Innovative Method to Measure Solids Circulation in Spouted Fluidized Beds

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Objectives

- Develop method for directly measuring solids circulation in particulate systems
- Apply to experimental spouted beds to better understand solids circulation dynamics
- This study- Demonstrate potential for a particular approach using magnetic tracking

Background

Several other solids tracking methods have been developed over the past several decades:

- Visual observations in 2D or half-round columns
- In bed capacitance, momentum or optical probes
- Radioactive particle tracking (CARPT)
- MRI/NMRI methods
- Positron emission tomography(PET)
- Various residence time distribution methods

Advantages of Magnetic Tracer

- True 3D tracking of single particles without in-bed probes
- Simpler and more general than MRI and PET
- Safer than CARPT and PET
- Much cheaper that CARPT, MRI and PET
- Adaptable to various bed configurations

Limitations

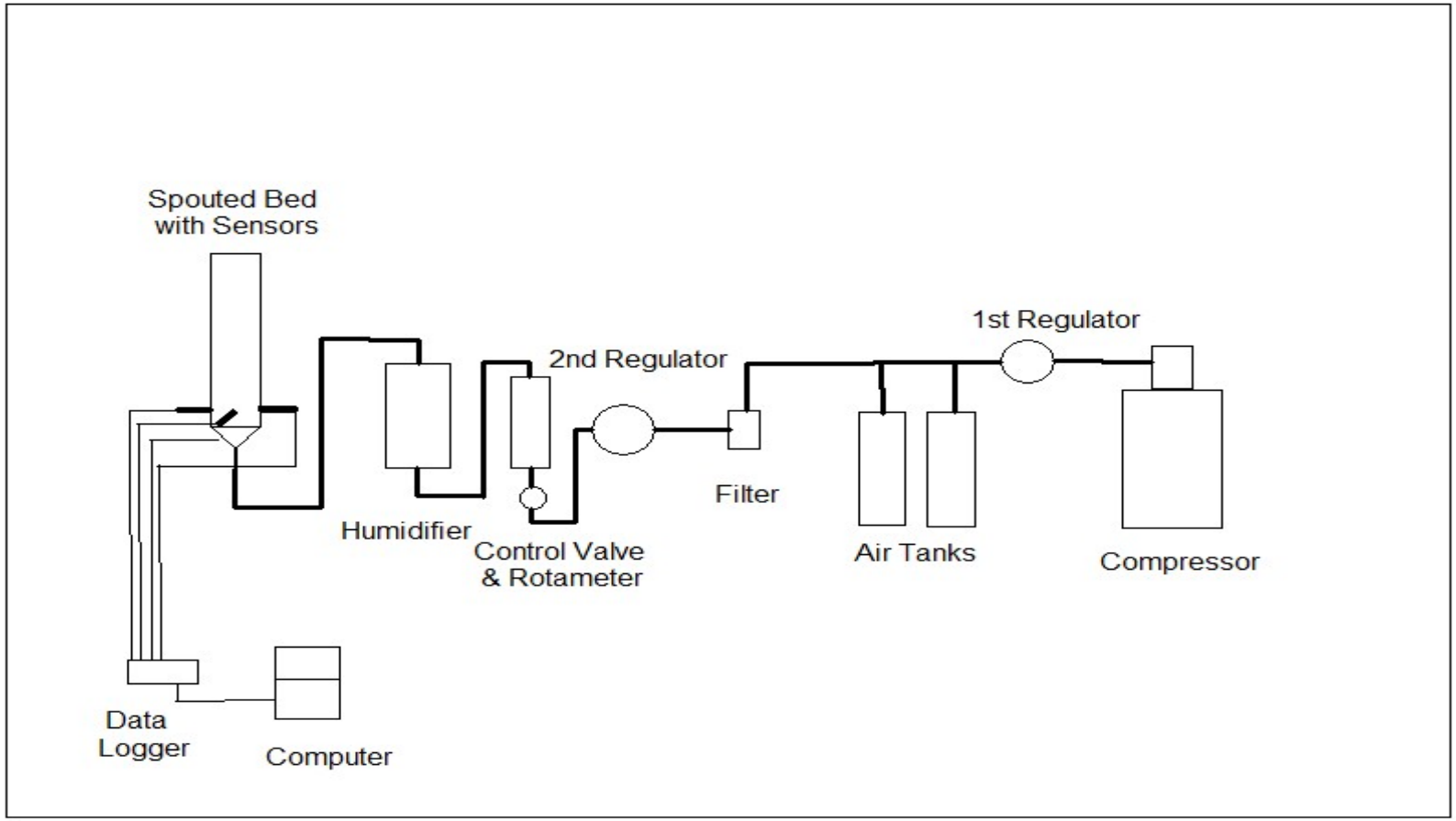
- Small size beds (more sensitive probes are available to study larger beds)
- Non-Magnetic bed structure required
- Low Temperature (< 300F)

Approach

Measure magnetic field from ‘tracer’ particle with an embedded magnet:

