

Literature Review

The key paper for this project is titled “Evaluation of equilibrium and non-equilibrium evaporation models for many-droplet gas-liquid flow simulations”. Which details eight different droplet evaporation models [1].

The purpose of this project is to evaluate the accuracy of those models with experimental data in existing literature which has not been done before.

The 8 models in [1] are denoted by Mx where x is the model number. The 8 models are defined by the same four Lagrangian equations:

$$\frac{dX_i}{dt} = v_i \quad (1)$$

$$\frac{dv_i}{dt} = \left(\frac{f_1}{\tau_d} \right) (u_i - v_i + g_i \quad (2)$$

$$\frac{dT_d}{dt} = \frac{f_2 Nu}{3Pr_G} \left(\frac{\theta_1}{\tau_d} \right) (T_G - T_d) + \left(\frac{L_V}{C_L} \right) \frac{\dot{m}_d}{m_d} - H_{\Delta T} \quad (3)$$

$$\frac{dm_d}{dt} = -\frac{Sh}{3Sc_g} \left(\frac{m_d}{\tau_d} \right) H_M \quad (4)$$

Equation 1 and a simpler form of equation 2 were used in the IP this project is based off. The differential equation for position was solved using the trapezoidal rule, as this method has second order accuracy and the result is a linear first order equation:

$$X_{n+1} = x_n + \frac{v_n + v_{n+1}}{2} \Delta t \quad (5)$$

[2]

For equation 2, the acceleration of the droplet is defined using Stokes’ Law which in its simplest form is given as:

equation

is dependent on three terms. Acceleration due to gravity g_i , and the difference between the carrier gas velocity and the velocity of the particle, $u_i - v_i$. The third term is a correction for Stokes drag that is dependent on the time constant for Stokes flow. This equation can be derived by considering the forces acting on the particle:

equation

A formulation for f_1 is given in [1] as:

$$f_1 = \frac{1 + 0.0545Re_d + 0.1Re_d^{0.5}(1 - 0.03Re_d)}{1 + a|Re_b|^b} \quad (6)$$

Which is an empirical result produced from a data fit. It is therefore only applicable for specific conditions,.

What defines the models are the variables f_1 , f_2 , Nu , Sh , $H_{\Delta T}$ and H_M . Although the main variation in the models stems from f_2 , $H_{\Delta T}$ and H_M . M1 and M2 are the two simplest models with:

Model	Name	f_2	$H_{\Delta T}$	H_M
M1	Classical rapid mixing	1	0	$\ln [1 + B_{M,eq}]$
M2	Abrmazon-Sirignano	$\frac{-\dot{m}_d}{m_d B_T} \left[\frac{3Pr_G \tau_d}{Nu} \right]$	0	$\ln [1 + B_{M,eq}]$

One of the most recent citations uses Models M1 and M2 to simulate the evaporation of fuel particles in flame combustion. However, it uses $\frac{\beta}{e^{\beta}-1}$ instead of 1 for f_2 for M1 [3]. Which as noted in [1] was not considered commonly used at the time that paper was published.

Potentially useful papers:

Experimental and numerical investigation of droplet evaporation under diesel engine conditions

“Evaporation of mono-disperse fuel droplets under high temperature and high pressure conditions is investigated. The time-dependent growth of the boundary layer of the droplets and the influence of neighbouring droplets are examined analytically. A transient Nusselt number is calculated from numerical data and compared to the quasi-steady correlations available in literature. The analogy between heat and mass transfer is tested considering transient and quasi-steady calculations for the gas phase up to the critical point for a single droplet. The droplet evaporation in a droplet chain is examined numerically. Experimental investigations are performed to examine the influence of neighbouring droplets on the drag coefficients. The results are compared with drag coefficient models for single droplets in a temperature range from $T = 293 - 550K$ and gas pressure $p = 0.1 - 2MPa$. The experimental data provide basis for model validation in computational fluid dynamics.” [4]

Direct numerical simulation of a confined three-dimensional gas mixing layer with one evaporating hydrocarbon-droplet-laden stream

“Direct numerical simulations are performed of a confined three-dimensional, temporally developing, initially isothermal gas mixing layer with one stream laden with as many as 7.3×10^5 evaporating hydrocarbon droplets, at moderate gas temperature and subsonic Mach number. Complete two-way phase couplings of mass, momentum and energy are incorporated which are based on a thermodynamically self-consistent specification of the vapour enthalpy, internal energy and latent heat of vaporization. Effects of the initial liquid mass loading ratio (ML), initial Stokes number (St0), initial droplet temperature and flow three-dimensionality on the mixing layer growth and development are discussed. The dominant parameter governing flow modulation is found to be the liquid mass loading ratio. Variations in the initial Stokes number over the range 0.5 6 St0 6 2:0 do not cause significant modulations of either first- or second-order gas phase statistics. The mixing layer growth rate and kinetic energy are increasingly attenuated for increasing liquid loadings in the range 0 6 ML 6 0:35. The laden stream becomes saturated before evaporation is completed for all but the smallest liquid loadings owing to: (i) latent heat effects which reduce the gas temperature, and (ii) build up of the evaporated vapour mass fraction. However, droplets continue to be entrained into the layer where they evaporate owing to contact with the relatively higher-temperature vapour-free gas stream. The droplets within the layer are observed to be centrifuged out of high-vorticity regions and to migrate towards high-strain regions of the flow. This results in the formation of concentration streaks in spanwise braid regions which are wrapped around the periphery of secondary streamwise vortices. Persistent regions of positive and negative slip velocity and slip temperature are identified. The velocity component variances in both the streamwise and spanwise directions are found to be larger for the droplets than for the gas phase on the unladen stream side of the layer; however, the cross-stream velocity and temperature variances are larger for the gas. Finally, both the mean streamwise gas velocity and droplet number density profiles are observed to coincide for all ML when the cross-stream coordinate is normalized by the instantaneous vorticity thickness; however, first-order

thermodynamic profiles do not coincide.”[5]