MODELING AND ANALYSIS OF DIESEL ENGINE WITH ADDITION OF HYDROGEN-HYDROGEN-OXYGEN GAS

by

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The brown gas or hydrogen-hydrogen-oxygen gas is considered as a hydrogen fuel with oxygen present in it. The effect of hydrogen-hydrogen-oxygen gas induction in a direct injection diesel engine using GT-POWER software is discussed in relation with the rate of pressure rise and heat release rate. The engine is modeled in GT-POWER environment. The single zone combustion model has been adapted with Woshini heat transfer model. In this model the effect of induction of hydrogen-hydrogen-oxygen gas has been incorporated and analyzed for 1, 3, and 5% of hydrogen-hydrogen-oxygen gas in volume basis. The injection rate is modified for accommodating the hydrogen-hydrogen-oxygen gas in the model. The results have given the promise of higher rate of heat release with shorter combustion duration. Higher levels of hydrogen-hydrogen-oxygen gas have shown the advanced start of combustion as well as reduce the combustion duration.

Key words: hydrogen-hydrogen-oxygen gas, GT-POWER, single zone model

Introduction

Researchers are focusing around hydrogen, natural gas and syngas as the alternate fuel in the compression ignition engine. There is the flexibility of using two fuels, (1) the diesel fuel helps to reduce internal valve wear, and (2) there is no ignition system to maintain, and when combined with an alternative fuel there is a marked reduction in CO_2 emission [1, 2, 3, 7]. Hydrogen has an auto-ignition temperature of 858 K requiring an ignition source to burn and when it is used in a dual fuel diesel engine, the diesel combustion will act as the ignition source [2]. Hydrogen has advantageous properties such as a high flame speed, short quenching distance, high heating value, and high diffusivity [3-7]. As hydrogen storage has problem of safety and space, on-board hydrogen-oxygen generator, which produces hydrogen-hydrogen-oxygen (HHO) gas through electrolysis of water, has significant potential to overcome [4-8]. The HHO gas is defined as a combustible gas composed of conventional hydrogen and conventional oxygen gases having the exact stoichiometric ratio of 2/3 (or 66.66% by volume) of hydrogen and 1/3 (or 33.33% by volume) of oxygen [5, 6].

The addition of HHO gas will reduce the duration of combustion due to higher flame velocity [4-8]. The HHO gas is called as brown gas can be produced by electrolysis of water and chemical reaction. The transition from the conventional H-O-H species to the new HxH-O species is predicted by a change of the electric polarization of water caused by the electrolys-

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es. When H-O-H is liquid, the new species HxH-O can only be gaseous, thus explaining the transition of state without evaporation or separation energy. Finally, the new species (HxH)-O is predicted to be unstable and decay into HxH and O, by permitting a plausible interpretation of the anomalous constituents of the HHO gas as well as its anomalous behavior [4]. The overall effect of addition of HHO gas to in cylinder pressure is not high there is nominal pressure rise but location of peak pressure always shifts to near top dead center (TDC) because of faster combustion. GT-POWER is based on 1-D gas dynamics, representing flow and heat transfer in piping and related component. As this tool is 1-D simulation tool, the time frame required for the simulation is negligible. Thus it reduces time and cost involved and helps to predict results with fair accuracy [10]. The dual fuel capabilities of the diesel engine will reduce the dependency on fossil fuels [11, 12].

Model creation

The model creation is an important task in the simulation work where the developed model must represent the original system in its response to the input. The creation is detailed below. The model is created in the GT-POWER environment.

Table 1. Engine specification

Description	Specification
Model	Kirloskar, EA10 make
General details	Four stroke, compression ignition, constant speed, vertical, water-cooled, direct injection
Number of cylinders	One
Bore	102 mm
Stroke	116 mm
Rated speed	1500 rpm
Swept volume	948 cm^3
Compression ratio	16.3:1

Table 2. comparison of different fuels properties [14]

Properties	Gasoline (Isooctane)	Hydrogen	Diesel
Minimum ignition energy [mJ]	0.24	0.02	–
Flammability limit (F/A equivalence ratio)	0.7-4	0.1-7.1	–
Flame propagation speed [cms^{-1}]	41.5	237	30
Lower heating value (at 25 °C; p = 1 atm) [kJg^{-1}]	44.5	119.93	42
Self-ignition temperature [°C]	240-480	585	280

Engine specification

The dual fuel capability of a direct injection (DI) diesel engine is analyzed with diesel and HHO gas as fuels. The specification of the engine used for modeling in GT-POWER is given in tab. 1. The properties of fuels used for this study is given in tab. 2.

