5-23-2016

Spouting behavior of binary mixtures of spherical and cylindrical particles

Douglas W. Marshall
Fuel Design and Development, Battelle Energy Alliance, LLC, Idaho Nuclear Laboratory, Idaho Falls, Idaho, USA, douglas.marshall@inl.gov

Nicholas W. Eimers
Capstone Engineering, Vancouver, Washington, USA

Nathan A. Yergenson
Apex Manufacturing Solutions, Boise, Idaho, USA

David C. Drown
Associate Professor, Department of Chemical and Materials Engineering, University of Idaho, Moscow, Idaho, USA

Spouting Behavior of Binary Mixtures of Spherical and Cylindrical Particles

Douglas W. Marshall, Technical Lead

Fuel Design and Development
Battelle Energy Alliance, LLC
Idaho National Laboratory

May 22 - 27, 2016

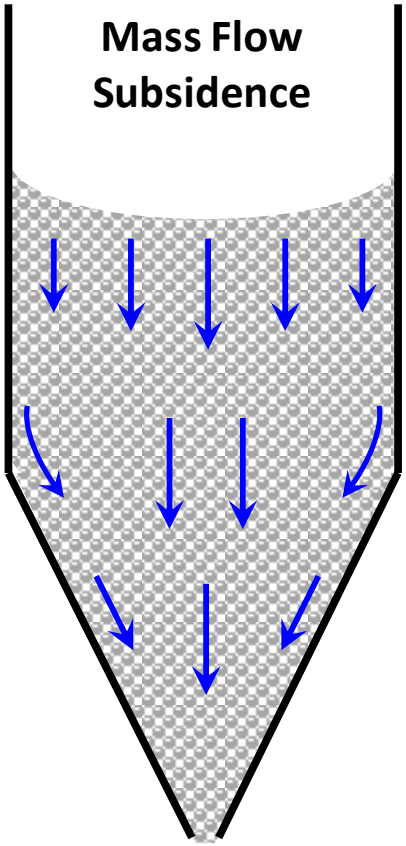
www.inl.gov

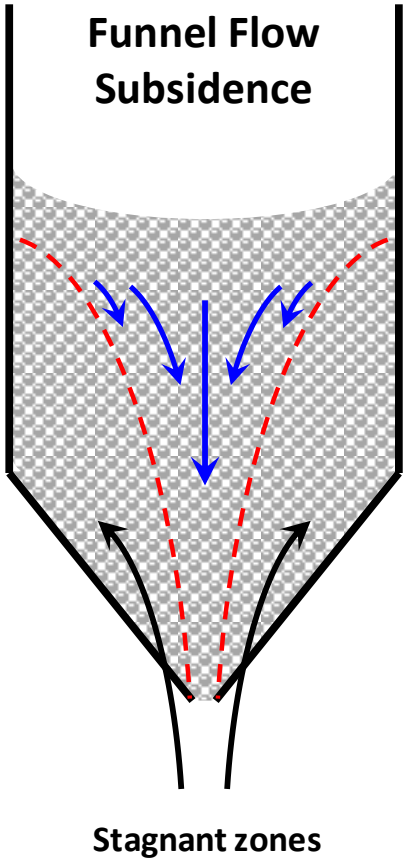
Idaho National Laboratory

Outline

- Why a explore a binary mixture?
- Test Configuration
  - Full size, 2-D spouted bed
  - Dual gas paths (primary and auxiliary)
- U_{ms} determination
- Observed bed circulation patterns
- Conclusions

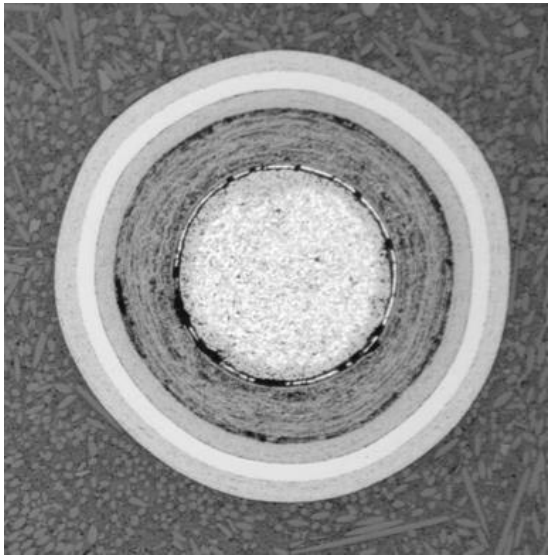
Definition of Mass or Funnel Flow Subsidence





