A COMPUTATIONAL MODEL OF SUBMERGED COMBUSTION

by

S.V. Zhubrin

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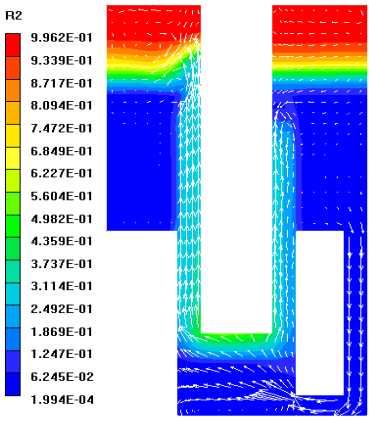
Submerged combustion is a process that brings combustion into the fluid to be heated. It provides direct contact of the combustion gases with the liquid surrounding a burner. The technology has a number of advantages important for a wide range of industrial applications [1].

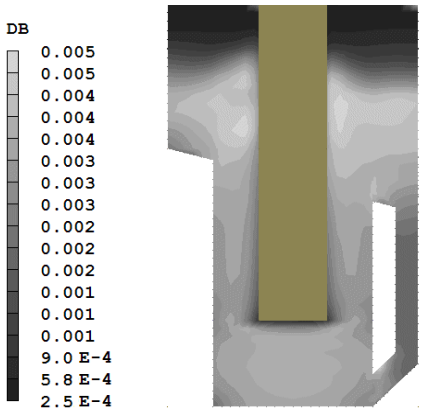
SUBCo, a computational model of submerged combustion developed for PHOENICS (www.cham.co.uk) uses idealization of interpenetrating continua. This provides mathematical description of the behaviour of liquid and fragmented-within-liquid gas phases in a two-phase flow with inter-phase slip and heat- and mass transfer. The latter takes place between, usually colder, liquid phase and hot gaseous products of combustion submerged into it. The local share of space occupied by each phase is given by the phase volume fraction which is obtained from its own conservation equation. In its IPSA [2] embodiment, which is unique to PHOENICS, the latter is written for each phase, and involves phase density; phase velocities; a diffusion coefficient, accounting for the effect of turbulence on gas phase dispersion; and the mass transferred into and from each phase per unit time and per unit volume, comprising the processes of evaporation and condensation. The phase volume fractions are also related to each other through the summation-to-unity closure equation.

For any other liquid or gas property, the conservation equations are written in a format similar to volume-fraction balance but with addition of turbulent diffusion coefficients, with the value of property in the mass transferred into the phase, and with the corresponding mass transferred out of the phase; with inter-phase exchange of momentum and heat, and with additional non-inter-phase sources such as rates of exothermic chemical transformations of fuel-air gas phase mixture into gaseous combustion products. To represent the generation of the latter the within-gas chemistry-turbulence interactions are handled by eddy dissipation approach. Two turbulent diffusion terms are featured in the conservation equations; one, is responsible for the exchange of conserved property through turbulent diffusion of phase, and the other is the within-phase turbulent diffusion.

All conservation equations are solved for a number of gas-phase variables, typically including: three velocity components, enthalpy, transfer of thermal radiation, and the mass fractions of all the major participating chemical species, and, if necessary, minor ones of pollutants. For the liquid phase, equations are solved for the three velocity components, enthalpy and the mass fractions of liquid components.



Water circulation vectors. and gas phase volume fraction contours in gas-lift evaporator.



Contours of gas-fragment sizes

For the calculations of turbulent transport both phases are assumed to share the same mixture turbulent viscosity and corresponding diffusion coefficients [3]. The value of mixture turbulent viscosity is calculated as volume-fraction average of phase-stream turbulent viscosities. Phase-stream viscosities are calculated via the phase absolute velocities and the distance to the nearest wall. The latter is computed from distance-function differential equation taking into account the arrays of sub-cell solid inserts [4], if any.

To compute the field distribution of dominated fragment sizes of gas phase in gas-liquid flow with phase inversion a constitutive relation for the inter-phase momentum [5] and a model based on equilibrium limit of the transport equation for fragment size [6,7] are employed with allowance for size diminution/enlargement due to mass transfer and for other mechanisms which may cause a fragment-size change, such as gas breakup and/or coalescence.

The present contribution has shown that IPSA solver of PHOENICS can be promptly converted into an efficient computational tool which allows the calculations of the momentum, heat- mass transfer, chemical and phase-change transformations for the technology of submerged combustion. The developed methodology can readily incorporate further combustion sub-models with advanced turbulence-chemistry (and radiation) interactions, such as Stream Recognition Model [8], and gas-fragment-size evolutions, for instance those in which gas-phase fragmentation is influenced by the local gas-liquid population balances.

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