The Influence of Jet Precession on Particle Distributions

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In memory of my Father

Carl - Heinz Birzer

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

Dedication iii

Abstract v

Acknowledgements vii

Declaration ix

List of Tables xv

List of Figures xxii

Notation xxiii

1 Introduction 1

1.1 Pollutant emissions from rotary cement kilns .......................... 1
1.2 The Precessing Jet .......................................................... 6
1.3 Combustion of particles in suspension .................................. 9
1.4 Two-phase particle-laden jet flows ..................................... 12
  1.4.1 Governing parameters .................................................... 12
  1.4.2 Jet and channel flows ...................................................... 18
  1.4.3 Summary ................................................................. 22
1.5 Preferential concentration and particle clustering ..................... 28
1.6 Summary ................................................................. 33
2 Equipment

2.1 Wind tunnel

2.2 Solid phase

2.3 Feeder

2.4 Nozzle

2.5 Experimental arrangement

2.6 Flow parameters

3 Measurement techniques

3.1 Existing techniques

3.2 Planar nephelometry

3.2.1 Nephelometry

3.2.2 Extension from single-point to planar measurements

3.2.3 Correction factor, $C_\kappa$

3.2.4 Assumptions for planar nephelometry

4 Influences of jet precession on mean and fluctuating components of particle distributions

4.1 Introduction

4.2 Results and discussion

4.3 Conclusions

5 Influences of particle mass loading on mean and fluctuating components of particle distributions

5.1 Introduction

5.2 Results and discussion

5.3 Conclusions
List of Tables

1.1 Experimental flow conditions from selected investigations of particle-laden simple jets ........................................... 24
1.2 Flow conditions from selected investigations of particle-laden co-annular jets ............................................................ 27
4.1 Operating conditions -variable jet precession experiments. ............. 60
5.1 Operating conditions -variable particle mass loading experiments. ... 83
List of Figures

1.2 A schematic diagram of the Precessing Jet nozzle. 6

2.1 Layout of the wind tunnel. 40

2.2 a) The 20 $\mu$m nominal diameter glass spheres used in the investigation under magnification. b) The size distribution of the particles, as measured by a Malvern-Particle Sizer. 41

2.3 Example of the loadcell output. 43

2.4 Schematic diagram of the nozzle. 44

2.5 Layout of the laser and optics. 47

3.1 Uncorrected and corrected mean particle distributions. Raw data courtesy of Foreman [2008]. 56

3.2 Uncorrected and corrected signal intensity at $x/D_{PJ} = 1$ for mean signal in the current data. 57

4.1 Mean particle distributions for $0.00 \leq G_{PJ}/G_{ANN} \leq 4.90$. Images are normalised to the maximum signal in each image. 61

4.2 Radial profiles of normalised mean signals at $x/D_{PJ} = 0.1$ indicating bias due to asymmetry of the particle distributions in the annulus. 62

4.3 Instantaneous images for $0.00 \leq G_{PJ}/G_{ANN} \leq 4.90$. 63

4.4 A set of images of the relative fluctuations, $S'/\overline{S}$, for $0.00 \leq G_{PJ}/G_{ANN} \leq 4.90$. The false colour map is optimised for each case. 65

4.5 Radial profiles of relative relative fluctuations at $x/D_{PJ} = 0.1$. 66
4.6 Normalised axial mean particle distributions along the nozzle axis for varying values of $G_{PJ}/G_{ANN}$. ................................. 67

4.7 Schematic diagram of the mean particle distribution, showing the location of the centreline concentration peak and the convergence and divergence regions. .................................................. 68

4.8 Inverse axial mean particle distributions along the nozzle axis for varying values of $G_{PJ}/G_{ANN}$ and $x/D_{PJ} \geq x_p$. ................................. 68

4.9 Normalised length to the centreline concentration peak ($x_p/D_{PJ}$) and normalised peak signal ($S'/\overline{S}$) for varying $G_{PJ}/G_{ANN}$. ............... 69

4.10 Radial profiles of normalised mean signals at the centreline concentration peaks, (i.e. the neck region). ............................................... 71

