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# Engine Modelling of a Single Cylinder Diesel Engine Fuelled by Diesel-Methanol Blend

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# Engine Modelling of a Single Cylinder Diesel Engine Fuelled by Diesel-Methanol Blend

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**Abstract.** Performance on diesel engines with various combustion chamber sizes and fuel injection require effective handling so that the root combustion process in large diesel engines is timely. This study compares the experimental data with simulation through the single cylinder diesel modelling using GT-Power software. This simulation utilises parameters in diesel engines of 1000 and 2000 rpm speeds with methanol and diesel fuels. This modelling aims to develop a single cylinder diesel engine by measuring all components on the machine. The comparison between the simulation results and experimental data indicate similar collaboration with a difference about 5%–10%. Based on the results, the modelling of developed machine shows that simulation using GT-Power software is able to successfully validate all machine data parameters up to 90%. This simulation result can be expressed accurately similar to the experimental results and can be used as standardization for a single cylinder diesel engine design.

**Keyword:** Diesel engines, GT-Power, diesel-methanol blend

## 1. Introduction

Details on the diesel engine, size range, and engine performance vary greatly. Generally, the space and dissimilar combustion geometry characteristics for fuel injection need to be dealt effectively due to various design issues. Larger diesel engines need to achieve rapid airspeed from fuel combustion so that the process can be accomplished within time. Different types of geometry in the inlet port, piston shape, cylinder head, and injection pattern for the fuel were used so that the diesel engine with varied sizes can be achieved [1]. Typically, ratings on a machine indicate the strength at which the manufacturer's expected the product can provide better power, economy, robustness, and reliability that can satisfy a user's service conditions. Maximum torque and engine speed can be achieved because usually the results can be given simultaneously.

The compression of ethanol fuel has been used in the automotive with diesel and gasoline engines. Over the last decade, its application as a fuel additive for transportation has been in great demand among various cylinder developers because it can store high and light pressures as mentioned by [2–6]. Mostly, methanol fuel is used as an additive to gasoline fuel in both modified and non-modified vehicles through retrofit conversion in the market and has retained market price capability [7–11]. Vehicles with

converted fuels will experience power loss and permissions for driveability, due to mounting or retrofit design. Significantly, the capabilities and strengths of the vehicles will increase so that they can be realised with retrofit kits especially on more sophisticated vehicles, or manufactured vehicles. Involvement of engine and vehicles manufacturers as original engine equipment developers is increasing. Especially in the use of diesel engine replacement applications with heavy duty, the number of these requests is still considered very limited and scattered so that large-scale manufacturing is still guaranteed. The design can come from gasoline or diesel engines to achieve that goal. While the original equipment machinery is ready and also available, however, for diesel engines has been transformed by the plant into the ignition and may continue, replacement equipment involving diesel fuel refuelling with the carburettor and also gas and addition of ignition system and spark plug on the combustion engine.

This study explores the application of using methanol fuel as a diesel fuel additive and the its impact on diesel engine performance in simulations. Diesel engines use methanol fuel additives for diesel fuel optimisation by comparing the use of methanol and diesel fuels in simulations [12,13]. GT-Power software is a very prominent simulation that can be used by industrial machinery, vehicle, and supplier is very suitable for analysis of various problems on the machine [14–16]. GT-Power also able to analyse all types of internal combustion engines and has been available for many components to model the next idea. GT-Power is based on the dynamics of one-dimensional usage, with heat transfer through piping as well as several other components in the machine's working system. The one-dimensional model simulation in GT-Power is the development of GT-Suite software or the Gamma Technologies family [14,15]. The use of four steps on diesel injection engines is manual measurement, and modelling using GT-Power to investigate machine performance will be discussed in this study.

