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Investigation of Diesel Engine Performance Based on Simulation

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Abstract: The single cylinder modeling and simulation for four-stroke direct-injection diesel engine requires the use of advanced analysis and development tools to carry out of performance the diesel engine model. The simulation and computational development of modeling for the research use the commercial of GT-SUITE 6.2 software. In this research, the one dimensional modeling of single cylinder for four-stroke direct-injection diesel engine developed. The analysis of the model is combustion performance process in the engine cylinder. The model simulation covers the full engine cycle consisting of intake, compression, power and exhaust. In this model it can to know the diesel engine performance effect with simulation and modeling in any speeds (rpm) parameters. The performance trend of the diesel engine model developed result of this model based on the theoretical and computational model shows in graphics in the paper.

Keywords: Diesel engines, performance, simulation

INTRODUCTION

The diesel engines is a type of internal combustion engine, more specifically it is a compression ignition engine, in which the fuel is ignited solely by the high temperature created by compression of the air-fuel mixture[1, 5, 6, 9]. The engine operates using the diesel cycle. Unlike a gasoline engine, the incoming air is not throttled, so the engine would over-speed if this was not done. Older injection systems were driven by a gear system from the engine[3, 5].

A four-stroke direct-injection diesel engine typical was measured and modeling in this paper. The GT-POWER computational model shown is one-cylinder diesel engine. GT-POWER is the leading engine simulation tool used by engine and vehicle makers and suppliers and is suitable for analysis of a wide range of engine issues[2]. GT-POWER is designed for steady-state and transient simulation and can be used for analyses of engine and powertrain control. It is applicable to all type of internal combustion engines and provides the user with many components to model any advanced concept. GT-POWER is based on one-dimensional gas dynamics, representing the flow and heat transfer in the piping and in the other component of an engine system. GT-POWER is one dimensional model from GT-SUITE software applications, see Riegler[8] and Bakar[4].

The details of the diesel engine design vary significantly over the engine performance and size range. In particular, different combustion chamber geometries and fuel injection characteristics are required to deal effectively with major diesel engine design problem achieving sufficiently rapid fuel-air mixing rates to complete the fuel-burning process in the time available[9, 10, 11]. A wide variety of inlet port geometries, cylinder head and piston shapes, and fuel-injection patterns are used to accomplish this over the diesel size range.

The engine ratings usually indicate the highest power at which manufacturer expect their products to give satisfactory of power, economy, reliability and durability under service conditions. Maximum torque and the speed at which it is achieved, is usually given also. According to Heywood[1] and Ganesan[7], that the importance of the diesel engine performance parameters are geometrical properties, the term of efficiency and other related engine performance parameters. The engine efficiencies are indicated thermal efficiency, brake thermal efficiency, mechanical efficiency, volumetric efficiency and relative efficiency. The other related engine performance parameters are mean effective pressure, mean piston speed, specific power output, specific fuel consumption, intake valve mach index, fuel-air/air-fuel ratio and the fuel calorific value.

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In the diesel engine geometries design, diesel engine compression ratio is maximum cylinder volume or the displaced volume or swept (V_d) and clearance volume (V_c) divided by minimum cylinder volume (V_c). The diesel engine compression ratio as below:

$$r_c = \frac{V_d + V_c}{V_c} \quad (1)$$

And the power delivered by the diesel engine and absorbed by the dynamometer is the product of torque and angular speed. Diesel engine power definition as:

$$P = 2\pi NT \quad (2)$$

Every engines efficiencies defined by Ganesan[7]. Indicated thermal efficiency (η_{ith}) is the ratio of energy (E) in the indicated power (ip) to the input fuel energy. Brake thermal efficiency (η_{bth}) is the ratio of energy in the brake power (bp), Mechanical efficiency (η_m) is defined as the ratio of brake power (bp) or delivered power to the indicated power (ip) or power provided to the piston and it can also be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency. Relative efficiency or efficiency ratio (η_{rel}) is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle, the efficiency ratio is a very useful criteria which indicates the degree of development of the engine. The one of the very important parameters which decides the performance of four-stroke engines is volumetric efficiency (η_v), where four-stroke engines have distinct suction stroke and therefore the volumetric efficiency indicates the breathing ability of the engine. The volumetric efficiency is the volume flow rate of air into the intake system divided by the rate at which the volume is displaced by the system. The normal range of volumetric efficiency at full throttle for SI engines is 80% to 85% and for CI engines is 85% to 90 %, Ganesan[7].

