Scale growth study in a concentric reducer:
Measurement of instantaneous velocity using
Particle Image Velocimetry

By
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Master of Engineering

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To my parents with respect
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Abstract

Gibbsite scale growth in pipe fittings is a major problem for an alumina refinery. A recent investigation into the scale growth mechanism at an alumina refinery found almost 60 % more scale growth in a reducer when compared with the connecting straight pipe sections for similar flow conditions.

Scale growth occurs where liquor (supersaturated solutions) come in contact with solid surfaces and it is affected by the liquor flow velocity besides other physical and chemical parameters. The present work is dedicated to study the hydro-dynamical aspects of the mechanism of scale growth. In particular, the role of the phenomenon of turbulent bursting, stream wise and cross stream fluctuating velocity components \((U_x\) and \(U_y\)) was investigated as the flow moves through the reducer. Particle Image Velocimetry (PIV) technique was used to get a full view of the reducer and the readings close-to-the-wall of the reducer at Reynolds number of 27,000 and 44,000 upstream which corresponds to Reynolds number of 41,500 and 66,000 downstream of the reducer respectively.

The results showed an increase in cross stream and a decrease in magnitude of stream wise fluctuating velocity components, whereby we presume that the increased cross stream fluctuating velocity component increases the frequency of impacts of the scaling particles on the wall thus initiating excessive scale growth in the reducer when compared with the connecting straight pipe sections, for similar flow conditions.
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<tr>
<td>2D</td>
<td>Two dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three dimensional</td>
</tr>
<tr>
<td>A/C ratio</td>
<td>Alumina to Caustic ratio</td>
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<tr>
<td>AIA</td>
<td>Analogue interface adapter</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Centigrade</td>
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<tr>
<td>CCD</td>
<td>Charge-Coupled Device</td>
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<tr>
<td>CCI</td>
<td>Charge Contrast Imaging</td>
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<tr>
<td>CFD</td>
<td>Computational Fluid Dynamics</td>
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<td>CQU</td>
<td>Central Queensland University</td>
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<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>$\rho_p$</td>
<td>Density of Particle</td>
</tr>
<tr>
<td>$\rho_f$</td>
<td>Density of fluid</td>
</tr>
<tr>
<td>DNS</td>
<td>Direct Numerical Simulation</td>
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<tr>
<td>$d_p$</td>
<td>Diameter of particle</td>
</tr>
<tr>
<td>$dt$</td>
<td>Time separation between 2 pulses</td>
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<tr>
<td>$e_r$</td>
<td>Percentage error</td>
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<tr>
<td>FFT</td>
<td>Fast Fourier Transformation</td>
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<tr>
<td>$g$</td>
<td>Acceleration due to gravity</td>
</tr>
<tr>
<td>g/dm$^3$</td>
<td>Grams per decimetres</td>
</tr>
<tr>
<td>gpl</td>
<td>Grams per litre</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>--------------------------------------------------</td>
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<td>HFA</td>
<td>Hot Film Anemometry</td>
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<tr>
<td>HWA</td>
<td>Hot Wire Anemometry</td>
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<tr>
<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>kPa</td>
<td>Kilopascal</td>
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<tr>
<td>kW</td>
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<td>Laser Induced Fluorescence</td>
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<tr>
<td>m/sec</td>
<td>Metre per second</td>
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<tr>
<td>mJ</td>
<td>Millijoule</td>
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<tr>
<td>mm</td>
<td>Millimetre</td>
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<tr>
<td>mm/sec</td>
<td>Millimetre per second</td>
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<tr>
<td>MQD</td>
<td>Mean Quadratic Difference</td>
</tr>
<tr>
<td>msec</td>
<td>Millisecond</td>
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<td>NaI</td>
<td>Sodium Iodide</td>
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<td>Nd:YAG</td>
<td>Neodymium: Yttrium Aluminium Garnet</td>
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<td>nm</td>
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<td>PELM</td>
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<td>PIP</td>
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<td>Proper Orthogonal Decomposition</td>
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<td>ps</td>
<td>Pico second</td>
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<td>QAL</td>
<td>Queensland Alumina Limited.</td>
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$r$  Radius at a certain distance “x” from the centre in a section

$R$  Full radius of the section

Re  Reynolds number

RPM  Revolution per minute

SEM  Scanning Electron Microscope

TB  Turbulent Bursting

TKE  Total Kinetic Energy

TPD  Transfer Pulse Delay

$u$  Velocity of fluid at a certain distance “y” from centre of section

$U$  Centre-line velocity

$\mu$m  Micrometer

$\mu$sec  Microsecond

$U_o^2$  Average velocity

$U_x'$  Fluctuating velocity component in x – direction (stream-wise)

$U_y'$  Fluctuating velocity component in y – direction (cross-stream)

$\nu$  Kinematic viscosity of fluid

VFD  Variable frequency drive

$V_s$  Sedimentation velocity

$\delta$  Boundary layer thickness
List of Publication

Following conference papers were published as a result of this Masters in Mechanical Engineering,

1) Energy saving potentials in an Alumina refinery : A review
   Central Region Engineering Conference” 5-6 Sept. 2003, Rockhampton.

2) Viability of steam injection in gas turbines (co-authored)
   BSME-ASME,
   International conference on Thermal Engineering, 2-4\textsuperscript{th} January 2004, Dhaka,
   Bangladesh.

3) Scale growth study in a concentric reducer: Measurements of instantaneous velocity using Particle image velocimetry
   VSJ – SPIE
   International conference on advanced optical diagnostics in fluids, solids and combustion,
   4-6 December 2004, University of Tokyo, Tokyo, Japan.

A journal publication is in progress to be published in a major fluid mechanics journal such as
Journal of Fluid Mechanics, or Experiments in Fluids or Journal of Turbulence etc.
Acknowledgment

I won’t be able to do justice with my words while writing this page but I will try in the following lines to accept the assistance of few outstanding individuals and institutes involved with the achievement of present study. Firstly, I am thankful to the CQU for a scholarship and PELM centre that provided me the means and resources to complete my work leading to Masters Degree in Engineering.

I would especially like to thank Professor Martin C. Welsh, who apart from being far away from the campus and having a very busy schedule helped me a lot in my work and guided me whenever I required his advice. Also I want to thank A/Prof. Masud Khan, Dr. Mohammad Rasul and especially Dr. Alex Deev who assisted me in every way he could even on weekends. I would like to show special gratitude to A/Prof. Masud Khan and Dr. Mohammad Rasul who supervised my work and corrected my write-ups. I am gratified to these people, especially Prof. Martin C. Welsh from the depths of my heart.

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