An investigation of the importance of performance parameters on a single cylinder diesel engine is one of the properties of geometry, the terms of the efficient and other related engine parameters as discussed by [1,17–19]. Efficiency in cylindrical diesel engine mounts is as shown in thermal, relative, mechanical, volumetric, and brake heat efficiencies. Performance of the parameters associated with the engine are the pressure of the average effective, the specific power output, the engine intake valve index, the average speed of the piston, the ratio of air or air to the fuel, specific fuel consumption, and the carbon value of the fuel.

This study compares the experimental simulations by modelling a single cylinder diesel engine by using GT-Power software, as well as measuring the overall parameters of the machine with methanol and diesel fuels. The properties of diesel and methanol fuels are different in various facets and combustion systems. The differences in properties between diesel and methanol fuels are as shown in table 1. At this stage, these properties can be investigated at brake power such as brake torque, volumetric efficiency, consumption of brake specific fuel, and pressure on the cylinder.

## 2. Simulation and Setup

Modelling of the single cylinder diesel engine using comparable auxiliary methanol diesel fuel is discussed in this study. The specifications of the single cylinder diesel machine are as shown in table 2 while the engine used in this experiment is as shown in figure 1. This study was done by simulation using GT-Power software from the result of single cylinder injection diesel engine modelling using four steps and aims to investigate the impact of engine performance. Modelling was done based on the steps that have been determined by starting to open the component in the diesel engine based on the option to measure the parts contained in the machine. Furthermore, all machine components in the machine were inserted into the GT-Power library for matching before the next step. To create a new model in GT-Power, first select windows after that select the title in the template library contained in the list.

**Table 1.** Properties of methanol and diesel fuels.

| Fuel Properties | Diesel | Methanol |
|-----------------|--------|----------|

| | | |
|---|---|---|
| Chemical formula | $C_{14}H_{28}$ | $CH_3OH$ |
| Flame speed rate (cm/s) | 33 | 35 |
| Boiling temperature ($^o$C) | 190-280 | 64.7 |
| Denscity (g/cm$^3$, at 2$^o$C) | 0.84 | 0.79 |
| Flash point ($^o$C) | 51 | 11 |
| Auto ignition temperature ($^o$C) | 254 | 464 |
| Lower heating value (MJ/kg) | 42.74 | 20.27 |
| Cetane number | 56.5 | 4 |
| Stoichiometric air/fuel ratio | 14.7 | 6.66 |
| Octane number | Not applicable | 109 |
| C/H ratio | 0.50 | 0.25 |
| Kinematic viscocity at | $2.5^* 10^{-6}$ | $75^* 10^{-6}$ |
| Carbon content (wt.%) | 86 | 37.5 |
| Hydrogen content (wt.%) | 14 | 12.5 |
| Oxygen content (wt.%) | 0 | 50 |
| Sulfur content (wt.%) | <50 | - |
| Heat of vaporization (MJ/kg) | 0.27 | 1.11 |

**Table 2.** Engine specifications.

| Model | Yanmar Model TF120M |
|---|---|
| Stroke (mm) | 96 |
| Fuel injection type | Direct Injection |
| Fuel tank capacity | 11 L |
| Displace volume (cm$^3$) | 638 |
| Compression ratio | 17.7:1 |
| Max power | 7.7 kW @ 2400 rpm |
| Max torque | 161 Nm @ 4500 rpm |
| Bore (mm) | 92 |
| Continuous rating output | 10.5 HP @ 2400 rpm |
| Maximum rating output | 12.0 HP @ 2400 rpm |
| Cooling system | Water-radiation |
| Type | Horizontal single-cylinder 4-stroke diesel engine |

