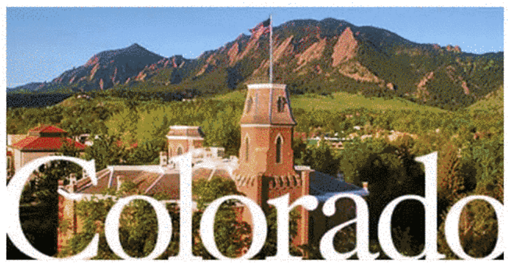
Using Cohesion Models to Explain Pressure Overshoot in Gas-Fluidized Beds

C. M. Hrenya
Department of Chemical and Biological Engineering
University of Colorado



KITP Granular Physics Conference - June 2005

Student: Michael Weber
Funding: National Science Foundation
Acknowledgments: DOE NETL and Prof. Murthy (Purdue Univ.)

Overview

System of Interest: ***fluidized bed with cohesive particles***

Long-Term Goal: ***incorporation of cohesion into continuum framework***

- Kim and Arastoopour (*AIChE J., 2002*)

Objective: ***assess effectiveness of simple cohesion model***

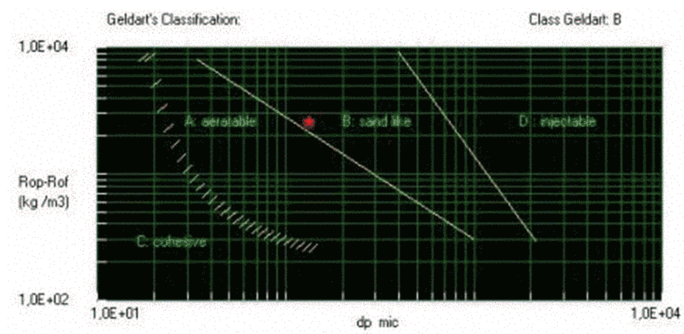
- Square-well model: binary, instantaneous interactions

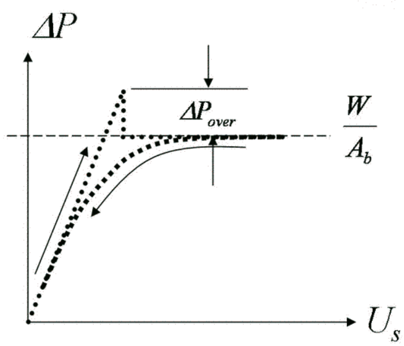
Approach: ***Eulerian-Lagrangian model***

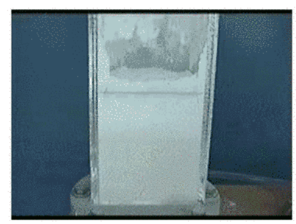
- Square-well model vs. Hamaker model for van der Waals forces

Effects of Cohesion in Fluidized Beds

1) Fluidization Quality
2) Mixing Levels
3) Pressure Overshoot (?)







Prof. Rhodes website, Monash University

Eulerian-Lagrangian model

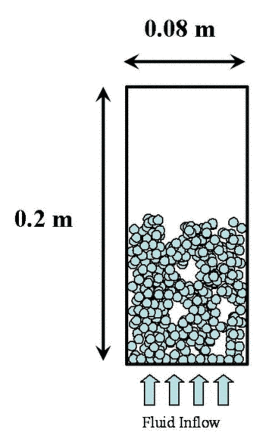
MFIX framework (DOE NETL)