4.11 Relative fluctuation of the centreline particle distribution. ............... 72

4.12 Radial profiles of normalised mean signals at $x/D_{PJ} = 4$. ............... 73

4.13 Radial profiles of normalised mean signals at $x/D_{PJ} = 7$. ............... 73

4.14 Radial profiles of relative relative fluctuations at $x/D_{PJ} = 4$. ........... 75

4.15 Radial profiles of relative fluctuations at $x/D_{PJ} = 7$. ............... 75

4.16 Mean particle concentration halfwidth profiles. .................................. 76

5.1 A set of images of the mean particle distributions for $G_{PJ}/G_{ANN(f)} = 6.19$ and varying $\beta$. The false colour map is optimised for each image to highlight variation in particle distributions. ....................... 84

5.2 A set of images of the instantaneous particle distributions. The false colour map is optimised for each image to highlight variation in particle distributions. .................................................. 85

5.3 A set of images of the relative fluctuations, $S'/\overline{S}$. The false colour map is optimised for each image to highlight variation in particle distributions. 85

5.4 Radial profiles of normalised mean signals at $x/D_{PJ} = 0.1$ indicating bias due to asymmetry in the annulus. ................................. 86
5.5 Normalised axial mean particle distributions along the nozzle axis for varying values of $\beta$ and $G_{PJ}/G_{ANN(J)} = 6.19$.

5.6 Normalised length to the centreline concentration peak ($x_p/D_{PJ}$) and normalised peak signal ($S'/S$) for varying $\beta$ and $G_{PJ}/G_{ANN(J)} = 6.19$.

5.7 Concentration halfwidth profiles for $G_{PJ}/G_{ANN(J)} = 6.19$.

5.8 Halfwidth at $x/D_{PJ} = x_p$, 4 and 7 for $G_{PJ}/G_{ANN(J)} = 6.19$.

5.9 Halfwidth at $x/D_{PJ} = 4$ and 7 for $\beta = fixed$ ($\beta = 0.14 \pm 0.02$) - solid lines, and $\beta = variable$ ($G_{PJ}/G_{ANN(J)} = 6.19$) - dashed lines.

5.10 Axial locations of the 90% and 50% centreline peak concentration values, downstream from the centreline peak concentration location for $\beta = fixed$ ($\beta = 0.14 \pm 0.02$) - solid lines, and $\beta = variable$ ($G_{PJ}/G_{ANN(J)} = 6.19$) - dashed lines.

6.1 Identification of particle clusters for a range of threshold values using the threshold method, (adapted from Zimmer et al. [2002a]).

6.2 Stages of the methodology used to identify particle clusters.

6.3 Two instantaneous and one mean image of particle distributions emerging from a Precessing Jet nozzle.

6.4 Identified clusters superimposed on three different instantaneous images of particle distributions. The value of the smoothing parameter, $L$, is indicated for each row.

6.5 Typical examples of the influence of $L$ on the shape of each cluster identified from two images.

6.6 A plot of $A_c$, $N_c$ and $A_{total}$ per image for varying $L$.

6.7 PDF of the axial location of clusters centroids identified for varying $L$.

6.8 PDF of the radial location of clusters centroids identified for varying $L$.

6.9 PDF of the radial location of clusters centroids identified in the limited axial range ($3 \leq x/D_{PJ} \leq 7$) for varying $L$.

6.10 PDF of equivalent diameters, $d_{eq}$, for clusters identified for varying $L$. 

xix
6.11 PDF of equivalent diameters, $d_{eq}$, for clusters identified in the limited axial range ($3 \leq x/D_{PJ} \leq 7$) for varying $L$. 

6.12 A plot of $\overline{d_{eq}}$ per image for varying $L$ for clusters in the region $x/D_{PJ} < 10$ (solid lines) and $3 \leq x/D_{PJ} \leq 7$ (dashed lines). 

6.13 PDF of the perimeters of clusters, $P_c$, identified for varying $L$. 

6.14 PDF of the perimeters of clusters, $P_c$, identified in limited axial range ($3 \leq x/D_{PJ} \leq 7$) for varying $L$. 