$$\eta_{ith} = \frac{ip}{E} \quad (3)$$

$$\eta_{bth} = \frac{bp}{E} \quad (4)$$

$$\eta_m = \frac{bp}{ip} \quad (5)$$

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_{disp} N/2} \quad (6)$$

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air - standard efficiency}} \quad (7)$$

The other related engine performance was defined by Heywood[1], Kowalewicz[5], Stone[6] and Ganesan[7]. Mean effective pressure (mep) where n_R is the number of crank revolutions for each power stroke per cylinder (two for four-stroke, one for two-stroke cycles) as:

$$mep = \frac{Pn_R}{V_d N} \quad (8)$$

The measure of an engine's efficiency which will be called the fuel conversion efficiency is given by Heywood[1]:

$$nf = \frac{W_c}{m_f Q_{HV}} = \frac{(Pn_R/N)}{(m_f n_R/N)Q_{HV}} = \frac{P}{m_f Q_{HV}} \quad (9)$$

Specific fuel consumption as:

$$sfc = \frac{m_f}{P} \quad (10)$$

In engine testing, both the air mass flow rate m_a and the fuel mass flow rate m_f are normally measured. The ratio of these flow rates is useful in defining engine operating conditions are air/fuel ratio (A/F) and fuel/air ratio (F/A).

The following relationships between diesel engine performance parameters can be developed.

For power P:

$$P = \frac{\eta_f m_a N Q_{HV}(F/A)}{n_R} \quad (11)$$

$$P = \frac{\eta_f \eta_v N V_d Q_{HV} \rho_{a,i}(F/A)}{2} \quad (12)$$

For torque T :

$$T = \frac{\eta_f \eta_v V_d Q_{HV} \rho_{a,i}(F/A)}{4\pi} \quad (13)$$

For mean effective pressure:

$$mep = \eta_f \eta_v Q_{HV} \rho_{a,i} (F/A) \qquad (14)$$

The specific power or the power per unit piston area is a measure of the engine designer's success in using the available piston area regardless of cylinder size. The specific power as below:

$$\frac{P}{A_p} = \frac{\eta_f \eta_v N L Q_{HV} \rho_{a,i} (F/A)}{2} \qquad (15)$$

Mean piston speed:

$$\frac{P}{A_p} = \frac{\eta_f \eta_v N \overline{S}_p Q_{HV} \rho_{a,i} (F/A)}{4} \qquad (16)$$

The specific power is thus proportional to the product of mean effective pressure and mean piston speed[1]. These relationship illustrate the direct importance to engine performance of high fuel conversion efficiency, high volumetric efficiency, increasing the output of a given displacement engine by increasing the inlet air density, maximum fuel/air ratio that can be useful burned in the engine and high mean piston speed.

MATERIALS AND METHODS

The development of the single cylinder modeling and simulation for four-stroke direct-injection (DI) diesel engine was presented in this paper. The specification of the selected diesel engine model was presented in Table 1.

Table 1: Specification of the diesel engine

Engine Parameters	Value
Bore (mm)	86.0
Stroke (mm)	70.0
Displacement (cc)	407.0
Number of cylinder	1
Connecting rod length (mm)	118.1
Piston pin offset (mm)	1.00
Intake valve open (^{0}CA)	395
Intake valve close (^{0}CA)	530
Exhaust valve open (^{0}CA)	147
Exhaust valve close (^{0}CA)	282
Maximum intake valve open (mm)	7.095
Maximum exhaust valve open (mm)	7.095
Valve lift periodicity (deg)	360

The first step to develop the GT-POWER modeling is open the diesel engine to measure the engine components size to input to the GT-POWER library of the all engine components data. To Create the GT-POWER model, select Window and then Tile With Template Library from the menu. This will place the GT-POWER template library on the left hand side of the screen. The template library contains all of the available templates that can be used in GT-POWER. Some of these templates (those that will be needed in the project) need to be copied into the project before they can be used to create objects and parts. For the purpose of this model, click on the icons listed and drag them from the template library into the project library. Some of these are templates and some are objects that have already been defined and included in the GT-POWER template library.