Modeling engine cylinder

The engine is modeled carefully to insert its kinematics and rigid dynamics with its crank train configurations in the GT-POWER. The model created for representing the original engine for validation with the experimental data is shown in fig. 1. The details given as input for modeling are the engine type, speed or load specification, and cylinder geometry. In general 1-D simulation of an engine model consist of intake system, exhaust system, fuel injection system, exhaust gas recirculation (EGR), engine cylinders, and valve train. This work mainly concentrate on the in cylinder combustion process, the air breathing system is not included for simplicity and this does not affect the required output.

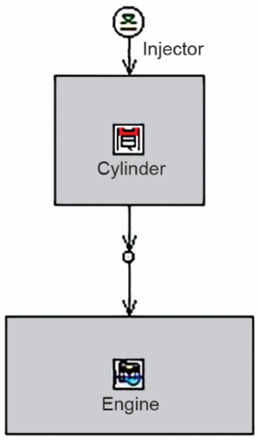

Figure 1. GT-POWER single cylinder diesel engine

There are templates available for each and every component present in the model. The required inputs have to be given for the particular type of engine. The template requires the amount of fuel injected per stroke, injection timing, nozzle dimension, properties of diesel fuel. The dimensions and the injection connection allows for injection of a periodic pressure or mass rate profile. The injection rate profile matched with the base diesel operation is given in fig. 2. The core approach of this model is to track the fuel jet as it breaks into droplets, evaporates, mixes and burns. As such an accurate injection profile is absolutely required to achieve meaningful results.

The template used to specify the attributes of engine cylinders are: initial state, wall temperature, heat transfer, flow, and cylinder pressure analysis mode. These conditions must be assigned with care for matching with the experimental pressure-crank angle and heat release rate. The Woshini's heat transfer model is selected for this study. The measured and predicted mode provides a method for easier calibration of a predictive combustion model. This mode will perform both a burn rate calculation from measured cylinder pressure and a forward run of the predictive combustion model using the same initial conditions.

In GT-POWER, combustion refers to the transfer of a defined amount of unburned fuel mass and air along with the associated enthalpy from an unburned zone to a burned zone in the cylinder, the release of the chemical energy in the fuel-air mixture and the calculation of species, and concentrations that result. The base diesel performance of the model is calculated and validated with the experimental data for its P-Θ diagram and heat release rate.

Induction of HHO gas in GT-POWER dual fuel (HHO gas-diesel) model

For induction of HHO gas into the cylinder, the initial conditions have been changed from only air to air and required percentage of HHO gas. The addition of HHO gas is considered here as volume basis and it has to be given as input to the model as the replacement of diesel fuel according to energy basis. The sample calculations for 1% by volume replaced with HHO gas is given below:

- assumed volumetric efficiency is 83%,
- 1% of intake is added with HHO gas,
- the HHO gas is stoichiometric mixture of hydrogen and oxygen by volume. It consists of 2 parts of hydrogen and 1 part of oxygen by volume,
- as oxygen does not contain any energy only hydrogen energy is used to replace diesel fuel, and
- the hydrogen volume is used for energy calculation considering energy density of 9835.05 KJ/m^3 at 1 bar and 300 K temperature [4].

The present study assumed that the fuel injection timing and rate is remained constant. Therefore the fuel injection duration is reduced for different proportions of HHO addition and shown in fig. 3. In this study the addition of HHO gas is limited with 5% and the chosen values are 1, 3, and 5%.

The values of inputs are given with the HHO gas to find out the engine performance in valid model. The effect of HHO gas induction is detailed in the next section.

