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Development of Criteria and Identification of Particle Cluster Size based on Measurements of Void Fraction in Gas-Solid Systems

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Presentation Outline

- Research Objective
- Granular Theory Background
- Experimental Approach
- Experimental Setup
- Experimental Results of Shadow Sizing
- Preliminary Analyses of Data

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Objective of the Project

Generate detailed experimental data for defining cluster formation by utilizing granular temperature

- Identify particle clusters with different groupings of particles
- Granular temperature of these clusters
- Void Fraction
- Probability Density Function for different grouping of particle clusters

Granular Temperature Background

Kinetic Theory Leads to Equation for Temperature, T

Granular Temperature of solid particles is analogous to gas temperature

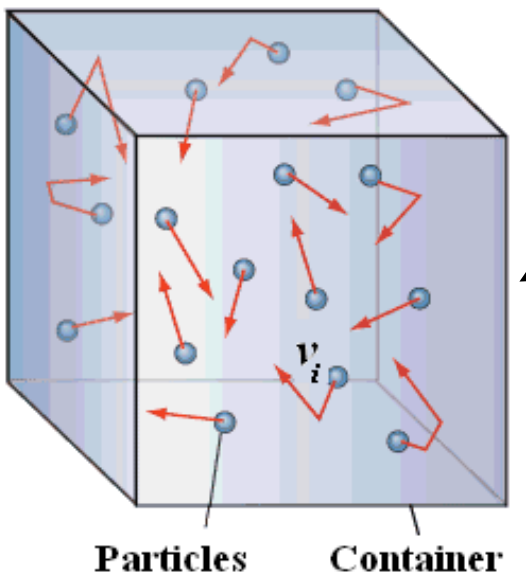
From the ideal gas law

$$PV = Nk_BT$$

where k_B is the Boltzmann constant and T the absolute temperature, thus:

$$PV = Nk_BT = \frac{Nmv_{rms}^2}{3} \Longrightarrow T = \frac{mv_{rms}^2}{3k_B}$$

v_{rms}^2 is the root-mean-square velocity



$$\mathrm{v}_{rms}^2 = \sum_{i=1}^{n} \mathrm{v}_i^2$$

Assumptions:

- Very large number of particles (for valid statistical treatment)
- Distance among particles much larger than molecular size
- Random particle motion with constant speeds
- Elastic particle-particle and particle-walls collisions (no loss of energy)
- Molecules obey Newton Laws

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Experimental Setup

- Mean particle diameter = 450 ± 25 µm
- Bulk density = 2500 kg/m^3
- Riser height = 3.048 m
- Riser diameter = 0.15 m
- Telecentric lens - Fixed view area and depth of field
- Matlab Image Acquisition Toolbox

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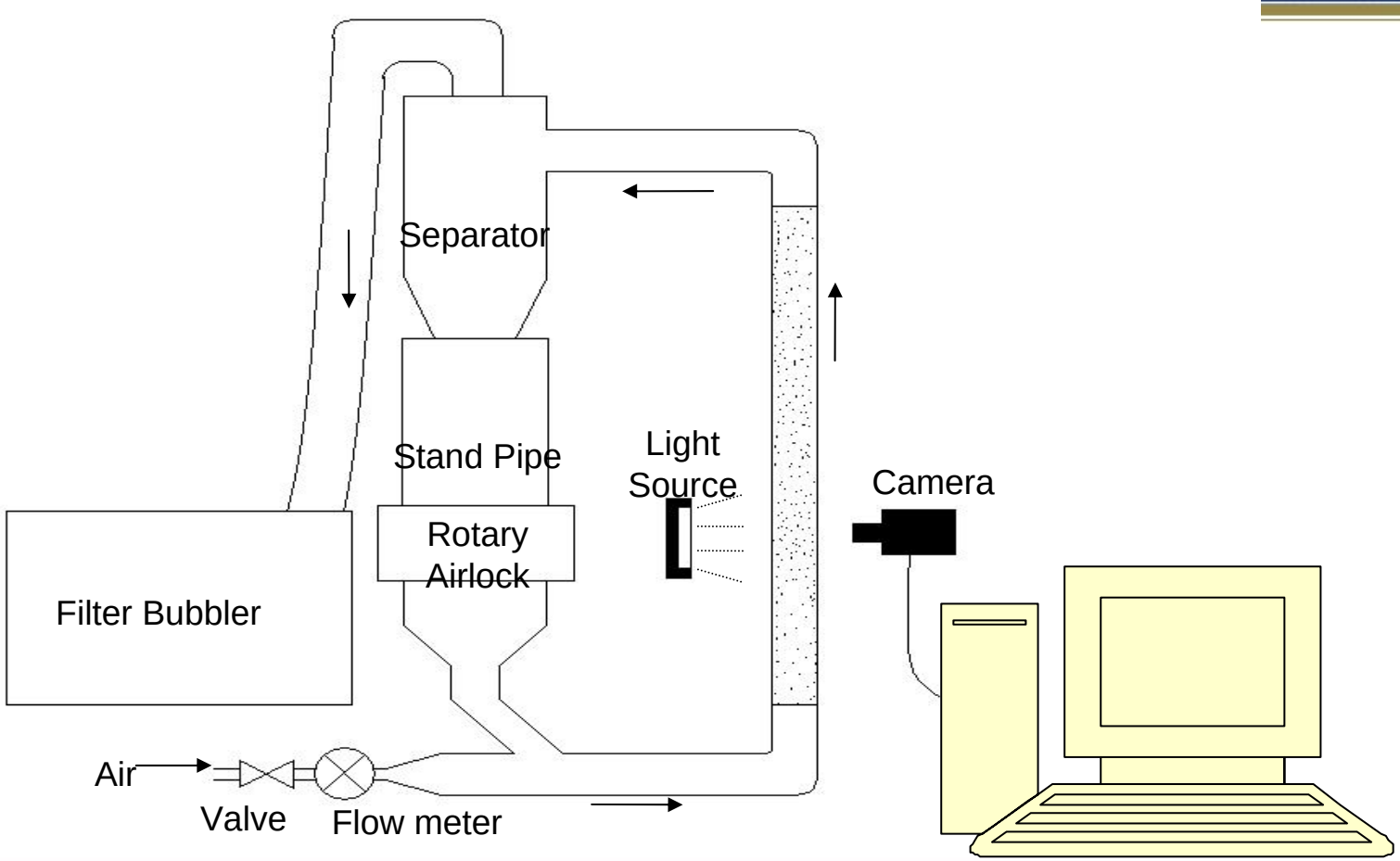
Experimental Setup



