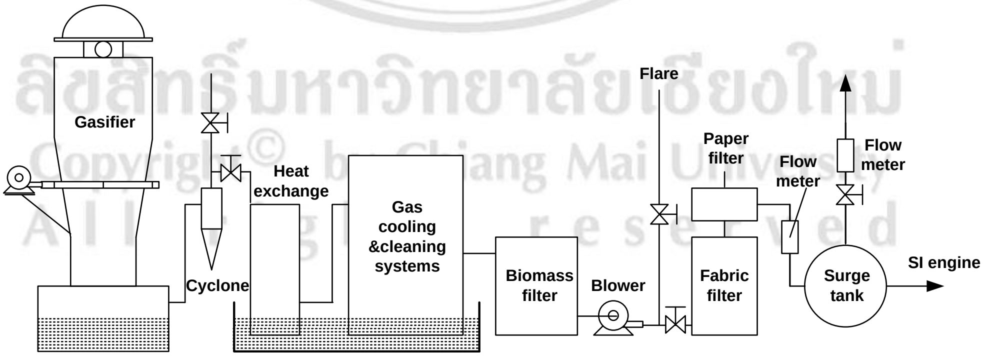

Figure 5.3 Schematic diagram of gas generator system (Homdoung et al, 2015)

5.1.2 Gas engine and diesel engine test rig

The gas engine tested was adapted from a diesel engine by changing the combustion chamber, compression ratios, ignition system and fuel to the producer gas from gas generator as shown in Figure 5.4. Details of the modification and specification of gas engine is shown in chapter 3. Figure 5.5 shows the electrical dynamometer fitted to the gas engine. It was a 5 kW of electrical generator and discharged to electrical loads from ten 100W bulbs with ten 500W heaters. Torque measure ments of the dynamometer was carried out using a load cell for calibration. To start, the engine an electric starter motor was installed that used a 12 volt battery as the power source and two belts for transmission. The Kubota diesel engine shown in Figure 5.6 was a single cylinder, 8.2 kW of power unit. It was the same basic engine that was converted to the gas engine. Detail specification of the diesel engine was provided in chapter 3. Figures 5.7-5.8 show schematic diagrams of the original diesel engine and gas setup. There were three sections in the gas engine setup; gas generator system, gas engine and load. The diesel engine experiment setup was similar to the gas engine but without the gas generator system and switching to diesel fuel.

Figure 5.4 Gas engine after modified

Figure 5.5 Electrical dynamometer and gas engine setup

Figure 5.6 Diesel engine before converting to the gas engine

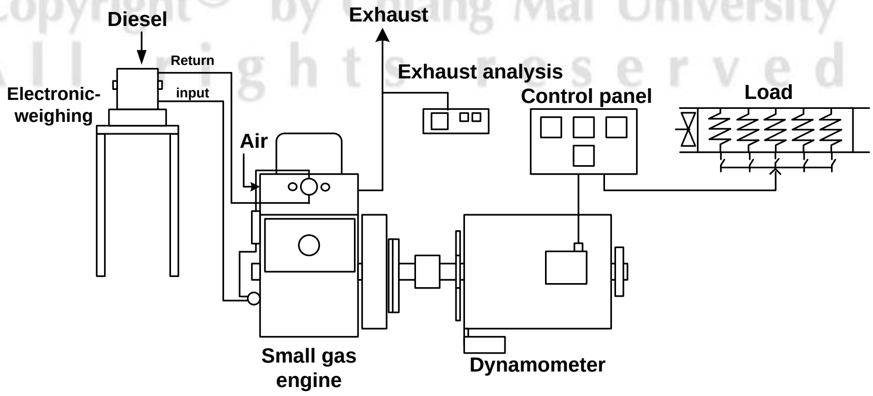

Figure 5.7 Schematic diagram of diesel engine setup (Homdoung et al, 2012)