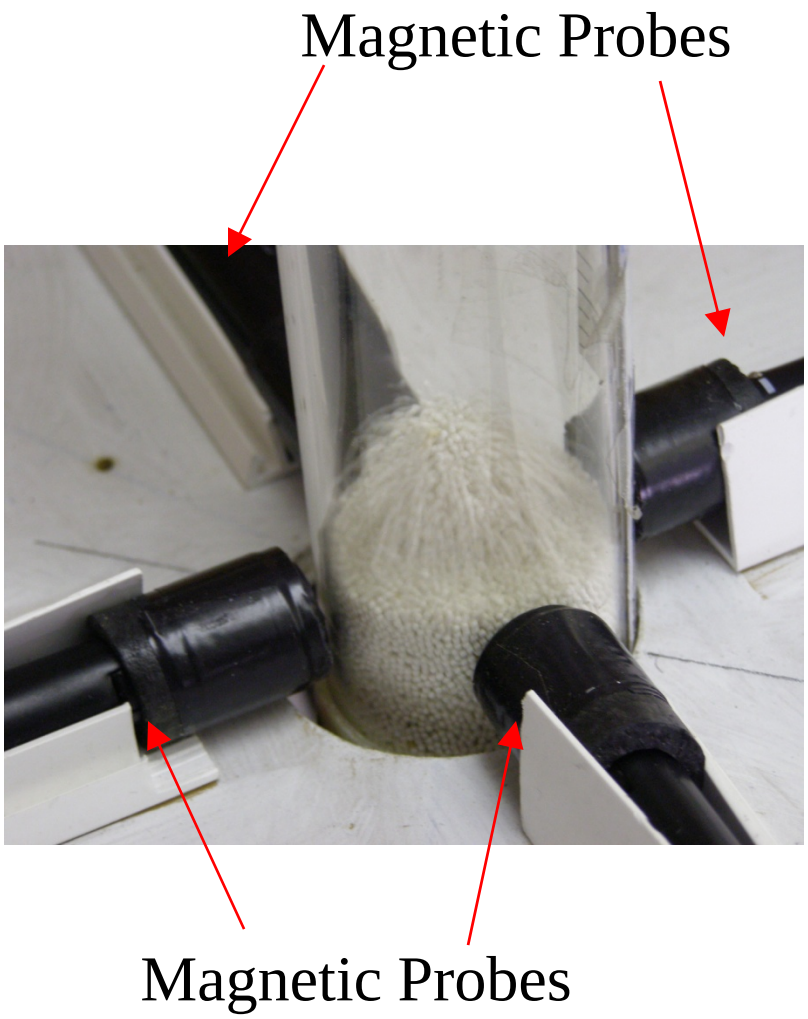
- Tracer particle made from neodymium magnet embedded in polymer (similar size and density to particles of interest)
- Externally mounted detectors monitor magnetic field from tracer in bed
- Algorithm calculates position from magnetic field readings
- 3D spatial trajectory provides detailed circulation statistics
- Variations in vertical position used to calculate particle recirculation frequency

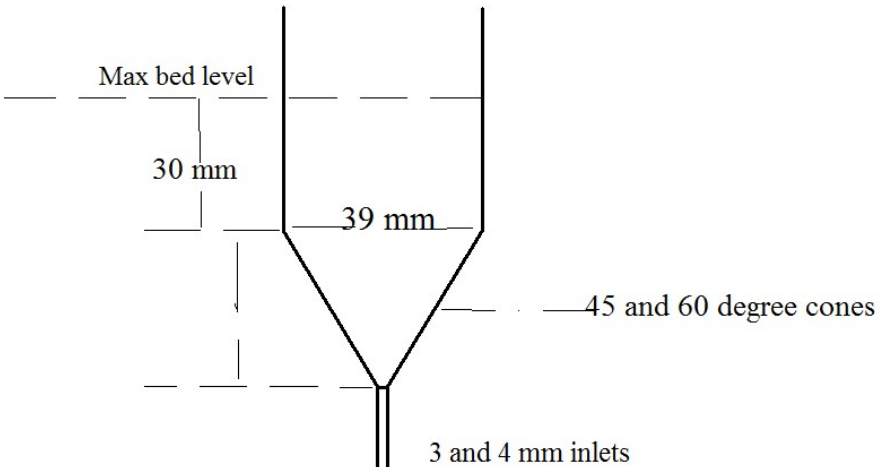
Experimental Setup

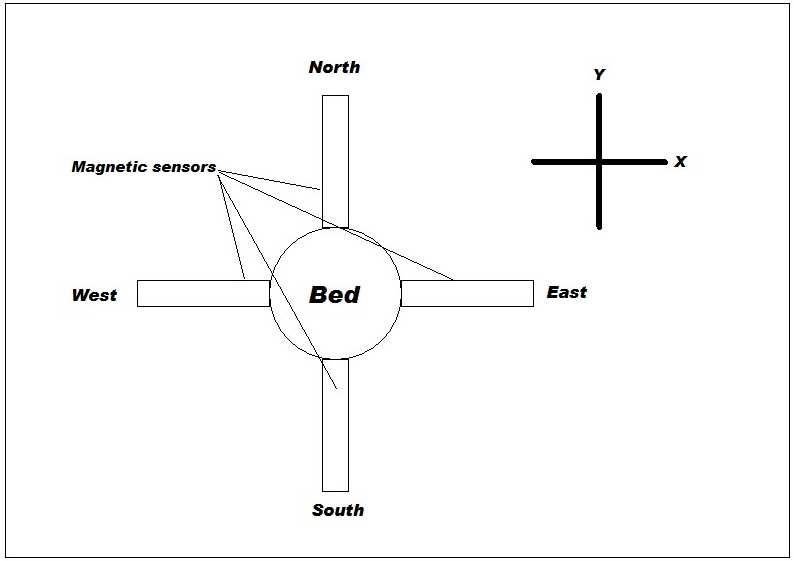


Small air-fluidized spouted bed at ambient temperature and pressure with multi-channel digital data acquisition