**Figure 1.** Engine experiment set up

In modelling, some templates are needed to be copied before creating a new object. Some icons that are necessary were selected for the new model creation. Among some templates and also objects have been assigned and inserted in the GT-Power template library which can't be separated, is part of the Gamma Technologies family [15]. According to [20-21] in this engine model, the damage such as tree systems, intake systems, fuel systems injection, systems exhaust, and machine cylinders may occur. While the machine selected, intake system there are components, data and different sizes. All system environments were run and terminated at the intake valve. The machine fuel system injection was focused to investigate performance machine and to support diesel fuel added with methanol from injections fuel, exhaust gases for disposal, and fresh air intake. Some machine cylinder components and injection fuel on a single cylinder diesel engine. Components such as data and size were included in the GT-Power list. Components such as cylinders, engines, and injectors. While the disposal is the last system contained in the machine. This system started from the valve to the last which was the environment. All materials that come to diesel must be connected to orifficeconn. Then, the diesel engine was modelled with GT-Power as the development of this research. The required components are fuel and diesel engine data to be able to build a new engine model. To build a model on the GT-Power list of information is needed, among other libraries. However, not all models must require all items. If the initial stage is to build the model, the optimal value for some items that are already on the list must be determined to do the simulation. The definition of an attribute should be specified as a parameter that can be executed in some cases to determine the optimal value.

The compression ratio, inline or configuration V, combustion size, V-angle (optional), two or four strokes were the data in machine characteristics. Meanwhile, the data in the geometry of the cylinder were stroke, offset pin, bore, head bowl geometry, the length of connecting rod, piston area, high clearance, and head area. All components in the geometry were also the data in the exhaust and intake systems. As for the throttle data, the throttle angle discharge coefficient in both the flow direction and the throttle location were considered. For fuel injector, the data such as the number of injector and location, injection speed, LVH, fuel type, number of nozzle hole, and nozzle diameter were considered. While the data contained in the exhaust and intake valve such as the disposal coefficient, valve diameter, valve lash, and elevator profile. Pressure, humidity and temperature were the data used at ambient

conditions. This study focuses on the use of diesel fuel which was added with methanol through simulation. Modelling for development of the single-cylinder direct injection engine diesel with GT-Power is as shown in figure 2.



**Figure 2.** Engine single cylinder.
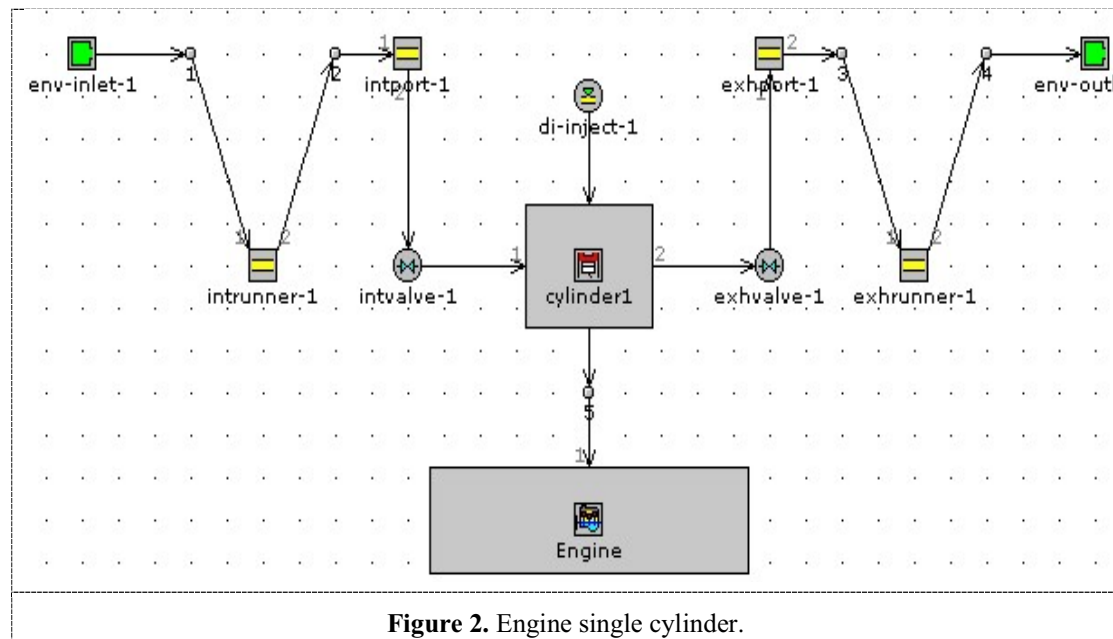
The data model included in GT-Power was the air composition of 76.7% N2 and 23.3% $O_2$ for the pressure of 1 bar and temperature of 26,85 °C was included into env-01 and env-02. Intrnner air filter or intake runner is an intake system for air filters, outrunner-01 and air filter-01. This diesel machine represents parts of the system intake pipes and certain parameters as shown in Table 3. Model diesel engine disposal system on GT-Power consisted of exhport-01, exhrunner-01, exhrunner-exit-01, and muffler-01. The exhaust system pipe also represented by parts contained in diesel engines with special parameters as shown in Table 4. Machine models using GT-Power such as involve-01 represents from valve and exhvalve-01 represents exhaust valve. Table 5 shows the machine diesel parameter components of the valve.