Gas Phase: continuum

- 2D
- 27 x 30 cells

Particle Phase: discrete

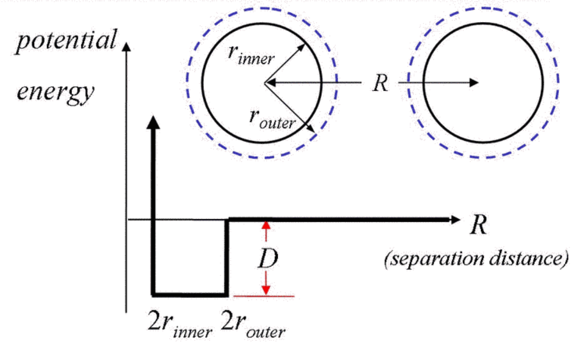
- extension of soft-sphere model (Prof. Murthy, Purdue)
- Linear-spring / dashpot
- inelastic, frictional spheres
- 4000 1-mm particles
- $\mu = 0.3$, $e = 0.94$, $t_{coll} = 9.25 \times 10^{-5}$ s



Cohesion Models

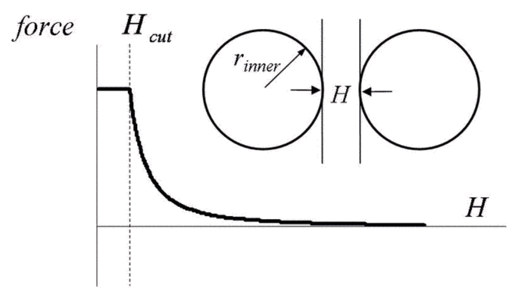
Square Well

- inputs: well depth ***D*** and outer radius r_{outer}
- **attractive force is *impulsive***

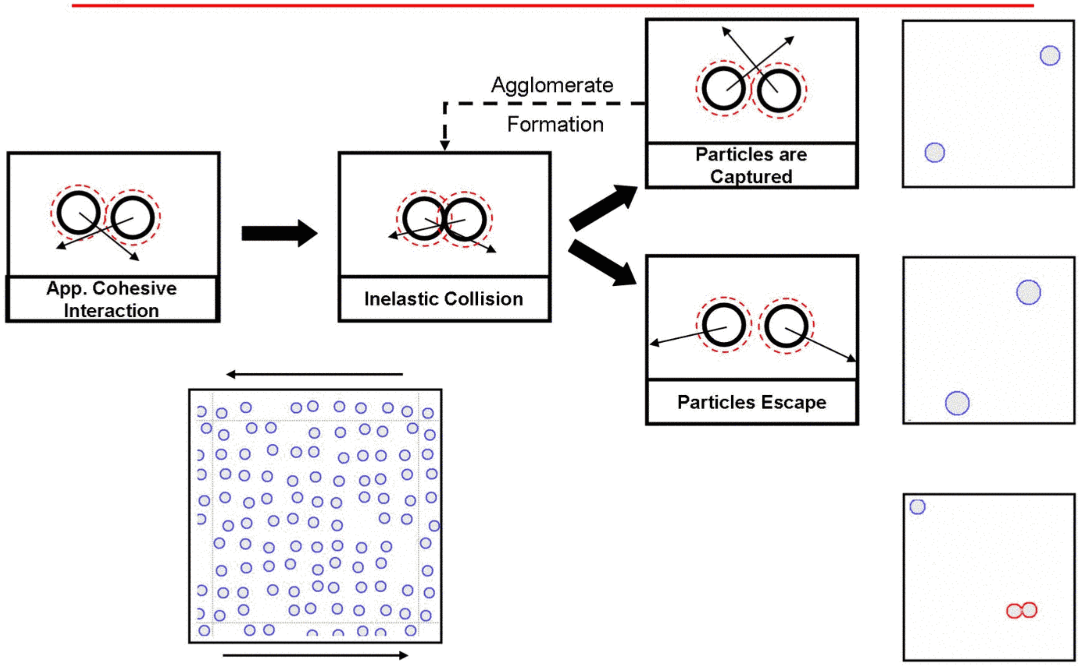


Hamaker

- inputs: Hamaker constant ***A*** and cutoff distance H_{cut}
- **attractive force varies continuously with separation distance *H***

