05P-250

A Soot Model for Diesel Engine CFD Applications

Ossi Kaario
Technical Research Centre of Finland, VTT Processes

Martti Larmi
Helsinki University of Technology

ABSTRACT

Soot modeling has become increasingly important as diesel engine manufacturers are faced with constantly tightening soot emission limits. As such the accuracy of the soot models used is more and more important. In this study a soot formation and oxidation model has been developed. The proposed model is undemanding from the computational point of view and it was partly formulated according to recent experimental data obtained from diesel engine like conditions and by detailed soot chemistry modeling. The new soot model is compared to the Hiroyasu-Magnussen soot model and the results in a large bore medium speed diesel engine show correct trends and more consistent behavior than the Hiroyasu-Magnussen soot model.

INTRODUCTION

Soot modeling has become increasingly important as legislation allows less and less soot to be emitted from diesel engines. Engine manufacturers need to find ways to reduce the amount of soot produced by their engines. Computational Fluid Dynamics or CFD modeling in conjunction with proper soot models is a way of looking into the problem and finding ways to reduce the soot emissions.

Because soot chemistry involves at least hundreds of species and thousands of reactions, it is practically impossible to use detailed modeling approaches in conjunction with CFD. Therefore, simplified models must be used. Often the problem with simplified models is their predictive accuracy.

There are currently only a few models that are often used within diesel engine soot modeling, one of the most often used is the so-called Hiroyasu-Magnussen soot model. The Hiroyasu-Magnussen soot model consists of soot formation model by Hiroyasu et al. [1] and the soot oxidation model by Magnussen and Hjertager [2]. Both parts of the model are relatively simple expressions that can be easily incorporated into a CFD software.

A lot of experimental work as well as detailed soot chemistry modeling has been recently done in order to have a deeper understanding of soot production and oxidation processes in diesel-like conditions. Kitamura et al. [1] showed the strong temperature and fuel air equivalence ration dependence of soot production by using detailed soot chemistry modeling. Pickett and Siebers [2] made measurements in diesel engine like conditions and studied e.g. the effect of ambient temperature on soot production. This study uses this new data and puts it into a new soot formation and oxidation model that is simple in form but with more accurate predictive capabilities than with the Hiroyasu-Magnussen model mentioned above.

The proposed new soot model as well as the Hiroyasu-Magnussen soot model have been implemented into fluid solver Star-CD version 3.2. The models are compared in one large bore (200mm) diesel engine with three different loads. It is shown that the proposed new soot model works well in a large bore diesel engine in different operation conditions.

SOOT MODELS

HIROYASU SOOT FORMATION MODEL

The Hiroyasu soot formation model was developed by Hiroyasu et al. [3] and it was later applied to multidimensional diesel combustion by Belardini et al. [4]. The version adopted here is taken from Chan et al. [5]

The soot formation rate [kg/m^{3}s] is given by

$$\frac{dm_{sf}}{dt} = A_f \, m_f \, P^{0.5} \, exp\left(-E/RT\right), \qquad (1)$$

where A_f is a constant (value of 1 used in this study), m_f is the fuel vapor mass fraction, P is the pressure [Pa], E is the activation energy (52.335 kJ/mol), R =8.314 [J/molK], and T is temperature [K].