Dynamic geometric designs such as diesel machine compression ratio represents the maximum volume of cylinders or auxiliary or deleted volume (Vd) and also the volume of permit (Vc) with minimum volume division (Vc). Delivering power by a diesel engine can be absorbed by a dynamometer of angular velocity and torque product. Any machine efficiency can be determined [22]. The energy constellation (E) is the thermal efficiency ($\pi_{ith}$) is the ratio of energy in the brake power (*bp*). Mechanical efficiency ($n_m$) is defined as the ratio of brake power (*bp*) or transported power to the indicated power (*ip*) or power provided to the piston. It can also be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency.

The ratio of thermal efficiency to the ideal cycle is the relative efficiency or the efficiency ratio ($\pi_{rel}$), the criterion indicating the rate of development of the machine is the efficiency ratio. Lu et al. [19] To determine the performance parameters of a four-stroke engine is by volumetric efficiency ($\pi_v$), the stroke difference that the four-stroke engine possesses the breathing ability of the engine. Defining volumetric efficiency as the velocity of the air volume into the intake with the volume level transferred by the system. The normal volumetric efficiency range lies in engine speeds of about 80% to 85% for SI machines and 85% to 90% for CI machines. Determination of engine performance such as [1,19,23–26]. The mean effective pressure (*mep*) in which $n_R$ is the sum of the crank revolutions on each stroke for cylinder power (two for four-stroke, one cycle for two-stroke) is defined according to equation (1).

$$mep = \frac{Pn_R}{V_d\,N} \tag{1}$$

Where *mep* is the mean effective pressure, $Pn_R$ is the power number of crank revolutions per power stroke, and $V_d\,N$ is the number displaced cylinder volume.

Measurement of engine fuel conversion efficiency can be defined by Equation (2), as provided by [22]:

$$nf = \frac{W_c}{m_f\,Q_{nv}} = \frac{(Pn_R/N)}{(m_f\,n_R/N)Q_{HV}} = \frac{P}{m_f\,Q_{HV}} \tag{2}$$

Where *nf* is the fuel conversion efficiency, $W_c$ is work per cycle, $m_f$ is the mass flow rate, $Q_{nv}$ is the fuel volumetric efficiency, $n_R$ is the number of crank revolutions per power stroke, $Q_{HV}$ is the fuel heating value and *P* represent the power.

In the engine test, the fuel consumption is measured as a flow rate mass flow unit per time ($m_f$). A more useful parameter is the specific fuel consumption (sfc) the fuel flow rate per unit power output. It measures the efficiency of an engine in using the fuel supplied as in equation (3).

$$SFC = \frac{m_f}{P} \tag{3}$$

Where *SFC* is the specific fuel consumption, $m_f$ is the fuel mass flow rate and *P* is power.