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Experimental Setup

Theory

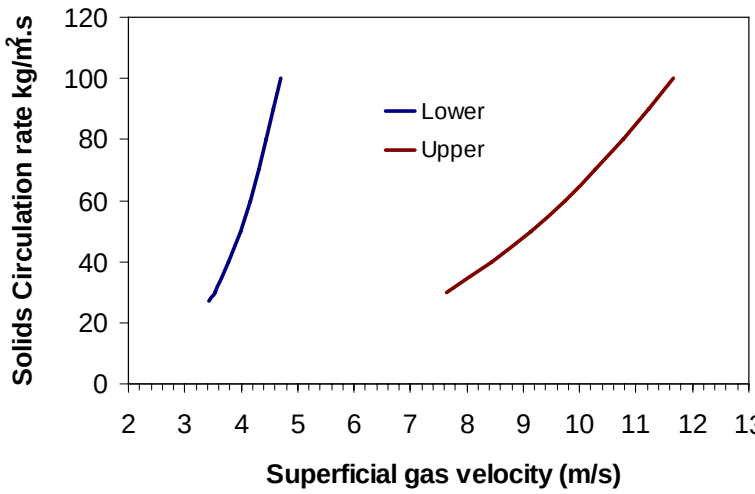
Operating boundary conditions for fast fluidization regime

Lower bound $$U_{tf} = \left(39.8\rho^{-0.311}\,\mathrm{Re}_t^{-0.078}\sqrt{gd_p}\right)^{0.763} J_p^{0.237}$$

Upper bound $$U_{fd} = \left(21.6\rho^{-0.542}\,Ar^{0.105}\sqrt{gd_p}\right)^{0.649} J_p^{0.351}$$

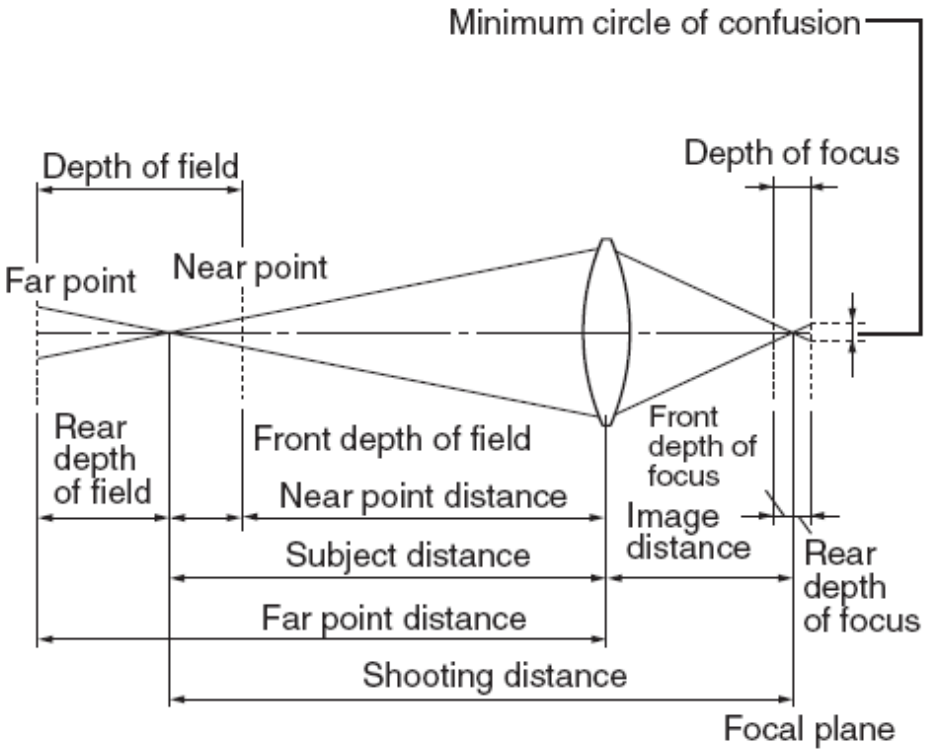
Archimedes # $$Ar = \frac{\rho\left(\rho_p - \rho\right)g d_p^3}{\mu^2}$$

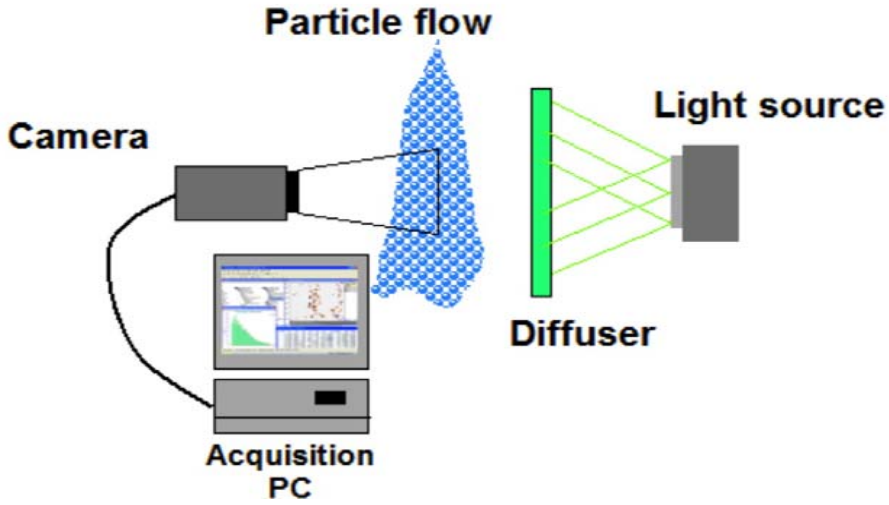
Reynolds # $$\mathrm{Re}_t = \frac{\rho U_{pt} d_p}{\mu}$$



Experimental Approach

Shadow Sizing: a short light flash and a synchronization device are used to freeze the particle motion.