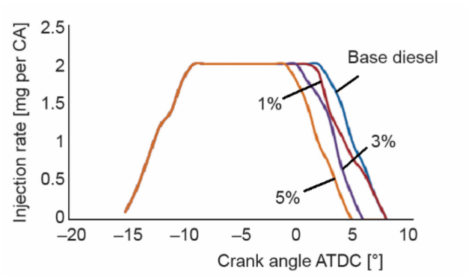

Figure 3. Injection rate for different HHO gas induction rate

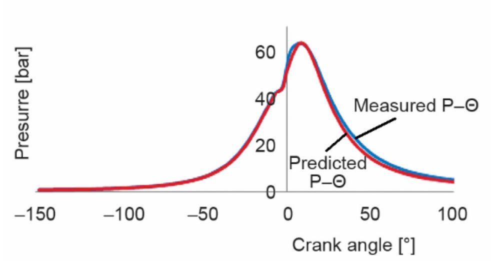

Figure 4. Validation of base diesel GT-POWER model for in cylinder pressure

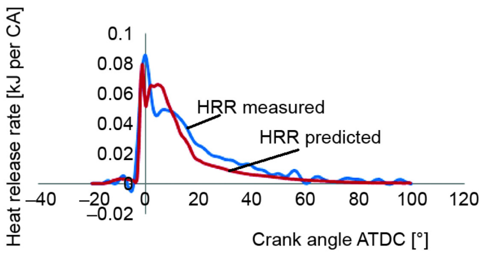

Figure 5. Validation of base diesel GT-POWER model for apparent heat release rate

Results and discussion

The results are discussed with the validation of model and the effect of additional intake of HHO gas in various proportions in volume basis.

Model validation for base diesel

The validation of the created GT model is done with literature values and match with the experimental results. Validation is done with two most important parameters such as in-cylinder pressure and heat release rate (HRR).

In-cylinder pressure

Analyzing the pressure trace gives us very important information about the in-cylinder combustion process. As shown in fig. 4, GT-POWER predicted values and measured experimental values are in good agreement. Especially most important parameter like location of peak cylinder pressure and its magnitude are exactly matching.

Heat release rate

The fuel injection rate is assumed in such a way so that the calculated HRR closely matches with the measured experimental values. As shown in fig. 5, the GT-Power predicted values of parameters like ignition delay or start of combustion angle and peak heat release rate is closely matching with the measured values. This confirms the model is giving the results that are close or matching with the experimental values. So this model can be useful for analyzing the engine with modification, in this case as fuel (HHO).

Model validation for diesel-HHO gas dual fuel engine

The model is modified for the addition of HHO gas in the intake with the air. The HHO gas is substituted by 1, 3, and 5% in volume basis. The predicted pressure traces and heat release rate are compared with base diesel experimental values.

Effect of HHO gas induction in cylinder pressure traces

The variation in cylinder pressure with the addition of 1, 3 and 5% of HHO gas in to the diesel engine is shown in fig. 6. The HHO gas contains hydrogen and oxygen, hydrogen is having good combustion properties such as low ignition energy, high flame speed, high diffusion rate, early combustion of HHO gas, along with premixed diesel occurs. The peak pressure occurs for base diesel is 9° after top dead center (ATDC) and it is shifted to 7° ATDC for 5% HHO gas replacement. This clearly indicates the shorter combustion duration due to the presence of hydrogen. Addition of 1% and 3% HHO gas has very less effect on peak pressure occurrence. The peak pressure is dropped for the HHO gas induction may due to the lower in volumetric efficiency and higher rate of heat transfer. But the rate of pressure rise is higher for the HHO inducted case (fig. 7). As the amount of HHO gas substitution increases; rate of pressure rise increases and it is highest in the case of 5% HHO gas. This may be due to the level of premixed combustion because of HHO addition in the intake. The high flame velocity of the hydrogen and more premixed phase of combustion increases the combustion of the engine.