Spouted Bed & Probe Details

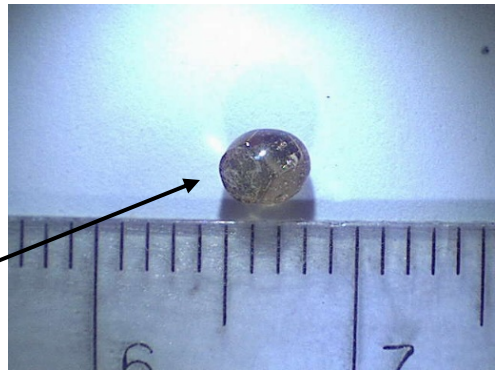






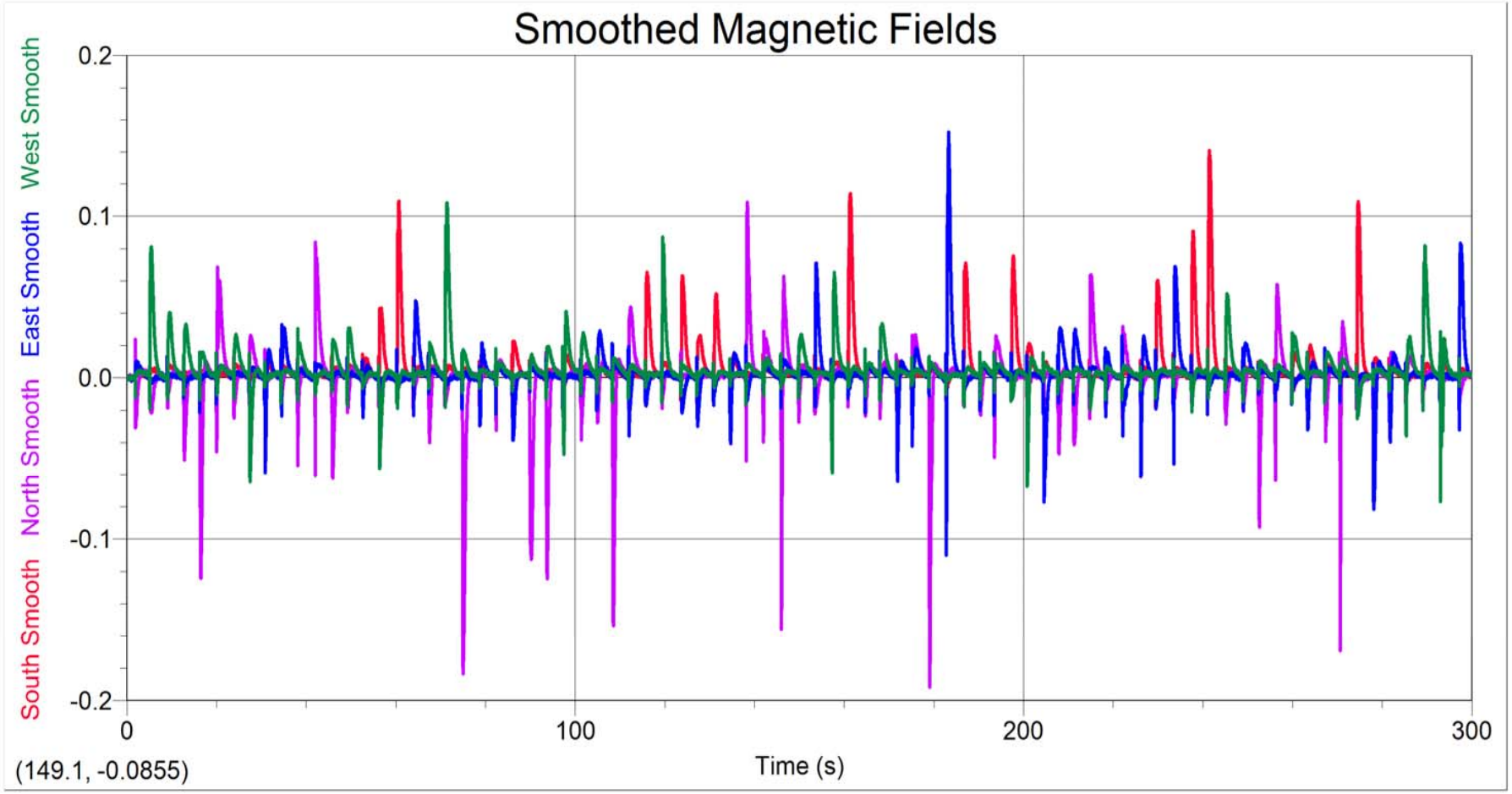
Magnetic Tracer Preparation

- Neodymium magnets available as cubes, cylinders and discs down to about 1 mm
- Three methods
  - Solid polymer coating
  - Imbedding in plastic bead
  - Foaming polymer coating
- Sizes 1 to 4 mm
- Densities 1.5 to 5.5 g/cc