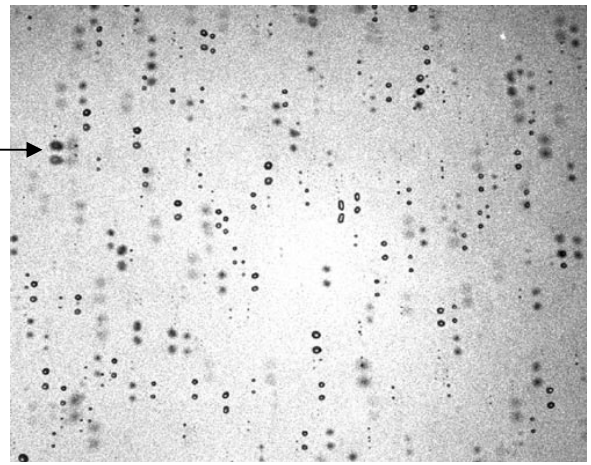
Experimental Approach

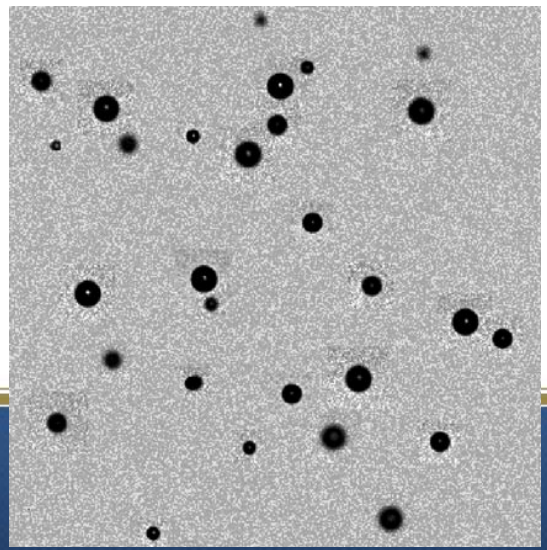
Solids volume fraction is

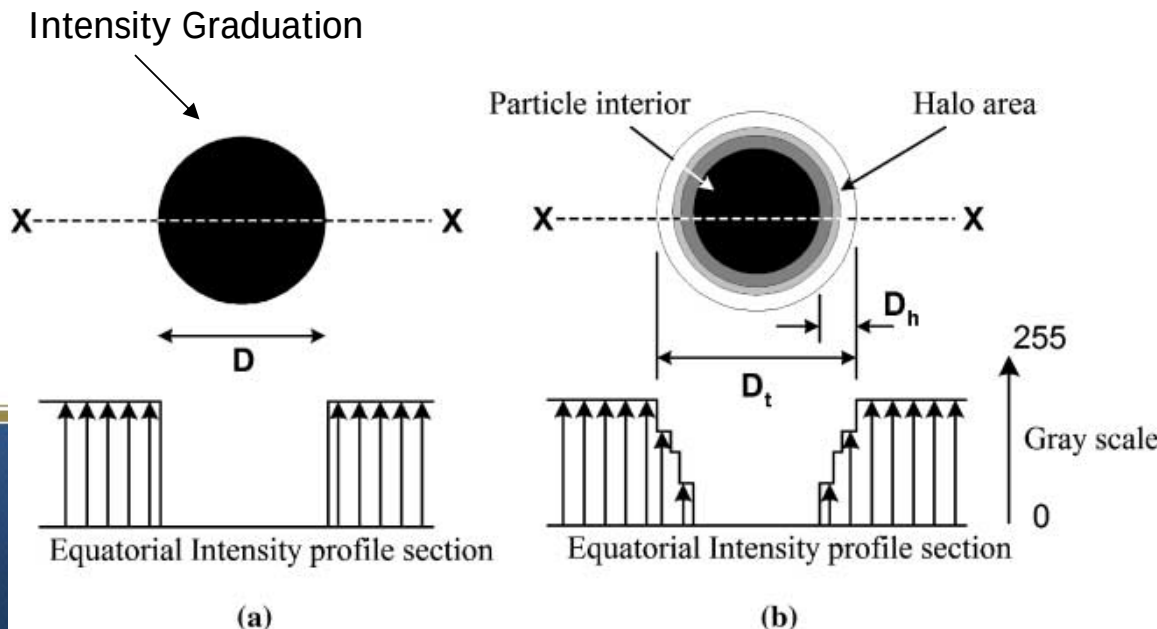
$$\varepsilon_s = \frac{nV_p}{Ah}$$

n is the number of particles
V_p is the volume of single particle
A is the view area
h is the depth of view

Double-frame image
Lecuona et al (2000)