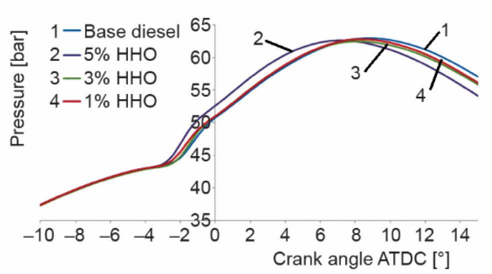

Figure 6. Effect of HHO gas induction on in-cylinder pressure traces

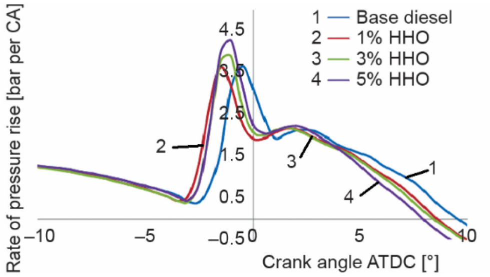

Figure 7. Effect of induction of HHO gas on rate of pressure rise

Effect of HHO gas induction on HRR

The effect of HHO gas addition has clear effect on HRR can be seen from fig. 8. The addition of HHO gas increases the amount of energy burn in premixed phase. This can be visualized from the duration for 50% burning of air fuel mixture shown in fig. 9. The fuel burning rate is giving the insight comparison of fuel-related combustion effects. This is very important for the improvement of engine controlling unit (ECU for controlling emission by changing injection timing during new engine development. The fuel burning rate is drastically reduced for increase in the HHO gas addition.

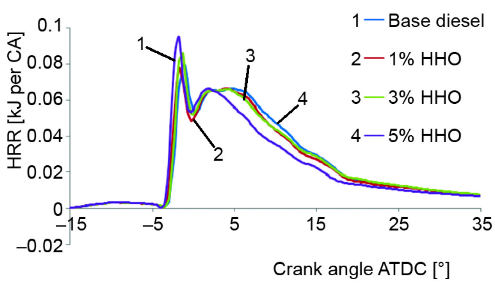

Figure 8. Effect of HHO gas induction on HRR

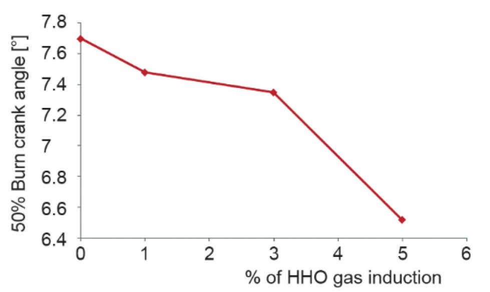

Figure 9. Effect of HHO gas induction on 50% burn crank angle

The more premixed phase of combustion increases the heat release rate and shorter combustion duration for the HHO gas induction [9, 11]. The shorter combustion duration looks like the instantaneous combustion or constant volume combustion. This directly sources the higher thermal efficiency. The shorter combustion duration may increase the rate of heat transfer. This may affect the engine by flame quenching, but due to the quenching property of hydrogen will compensate that.

The results are clearly mentioning that the HHO gas induction will improves the engine performance, combustion, and emission characteristics.

Conclusions

The modeling of an engine will give freedom to researchers for development in related aspects without facing any practical difficulties. For developing such models, the GT-POWER software package is giving the flexibility and easier way. The addition of HHO gas into the diesel engine was analyzed using the GT-POWER model. The model is developed and validated with the experimental results of pressure rise and rate of HRR. The cylinder pressure and rate of heat release were chosen only because they indicate the quality of combustion, performance and emission from an engine. The following points were observed from the results.

- There is not much variation in peak cylinder pressure value but location of peak cylinder pressure is shifted towards TDC due to short combustion duration for the increase in HHO addition and more premixed phase of combustion. The rate of pressure rise is confirming the same.
- The increase in heat release rate for the increase in HHO gas induction due to more premixed phase of combustion. The 50% burn crank angle is supporting the above.
- The superior combustion properties of HHO gas such as high flame speed and high diffusion rate influences the combustion. It is also observed that ignition delay is slightly decreases; it may due to addition of extra oxygen.

Thus the induction of HHO gas in higher proportion will definitely improves the combustion and performance of the diesel engine in dual fuel mode of operation.

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