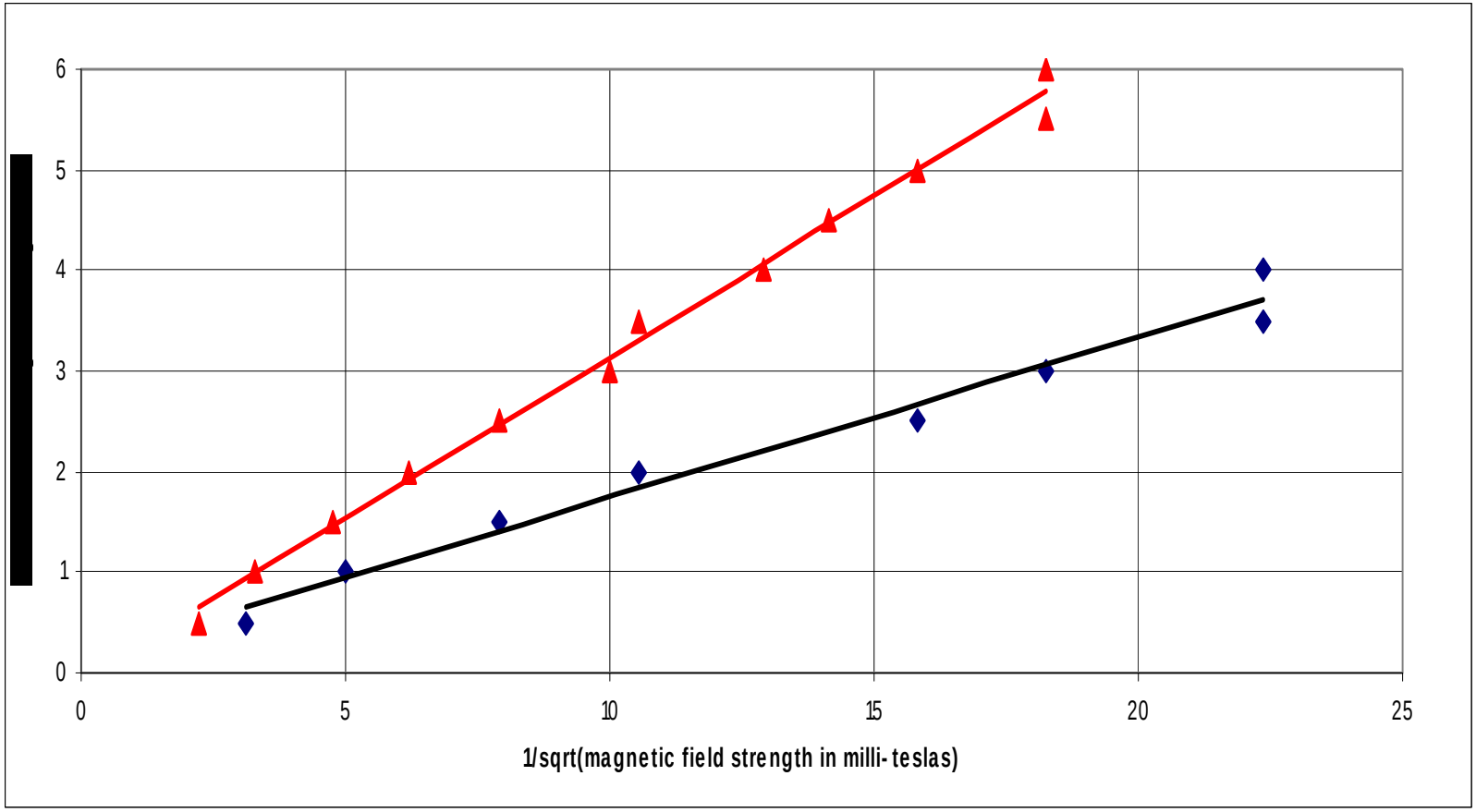
Magnetic Field signals

Each probe records a time varying signal as the tracer moves



Tracking Algorithm (1)

- Normal (perpendicular orientation) field strength-distance relationship calibrated for each tracer and probe type



Tracking Algorithm (2)

- Tracer magnetic axis aligns with earth magnetic field in bed
- Probe signal function of tracer distance & magnetic axis angle
- Probe orientation and geometric construct eliminates angle dependence for X & Y
- Vertical position (Z) from Pythagorean Theorem

$$d = \alpha \sqrt{\frac{\cos(\phi)}{M}}$$

$$X = \left(\frac{\sqrt{\frac{1}{|Me|}} - \sqrt{\frac{1}{|Mw|}}}{\sqrt{\frac{1}{|Me|}} + \sqrt{\frac{1}{|Mw|}}} \right)$$

$$Y = \left(\frac{\sqrt{\frac{1}{|Mn|}} - \sqrt{\frac{1}{|Ms|}}}{\sqrt{\frac{1}{|Mn|}} + \sqrt{\frac{1}{|Ms|}}} \right)$$

$$Z = \sqrt{\alpha^2 \left(\frac{\cos(\phi n)}{|Mn|} \right) - R^2 \left(X^2 + (1 - Y)^2 \right)}$$

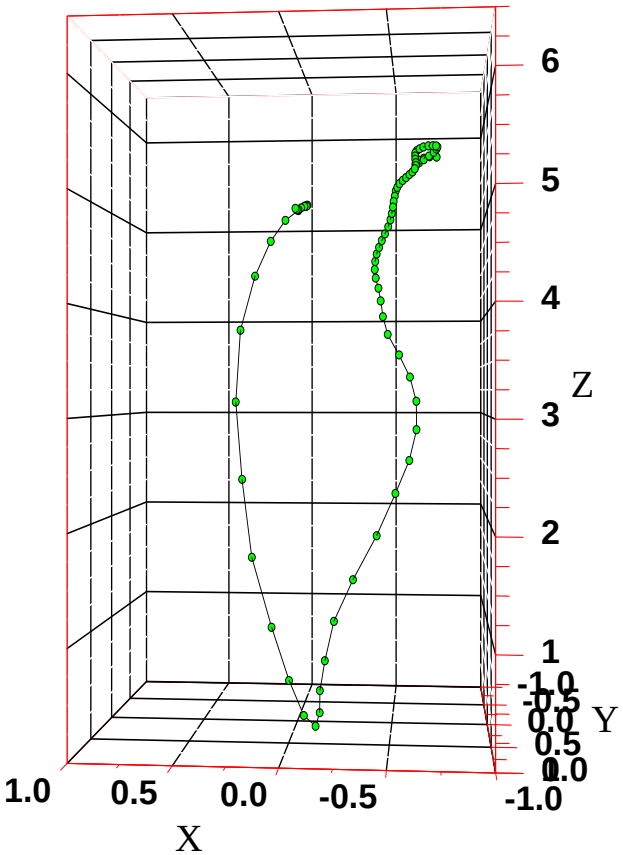
$$Z = \sqrt{\alpha^2 \left(\frac{\cos(\phi s)}{|Ms|} \right) - R^2 \left(X^2 + (1 + Y)^2 \right)}$$

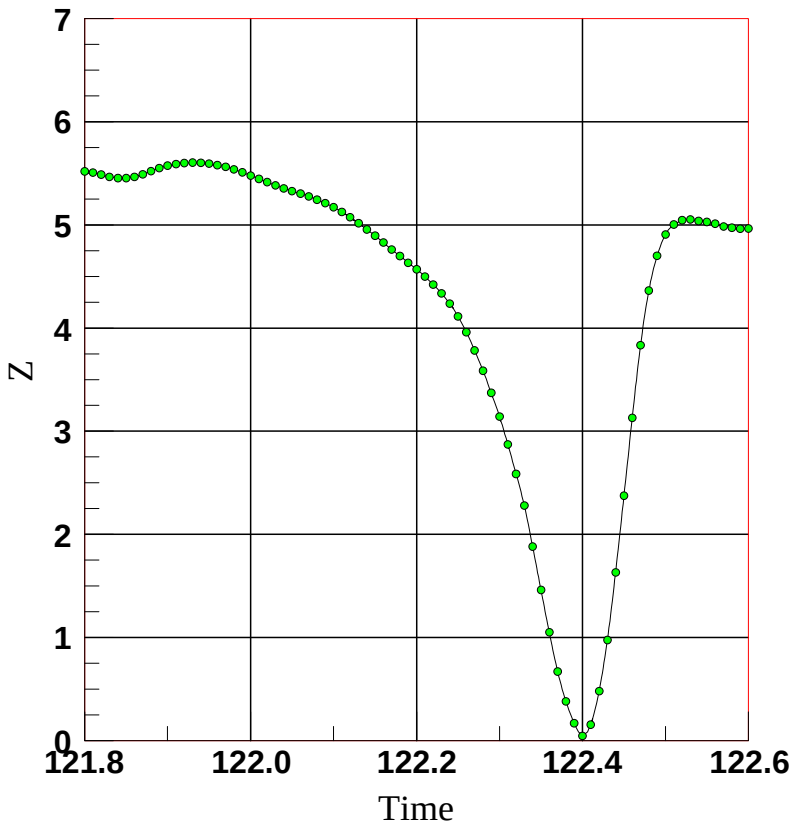
$$Z = \sqrt{\alpha^2 \left(\frac{\cos(\phi e)}{|Me|} \right) - R^2 \left((1 - X)^2 + Y^2 \right)}$$

$$Z = \sqrt{\alpha^2 \left(\frac{\cos(\phi w)}{|Mw|} \right) - R^2 \left((1 + X)^2 + Y^2 \right)}$$

