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Assessment of an Eulerian CFD model for prediction of dilute droplet dispersion in a turbulent jet

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Abstract

The turbulent dispersion of non-evaporating droplets in an axisymmetric round jet issuing from a nozzle is investigated both experimentally and theoretically. The experimental data set has a well-defined inlet boundary with low turbulence intensity at the nozzle exit, so that droplet dispersion is not affected by the transport of nozzle-generated fluctuating motion into the jet, and is influenced solely by turbulence in the gas phase produced in the shear layer of the jet. This data set is thus ideal for testing algebraic models of droplet fluctuating motion that assume local equilibrium with the turbulence in the gas phase. Moreover, the droplet flux measurements are sufficiently accurate that conservation of the total volume flow of the droplet phase has been demonstrated. A two-fluid turbulence modelling approach is adopted, which uses the k–ε turbulence model and a simple algebraic model that assumes local equilibrium to predict the fluid and droplet turbulent correlations, respectively. We have shown that the k–ε turbulence model lacks generality for predicting the spread of momentum in jets with and without a potential core. However, in general, the model predicts the radial dispersion of droplets in the considered turbulent jet with reasonable accuracy over a broad range of droplet sizes, once deficiencies in the k–ε turbulence model are taken into account.

Keywords: Jet flow; Droplet dispersion; Tchen theory; Turbulent dispersion; Eulerian approach

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1. Introduction

The turbulent dispersion of particles in a gas steam is of great importance in many applications, including the modelling of flash smelting [1], the design of electrostatic precipitators [2], determination of indoor air quality [3], understanding the transport of material in ducts with application to pulverised coal transport [4] or fly ash in combustion gases [5] and the modelling of droplet sprays [6]. The approaches used to model the turbulent particle dispersion in a gas range widely from Lagrangian methods (often embedded in commercial CFD software) to Eulerian approaches where additional transport equations may be solved for the

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Nomenclature

$c_{\alpha\beta}^{(d)}$	local instantaneous inter-phase drag coefficient
C	constant for turbulence model or cross-trajectory model
C_{D}	droplet drag coefficient
d	droplet diameter
D_{α}^{t}	scalar dispersion coefficient
$D_{\alpha\beta}^{\mathrm{t}}$	gas-droplet turbulent dispersion coefficient
F	volumetric flux ($\mathrm{cm}^3/\mathrm{cm}^2$ s)
G	production term in turbulence transport equation
k	turbulent kinetic energy
m_{L}	mass loading ratio (ratio of total droplet and gas mass-flows)
N_{β}	number of droplet phases
P	pressure
$q_{\alpha\beta}$	gas-droplet fluctuating velocity correlation
r	volume fraction
R	radial distance (mm)
$R_{1/2}$	half radius (mm)
Re	Reynolds number
St	Stokes number
S_{TD}	turbulence modulation term in turbulence transport equations
u'	fluctuating velocity
$\overline{u'u'}$	axial kinetic stress
$\overline{u'v'}$	turbulent shear stress
U	mean velocity or axial mean velocity
$\overline{v'v'}$	radial kinetic stress
V	radial mean velocity
$V_{\alpha\beta}^{\mathrm{R}}$	local instantaneous relative velocity between the droplet and gas phases
V_{β}^{d}	gas-droplet drift velocity
$\langle \lvert V_{\mathrm{r}} \rvert \rangle$	local instantaneous slip velocity
X	axial distance
Z	dimensionless axial distance from nozzle

Greeks

δ	Kronecker delta
ε	turbulence energy dissipation rate
μ	laminar or turbulent viscosity
$\nu_{\alpha}^{\mathrm{t}}$	turbulent kinetic viscosity of gas
ρ	density
σ	turbulent Prandtl or Schmidt (Sc) number
$\tau_{\alpha}^{\mathrm{t}}$	eddy lifetime
$\tau_{\alpha\beta}^{\mathrm{F}}$	droplet relaxation time
$\tau_{\alpha\beta}^{\mathrm{t}}$	eddy–droplet interaction time
ξ_{r}	relative velocity in cross-trajectory model

Superscripts and subscripts

α	gas phase
β	droplet phase
t	turbulent