The Influence of Jet Precession on Particle Distributions

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In memory of my Father

Carl - Heinz Birzer

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Abstract

This thesis assesses the extent to which jet precession can be used to control the mean and instantaneous particle distributions in particle-laden jet flows. Investigations were conducted, providing quantitative, planar measurements of instantaneous particle distributions in the first 10 nozzle diameters of a particle-laden co-annular nozzle with centrally located Precessing Jet (PJ). Equipment was specifically designed to conduct the investigations, a laser diagnostic technique developed and a methodology to quantify particle clusters was devised. The experimental facilities are scaled to simulate the near burner region of a typical rotary cement kiln. The laser diagnostic technique, called *planar nephelometry*, enables non-intrusive, quantitative, instantaneous, planar measurements of particle distributions without the need to identify individual particles. The methodology to quantify particle clusters is designed to enable statistical comparison of clusters without ambiguity.

Measurements of the influence of particle mass loading and jet precession on the distribution of particles emerging from an particle-laden co-annular nozzle, with a centrally located PJ nozzle, are presented. These data include mean and standard deviation of the particle distributions and statistics on particle cluster characteristics. The results indicate that small amounts of momentum through the PJ nozzle causes an elongation of the jet, but larger amounts of momentum through the PJ nozzle will result in a wider mean particle distribution and greater mean centreline decay rate. An increase in jet precession also results in an increase in the fluctuations in the particle distributions.

The transition is determined by the interplay of momentum of the particle-laden and precessing streams.

The physical characteristics of identified particle clusters in the instantaneous planar flow field are also influenced by jet precession. An initial increase in the amount of jet precession results in an overall decrease in the average number of both small- and large-clusters. The size of small-clusters generally reduces with increasing jet precession, whereas large-clusters reach maximum sizes for an intermediate relative momentum of jet precession. Analogous to the influence of jet precession on the mean distribution of particles, increasing jet precession also results in a greater spread of small- and large-clusters.

Results also indicate that increasing the mass flow rate of particles results in an elongation of the jet. However, these variations correspond to an increase in annular jet momentum, rather than an addition of secondary phase. The particle mass flow rate has a minor influence on the general characteristics of particle clusters.

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Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Notation

Latin

a	acceleration [ms^2]
A	area [m^2]
A_{total}	total cluster area [m^2]
$\overline{A_c}$	average cluster area [m^2]
a_{slip}	acceleration of a particle relative to a fluid [ms^{-2}]
C	constant [-]
C_D	drag coefficient [-]
C_κ	correction factor [-]
d	particle diameter [m]
D	nozzle / jet diameter [m]
d_{eq}	cluster equivalent diameter [m]
$\overline{d_{eq}}$	average cluster equivalent diameter [m]
f_p	frequency of precession [Hz]
F	force [N]
F_D	drag force [N]
G	momentum flux [Nm^{-2}]
I'	local corrected intensity of laser sheet [a.u.]
I_0	incident illumination [a.u.]
L	characteristics length [m]
m	mass [kg]
$\dot{m}$	mass flow rate [kgs^{-1}]
$\overline{N_c}$	average number of clusters [-]
n_p	number of particles in the volume [-]
P_c	cluster perimeter [m]

PF	pulverised fuel
PJ	Precessing Jet
r	radial location [m]
r_p	particle radius [m]
Re	Reynolds number [-]
S'	fluctuating signal [a.u.]
S	signal [a.u.]
$\overline{S}$	mean signal [a.u.]
Sk	Stokes number [-]
t	time [s]
u	velocity [ms^{-1}]
u_{slip}	velocity of a particle relative to a fluid [ms^{-1}]
U	characteristic fluid velocity [ms^{-1}]
V	volume [m^3]
$\dot{V}$	volume flow rate [m^3s^{-1}]
x	axial distance [m]
x_p	axial location of peak signal [m]

Greek

β	particle mass loading ratio [-]
λ	wavelength [m]
λ_I	integral-length / Taylor macro-scale [m]
λ_K	Kolmogorov length scale [m]
λ_M	characteristic width of flow / macro-scale [m]
λ_T	Taylor micro-scale [m]
μ	dynamic viscosity [Nsm^{-2}]
ϕ	particle / fluid volume fraction [-]
Φ	signal [a.u.]
ψ_{as}	Mie-scattering cross section [m^2]
ρ	density [kg/m^3]
τ	response time [s]
τ	transfer efficiencies [-]
ω	solid angle [rad]

Subscripts

ANN	annular stream
$ANN(f)$	fluid based annular stream
E	exit of nozzle
f	fluid
i	illumination
$inlet$	inlet of the nozzle
l	large-clusters
p	particle
p	pixel
P	peak
PJ	Precessing Jet
s	collection
s	small-clusters
$total$	total of three flow streams
V	volume
1	inlet orifice / throat
2	outlet orifice / lip
2,1	area / diameter
3,2	volume / area