Experimental Approach

From velocity

$$\theta = \frac{1}{3}\left(\sigma_\theta^2 + \sigma_r^2 + \sigma_z^2\right)$$

where: $\sigma_z^2 = \left(u_z - \bar{u}\right)^2$

u_z is particle velocity

$\bar{u}$ is the average particle velocity

From voidage for dilute flows

$$\theta \propto \varepsilon_s^{2/3}$$

From voidage for dense flows

$$\theta \propto 1/\varepsilon_s^2$$

Probability density function

$$p_x = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left(-\left(\frac{x-a}{b}\right)^c\right)$$

a is the location parameter
b is the scale parameter
c is the shape (slope) parameter

Taken from: Gidaspow (1994)

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Shadow Size Image

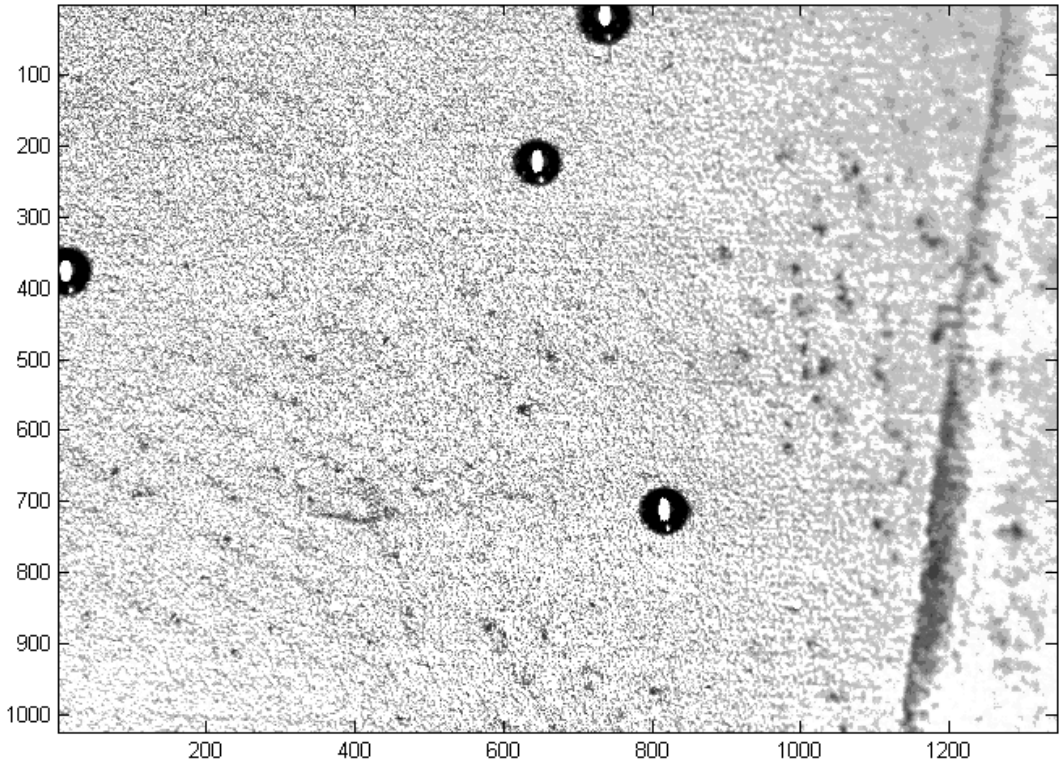
Number of Particles = 4

View Area = 58.08 mm^2

Depth of field = 1 mm

Volume of Particle = 0.048 mm^3

Solids Volume Fraction = 0.2%



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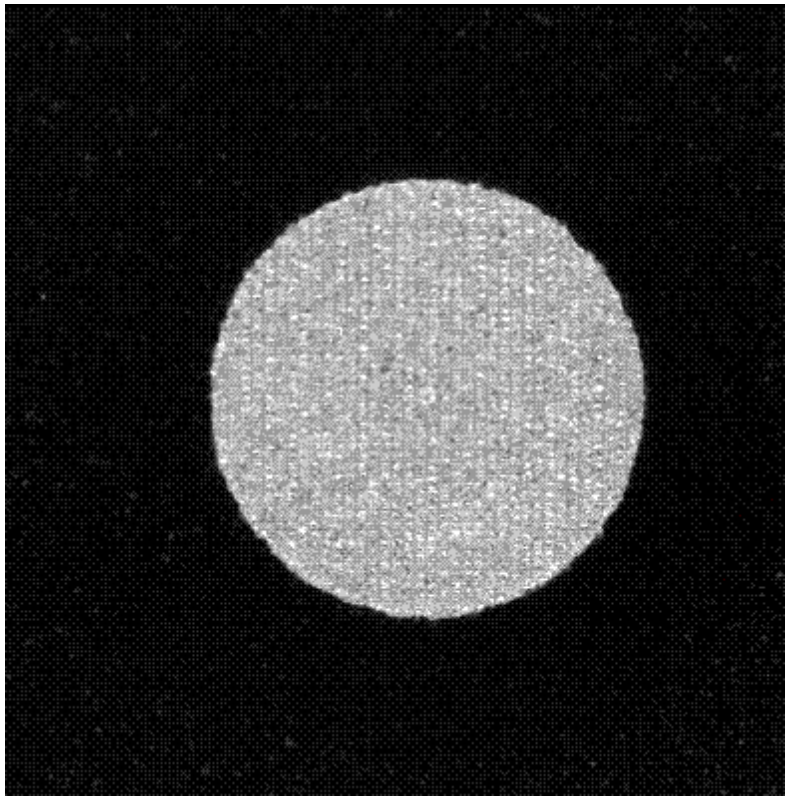
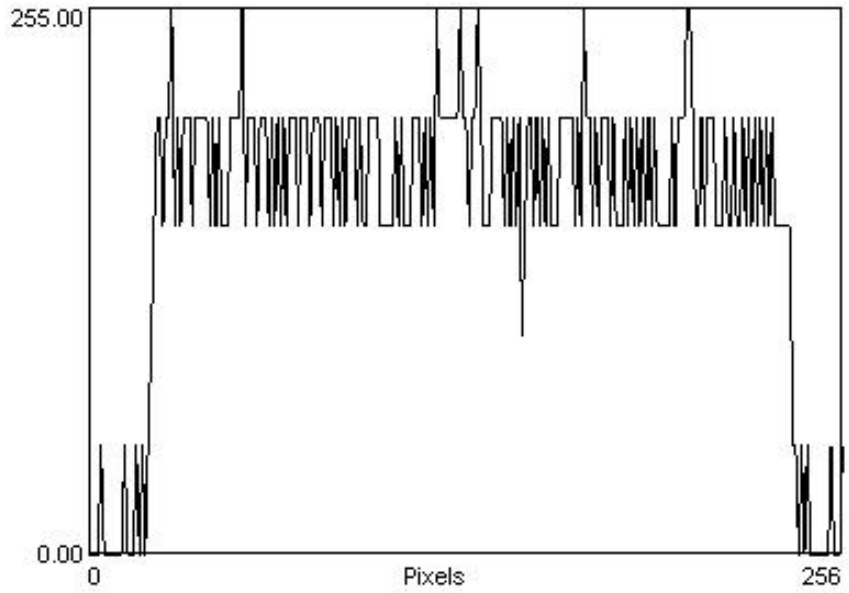
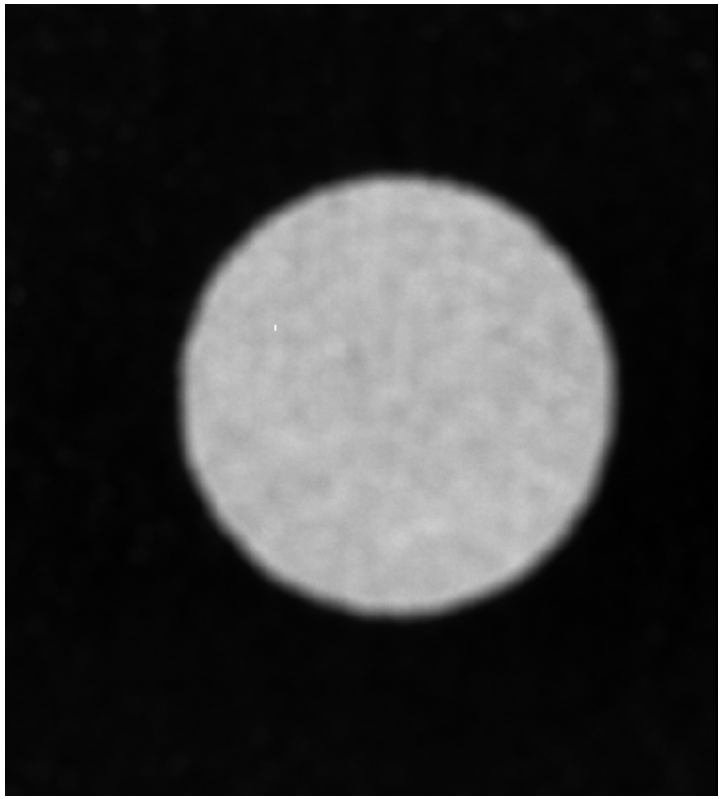
Intensity Graduation Profile