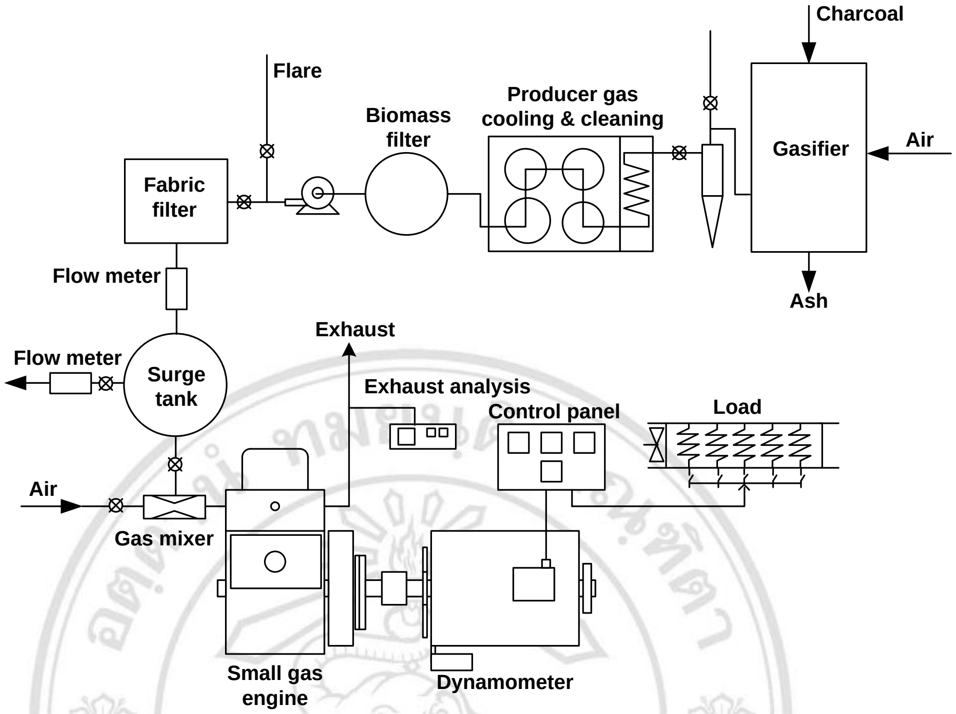

Figure 5.8 Schematic diagram of the gas engine setup (Homdoung et al, 2014)

5.1.3 Instrumentation

Timing light and digital tachometer

Figure 5.9 (a) shows the timing light for tuning the engine. The timing light measures the spark angle in relationship to TDC, allowing the position to start burning of the fuel in the cylinder while the engine was running. It was powered with 12-volt battery power and is a JTC Model 1626. Figure 5.9 (b) shows the digital tachometer that measured engine speed of the engines. The tachometer was a brand of DIGICON Model DT-246L with 5~99,999 rpm of measuring range.

Exhaust emission analyzer

Analysis of CO and HC on the engines was carried out using a KOEN model KEG-200 based on non-dispersive infra-red method (NDIR sensor), as shown in Figure 5.10. Measuring range of CO and HC were 0.00~9.99% and 0~15,000 ppm respectively. The results of CO and HC were 0.001%

and 1 ppm respectively. For smoke density measurements, the HESHBON model HBN 1500B with optical filter reflection type pump and digital display was employed. The measurement range of the smoke density was 0-100% and 0.1% of resolution. The smoke density analyzer is shown in Figure 5.11. Noise analysis of the engine was done by a sound level meter on the running engine. The noise analyzer used DIGICON model DS-40 is shown in Figure 5.12. The measurement range was between 35-730 dB and with a digital display.

(a) (b)

Figure 5.9 Timing light and digital tachometer

Figure 5.10 CO and HC analyzer

Figure 5.11 Smoke density analyzer

Figure 5.12 Noise analyzer of engine

Gas flow meter

The producer gas flow was measured by an anemometer to determine the velocity of the gas (Kinorn, 2007). It was a LUTRON ELECTRONIC model YK-80 AM and metal vane. Measuring range of meter was 0.4-35 m/s, 2% of accuracy and 0.1 m/s of resolution. The working temperature of meter must less than 60˚C. The gas flow meter and setup are shown in Figure 5.13, and consisted of two meters long PVC pipes on either side of the meter to give the lamina readings of the gas's velocity. This velocity averages out at about 4m/s or 30m^3/hr.