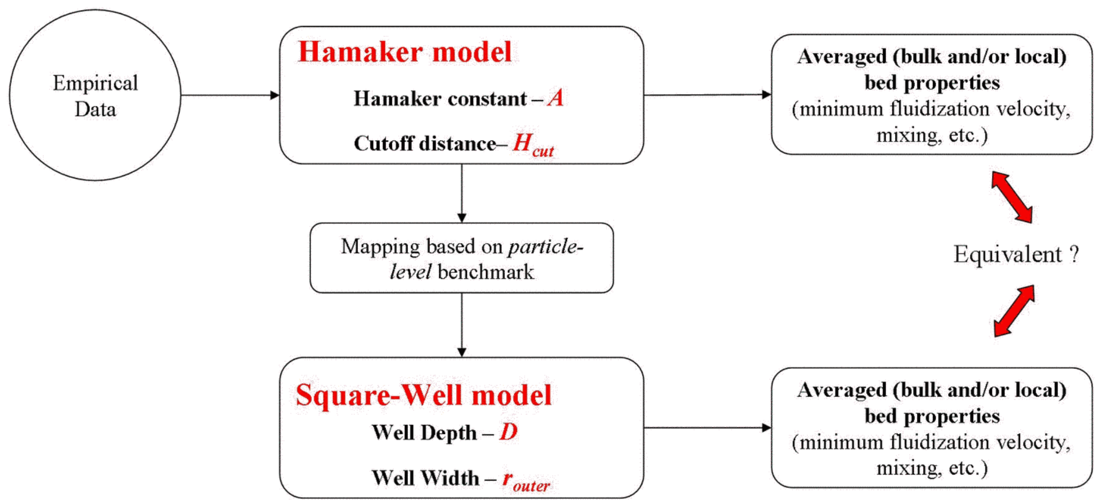


Square-Well: Particle interaction sequence



Weber, Hoffman, and Hrenya (Gran. Matter, 2004)