The engine in this model was breakdown to the tree system, there are intake system, engine cylinder and fuel injection system, and exhaust system. In the selected diesel engine, the intake system its have any component, size and different data. The system was started from environment till the intake valve. All of the intake system components in the GT-POWER model are environment, intrunnerairfilter, air filter, intrunner, inport, intvalve. Fig. 1 shows the intake system components. Every components in this system they need any data to complete the data form and running the model.

Engine cylinder and fuel injection system is focused in engine cylinder performance were support diesel fuel from fuel injection system, fresh air intake system and exhaust gas to exhaust system. There are any components in the engine cylinder and fuel injection system in the diesel engine, but the basic for all diesel engines is the same component. The components, size and data must be record and inserted to the GT-POWER form. All of the engine cylinder and fuel injection system component are injector, cylinder and engine. Fig. 2 shows the engine cylinder and fuel injection system components. Every components in this system they need any data to complete the data form and running the model.

The last system in the diesel engine is the exhaust system. In this system was started from exhaust valve and finished in the environment. The GT-POWER components in the exhaust system are exhvalve, exhport, exhrunner, muffler, exhrunnerexit, and environment. Fig. 3 shows the exhaust system components. Every components in this system they need any data to complete the data form and running the model.

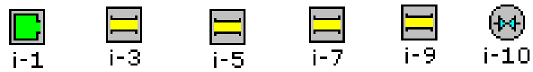

Fig. 1: Intake system components

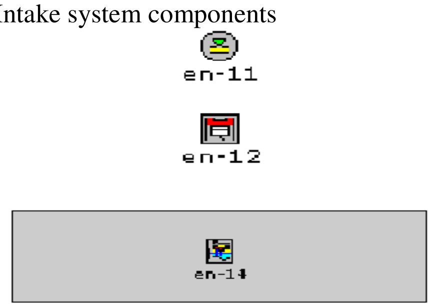

Fig. 2: Engine cylinder & fuel injection components

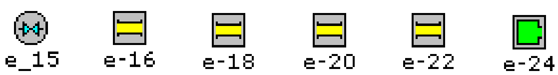

Fig. 3: Exhaust system components

After finished the every system model in the diesel engine system developed, its can to develop the diesel engine modeling using GT-POWER model. The diesel engine modeling using GT-POWER computational model, there are the intake system model, engine cylinder and fuel injection system model, and exhaust system model. The intake system and the engine cylinder and fuel injection system were connected in the intvalve in the intake system and cylinder in the engine cylinder and fuel injection system. The engine cylinder and fuel injection system connected to the exhaust system in the cylinder in the engine cylinder and fuel injection system with exhvalve in the exhaust, shown in Fig. 4. All of this diesel engine components connected by orifficeconn. If the work was finish its can developed the diesel engine modeling using GT-POWER software. The Fig. 5 shows the diesel engine modeling using GT-POWER modeling.

Data needed for building an engine model. A list of information that is needed to build a model in GT-POWER is included in library. Not every item will be needed for all models, and sometimes additional information will be needed, but the list is generally a good starting point. If the model is being built at an early design stage, determining optimal values for some of the items listed may be the purpose of the simulation. If this is the case, those particular attributes should be defined as parameters and run for a series of cases to determine an optimal value. Data in engine characteristics are compression ratio, firing order, inline or V configuration, V-angle (optional), 2 or 4 stroke. Data in cylinder geometry are bore, stroke, connecting rod length, pin offset, piston TDC clearance height, head bowl geometry, piston area and head area. Data in intake and exhaust system is geometry of all components. Data in throttles are throttle location and discharge coefficients versus throttle angle in both flow directions. Data in fuel injectors are location and number of injectors, number of nozzle holes and nozzle diameter, injection rate, fuel type and LHV. Data in intake and exhaust valves are valve diameter, lift profile, discharge coefficient, valve lash. Data in ambient state are pressure, temperature and humidity. Performance data can be very useful when tuning a model after it has been built.