At the time of machine testing, both the flow rate in the fuel ($m_a$) and the velocity of the air flow ($m_f$) period are measured. The ratio of the flow rate is used to define when the engine is being operated such as the ratio of fuel/air (F/A) and fuel/air ratio (A/F). Performance parameters on diesel engines can be developed. In some cases, the power (P) of engine can be measured using equations (4) and (5).

$$P = \frac{n_f\,m_a\,NQ_{HV}\,(F/A)}{n_R} \tag{4}$$

Where $n_f$ is the fuel conversion efficiency, $M_a$ is the air mass flow rate, $Q_{HV}$ is the fuel heating value, $n_R$ is the number of crank revolutions per power stroke, and F/A is the fuel-air.

$$P = \frac{n_f\,n_v\,NV_d\,Q_{HV}\,P_{a,i}\,(F/A)}{2} \tag{5}$$

Where $n_f$ is the fuel conversion efficiency, $n_v$ is volumetric efficiency, $NV_d$ is the number displaced cylinder volume, and $Q_{HV}$ is the fuel heating value.

Equation (6) was used for torque (T) measurement whole equation while equation 7) was used for mean effective pressure.

$$T = \frac{n_f\,n_v\,NV_d\,Q_{HV}\,P_{a,i}\,(F/A)}{4\pi} \tag{6}$$

$$mep = n_f\,n_v\,Q_{HV}\,P_{a,i}\,(F/A) \tag{7}$$

Where $n_f$ is the fuel conversion efficiency, $n_v$ is the volumetric efficiency, $Q_{HV}$ is the fuel heating value, and *F/A* is the fuel-air.

The power specification per unit on the piston is the result of the engine design using the available piston zones at the time regardless of cylinder size. The measurement of power specifications on pistons can be obtained using equation (8).

$$\frac{P}{A_p} = \frac{n_f \, n_v \, NLQ_{HV} \, P_{a,i} \, (F/A)}{2} \tag{8}$$

Where $A_p$ is the piston crown area, $n_f$ is the fuel conversion efficiency, $n_v$ is the volumetric efficiency, $NLQ_{HV}$ is the fuel heating value, $F/A$ is the fuel-air. The piston velocity can be measured using equation (9).

$$\frac{P}{A_p} = \frac{n_f \, n_v \, NS_p \, Q_{HV} \, P_{a,i} \, (F/A)}{4} \tag{9}$$

Where $A_p$ is the piston Crown area, $n_f$ is the fuel conversion efficiency, $n_v$ is the volumetric efficiency, $NLQ_{HV}$ is the fuel heating value, and $F/A$ is the fuel-air.

Pavlov et al. [1] argued that the specific strengths are proportional to the product when observed from the average piston velocity and mean pressure. It illustrates the importance of a direct link to efficient engine performance such as high fuel conversion, high-efficiency volumetric, improved engine output shifts related to the increased inlet air densities, maximum air or fuel ratios that can be used on combustion engines with an average speed of the piston.

**Table 3**. System intake for parameters engine

| Parameter | Intrunne Air-filter | Air-fil ter-01 | Intrun ner-01 | Int port-01 |
|---|---|---|---|---|
| Length (mm) | 80 | 69.64 | 59.7 | 55.2 |
| Dia. inlet end (mm) | 44.8800 | 159.63 | 40.44 | 40.69 |
| Wall temperature. (ºC) | 28.85 | 28.85 | 76.85 | 176.85 |
| Dia. outlet end (mm) | 62.13 | 159.63 | 40.1 | 32.78 |
| Disc. length (mm) | 34.4 | 34.4 | 34.4 | 34.4 |

**Table 4**. System exhaust for parameters engine

| Parameter | Exhport -01 | Exhrun ner-01 | Muffler -01 | Exhrun nerexit-01 |
|---|---|---|---|---|
| Length (mm) | 40.4 | 98 | 283.4 | 25.6 |
| Wall temperat. (ºC) | 480 | 480 | 480 | 480 |
| Dia. outlet end (mm) | 29.82 | 27.86 | 138.88 | 34.6 |
| Disc. length (mm) | 47.3 | 47.3 | 47.3 | 47.3 |
| Dia. inlet end (mm) | 26.38 | 27.86 | 138.88 | 34.6 |