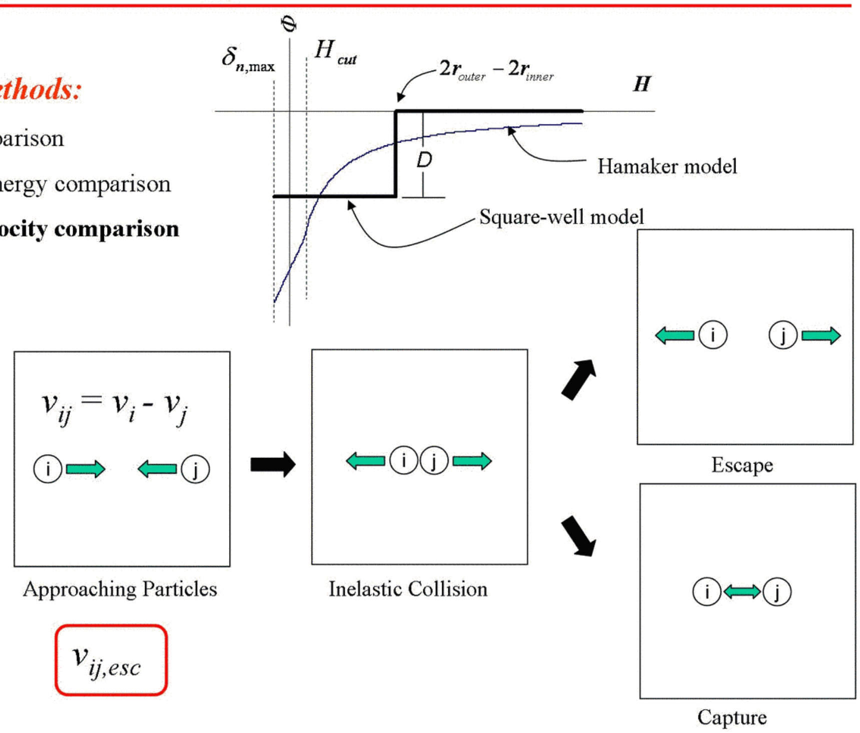
Mapping between cohesion models



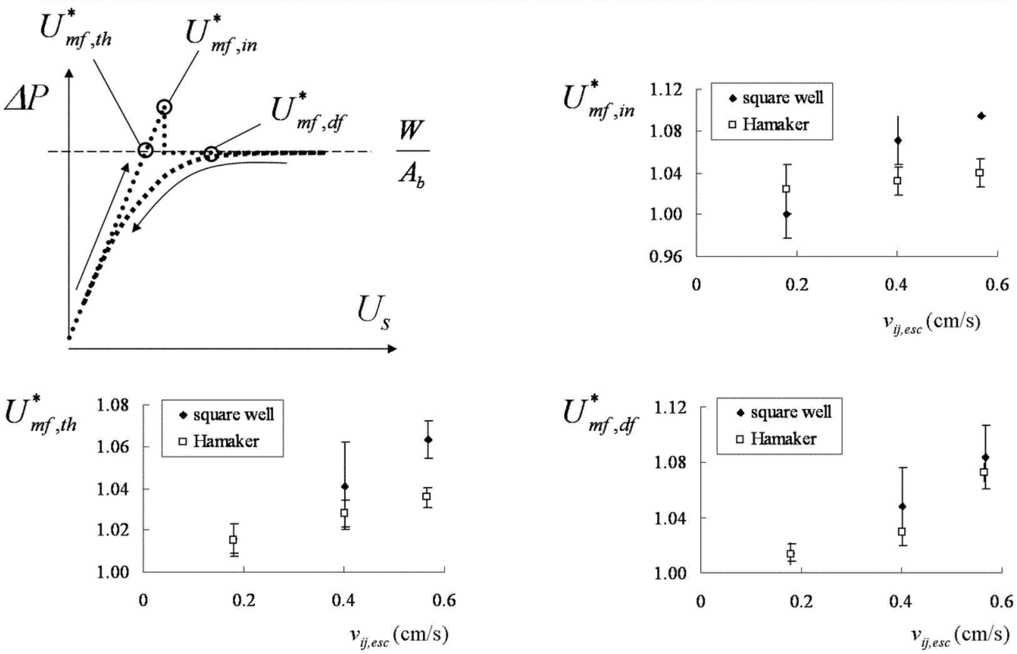
Mapping: Methodology

Possible Methods:

- Force comparison
- Potential energy comparison
- **Escape velocity comparison**