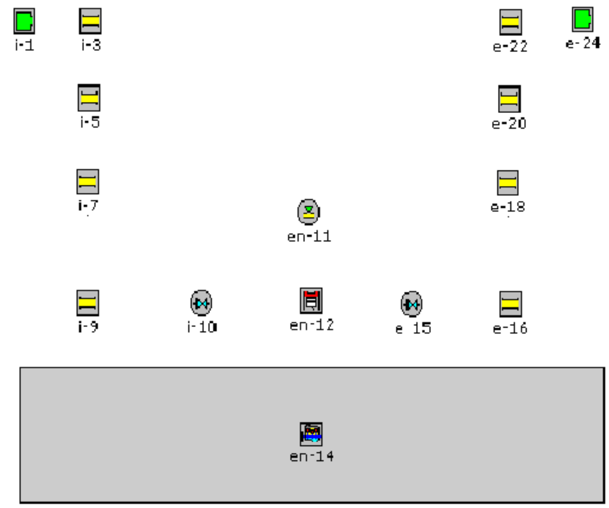

Fig. 4: Single-cylinder Diesel engine components

Before running the model the preparing to run the model simulation needed. Preparing to run the model simulation are review the completed model, run setup, case setup, plot requests and plot setup. All of the parameters in the model will be listed automatically in the case setup and each one must be defined for first case of the simulation. Frequently, computation time can be reduced in steady state simulations by planning the order of the simulations and utilizing the initialization state in run setup. Cycle and/or time plots may be requested by selecting the appropriate plot from the plot options folder within each part. All plots requested in individual parts will be stored regardless of whether the user chooses to use plot setup.

If the model has been prepared for simulation, the GT-POWER simulation may be started and this will start the simulation running. A window will he progress of simulation in the form of scrolling text. Once the input has been read successfully, the simulations will begin, and occasional reports of the progress will be given.

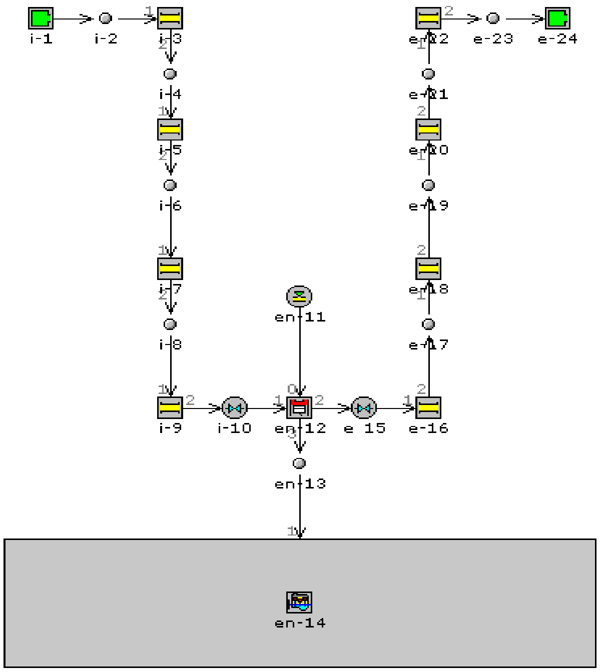

Fig. 5: GT-POWER single-cylinder diesel engine

RESULTS AND DISCUSSION

Whenever a simulation is run, GT-SUITE produces several output files that contain simulation results in various formats. Most of the output is available in the post-processing application GT-POST. GT-POST is powerful tool that can be used to view animation and order analysis output[2]. After the simulations are finished, report tables that summarize the simulations can be produced. These reports contain important information about the simulation and simulation result in a tabular form. The computational simulation of the engine model result is informed the engine performance.

The running simulation result is all of the engine performance data with the different engine speeds (rpm). This model was running on any different speed in rpm, there are 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000. In this paper the simulation result of engine performance are exhaust valve lift, intake valve lift, air-fuel ratio, indicated power (*ip*), brake power (*bp*), brake mean effective pressure (*bmep*), indicated mean effective pressure (*imep*), engine cylinder pressure, brake torque (*bt*), indicated torque (*it*), indicated specific fuel consumption (*isfc*), brake specific fuel consumption (*bsfc*).