3-D Trajectories

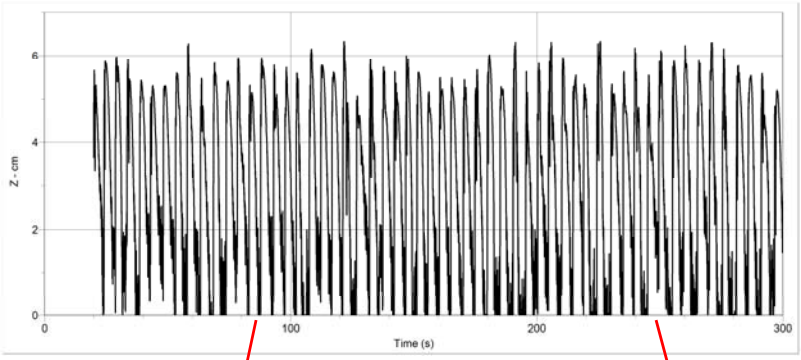
Net result is reconstruction of 3D tracer trajectory versus time



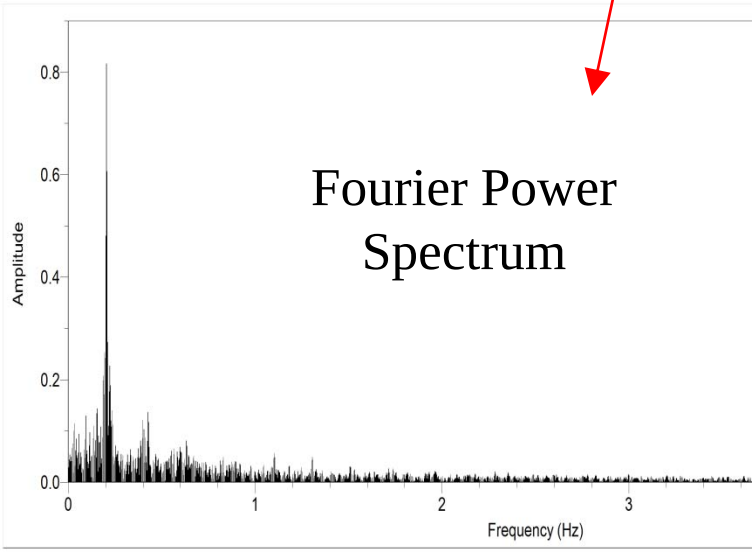


Analysis (1)

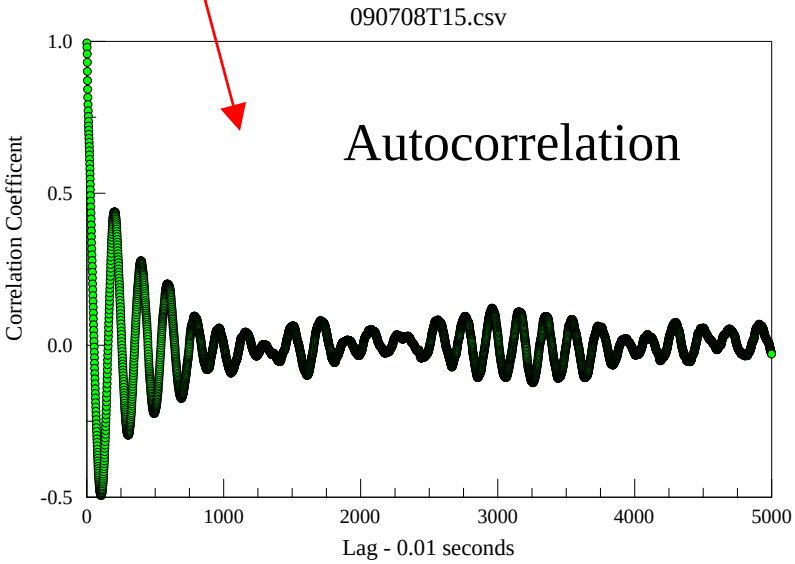
Many statistics can be computed from the dynamic trajectories



