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Closed Cycle Simulation of DI Diesel Engine with Six Zone Combustion Model

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ABSTRACT

In this study, diesel engine simulation is carried out with a new phenomenological multi-zone combustion model. This model is used to simulate the diesel cycle including fuel injection and combustion processes. The model has been developed using well-known combustion imaging studies of Dec, the spray penetration studies by Siebers, and assumptions of Maiboom. This model divides the combustion chamber into six zones and provides local information such as temperature, mean equivalence ratio and composition in each zone. In order to determine the amount of emissions, the Zeldovich model is used for the NO and NSC model for soot. A comparison of model predictions with available experimental data shows very good agreement for different main engine parameters such as engine speed and load, inlet air temperature and pressure, exhaust gas recirculation (EGR) rate, injection pressure and injection timing.

KEYWORDS

Diesel, Quasi-Dimensional Model, Soot, NO, Combustion

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1- INTRODUCTION

Modeling is generally a process of describing the physical phenomena of a particular system using governing mathematical equations. Usually, these models can improve engine design by having a better understanding of fundamental physical processes occurring within the system. Engine modeling activities in recent decades have largely been concentrated on the better understanding of engines which has led to improved performance and lowering emissions. Engine models vary in complexity from zero-dimensional simple correlations with no spatial resolution to multi-dimensional models. Globally thermodynamic models can be classified into three categories: zero-dimensional, quasi-dimensional and multi-dimensional models.

This exercise would enable the application of the multi-zone models over a wider range of engine systems and operating conditions. The objective of this study is to develop a more physically-based, quasi-dimensional multi-zone spray model and implement it into a full cycle diesel engine simulation so as to predict engine performance, fuel economy and pollutant emissions. The zonal spray combustion model should be able to:

· Incorporate a heat release model that can explicitly account for both premixed and diffusion-controlled combustion phases, as observed in measured heat release profiles.

· Predict NOx and soot pollutant emissions with acceptable fidelity.

· Cover a wide range of engine operating conditions and engines without losing accuracy.

The aim of the present paper is to propose a quasi-dimensional combustion model, being able to simulate the evolution of main fuel jet parameters as well as mean temperatures in each zone, thus permitting the interpretation of main experimental trends when modifying load, speed, injection timing, inlet temperature, EGR rate, and boost pressure.

2- MULTI-ZONE COMBUSTION MODEL

The conceptual models proposed by Dec [1] and Maiboom [2] and have been used to create the present quasi-dimensional combustion model. The model recognizes six zones and provides local information such as the various zone's temperature and the mean equivalence ratio. The figure below shows a quasi-steady jet where each of the six zones has been fully established. The six zones are the following:

According to Figure 1:

Zone 1: Liquid zone, from the nozzle hole to the maximum liquid penetration.

Zone 2: Air-fuel mixture between the maximum liquid penetration and the lift-off length

Zone 3: Premixed combustion zone

Zone 4: Diffusion combustion zone

Zone 5: Diffusion flame surrounding zones

Zone 6: Surrounding gas (air and EGR)

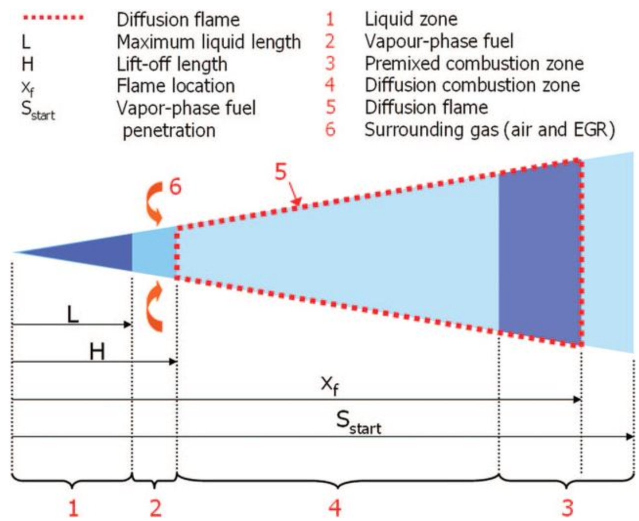

Figure 1: Zone Description [2]

3- SUB-MODELS FOR MULTI-ZONE COMBUSTION MODEL

The spray model is used to calculate the geometry of the fuel spray and defines the amount of cylinder gas entrained into the spray.

The liquid length model predicts the maximum distance that liquid fuel penetrates into the cylinder and is calculated based on the correlation developed at Sandia.

The lift-off length is extremely important in determining the characteristics of the flame because it determines how much air is entrained into the rich premixed reaction zone. It is in the rich premixed reaction zone where soot is initially formed. The correlation developed by Siebers is used to calculate the lift-off length.

Beyond the liquid length, the fuel vapor and air continue to mix and penetration continues into the combustion chamber. With the high temperatures in the cylinder, auto-ignition begins when the fuel-air equivalence ratio and the temperature in the spray reach combustible limits. Ignitable mixtures would be of necessary existence beyond the liquid length or on the sides of the spray where the fuel has evaporated and has the opportunity to heat above the boiling point. We assume that the fuel ignites at the maximum liquid penetration and then, a flame propagates in the premixed zone with a turbulent velocity as proposed in Barba's model [3]. After start of combustion, before the flame reaches the vapor penetration, the burning rate is controlled by the flame speed and the equivalence fuel-air ratio at the flame location. When the flame reaches the vapor-fuel penetration, the unburned fuel is consumed. A very simple law is used to predict premixed combustion by assuming that the burning rate is directly proportional to fuel availability or air availability in zone 3.

Mixture formation processes continue during the main combustion phase and strongly affect both the combustion course itself as well as pollutant formation. The chemistry of this phase is very rapid and the combustion process is controlled by the mixing rate. For the description of diffusion combustion, a mixing-frequency model which was developed by Maiboom is used [2]. In Barba's formula, the excess air has been introduced in the characteristic mixing length but in Maiboom's model, the combustion has been correlated directly to air availability in the diffusion zone in the case of fuel excess.

The first law of thermodynamics is implemented in order to calculate the cylinder pressure and spray zonal temperatures. We assume that the contents of each zone act as an ideal gas and the thermodynamic properties of the gas mixture in each zone are functions of temperature, pressure, and fuel-air equivalence ratio. The equilibrium code, which is used in this regard, includes 21 species based on the work of Asay [4].

Since the chemical equilibrium model is not able to precisely predict the amount of NOx, the kinetics model, which has been developed by Lavoie et al. [5], is used. Also, the rate of soot formation is calculated based on the model proposed by Lipkea and DeJoode [6].

3- CONCLUSIONS

A quasi-dimensional, multi-zone, direct injection diesel spray combustion model has been developed and implemented for a closed cycle simulation in a Caterpillar engine to predict and validate engine performance and emissions. This model provides an effective tool to analyze coupled thermodynamic and heat transfer processes in an engine. A comparison of model predictions with available experimental data is in very good agreement over a wide range of injection timing, the test results of which are available. The developed model is a fast and powerful tool to predict engine performance and emission levels but further work is needed to consider the interaction of spray and walls, and also multi-jet sprays emitted from different holes together with the effect of a sequential fuel injected system.

5- REFERENCES

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