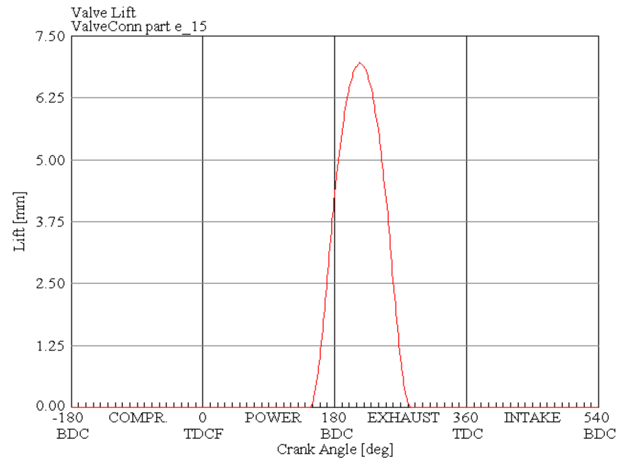

Fig. 6: Exhaust valve lift

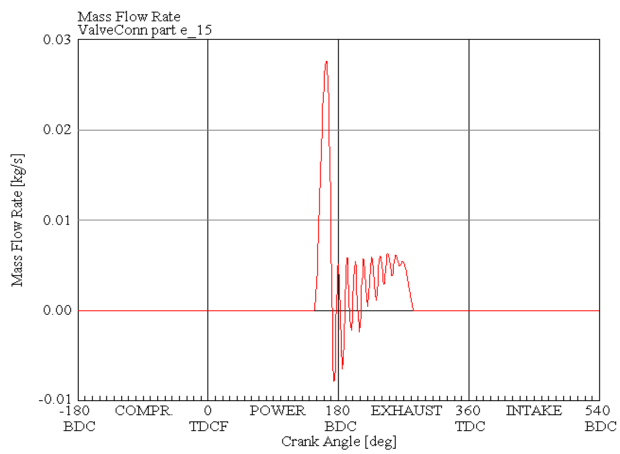

Fig. 7: Mass flow rate in exhaust valve

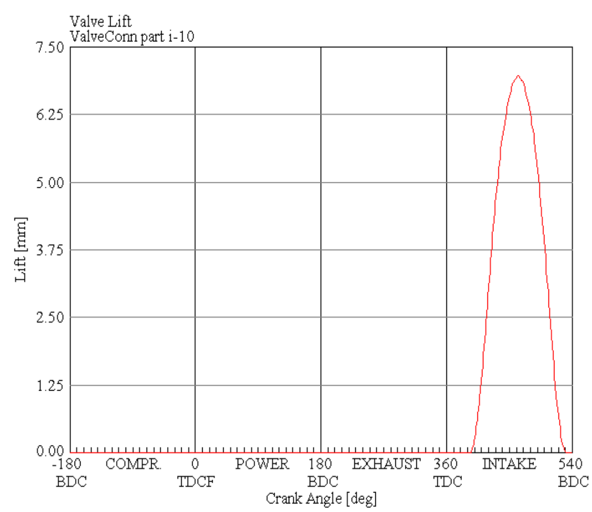

Fig. 8: Intake valve lift

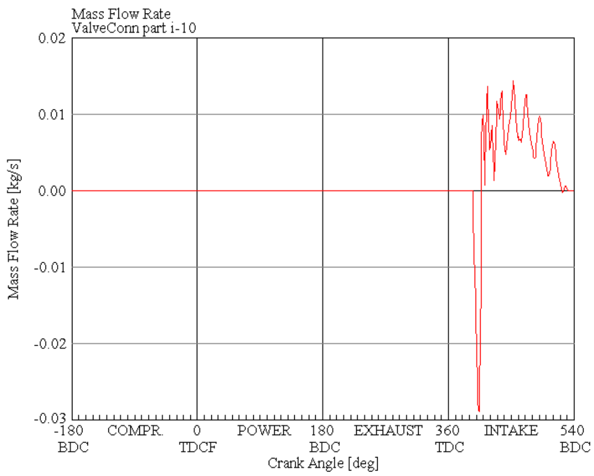

Fig. 9: Mass flow rate in intake valve

In the GT-POWER computational model the exhaust valve performance is shows in Fig. 6, in the engine model the exhaust valve open start from 147 on crank angle degree and close in 282 on crank angle degree. The maximum exhaust valve lift of the model is 7.095mm. The intake valve open shown in Fig. 8, the intake valve start from 395 on crank angle degree and close in 530 on crank angle degree. The maximum intake valve lift of the model is the same with exhaust valve lift 7.095mm. The mass flow rate performance of the intake valve and exhaust valve was shows in Fig. 7 and Fig. 9. The GT-POWER model simulation data output and figure of the intake and exhaust valve is the same with the original engine data.