Vertical tracer position versus time



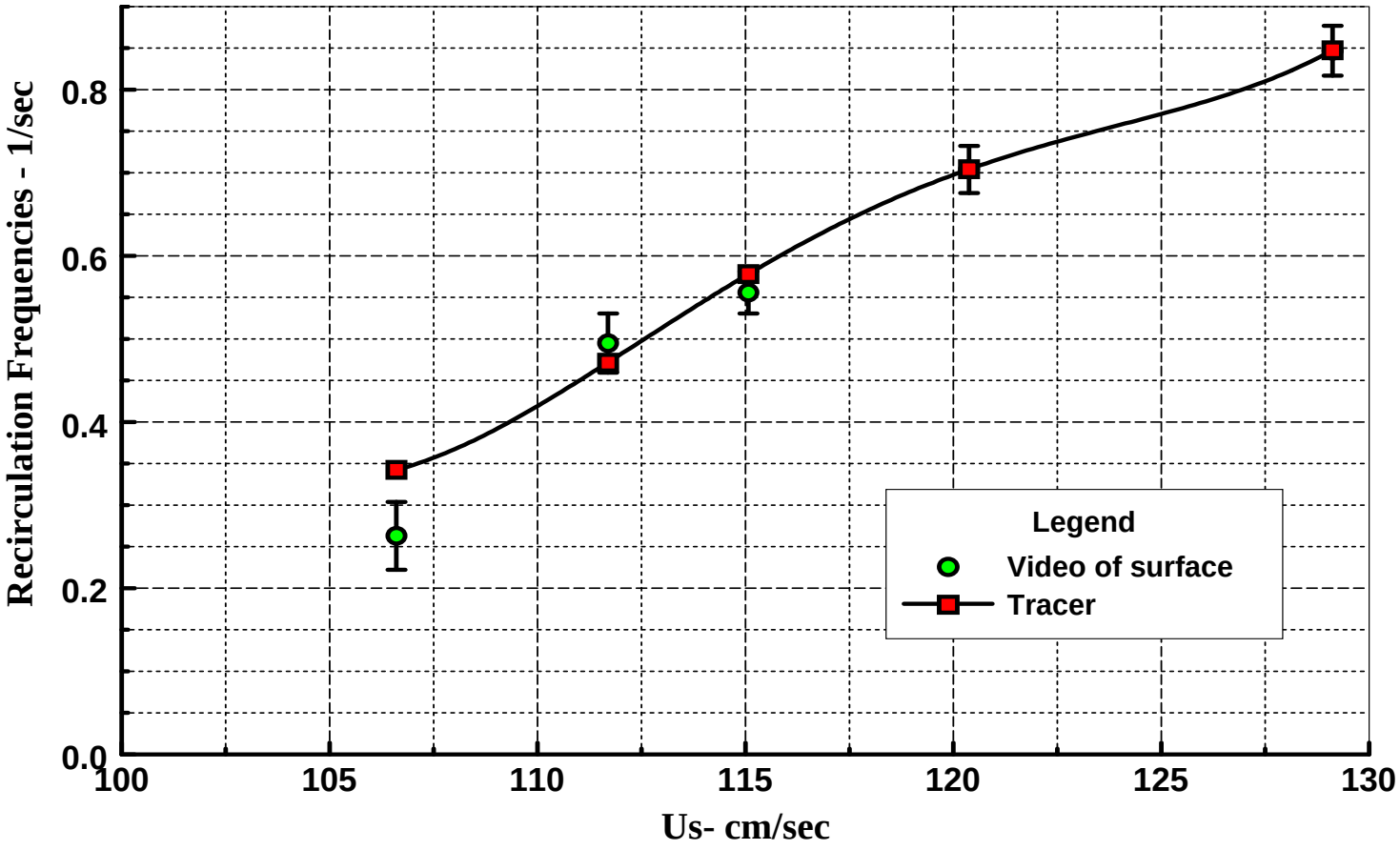
Fourier Power Spectrum



Autocorrelation

Analysis (2)