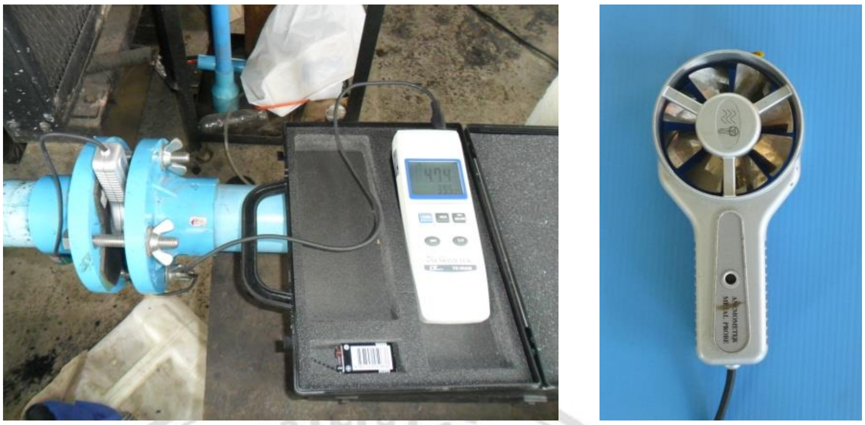

Figure 5.13 Gas flow meter

Electronic weighing scales

Electronic weighing scale was used to determine the fuel usage of charcoal to calculate the fuel consumption. The weighing scales for charcoal was DIGI model DS-530, digital display, shown in Figure 5.14. Measuring range of weighing scales was between 0.4-60 kg, 20 g of accuracy and 0.01g of resolution. The diesel fuel consumption use gravimetric fuel flow measurement method (Gupta, 2006), a JZA electronic weighing scale gravimetric fuel flow was measured. Measuring range was between 0-15 kg, 0.5 g of accuracy and resolution.

Figure 5.14 Electronic weighing scales

Thermometer

Thermometer is a device that measures temperature of gas generator system, gas engine and surrounding. Figure 5.15 shows data logger, thermo couples and temperature probe. Temperature measurement uses Type K of thermo coupled, that can measure temperatures up to 1200˚C, recorded and displayed on data logger. The YOKOKAWA model DX 220-1-2, 20 of channel and 0.1˚C of accuracy was used for this work.

Figure 5.15 Data logger, thermo couple and temperature probe

Multi meter

Electrical measurement for this work was performed for voltage, current and electric power from electrical load. This was carried out using F609 Chauvin Arnoux watt meter, as shown in Figure 5.16. Measurement range of Voltage was between of 0.2-600V with 1% of accuracy. The current was in a range of 0.2-400A with 1.5% of accuracy.

Manometer

The pressure measurement was carried out using KIMO U-tube and incline manometer monitor, as shown in Figure 5.17. The pressure was monitored in real time which is visible from gasifier, exit from gas generator and entry to the engine.

Figure 5.16 Multi meter use measures electrical load

Figure 5.17 U-tube and incline manometer

5.2 Experimental Procedure

5.2.1 Gas generating system

To start the gasifier, 1 kg of longan charcoal is loaded into the reaction chamber, another kg of charcoal is lit in a steel bucket. Once this external charcoal is burning well, it is put on top of the charcoal in the reaction chamber. The blower is switched on, and the chamber is then filled up with additional charcoal, and closed. Within 4 – 5 min, the gas can be lit at the top of the first flare. The temperature of the gasifier takes about 20 min to reach its optimum working temperature of the reduction zone (800 – 900°C). The first gas flare is closed and the water pump is activated so that the gas can be cooled and cleaned, and the gas blower forces the gas through the filters. The gas filters need to reach a temperature of 100˚C to stop any further condensation in the pipework. The second flare is the opened and lit. The flame and the reduction and drying zone temperatures are stable. The gas can then be sent towards the engine via the surge tank. The pressure temperature and gas flow rate are checked before entering the engine. The pressure of the gas in the system was between 100-1000 kPa. The gas temperature was between of 35-42˚C, when leaving the surge tank.

5.2.2 Gas engine operation

Before running the small producer gas engine from cold, the fuel needs to be rich mixture. This can be achieved by altering the screws on the air/gas mixer. Initially, adjustment distance of gas and air metering screws is about 8 mm and timing set at 30˚BTDC. After starting, the amount of air entering the engine was adjusted to lower the mixture. When the engine is stable, the air/fuel ratio needed to be changed to give the appropriate engine speed. Once, the appropriate speed was stabilized, data was taken over a ten minute period.

5.2.3 Compression ratio adjustment

Earlier researchers found that power output varied with the various CR in SI producer gas engine. The low CR is referred to CR of typical engine having CR lower than 11:1 High CR means the CR is higher than original engine. Increasing CR on producer gas engines lead to increased power output. The maximum CR at present was found to be 17:1 and produced good engine performance. In this work, it was decided to compare low and high CR’s. Therefore, the CR of small producer gas engine needs to use 9.7:1, 14:1 and 17:1 only.