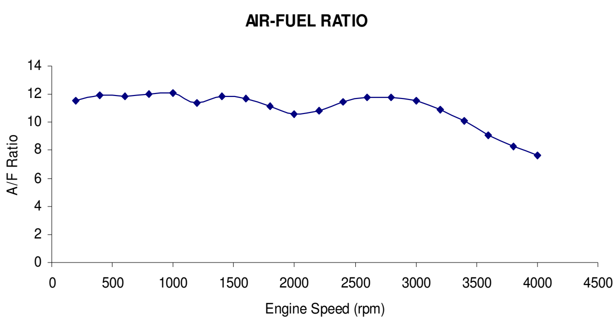

Fig. 10: Air-fuel ratio

The air-fuel ratio of the engine model performance shows in Fig. 10 above, the air-fuel ratio is high in the engine speed is low and the air-fuel ratio is low in the engine speed is high. The highest of the air-fuel ratio is 12.0747 on engine speed 1000 rpm and the lowest of the air-fuel ratio is 7.65304 on engine speed 4000 rpm. The trend of air-fuel ratio is decrease if the engine speed is increase.

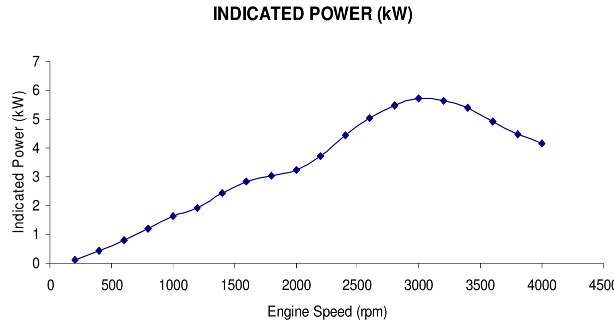

Fig. 11: Indicated power of engine model

Indicated power of an engine is tells about the health of the engine and also gives an indication regarding the conversion of chemical energy in the fuel into heat energy. Indicated power is an important variable because it is the potential output of the cycle. Therefore, to justify the measurement of indicated power, it must be more accurate than motoring and other indirect methods of measuring friction power. For obtaining indicated power the cycle pressure must be determined as a function of cylinder volume. It may be noted that it is of no use to determine pressure accurately unless volume or crank angle can be accurately measured. In this model the engine indicated power performance on variation speed shows in Fig. 11. The performance of indicated power the engine model is with variation on engine speed. On engine speed is 200 rpm the indicated power of engine is low, and if the engine speed is increase over than 200 rpm the indicated power is increase until in 3000 rpm. After the engine speed is over than 3000 rpm the indicated power is decrease and go to down. The engine indicated power model lowest is 0.134354 kW on minimum engine speed (rpm) in 200 rpm and the maximum indicated power of the engine model is 5.72486 kW on engine speed is 3000 rpm and after the engine speed is up of 3000 rpm the indicated power is decrease and go to down.