Background Information

- High Temperature Gas-cooled Reactor (HTGR)
  - Graphite moderated, helium cooled reactor (750°C ≤ T_{exit} ≤ 900°C)
  - Fuel kernels 425 µm - 500 µm; 10.8 - 11.2 g/cm^3
  - Kernels hermetically sealed in 4 coating layers (TRISO particle)
  - Layers form the primary containment for fission products

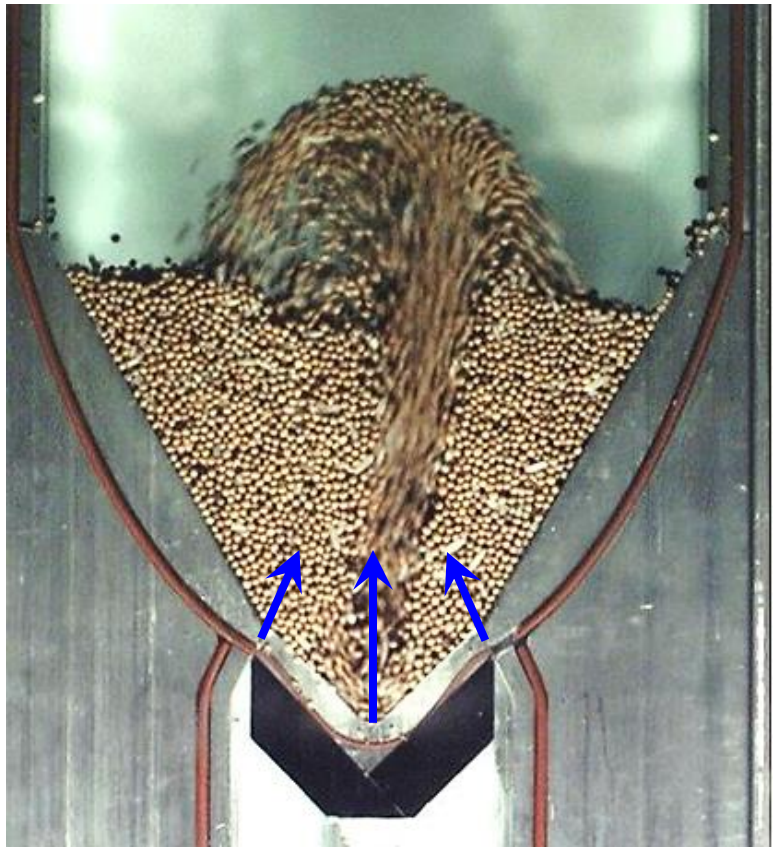


Hypotheses

- Basis
  - Spherical particles are more prone to funnel flow
  - Cylindrical particles are more prone to mass flow
- Hypotheses
  - A binary admixture of will exhibit attributes of both particles
  - Admixing cylindrical particles with fuel particles will promote mass flow and improve product consistency and sphericity

