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Validation and sensitivity analysis of a two zone Diesel engine model for combustion and emissions prediction

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Abstract

The present two zone model of a direct injection (DI) Diesel engine divides the cylinder contents into a non-burning zone of air and another homogeneous zone in which fuel is continuously supplied from the injector and burned with entrained air from the air zone. The growth of the fuel spray zone, which comprises a number of fuel-air conical jets equal to the injector nozzle holes, is carefully modelled by incorporating jet mixing, thus determining the amount of oxygen available for combustion. The mass, energy and state equations are applied in each of the two zones to yield local temperatures and cylinder pressure histories. The concentration of the various constituents in the exhaust gases are calculated by adopting a chemical equilibrium scheme for the C–H–O system of the 11 species considered, together with chemical rate equations for the calculation of nitric oxide (NO). A model for evaluation of the soot formation and oxidation rates is included. The theoretical results from the relevant computer program are compared very favourably with the measurements from an experimental investigation conducted on a fully automated test bed, standard "Hydra", DI Diesel engine installed at the authors' laboratory. In-cylinder pressure and temperature histories, nitric oxide concentration and soot density are among the interesting quantities tested for various loads and injection timings. As revealed, the model is sensitive to the selection of the constants of the fuel preparation and reaction sub-models, so that a relevant sensitivity analysis is undertaken. This leads to a better understanding of the physical mechanisms governed by these constants and also paves the way for construction of a reliable and relatively simple multi-zone model, which incorporates in each zone (packet) the philosophy of the present two zone model.

Keywords: Two zone Diesel model; Combustion; Emissions; Sensitivity analysis

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Nomenclature

D	cylinder bore (m)
E	internal energy (J), or activation energy (J/kmol)
E_{red}	reduced activation energy (K)
h	specific enthalpy (J/kg)
H	enthalpy (J)
m	mass (kg)
M	molecular weight (kg/kmol)
N	engine rotational speed (rpm)
p	pressure (Pa)
Q	heat (J)
R_{mol}	universal gas constant, 8314.3 J/kmol/K
R_{s}	swirl ratio
S	piston stroke (m)
t	time (s)
T	absolute temperature (K)
u	spray velocity (m/s)
V	volume (m^3)
$w_{\mathrm{a_{tot}}}$	total kmoles of air trapped in cylinder
$w_{\mathrm{f_{tot}}}$	total kmoles of fuel to be injected in cycle
W	work (J)
x	spray penetration (m)
z	number of injector nozzle holes

Greek

Δp	pressure drop (Pa)
$\Delta\varphi_{\mathrm{inj}}$	duration of fuel injection (°CA)
θ	spray angle (rad)
ρ	density (kg/m^3)
φ	crank angle (degrees)

Superscripts

–	mean value
·	time derivative

Subscripts

a	air
br	spray break-up
f	fuel
g	gas
inj	injected
j	spray number
ℓ	liquid fuel