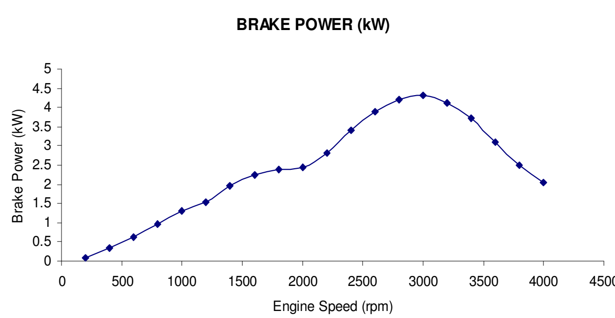

Fig. 12: Brake power of engine model

The brake power of the engine model is shows in Fig. 12. Brake power is usually measured by attaching a power absorption device to the drive-shaft of the engine. Such a device sets up measurable forces counteracting the forces delivered by the engine, and the determined value of these measured forces is indicative of the forces being delivered. The performance of the engine brake power model trend is the same with the engine indicated power. The brake power of engine lowest is 0.085246 kW on minimum engine speed (rpm) in 200 rpm and after that if the engine speed is increase the brake power is increase too until on engine speed 3000rpm. The maximum brake power of the engine model is 4.3139 kW on engine speed is 3000 rpm and after the engine speed is up of 3000 rpm the brake power is decrease and go to down.

The Fig. 13, Fig. 14 and Fig. 15 shows the indicated mean effective pressure, the brake mean effective pressure and pressure in engine cylinder of the diesel engine model simulation. Mean effective pressure is defined as that hypothetical constant pressure acting on the piston during its expansion stroke producing the same work output as that from the actual cycle. The constant depends on the mechanism used to get the indicator diagram and has the units is bar/m. The mean effective pressure is quite often used to calculate the performance of an internal combustion engine. If the work output is indicated output then it is called indicated mean effect pressure. The highest pressure of the engine cylinder pressure is in TDCF, because this step is need the highest pressure to combustion. The highest pressure is 72.522 bar after ignition on 4.209 crank angle degree. The highest indicated mean effective pressure and brake mean effective pressure is 5.79232 bar and 4.44 bar on both 2800 rpm engine speed. Before the engine speed is 2800 rpm the imep and bmep is low and increase until on 2800 rpm. After the engine speed is over than 2800 rpm the imep and bmep is go to down.