2-D Test Bed

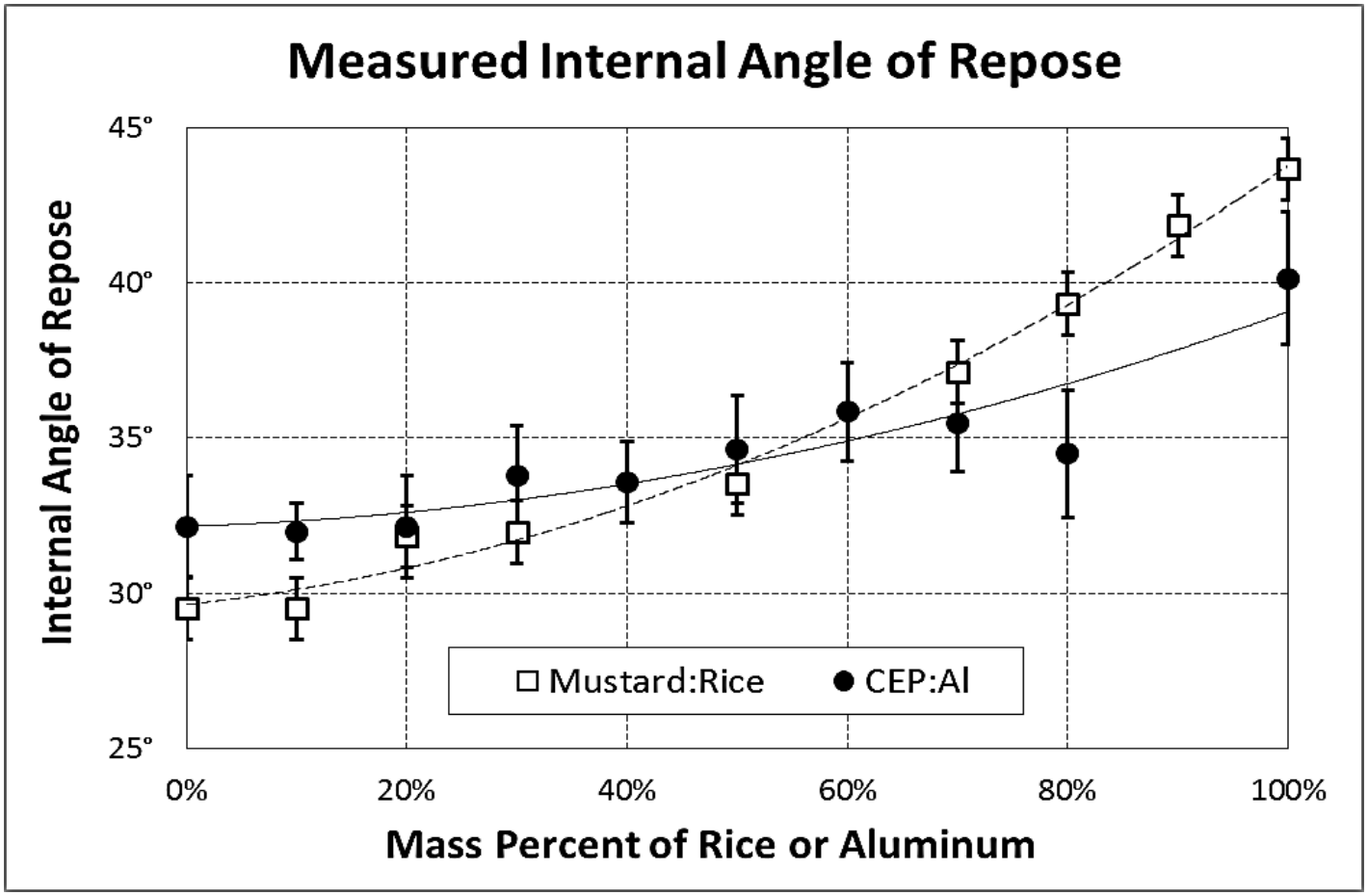
- 25.6 mm x 152 mm
- 60° included angle
- Dual gas paths
  - Primary
  - Auxiliary (0.23 mm @ 25°)
- Multi-orifice nozzle
  - 90° included angle
  - Three 3.2 mm orifices
- Pressures fluctuations measured upstream of the nozzle