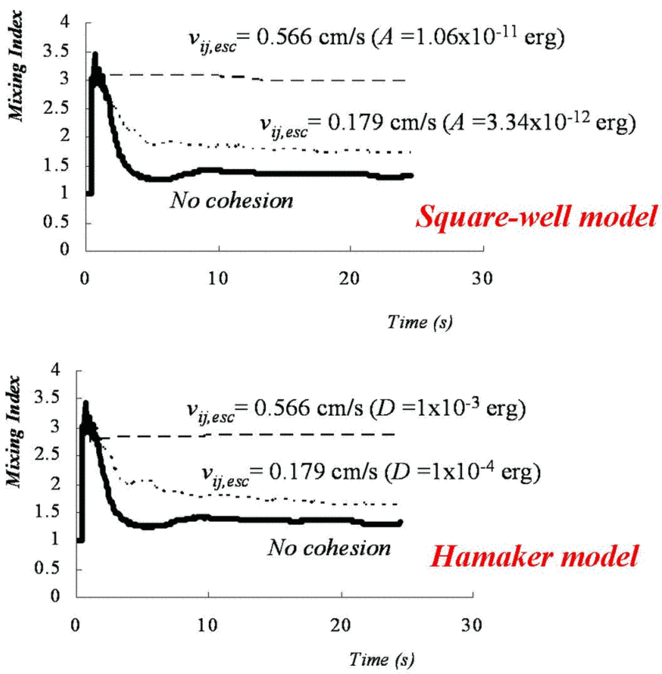


Mapping: Minimum Fluidization Velocities

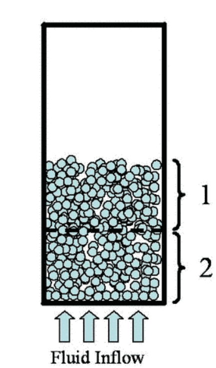


Escape velocity provides good common ground between models

Mapping: Mixing Index



$$I = \frac{\langle h_1 \rangle}{\langle h_2 \rangle}$$



Pressure Overshoot: Previous work

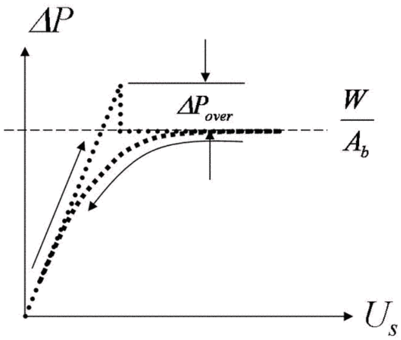
Experiments

- Pressure overshoot increases as bed width decreases *(Tsinontides and Jackson 1993, Loezos et al. ,2002; Srivastava and Sundaresan, 2002)*
- Pressure overshoot increases as moisture increases *(Tsinontides and Jackson 1993)*

Continuum Models

- Pressure overshoot increases with ***particle-wall friction: depends on bed width*** *(Jackson 1998)*
- Pressure overshoot increases with ***particle-particle cohesion: independent of bed width*** *(Jackson 1998)*

Challenge: *If overshoot depends on bed width, what is relative contribution of friction and cohesion?*

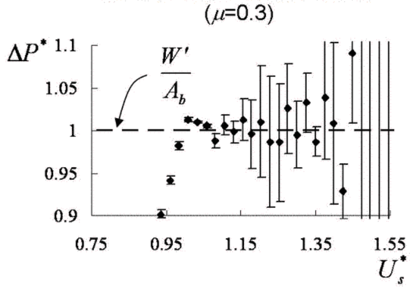


$$\frac{dp}{dy} = \beta(\nu)\frac{U_{sf}}{1-\nu}$$

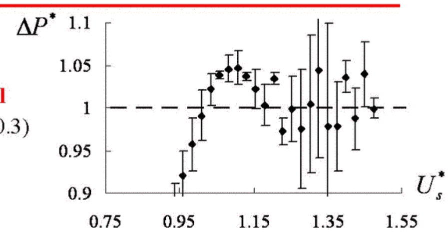
$$\frac{d\sigma_s}{dy} \pm \frac{4}{D}\mu j \sigma_s = \rho_p \nu g - \beta(\nu)\frac{U_{sf}}{1-\nu}$$

Pressure Overshoot: Cohesion vs. Friction

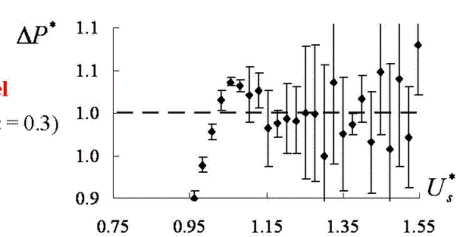
no cohesion, Normal Friction
(μ=0.3)



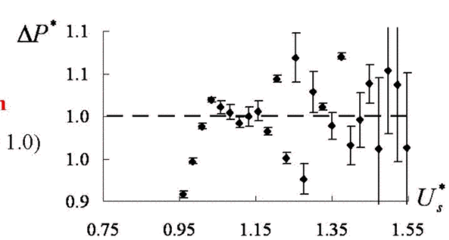
Square-Well model
(D = 5.0 x 10^{-4}, μ = 0.3)



Hamaker model
(A = 7.492 x 10^{-12}, μ = 0.3)