**Table 5**. Intake and exh parameters for engine

| Parameter | Intvalve-01 | Exhvalve-01 |
|---|---|---|
| CAM timing angle (ºCA) | 462.5 | 214.6 |
| Valve lash (mm) | 0.125 | 0.125 |
| Valve diameter (mm) | 35.54 | 29.04 |

## 3. Result and Discussion

This chapter discusses the results of simulations using GT-Power software. These results of were available in various formats. After the GT-Suite application has been processed, the graphical interface file was processed via GT-POST and displayed, all simulated data were captured and analysed. GT-POST is a very sophisticated tool that displays graphics and output data in the form of desired excel sheet. These results represent the performance of a single cylinder machine diesel that was modelled in some standard parameters usage.

The engine model responses with parameters inputted on GT-Power were all recorded and analysed during simulation runs, with the aim of better understanding on engine reactions to the impact of diesel

fuel use temperatures with methanol fuel. Different fuel temperatures were analysed with temperatures between from 300 K to 500 K before the simulation was performed. The engine speed for this test started from 1000, 2000, 3000, and 4000 rpm. Variable engine performance was consisted of heat brake efficiency, brake power, brake specific fuel consumption, brake torque, and effective brake pressure. Each burning fuel temperature has a different output trend so that it can provide different circumstances and reasons.

Figure 3 shows the simulation results by validating the experimental data for pressure differences on a single cylinder diesel engine. These results explain that the simulation results and experimental data have excellent consistency, and there is only a very small difference to some cases that has been done [27]. Overall, the maximum deviation of results between the simulations and the experimental data was less than 10%. Thus, in this case, it is considered to have excellent calibration, since it has been able to evaluate the effect on the combustion process of a single-cylinder engine diesel by using methanol and diesel fuels.
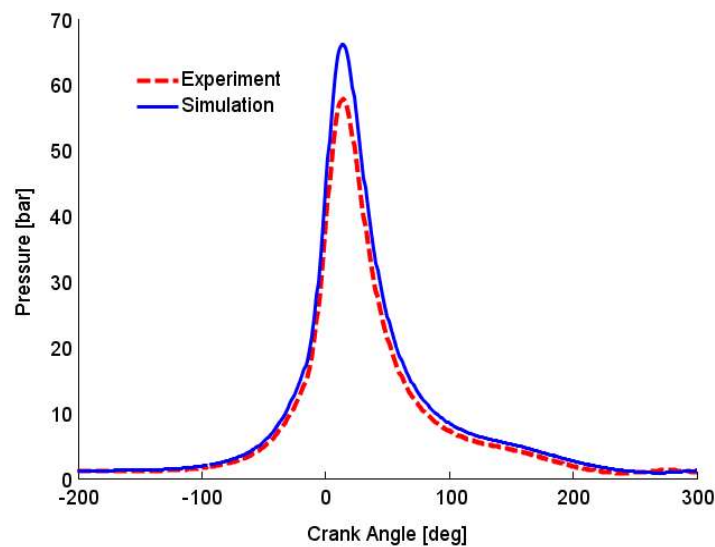