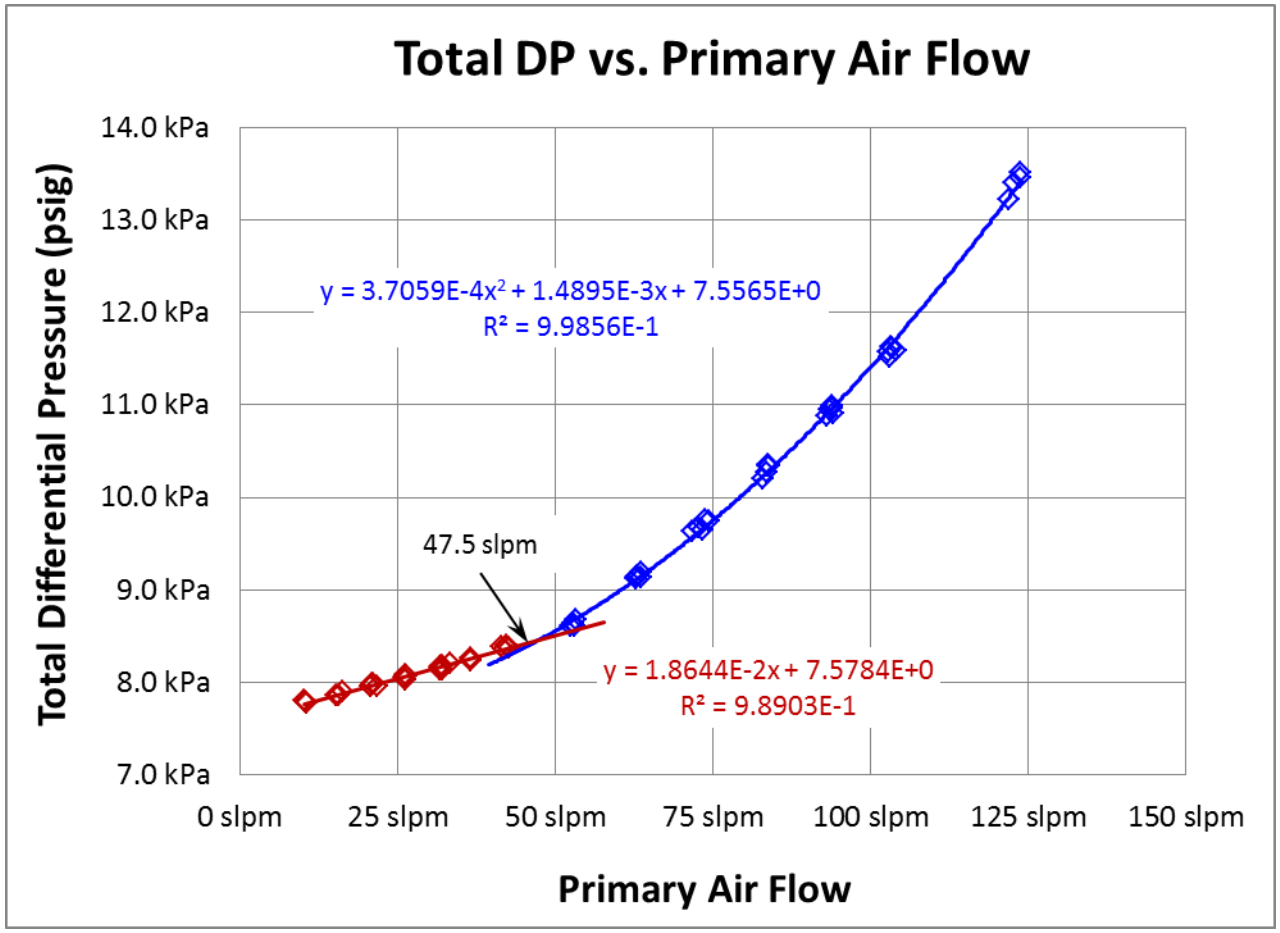
Scope of Testing

Particle Property	Yellow mustard seed	Long grain white rice	CARBO ECONOPROP (CEP)	Aluminum rodlets
Particle density (g/cm^3)	1.20	1.46	2.61	2.70
Mean particle diameter (mm)	1.90	1.82	0.66	0.76
Mean particle length (mm)	---	6.51	---	3.18
Aspect ratio	---	3.58	---	4.18
Sauter diameter, d_{32} (mm)	1.90	2.40	0.66	1.02
Volume diameter, d_v (mm)	1.90	3.19	0.66	1.40