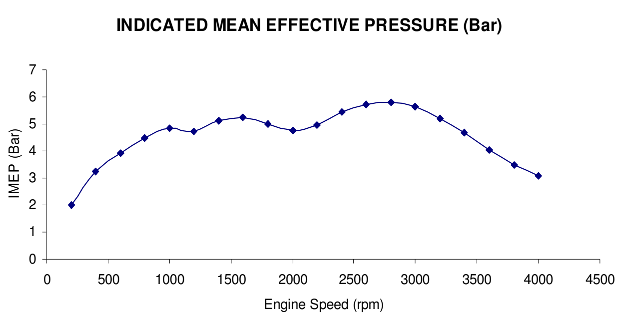

Fig. 13: Indicated mean effective pressure of model

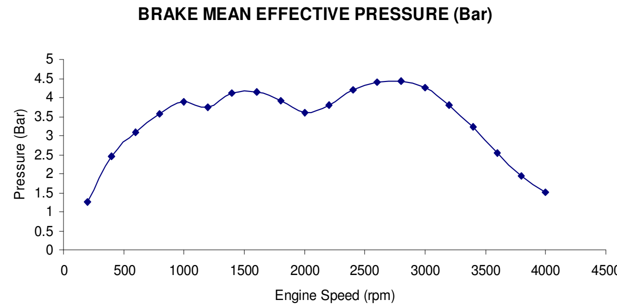

Fig. 15: Brake mean effective pressure of model

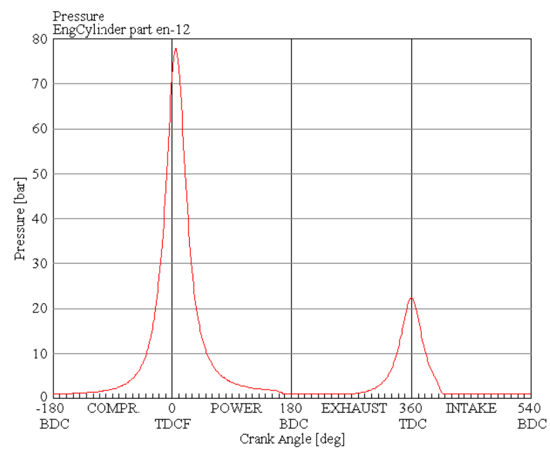

Fig. 15: Pressure in cylinder of engine model

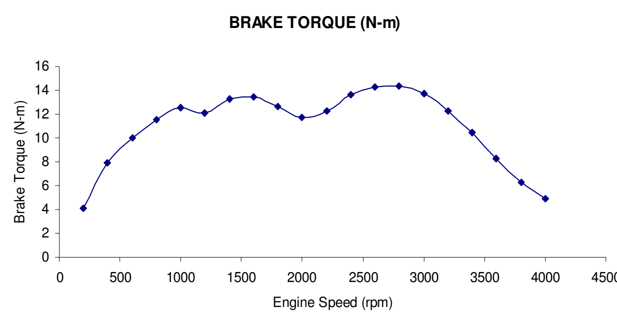

Fig. 16: Brake torque of engine model

Engine torque in experiment is normally measured with a dynamometer. The engine torque is a measure of san engine's ability to do work and power is the rate at which work is done. In this model simulation the torque of the engine shows in Fig. 16 as a brake torque and Fig. 17 as a indicated torque. The maximum brake torque and indicated torque is in 2800 rpm of engine speed. Before the engine speed is 2800 rpm brake torque and indicated torque is low and increase until on 2800 rpm. After the engine speed is over than 2800 rpm the brake torque and the indicated torque is go to down.

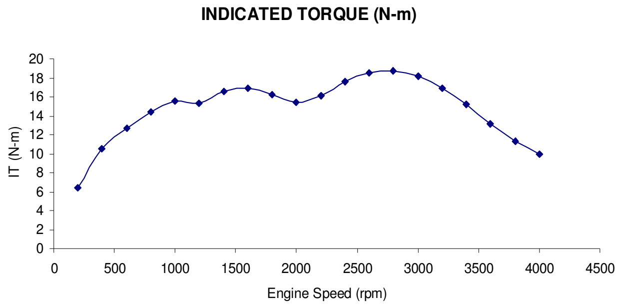

Fig. 17: Indicated torque of engine model

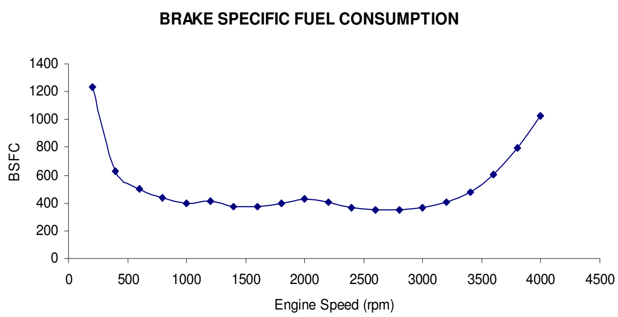

Fig. 18: Brake specific fuel consumption of model

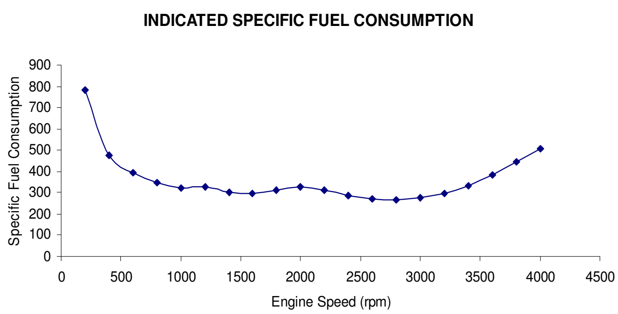

Fig. 19: Indicated specific fuel consumption of model

The brake specific fuel consumption and indicated specific fuel consumption is shown in Fig. 18 and Fig. 19. The model shown that the brake and indicated specific fuel consumption is very high if the engine speed is low until in 1000 rpm and high if the speed is over than 2800 rpm. The model simulation result shown that the indicated and brake specific fuel consumption is minimum and economic on 2800 rpm.

CONCLUSION

On the 407 cc of the single cylinder four-stroke direct injection diesel engine modeling shown that the highest brake power is 4.314 kW and indicator power is 5.725 kW in 3000 rpm of engine speed. The engine modeling brake torque maximum is 14.3662 N-m in 2800 rpm and indicated torque maximum is 18.743 N-m in 2800 rpm. In the engine speed is 2800 rpm, the engine model shown the lowest of the brake specific fuel consumption and the indicated specific fuel consumption. To validate the GT-POWER model result must be compared with the experiment or theoretically.

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