PROGRAMME EUROPEEN FRANCO-BRITANNIQUE INTERREG IIIA

FRANCO-BRITISH INTERREG EUROPEAN PROGRAMME

Les Sprays

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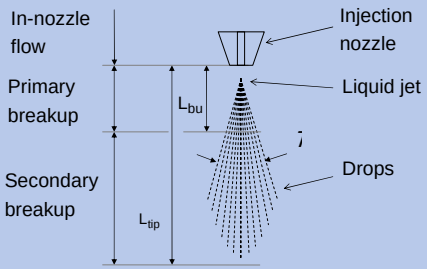
SPRAY STRUCTURE



PHENOMENA WHICH AFFECT THE SPRAY

Flow inside the injector2

COMPUTATIONAL MODEL OF SPRAY

Realistic 3D transient conditions

Visualised spray structure – droplet size spectra, velocities, temperature, spray penetration

+ air motion and turbulence

+ evaporation and chemical reactions

+ motion of droplets or particles

HOW CAN YOU BENEFIT FROM OUR STUDY?

- Full control of spray (parameters of dispersion phase, rate of penetration, evaporation, etc.)
- Efficient energy consumption
- Recommendations on configuration and setup of sprayers

RESULTS: MEASUREMENTS AND COMPUTATIONS

Calculations using KIVA-II CFD code – TAB, WAVE and Stochastic (Gorokhovski, 2003) models of spray breakup.

Validation test (experiments by Hirouasu and Kadota, 1974)

Experiment by C. Crua and K. Karimi, Univ. of Brighton

Spatial distribution of droplets predicted by stochastic breakup model (KIVA II)

RECENT PUBLICATIONS

- S. Sazhin (2006) Advanced models of droplet heating and evaporation, Progress in Energy and Combustion Science, v. 32, 162 – 214.
- S. Sazhin, T. Kristyadi, W. Abdelghaffar, and M. Heikal (2006) Models of fuel droplet heating and evaporation: comparative analysis. Fuel (in press).
- S. Martynov, D. Mason, M. Heikal, S. Sazhin and M. Gorokhovski. Modelling of cavitation flow in a nozzle and its effect on spray development, Submitted to the 13th Inte rnational Heat Transfer Conference, Sydney, Australia.
- S. Sazhin, S. Martynov, I. Shishkova, M. Gorokhovski, E. Sazhina, M. Heikal. Modelling of droplet heating, evaporation and break-up: recent developments, Submitted to the 13th International Heat Transfer Conference, Sydney, Australia.
- S. Sazhin, S. Martynov, C. Crua, E. Sazhina, M. Heikal, A. Chtab, M. Gorokhovskii and D. Katoshevski. Modelling of the dynamics and break-up of jets and sprays - Submitted to the 6th Eouromech Fluid Mechanics Conference, Sweden.

MODELLING OF DROPLET HEATING, EVAPORATION AND BREAK-UP: RECENT DEVELOPMENTS

S.S. Sazhin[1], S.B. Martynov[1], I.N. Shishkova[2] , C. Crua[1],
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Models for heating and evaporation of droplets

- Constant droplet temperature
- Infinite liquid thermal conductivity
- Conduction limit
- Effective conductivity
- Vortex model of droplet heating
- Navier-Stokes solution

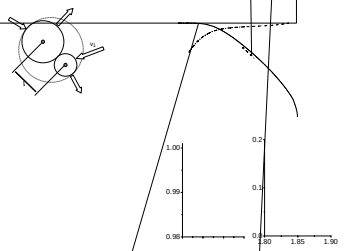
Sirignano, W. A. Fluid Dynamics and Transport of Droplets and Sprays, CUP, 1999.

Gas phase (convective)

Seven models using various approximations for Nu and Sh

Numerical algorithms

- Numerical algorithm based on the analytical solution (analytical solution at the end of the time step is considered as the initial condition for the next time step)
- Numerical solution of the discretised heat conduction equation (fully implicit approach)
- Numerical solution based on the parabolic model (surface temperature is calculated from the average droplet temperature at each time step)
- Numerical solution based on the assumption of no temperature gradient inside the droplet (conventional approach currently used in CFD codes)



Among liquid phase models, the analysis is focused on the model based on the assumption that the liquid thermal conductivity is infinitely large, and the so called effective thermal conductivity model. Seven gas phase models are compared. It is pointed out that the gas phase model, taking into account the finite thickness of the thermal boundary layer around the droplet, predicts the evaporation time closest to the one based on the approximation of experimental data. In most cases, the droplet evaporation time depends strongly on the choice of the gas phase model. In the absence of droplet break-up, the dependence of this time on the choice of the liquid phase model is weak. On the other hand, the droplet surface temperature at the initial stage of heating and evaporation does not practically depend on the choice of the gas phase model, while the dependence of this temperature on the choice of the liquid phase model is strong. In the presence of droplet break-up processes, the evaporation time and the total ignition delay depend strongly on the choice of both gas and liquid phase models.