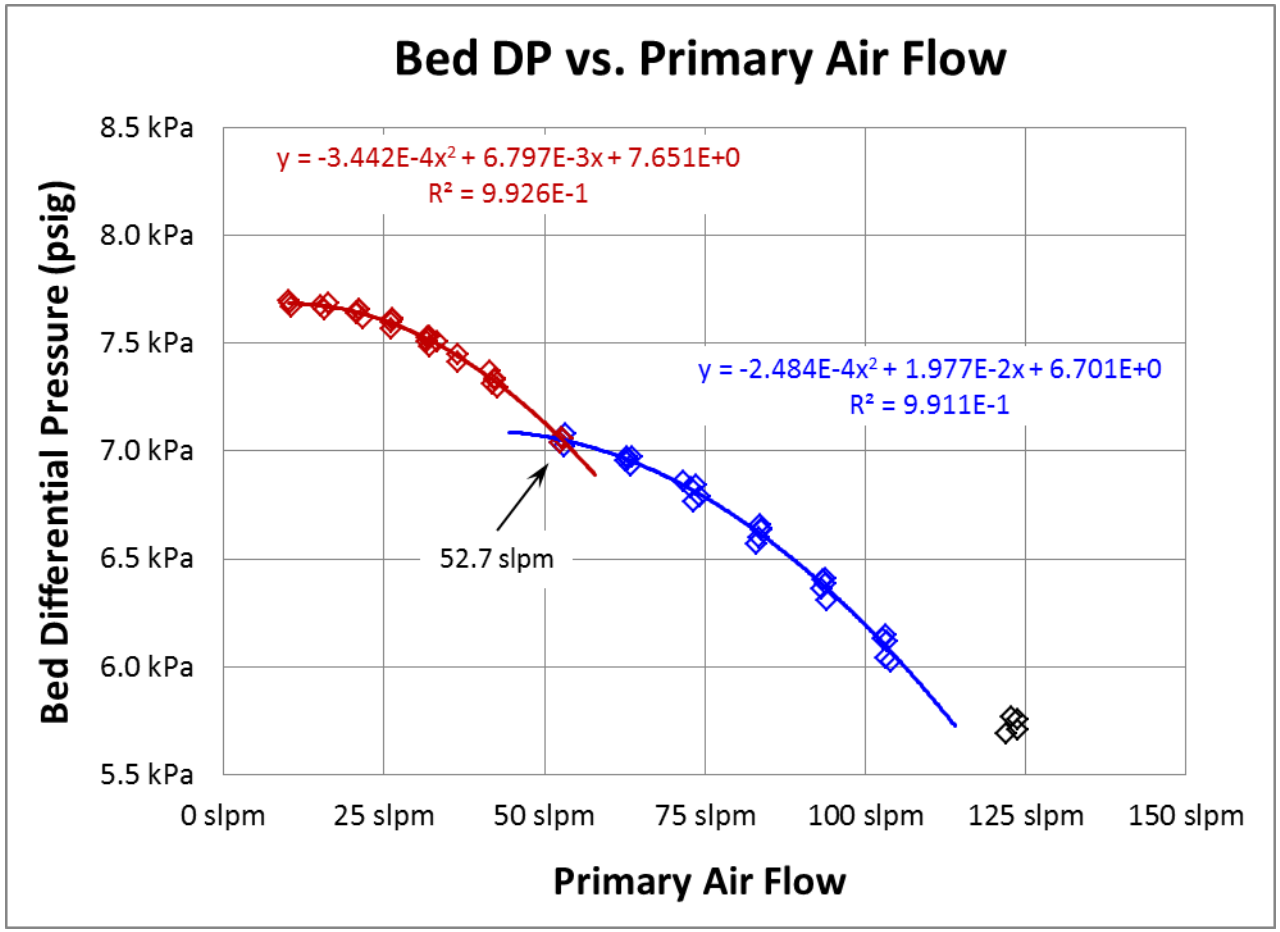
Internal Angle of Repose



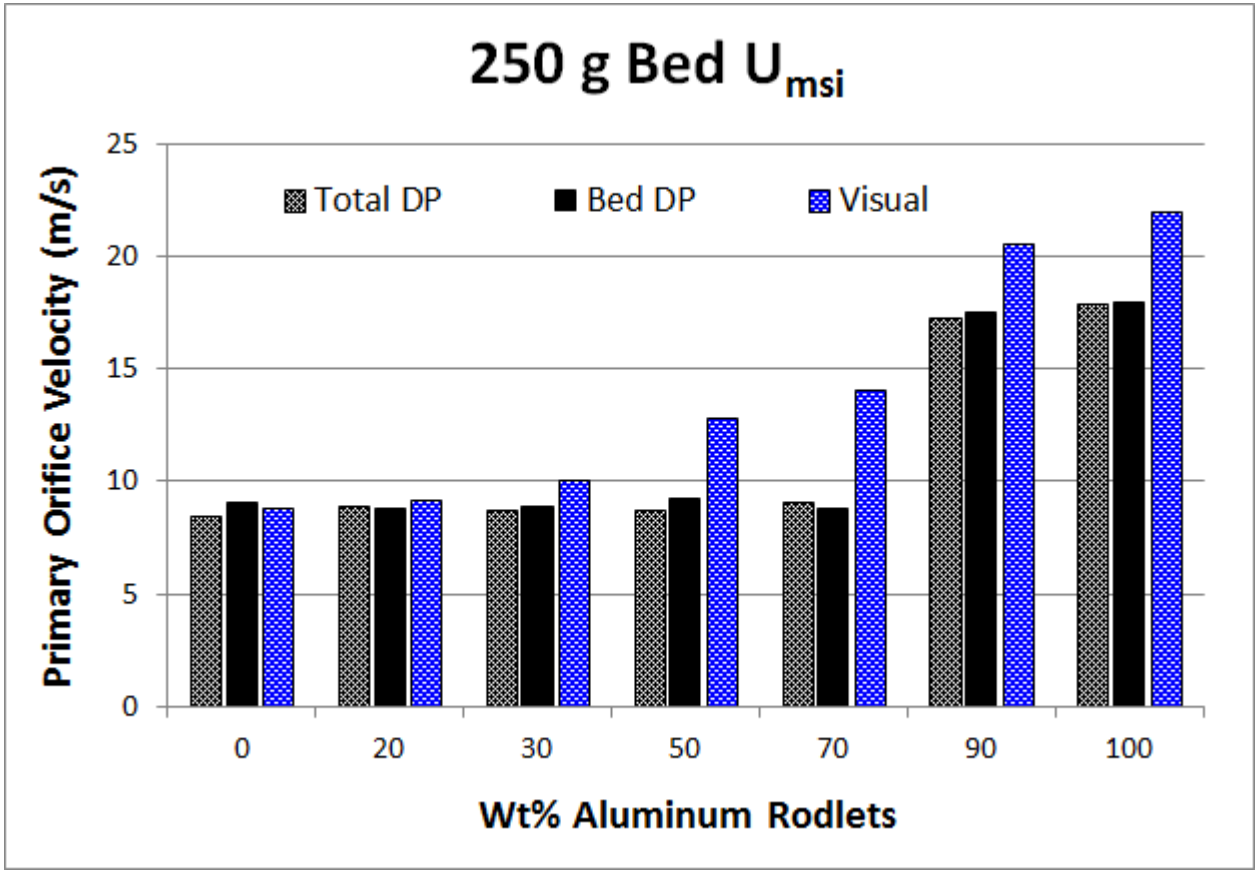
Total Differential Pressure



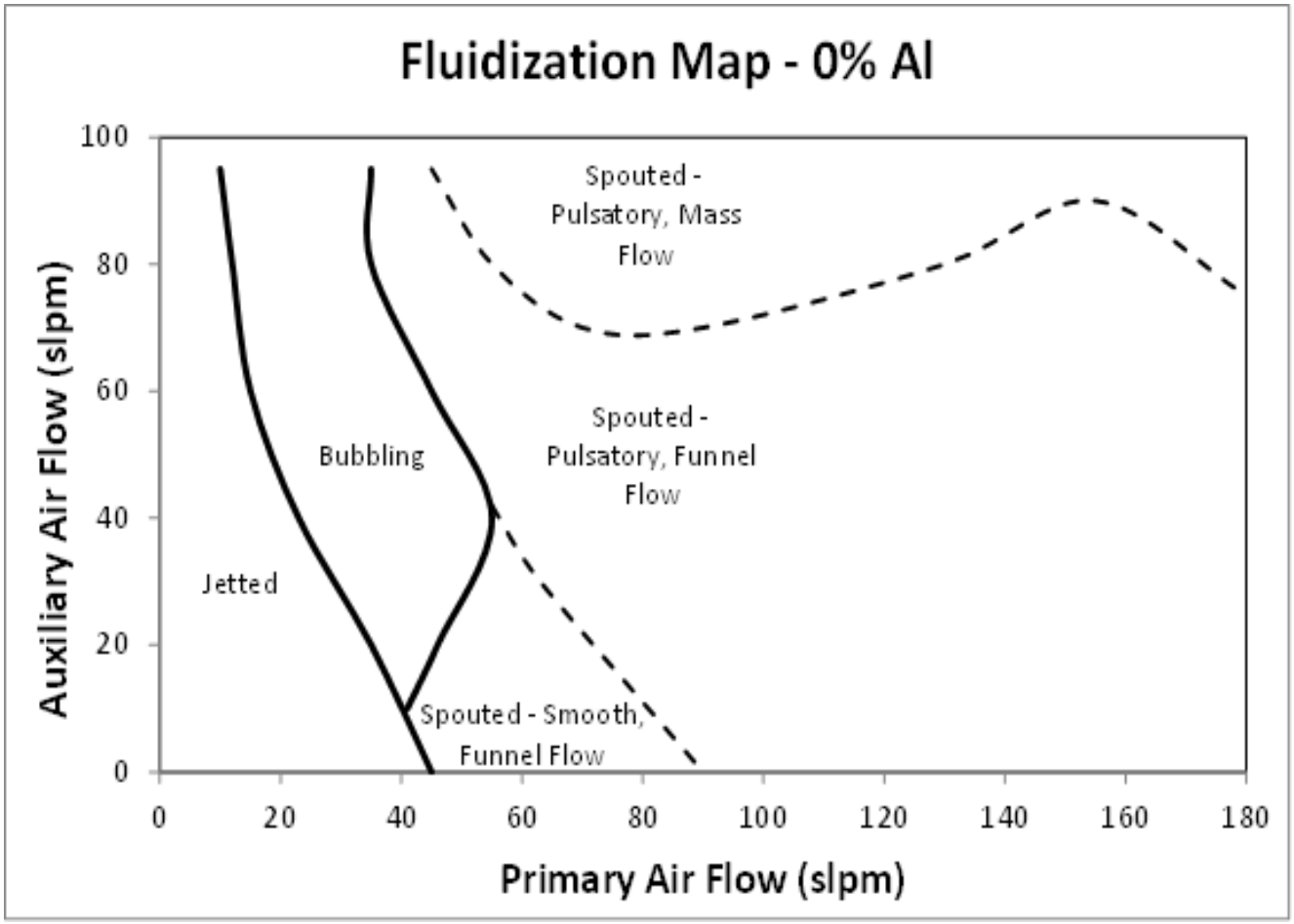
Bed Differential Pressure



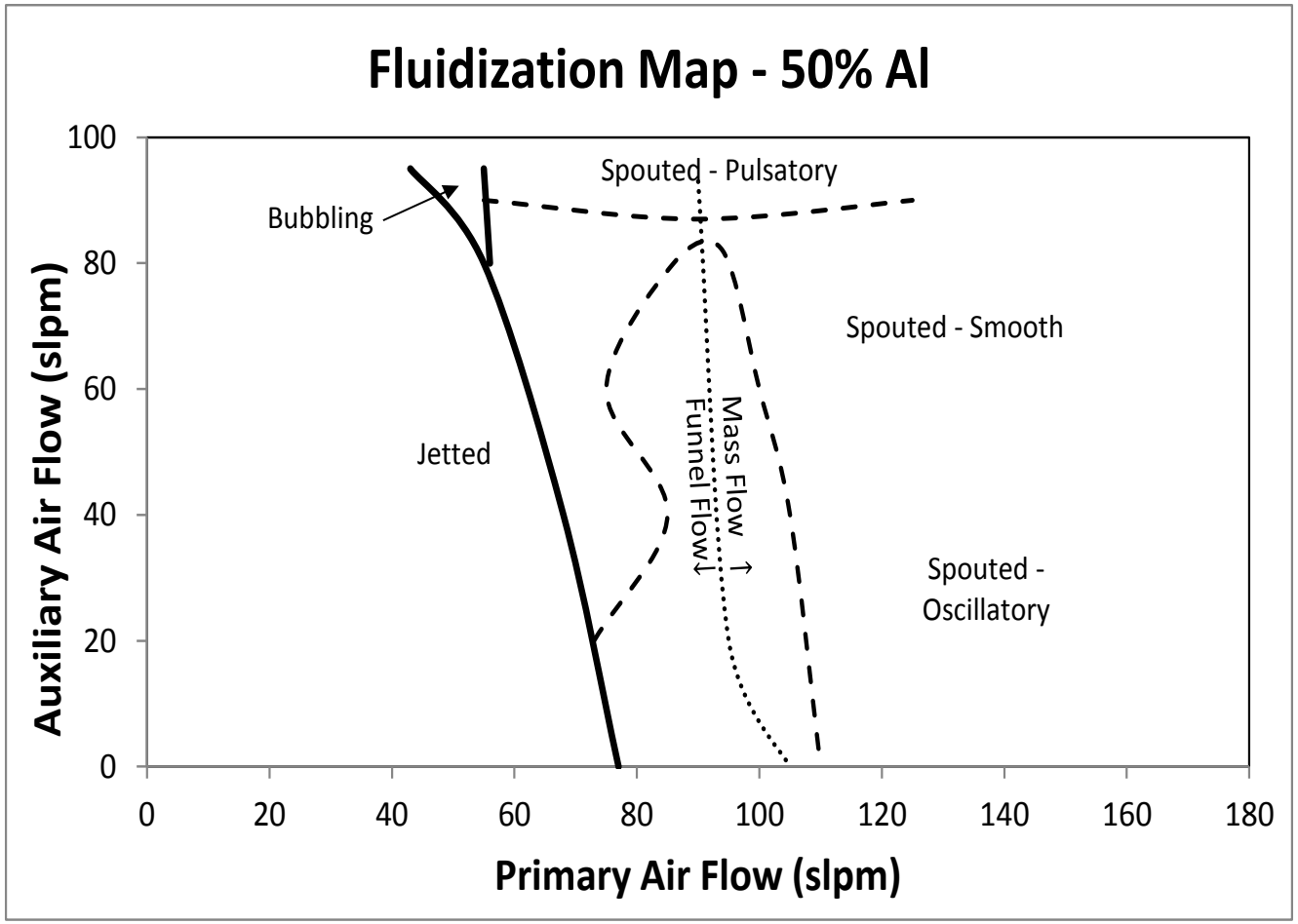
Extrapolated vs. Observed U_{msi}



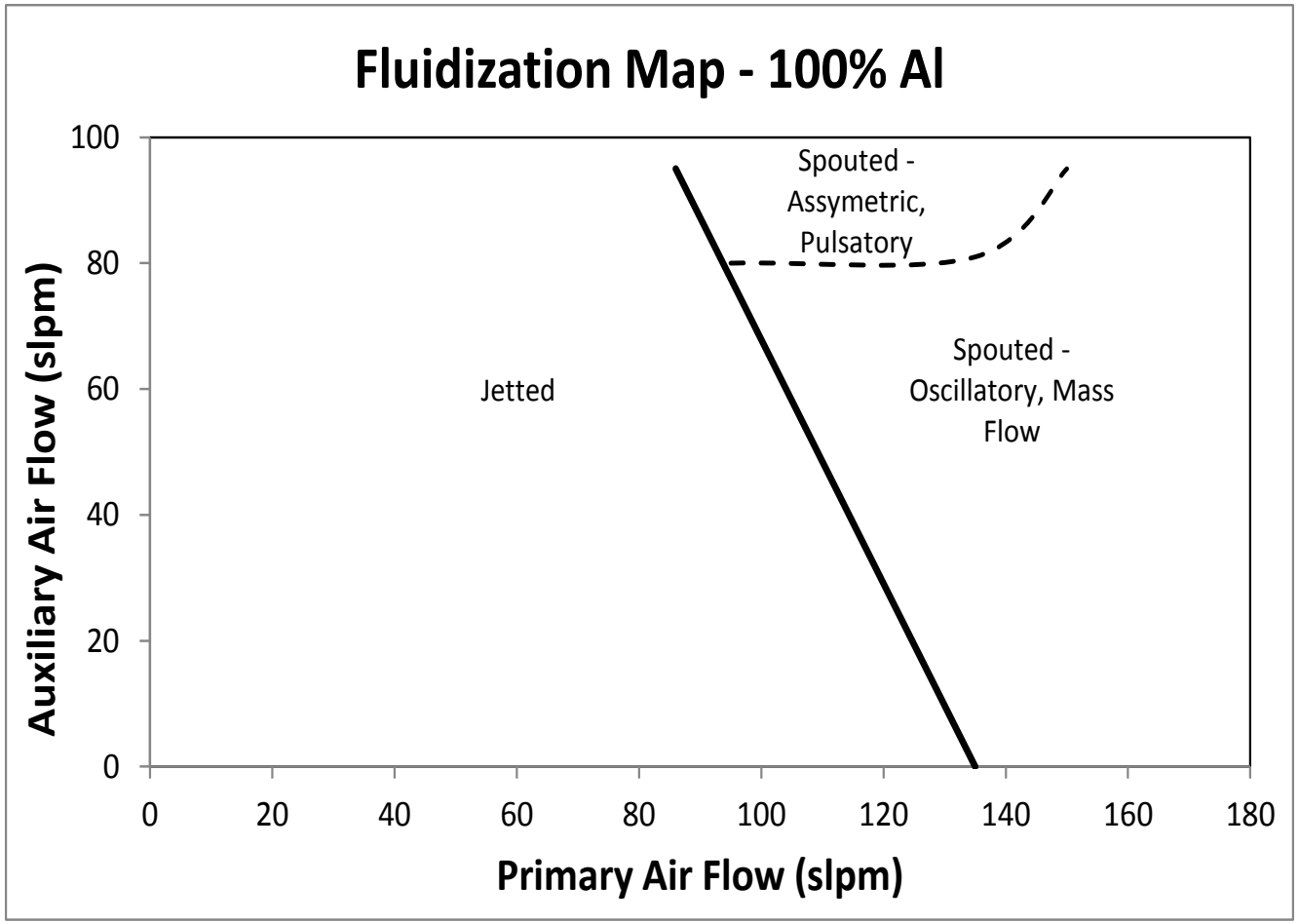
Fluidization/Spouting Maps



Fluidization/Spouting Maps



Fluidization/Spouting Maps



Observations

- Auxiliary gas flow
  - Induces bubbling between jetted and spouted regions
  - Promotes mass flow
- Stable spouting
  - Often associated with funnel flow
  - Easily achieved above 50 wt% rodlets
- Pulsatory spouting
  - Most often associated with spherical particles
  - Pulsations promote mass flow subsidence

Observations

- Funnel flow subsidence
  - Stagnation along walls is problematic
  - Fountain often narrower than the bed diameter
  - Cylindrical particles align with flow streamlines
  - Minor particle phase segregates to the spout “wall”
- Mass flow subsidence
  - Little or no stagnation
  - Fountain width fills freeboard diameter
  - Cylindrical particles align horizontally
  - Low particle segregation

Applicability to Nuclear Fuels

- Would likely improve product quality
- Product already meets specifications
- Liability for radioactive waste generation, added unit operations, reduced throughput, etc. not worth the benefit

Questions?

Douglas Marshall
douglas.marshall@inl.gov

Idaho National Laboratory
+1 (208) 526-3657