**Figure 3.** Comparison of simulated and experiment data

Figure 4 shows the result of P-V diagram in Cycle 1, wherein the event of intake that occurred before it was compressed. The cylinder was turned off for two cycles, and the intake valve was not deactivated so that the cylinder decreased into the sub-atmosphere during the piston movement as appropriate during the intake event. These results show a good correspondence between the simulation and the experiment during combustion, compression, and expansion in the thermodynamic cycle. The pressure on the gas exchange has shown slightly lower value than the measured result so that the difference will continue throughout the rest of the disabled stroke intake.
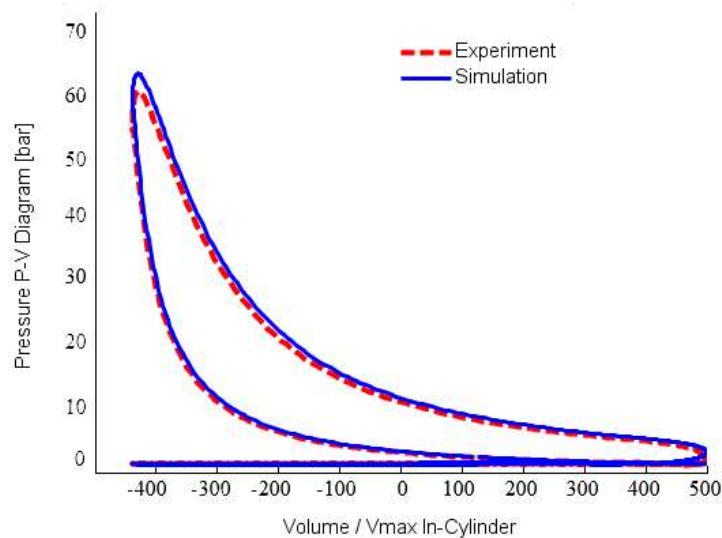
**Figure 4.** P-V diagram for cycle one firing event

At the time of transition, the temperature of the gas between the burning and the unburnt need to be determined. This moment can describe the beginning of the flame in the position of the sensor. To be able to determine the start of the flame, the initial result of the flux heat trace was taken and measured. This can allow us to pay more attention when the heat flux has changed rapidly due to the flame. At the time of initial trace, the heat flux has exceeded the threshold value of 1 W/cm$^2$ °CA extracted and selected as the beginning of the flame [28]. In this case, the fire at the crank angle has reached 358.5 °C. The ignition point went at 358 °CA, with a 900-rpm engine speed requiring of 3.8 m/s or 20.5 °C. Spark plugs with sensors about 30 mm gave an average of 7.89 m/s. The hot flux trace is shown in Figure 5. Where the data is the result of comparison between the experimental data and the simulation, as shown that this simulation can be trusted with an error difference of approximately 10%.
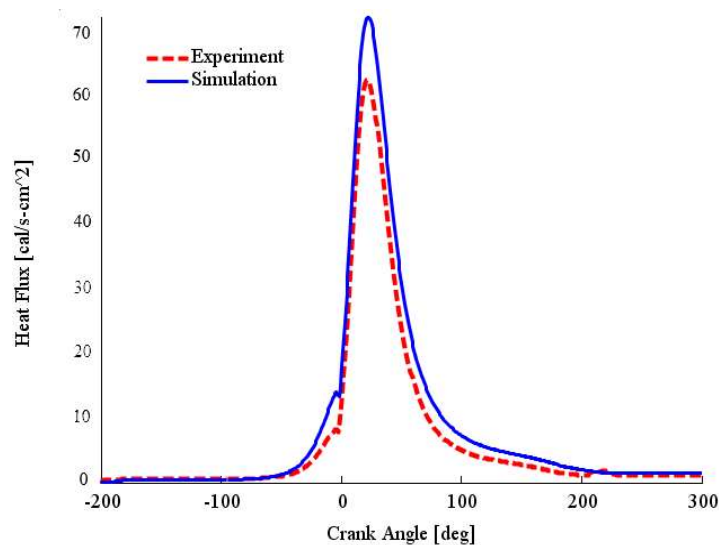