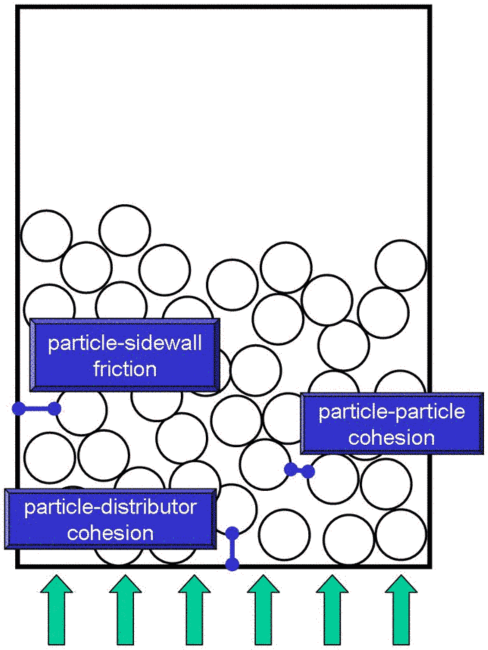


High Friction
(no cohesion, μ = 1.0)



The **pressure overshoot** is strongly affected by **cohesion**.

Pressure Overshoot: Square-Well model

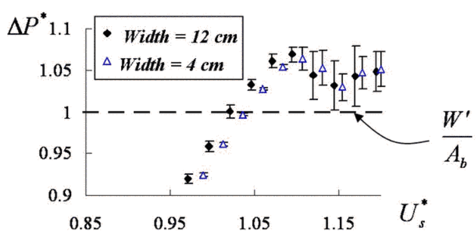


In simulations using **square-well** cohesion model, pressure overshoot primarily due to:
1 - ***particle-particle*** cohesion
2 - ***particle-distributor*** cohesion
3 - ***particle-sidewall*** friction

In simulations using **Hamaker** cohesion model, pressure overshoot primarily due to:
1 - ***particle-particle*** cohesion
2 - ***particle-sidewall*** friction
3 - ***particle-distributor*** cohesion

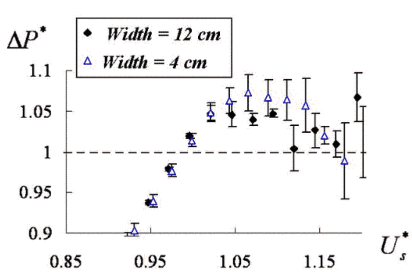
Pressure Overshoot: Bed Width

Square-well model



With ***Square-Well model***, pressure overshoot does not change as bed width is increased.

Hamaker model



With ***Hamaker model***, pressure overshoot decreases slightly as bed width is increased.

Conclusions

Escape-velocity mapping between Hamaker and square-well models is

- Strength: effective at predicting minimum fluidization velocity and mixing levels
- Weakness: not effective at predicting relative contributions of mechanisms for pressure overshoot

Mechanisms responsible for overshoot are

- Wall: Friction (*which may be influenced by cohesion*)
- Distributor Plate: Cohesion

Gordon Conference on Granular and Granular-Fluid Flows

When: **July 23-28, 2006**
Where: **The Queen's College**
Oxford, UK

Website: **http://www.grc.uri.edu/programs/2006/granular.htm**

Contacts: **Christine Hrenya (hrenya@colorado.edu) – Chair**
Bob Behringer (bob@phy.duke.edu) – Vice Chair

$$\left(\bar{k}\cdot\bar{v}_{rel,post-coll}\right)^2 = \frac{4D}{m} + \left(\bar{k}\cdot\bar{v}_{rel,pre-coll}\right)^2$$

$$\left(\bar{k}\cdot\bar{v}_{rel,post-coll}\right)^2 = \left(\bar{k}\cdot\bar{v}_{rel,pre-coll}\right)^2 - \frac{4D}{m}$$