Sazhin, S.S., Kristyadi, T., Abdelghaffar, W.A. and Heikal, M.R. (2006) Models for fuel droplet heating and evaporation: comparative analysis, Fuel, 85(12-13), 1613-1630.

Conclusions (Dynamic decomposition technique)

New decomposition technique for a system of ordinary differential equations is suggested, based on the geometrical version of the integral manifold method. This is based on comparing the values of the right hand sides of these equations, leading to the separation of the equations into 'fast' and 'slow' variables. The hierarchy of the decomposition is allowed to vary with time. Equations for fast variables are solved by a stiff ODE system solver with the slow variables taken at the beginning of the time step. The solution of the equations for the slow variables is presented in a simplified form, assuming linearised variation of these variables for the known time evolution of the fast variables. This can be considered as the first order approximation for the fast manifold. This technique is applied to analyse the explosion of a polydisperse spray of diesel fuel. Clear advantages are demonstrated from the point of view of accuracy and CPU efficiency when compared with the conventional approach widely used in CFD codes. The difference between the solution of the full system of equations and the solution of the decomposed system of equations is shown to be negligibly small for practical applications. It is shown that in some cases the system of fast equations is reduced to a single equation.

Bykov, V., Goldfarb, I., Gol'dshtein, V., Sazhin, S., Sazhina, E. (2006) System decomposition technique for spray modelling in CFD codes, Computers and Fluids

MODELLING OF CAVITATION FLOW IN A NOZZLE AND ITS EFFECT ON SPRAY DEVELOPMENT

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High-pressure atomisation in diesel fuel combustion technology

Cavitation in nozzles

Lagrangian models of sprays

Model of hydrodynamic cavitation

Model for the concentration of bubble nuclei

A model for the parameter n has been derived to meet the similarity criterion: $C \sqrt[3]{n}/D$ idem

p_v p_{min} = maximum tension in liquid, Pa;
p_v = vapour pressure, Pa;
n^* = adjustable liquid-specific number density parameter, $1/m^3$.

$$n = n^* \left(\frac{p_v - p_{min}}{p_v} \right)^{3/2}$$

Conclusions

- A homogeneous-mixture model of cavitation flow, extended in order to describe the liquid quality and viscous shear stress effects on cavitation flow.
- Assuming hydrodynamic similarity of cavitation flows, an algebraic model for the number density of active cavitation nuclei is suggested.
- The influence of viscous shear stress on cavitation flow has been clarified, and described in the model for the cavitation pressure threshold.
- The model was adjusted to describe sub-cavitation and super-cavitation flows in real-scale models of diesel injectors.

Acknowledgements

The authors are grateful to the European Regional Development Fund Franco-British INTERREG IIIa (Project LES SPRAYS Ref 162/025/247) for financial support of this work.

- Gorokhovski, M.A. and Saveliev, V.L., (2003). Analysis of Kolmogorov's model of breakup and its application into Lagrangian computation of liquid sprays under air-blast atomisation. Physics of Fluids,

OSCILLATING JETS AND SPRAYS IN MODERN TECHNOLOGIES

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SELECTED APPLICATIONS OF JETS AND SPRAYS

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ADVANCED MODELS FOR DROPLET HEATING AND EVAPORATION: EFFECT ON AUTOIGNITION OF DIESEL FUEL SPRAYS

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University of Brighton

ICEG

Models for heating and evaporation of droplets

The power generated in unit volume inside the droplet due to external radiation:

$$P(R) = 3\times10^{6} a \pi R_{d(\mu m)}^{b-1} \left(T_{ext}^{4} - \bar{T}^{4}\right)$$
$$\approx 3\times10^{6} a \pi R_{d(\mu m)}^{b-1} T_{ext}^{4},$$

$\bar{T}$ is the average droplet temperature ($\bar{T} \ll T_{ext}$)

$R_{d(\mu m)}$ is the droplet radius, μm;

a, b are polynomials of external temperature (quadratic functions in the first approximation).