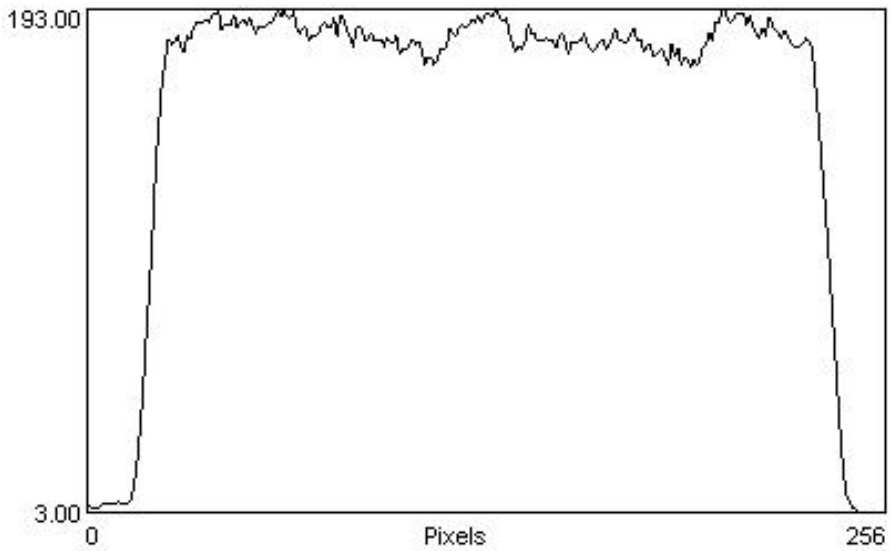
Inside depth of field



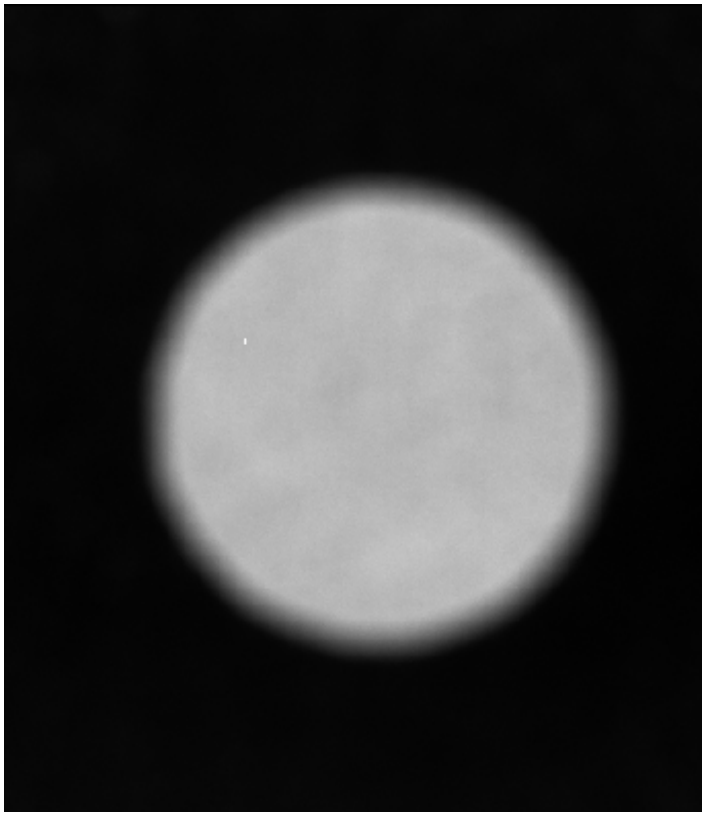
Intensity Graduation Profile



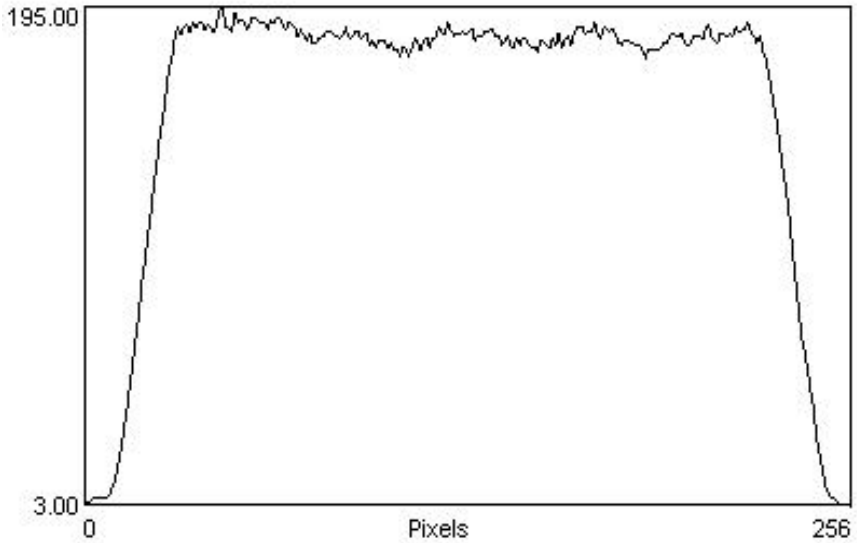
Outside depth of field, 1 mm



Intensity Graduation Profile

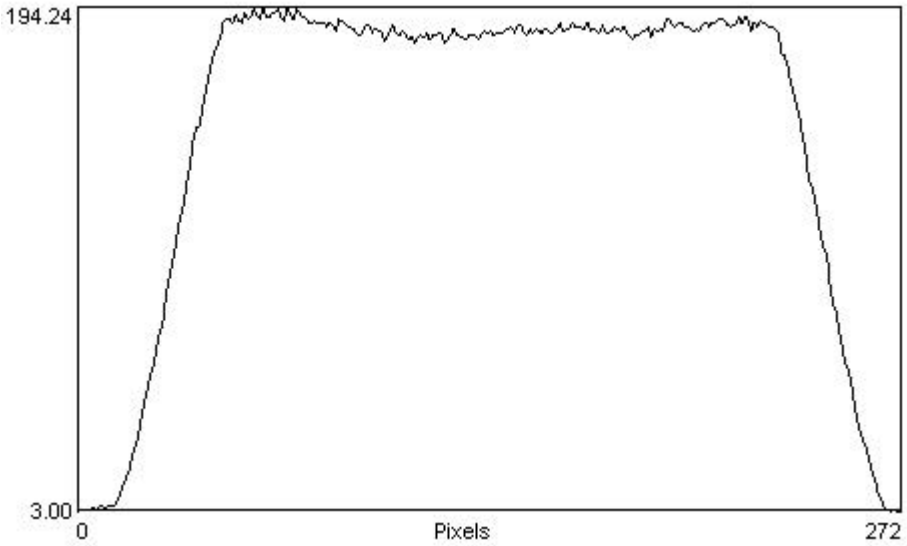


Outside depth of field, 2 mm



Intensity Graduation Profile

Outside depth of field, 3 mm



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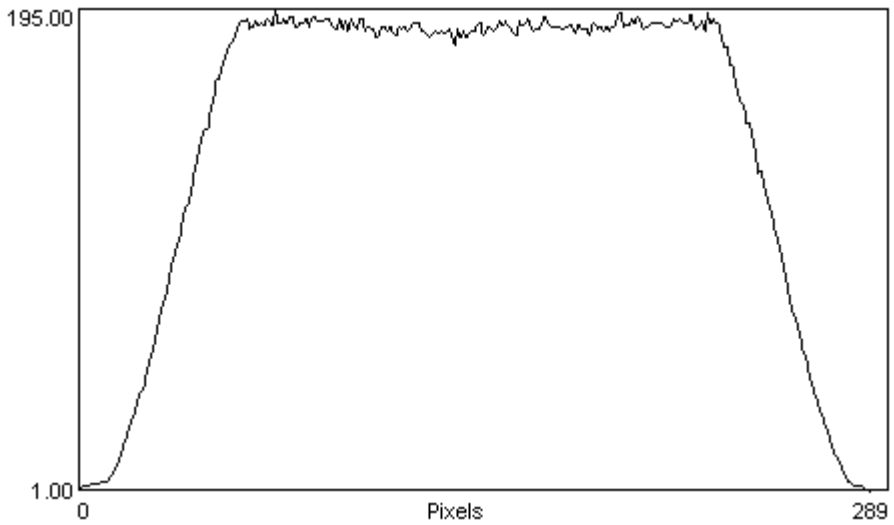
Intensity Graduation Profile