Direct visual tracking appears to validate magnetic tracer results

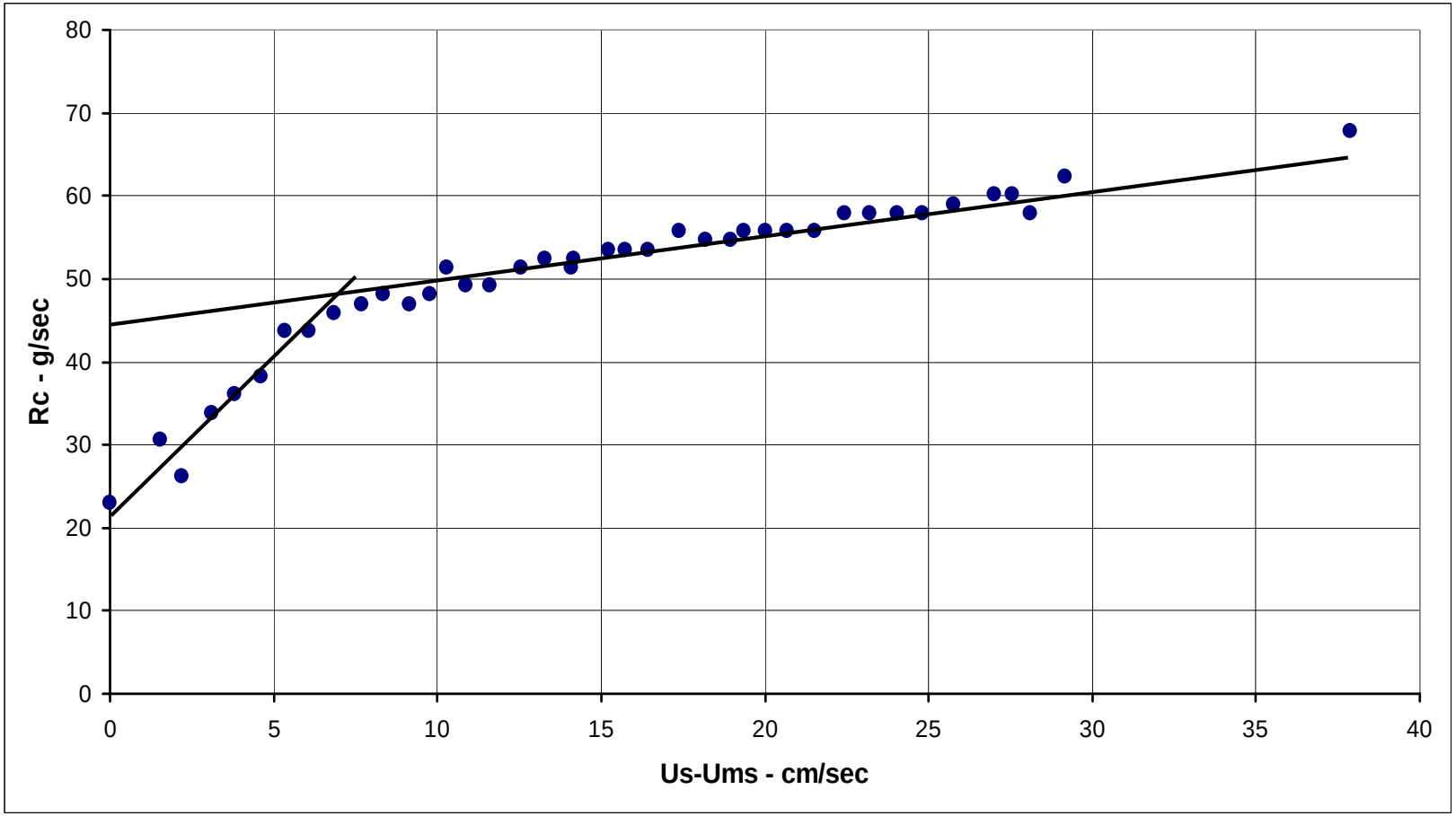


Experimental Conditions for Recirculation Study

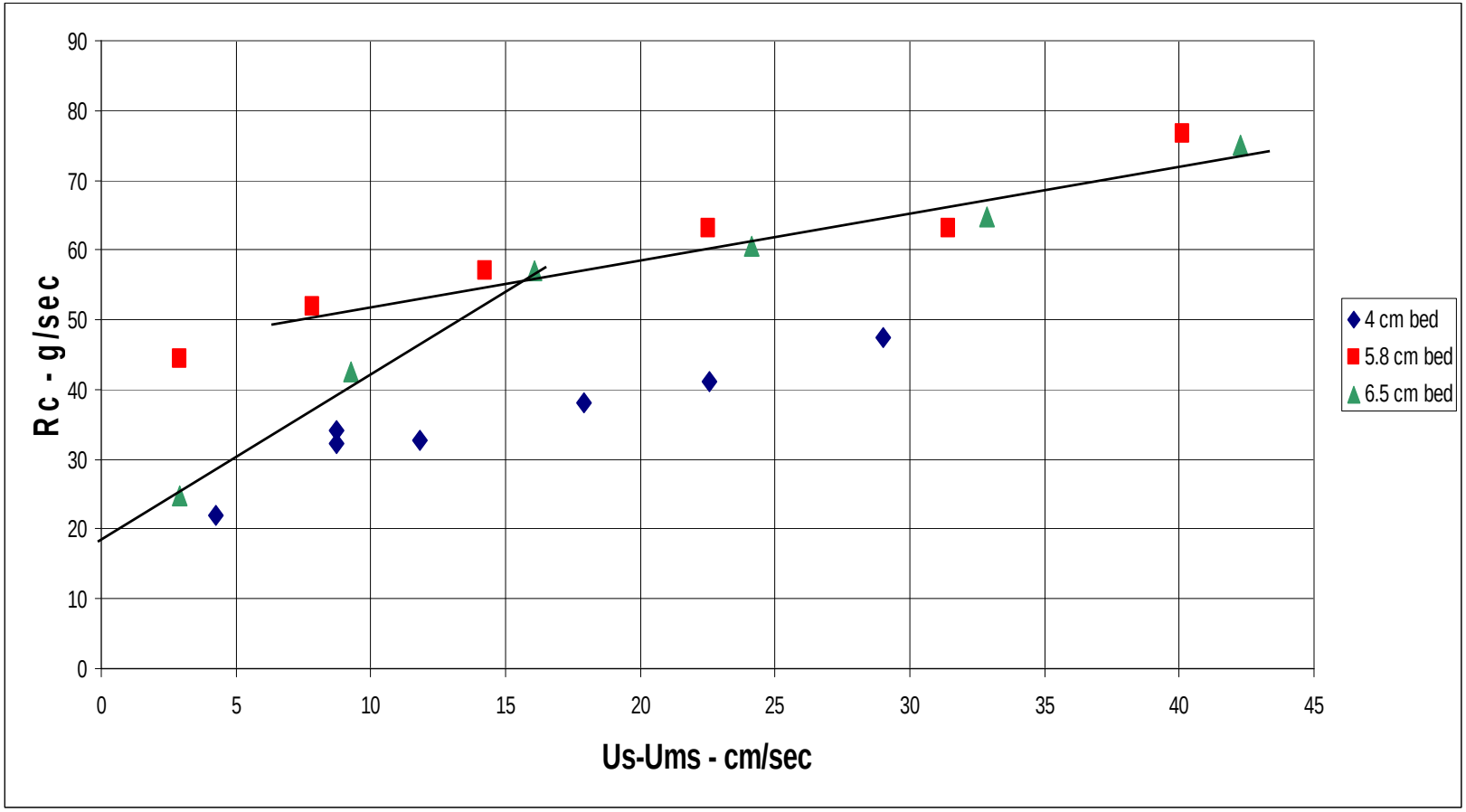
- Glass beads: 0.8, 1.0, 1.2, 1.5, 2.0 mm : 2.5 g/cc
- $ZrSiO_4$: 1.0 and 2.0 mm : 4.1 g/cc
- ZrO_2: 1.0 mm : 5.7 g/cc
- Millet Seed : 1.8 mm : 1.2 g/cc
- Nylon Sphere : 3.1 mm 1.1 g/cc
- Pasta : 2.8 mm : 1.2 g/cc
- Each material: 5 air rates at each of three bed depths
- 45 and 60 degree cone angles for some materials
- 3 and 4 mm air inlets for 60 degree cone
- Experiments sampled at 100 or 200 hertz
- Each run 5 minutes long
- Total of 500 runs