5.2.4 Air/fuel ratio tuning

Adjustment of air/fuel ratio was made by turning metering screws at the entry of producer gas and the air. In theory, air/fuel ratio of the engine is 1.2:1 but in this experiment, the best air/fuel ratio can be evaluated from maximum speed and maximum engine torque. Observation for the best air/fuel ratio tuning was stability and smooth running of the engine. The distance of metering screws should be nearly equal. Increasing engine speed or load can be achieved by increasing gas metering screws first, and then opening the air screw. Spin out of both metering screws must be less than 1/2 turn. Reduction of engine speed or load can be achieved by doing the opposite exercise.

5.2.5 Ignition timing adjustment

The ignition timing of small producer gas engine can be adjusted by moving the magnetic pick up when stationary or running. In an experiment, ignition timing was adjusted every 5˚BTDC in advance ignition timing direction. Adjustment range of the engine was between 0-65˚BTDC. The operation to adjust ignition timing can be carried out by the following technique. Firstly set timing to 30˚BTDC Primary, adjusted timing to 30˚BTDC, and then run the engine to its running temperature. Adjustment may start 20˚BTDC, Tuning air/fuel to suitable engine speed and load, and recording the engine torque. Vary ignition timing occurred every experiment. These settings were compared with other previously recorded conditions and similar tests. After that the three highest engine torques were selected for every engine speed evaluated.

5.2.6 Engine speed and load adjustment

Increasing speed of small producer gas engine was carried out by increasing producer gas and air together. Experimental engine speeds was in a range of

1100-1900 rpm. For the load, the experiment was carried out at different loads range of 20, 40, 60, 80 and 100%.

5.2.7 Implementation of environmental conditions

Measurement of exhaust emission of small producer gas engine included CO, HC, smoke density and noise. Experiments were carried out to select the best condition of bath tub and cavity combustion chambers. Exhaust emission measurement were performed, when starting engine running to working temperature according to given conditions. Process of measurement and record data was CO, HC smoke density and noise, respectively.

5.2.8 Experimental procedure of diesel engine.

The experiment with the reference diesel engine was similar to the small producer gas engine. The original CR of dual engine was 21:1, the experiments were carried out at different loads in a range of 20–100% and varied for 1100, 1300, 1500, 1700, 1900 rpm of engine speed. Increasing engine speed leads to higher fuel consumption. Measurement of exhaust emission of engine includes CO, HC, smoke density and noise, similar to small producer gas engine.

5.2.9 Data collection

Data record of experiment was for gas generator system and small producer gas engine performance. Gas generator system was recorded for ambient temperature, drying zone temperature, reduction temperature, available temperature, gas pressure and flow rate. Small producer gas engine performance was recorded for gas consumption, exhaust temperature, oil temperature, water temperature, electric power, load, engine speed, ignition timing, CR, power output, CO, HC, smoke density, noise and gas pressure entry engine.

5.2.10 Data processing

Data analysis for performance evaluation of the small producer gas engine and diesel engine was as follows:

The brake power of small producer gas engines is given by Eq. (5.1):

$$P_b = 2\pi N T_b \tag{5.1}$$

where T_b is the engine torque (Nm) and N is the engine speed of engine (s^{-1}). Brake specific fuel consumption ($BSFC$) can be calculated Eq. (5.2)

$$BSFC = \frac{\dot{m_b}}{P_b} \tag{5.2}$$

where $\dot{m_b}$ is the mass flow rate of biomass in small producer gas engine (kg/h) and diesel (kg/h). Brake thermal efficiency (BTE) is expressed as the ratio of output power to the power supplied by the fuel. Therefore, brake thermal efficiency of producer gas engine and diesel engine are given by Eqs. (5.3) and (5.4), respectively.

$$BTE = \frac{P_b}{\dot{V_{pg}} HV_{pg}} \tag{5.3}$$

$$BTE = \frac{P_b}{\dot{m_f} LHV_{Di}} \tag{5.4}$$

where $\dot{V_{pg}}$ is the producer gas flow rate (m^3/s), HV_{pg} and LHV_{Di} are the mean calorific value of producer gas (MJ/Nm^3) and lower heating valve of diesel (kJ/kg) while $\dot{m_f}$ will use in kilogram per second (kg/s). Brake specific energy consumption ($BSEC$) of producer gas engine and diesel can be calculated by Eqs. (5.5) and (5.6), respectively.

$$BSEC = \frac{\dot{V_{pg}} HV_{pg}}{P_b} \quad (5.5)$$

$$BSEC = \frac{\dot{m_f} LHV_{Di}}{P_b} \quad (5.6)$$