Outside depth of field, 4 mm



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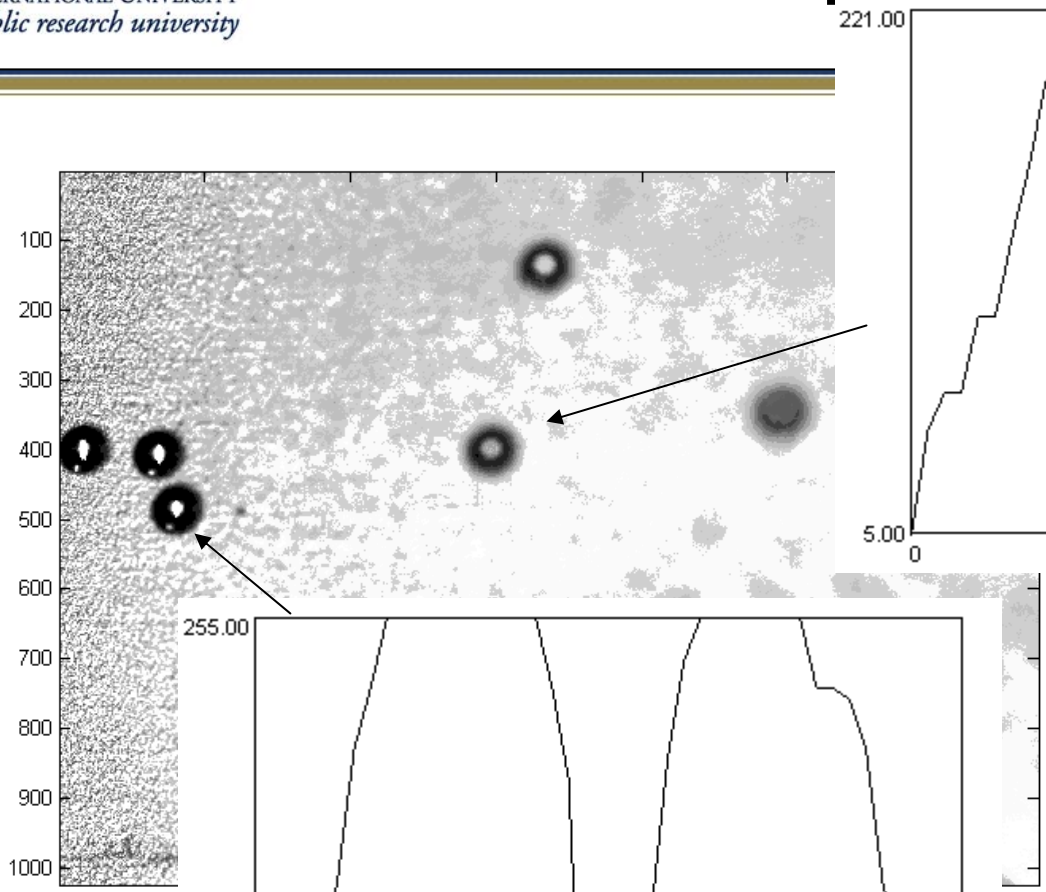
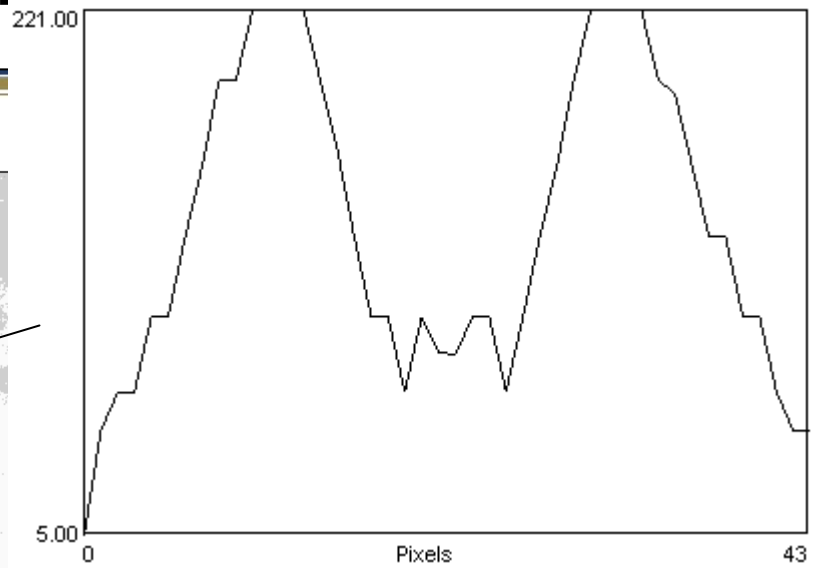
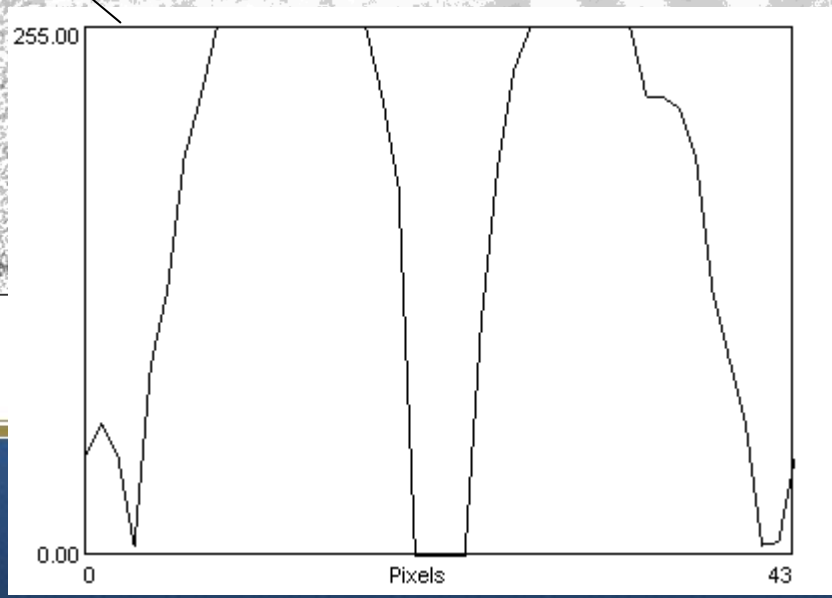
Experimental Results