Velocity Effect on Recirculation

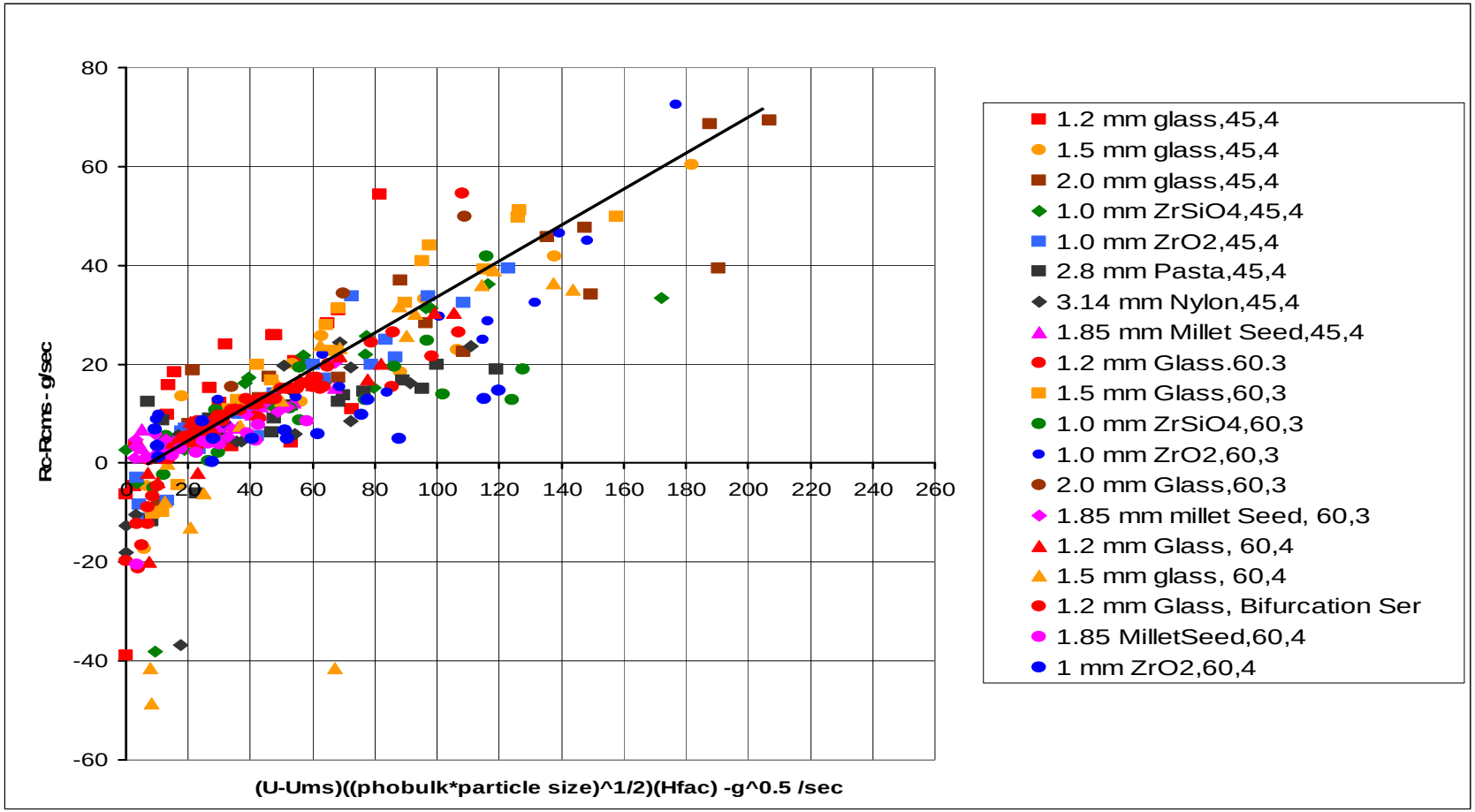
- 1.2 mm glass beads -



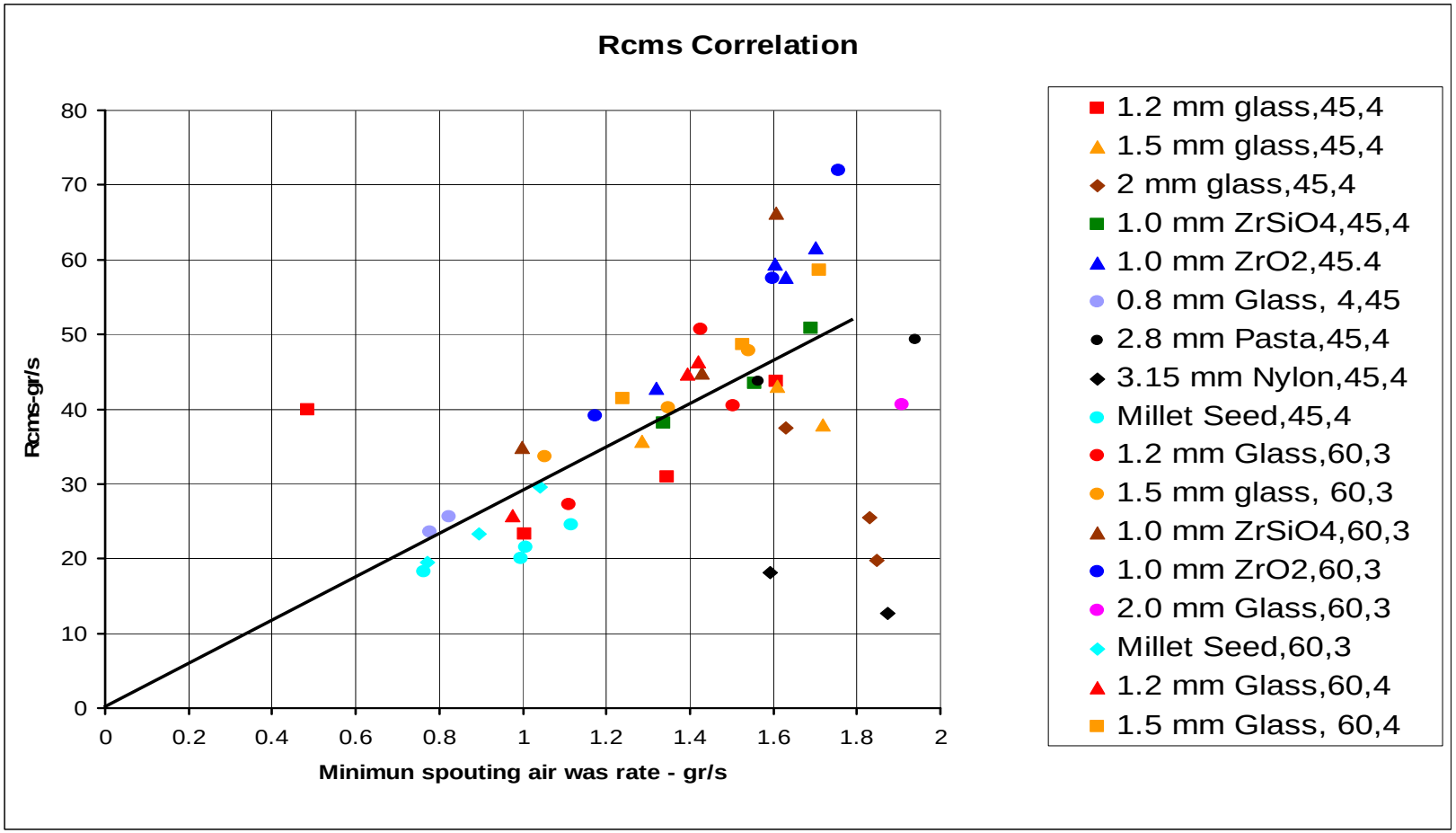
Bed Height Effect On Recirculation
- 1.2 mm glass beads -



Recirculation Rate Correlation



Recirculation Rate at Minimum Spouting



Work Plans

- More sensitive magnetic probes
- Larger diameter beds (e.g., 70 mm)
- Slugging beds (limited tests done)
- Beds of mixed particle sizes (limited tests done)
- Simulated biomass particles
- Tracking algorithms for different sensor configurations
- Stochastic-deterministic models for particle motion

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More Information

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