6.15 PDF of the perimeters of clusters, $P_c$, identified in the region $0 < x/D_{PJ} \leq 3$ for varying $L$. 

6.16 PDF of the number of clusters identified for varying $L$. 

6.17 PDF of the number of clusters for varying ensemble size. 

7.1 PDFs of the axial locations of small-cluster ($\frac{1}{10}D_{PJ} \times \frac{1}{10}D_{PJ} \lesssim A_c \lesssim D_{PJ} \times D_{PJ}$) centroids for varying $G_{PJ}/G_{ANN}$. 

7.2 PDFs of the radial locations of small-cluster centroids located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.3 A planar PDF of the small-clusters for varying $G_{PJ}/G_{ANN}$. 

7.4 Plots of $\overline{N_{c,s}}$, $\overline{A_{c,s}}$ and $A_{total,s}$ of small-clusters located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.5 PDFs of the number of small-clusters located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.6 PDFs of $d_{eq}$ for small-clusters located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.7 PDFs of $P_c$ for small-clusters located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.8 PDFs of the axial locations of large-cluster centroids for varying $G_{PJ}/G_{ANN}$. 

7.9 PDFs of the radial locations of large-cluster centroids located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 

7.10 A planar PDF of the large-clusters for varying $G_{PJ}/G_{ANN}$. 

xx
7.11 Plots of $N_{c,l}$, $A_{c,l}$ and $A_{total,l}$ of large-clusters in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 140

7.12 PDFs of $d_{eq}$ for large-clusters located region in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 142

7.13 PDFs of $P_c$ for large-clusters located in the near-, mid- and downstream edge-regions for varying $G_{PJ}/G_{ANN}$. 143

8.1 A planar PDF of the small-clusters for varying $\beta$. 149

8.2 PDF of the axial location of small-cluster centroids for varying $\beta$. 150

8.3 Plots of $N_{c,s}$, $A_{c,s}$ and $A_{total,s}$ located in the near-, mid- and downstream edge-regions for varying $\beta$. 151

8.4 Plots of $N_{c,s}$ and $A_{c,s}$ located in the near-, mid- and downstream edge-regions for constant $\beta$ (solid lines) and $G_{PJ}/G_{ANN(f)}$ = 6.19 (dashed lines). 153

8.5 A planar PDF of the large-clusters for varying $\beta$. 154

8.6 PDF of the axial location of large-cluster centroids for varying $\beta$. 155

8.7 Plots of $N_{c,l}$, $A_{c,l}$ and $A_{total,l}$ located in the near-, mid- and downstream edge-regions for varying $\beta$. 156

8.8 Plots of $N_{c,l}$ and $A_{c,l}$ located in the near-, mid- and downstream edge-regions for constant $\beta$ (solid lines) and $G_{PJ}/G_{ANN(f)}$ = 6.19 (dashed lines). 157

A.1 PDFs of the radial location of small-cluster centroids located in the near-, mid- and downstream edge-regions for varying $\beta$. 170

A.2 PDFs of the number of small-clusters located in the near-, mid- and downstream edge-regions for varying $\beta$. 171

A.3 PDFs of $d_{eq}$ for small-clusters located in the near-, mid- and downstream edge-regions for varying $\beta$. 172

A.4 PDFs of the radial location of large-cluster centroids located in the near-, mid- and downstream edge-regions for varying $\beta$. 173
A.5 PDFs of \( d_{eq} \) for large-clusters located in the near-, mid- and downstream edge-regions for varying \( \beta \) .................................................. 174

A.6 PDFs of \( P_c \) of large-clusters located in the near-, mid- and downstream edge-regions for varying \( \beta \) .................................................. 175
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 [-]
\(C_k\) 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\(^{-1}\)]
\(N_c\) average number of clusters [-]
\(n_p\) number of particles in the volume [-]
\(P_c\) cluster perimeter [m]
PF  pulsed fuel
PJ  Precessing Jet
r   radial location [m]
$\rl_p$  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 [m/s]
$\mathbf{u}_{\text{slip}}$  velocity of a particle relative to a fluid [m/s]
U  characteristic fluid velocity [m/s]
V  volume [m$^3$]
$\mathbf{V}$  volume flow rate [m$^3$/s]
x  axial distance [m]
x$\rl_p$  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 [Nsm$^{-2}$]
$\phi$  particle / fluid volume fraction [-]
$\Phi$  signal [a.u.]
$\psi_{as}$  Mie-scattering cross section [m$^2$]
$\rho$  density [kg/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