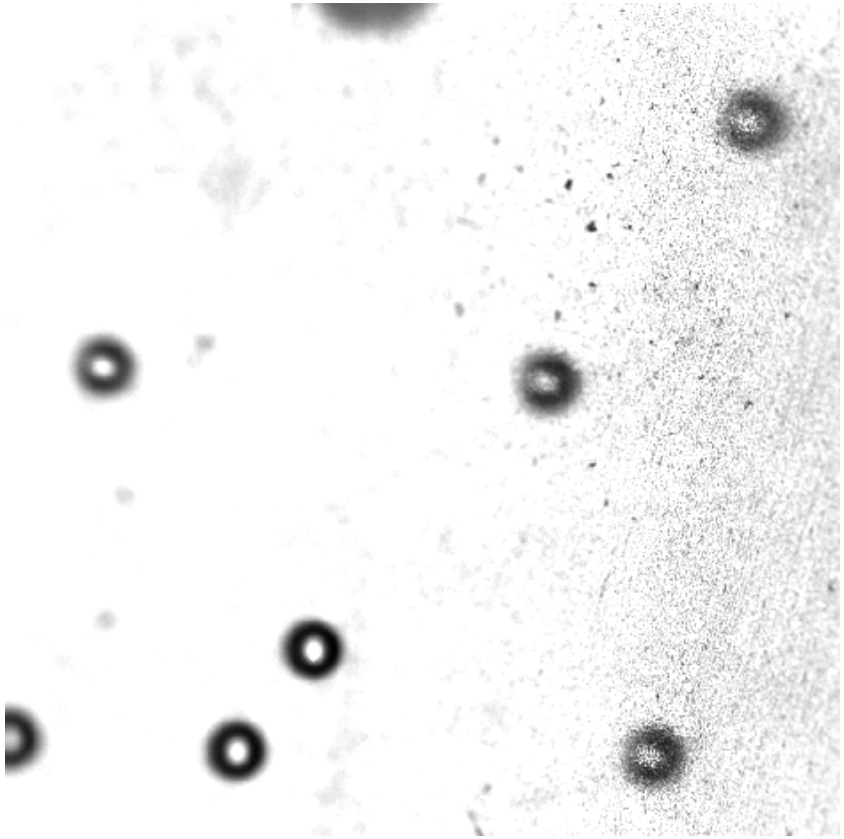




Experimental Results

Height = 0.609 m from bottom

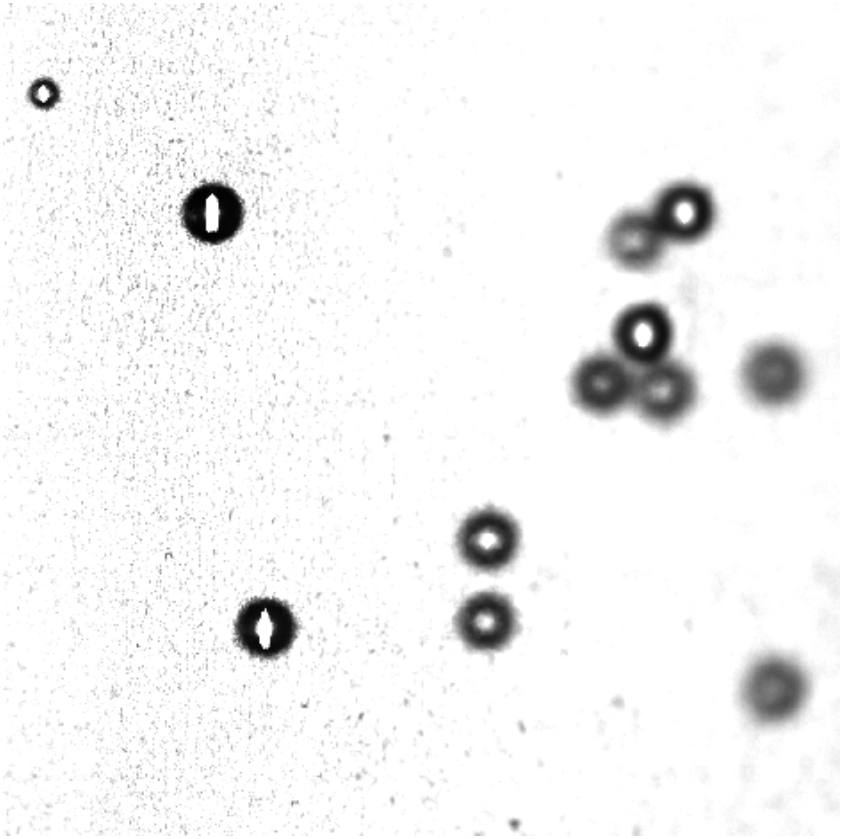
Depth = 50 mm from the wall



Experimental Results

Height = 0.304 m from bottom

Depth = 4 mm from the wall



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Summary of Research and Next Tasks

Spring 2008

- Particle positions have been obtained and clusters identified

Summer 2008

- Determine velocities (Overlapping particles, velocity threshold)
- The plastic particle number density will be increased using larger gas velocities to determine the limits of the shadow sizing technique for modeling clusters

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