Preface

Phenomenology of Diesel Combustion and Modeling

Diesel is the most efficient combustion engine today and it plays an important role in transport of goods and passengers on land and on high seas. The emissions must be controlled as stipulated by the society without sacrificing the legendary fuel economy of the diesel engines. These important drivers caused innovations in diesel engineering like re-entrant combustion chambers in the piston, lower swirl support and high pressure injection, in turn reducing the ignition delay and hence the nitric oxides. The limits on emissions are being continually reduced. Therefore, the required accuracy of the models to predict the emissions and efficiency of the engines is high. The phenomenological combustion models based on physical and chemical description of the processes in the engine are practical to describe diesel engine combustion and to carry out parametric studies. This is because the injection process, which can be relatively well predicted, has the dominant effect on mixture formation and subsequent course of combustion. The need for improving these models by incorporating new developments in engine designs is explained in Chapter 2. With "model based control programs" used in the Electronic Control Units of the engines, phenomenological models are assuming more importance now because the detailed CFD based models are too slow to be handled by the Electronic Control Units.

Experimental work is necessary to develop the basic understanding of the processes. Chapter 3 describes the experimental set up of the bomb for interferometry and real engine studies for validation of the phenomenological models. This chapter also includes the details of the measurement techniques for obtaining the experimental data needed for validating the phenomenology. Empirical relations have been obtained in Chapter 4 to describe the axial and radial variations of fuel concentration in the vaporising and burning sprays, and to evaluate penetration and air entrainment of the free and wall jet regions. The movement of the 'tail' of the spray in the post injection period has been studied. These equations form the basis for building the phenomenological models of ignition delay, emissions and heat release rate in subsequent chapters.

The norms for NO_x and HC emissions are so tight that prediction of ignition delay has become necessary. In Chapter 5, phenomenological calculations of the cooling of spray surface have shown that the physical parameters and fuel type influence the temperature of the mixture of air and the fuel vapour throughout its life up to the end of ignition delay. A model is proposed in Chapter 6 to predict rapid convective heat transfer between spray and wall by extending the analogy adopted by Woschni.

The rate of heat release in an indirect injection engine is modelled on the lines of its observed rate in a direct injection engine. The diffusion combustion is modeled as proportional to the available fuel and rate of air entrainment in Chapter 7. Chapter 8 introduces the concept of air useful for combustion. The ratio of momentum of the useful air to the total momentum of injected fuel near TDC at the end of ignition delay period is found to bear a universal relationship with the indicated efficiency and dry soot emissions in case of combustion chambers supported by air swirl. In Chapter 9, the combustion rate is precisely described using the concept developed in Chapter 7 by relating the fuel air mixing rate to the turbulent energy created at the exit of the nozzle as a function of the injection velocity and by considering the dissipation of energy in free air and along the wall. The absence of adjustable constants distinguishes the model from the other zero-dimensional or pseudo multi-dimensional models.

Hydrocarbon (HC) emissions from direct injection diesel engines are mainly due to fuel injected and mixed beyond lean combustion limit during ignition delay and fuel effusing from the nozzle sac at low pressure. The concept has been developed in Chapter 10 to provide an elegant model to predict the HC emissions. To contrast the phenomenon of HC formation in a Diesel and in a spark ignition engine, Chapter 11 is included. The absorption and desorption of fuel by cylinder lubricating oil films has been modelled using principles of mass transfer.

A new model for smoke explained in Chapter 12 characterizes the smoke emitted at higher loads from the wall spray formed after impingement. Smoke has been treated by ignoring the fast chemistry, as the slow physical mixing seems to be controlling. A new phenomenological model for NO_x emission is developed based on mixing controlled combustion incorporating localized wall heat transfer in Chapter 13. Based on the smoke formation and oil consumption, an estimate of the particulate matter is made in Chapter 14.

Chapter 15 and 16 on the modern methods of simulating diesel engines are contributed by Dr. Yu Shi and Prof. Dr. Rolf Reitz of Engine Research Centre at the University of Wisconsin, Madison. Chapter 15 reviews the basic approach of multi-dimensional CFD modelling of diesel combustion, and focusing on the advanced turbulence and combustion models. Recent efforts for reducing the computational expense of multi-dimensional CFD modelling are also discussed. CFD tools reveal details about invisible or technically difficult or costly in-cylinder processes of diesel combustion, so that guidance can be provided to improve engine designs in terms of emissions reduction and fuel economy; innovative combustion concepts can be evaluated numerically prior to experimental tests to reduce the number of investigated parameters and thus costs; important design parameters can be discovered by modelling engines of different sizes to establish engine size-scaling relationships and thus non-dimensionalizing engine designs; by integration with optimization methodologies, CFD tools can also directly impact the design of optimum engine systems, such as piston geometry and injection parameters. Each of these aspects is described by relevant case studies in Chapter 16.

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