**Figure 5**. Heat Flux In-Cylinder Crank Angle

The simulated results with experiments on the heat transfer coefficients were predicted by the correlation formulas in the original form as shown in Figure 6. The predicted heat transfer coefficient results are very clear. Where the accuracy of the results is allowed using the original equation. This is necessary to obtain correlation results that are tailored to a specific combustion engine on a single cylinder diesel engine [29]. The purpose of this study is to build models that can predict parameters on machines similar to experiments. So that the achievement of pressure on the cylinder can be adjusted, thus the pressure of the effect as shown, the correlation adjustment is required when heat transfer occurs. Each coefficient equation will be used in the simulation as the relevant setting. The main coefficients are needed to search for the overall equation.
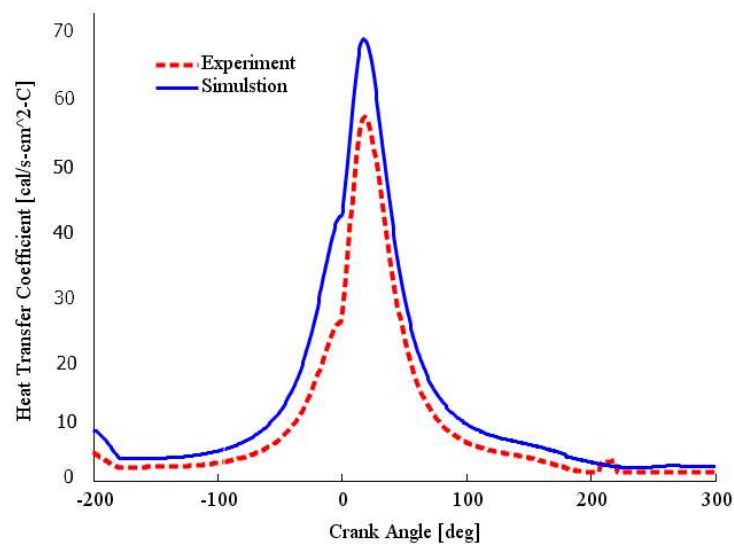


**Figure 6.** Heat transfer coefficient

The result of fuel variation in cylinder pressure has almost no difference between simulation and experiment as shown in Figure 7. The difference of fuel variation between the simulation and experiment modelled on GT-Power is approximately 5%. Thus, the simulation using GT-Power software can be utilised in other cases because this simulation has been able to adjust and read the parameters contained in the machine.
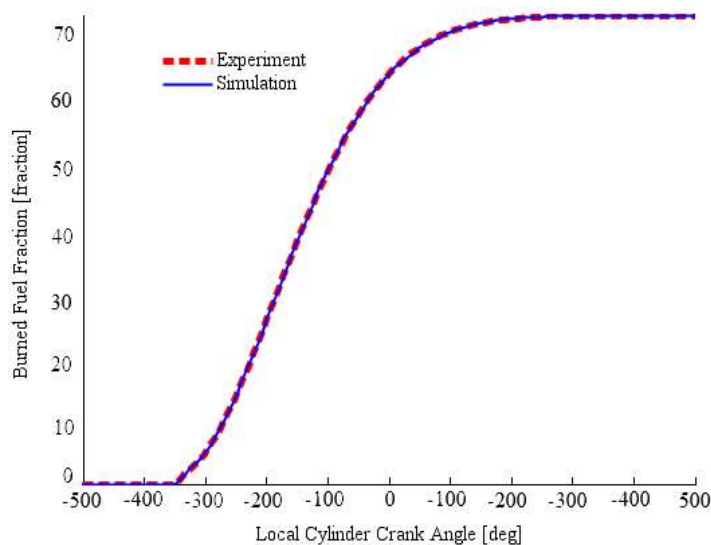
**Figure 7.** Burned fuel fraction in-cylinder

## 4. Conclusion

This study compares the simulations with experiments from diesel engines that were modelled using GT-Power software. This modelling used methanol and diesel fuel with engine speeds of 1100 and 2000 rpm. Simulation results with experimental measurements show that of all tested cases have similarities that reach between 5%–10%. This simulation aims to assess the parameters of a single cylinder diesel engine incorporated into the GT-Power software. With this result, it can be stated that this simulation has been successful and can be expressed accurately as a result of a real experiment on a diesel engine.

## Acknowledgments

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