Spray breakup models

- TAB (O'Rourke and Amsden 1987),
- WAVE KH-RT (Patterson and Reitz, 1998),
- Stochastic (Gorokhovski and Saveliev, 2003)
- The modified version of the WAVE model, which takes into account the damping effect of injection acceleration on the break-up rate constant:

$$B_1 = B_{1,eq}\left(3.8\times a^{+}\right)^{0.2}, \qquad a^{+} = \mathrm{Re}^{3/2}\frac{Q_g}{U_{jet}^{3}}\frac{dU_{jet}}{dt}$$

where $B_{1,eq}$ = 10 is the break-up time of the conventional WAVE model, and a^{+} is a dimensionless acceleration parameter. This empirical equation has been shown to provide a better description of the highly transient initial stage of spray penetration.

Numerical algorithms

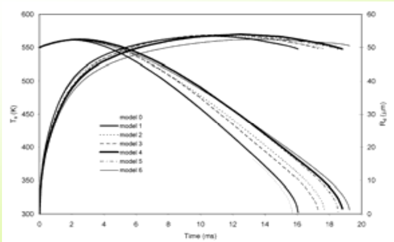
- ***Numerical algorithm based on the analytical solution (analytical solution at the end of the time step is considered as the initial condition for the next time step)***
- Numerical solution of the discretised heat conduction equation (fully implicit approach)
- Numerical solution based on the parabolic model (surface temperature is calculated from the average droplet temperature at each time step)
- Numerical solution based on the assumption of no temperature gradient inside the droplet (conventional approach currently used in CFD codes)

Experimental setup

- VCO type Diesel single-hole injection nozzle of 200 μm in diameter;
- Injection pressures 60 – 160 MPa,
- In-cylinder pressures 5 – 9 MPa,
- In-cylinder gas temperature 750 – 800 K.

Publications

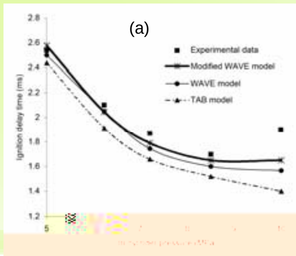
Results

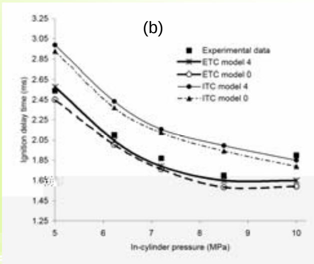


Plots of T_s and R_d versus time for the initial gas temperature T_{g0} = 880K, gas pressure p_{g0} = 3 MPa, droplet initial temperature T_{d0} = 300 K, radius R_{d0} = 50 m and velocity v_{d0}=1 m/s.

The overall volume of injected liquid fuel was taken equal to 1 mm^3, and the volume of air, where the fuel was injected, was taken equal to 883 mm^3.

The results were obtained based on the effective thermal conductivity (ETC) model, the analytical solution of the heat conduction equation, and using seven gas phase modelth24.6nrs





Predicted and experimentally measured ignition delay times versus in-cylinder pressure: (a) effect of breakup model (ETC liquid phase model and gas model 4 (Abramzon and Sirignano, 1989)), (b) effect of heating and evaporation models (spray breakup described using the conventional WAVE model). 1000 droplet parcels with initial droplet temperature 375 K were injected at 100MPa into a cylinder with initial temperature 750 K.

- Among liquid phase models, the analysis is focused on the model based on the assumption that the liquid thermal conductivity is infinitely large, and the so called effective thermal conductivity model.
- Seven gas phase models are compared. It is pointed out that the gas phase model, taking into account the finite thickness of the thermal boundary layer around the droplet, predicts the evaporation time closest to the one based on the approximation of experimental data. In most cases, the droplet evaporation time depends strongly on the choice of the gas phase model.

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- Sazhin, S.S., Krutitskii, P.A., Abdelghaffar, W.A., Sazhina, E.I
  Int. J Heat Mass Transfer, 47. 3327-3340.
- *Sazhina, E.M., Sazhin, S.S., Heikal, M.R., Babushok, V.I., Jo*
  Combustion Science and Technology, 160, 317-344.

Poster presented at the European Combustion Meeting, Crete, 2007

AUTOIGNITION OF *n*-PENTANE IN A RAPID COMPRESSION MACHINE: EXPERIMENT *versus* MODELLING

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Ignition and cool flame delay times of stoichiometric *n*-pentane/'air' mixtures were measured in a rapid compression machine with pressures at top dead centre (TDC) between 4 and 11 bar.

A so-called weighted temperature $T_w = 0.75T_m + 0.25T_c$ was calculated from the mean gas temperature T_m (deduced from the perfect gas law) and the core gas temperature T_c at the end of compression. The dependence of the delay times on these temperatures was investigated.