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# 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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Finally, thanks goes to all my friends and family that have supported me.



# 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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SIGNED: ..... DATE: .....





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# Notation

## Latin

$a$	acceleration [ $\text{ms}^{-2}$ ]
$A$	area [ $\text{m}^2$ ]
$A_{total}$	total cluster area [ $\text{m}^2$ ]
$\overline{A_c}$	average cluster area [ $\text{m}^2$ ]
$a_{slip}$	acceleration of a particle relative to a fluid [ $\text{ms}^{-2}$ ]
$C$	constant [-]
$C_D$	drag coefficient [-]
$C_\kappa$	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 [ $\text{Nm}^{-2}$ ]
$I'$	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 [ $\text{kgs}^{-1}$ ]
$\overline{N_c}$	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.]
$\bar{S}$	mean signal [a.u.]
$Sk$	Stokes number [-]
$t$	time [s]
$u$	velocity [ $\text{ms}^{-1}$ ]
$u_{slip}$	velocity of a particle relative to a fluid [ $\text{ms}^{-1}$ ]
$U$	characteristic fluid velocity [ $\text{ms}^{-1}$ ]
$V$	volume [ $\text{m}^3$ ]
$\dot{V}$	volume flow rate [ $\text{m}^3\text{s}^{-1}$ ]
$x$	axial distance [m]
$x_p$	axial location of peak signal [m]

## Greek

$\beta$	particle mass loading ratio [-]
$\lambda$	wavelength [m]
$\lambda_I$	integral-length / Taylor macro-scale [m]
$\lambda_K$	Kolmogorov length scale [m]
$\lambda_M$	characteristic width of flow / macro-scale [m]
$\lambda_T$	Taylor micro-scale [m]
$\mu$	dynamic viscosity [ $\text{Nsm}^{-2}$ ]
$\phi$	particle / fluid volume fraction [-]
$\Phi$	signal [a.u.]
$\psi_{as}$	Mie-scattering cross section [ $\text{m}^2$ ]
$\rho$	density [ $\text{kg}/\text{m}^3$ ]
$\tau$	response time [s]
$\tau$	transfer efficiencies [-]
$\omega$	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



