GAS-SOLID DYNAMICS IN CORRUGATED PLATE FLUIDIZED BEDS

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A New design of gas-solid fluidized bed by using CORRUGATED WALLS instead of conventional flat plates is under investigation

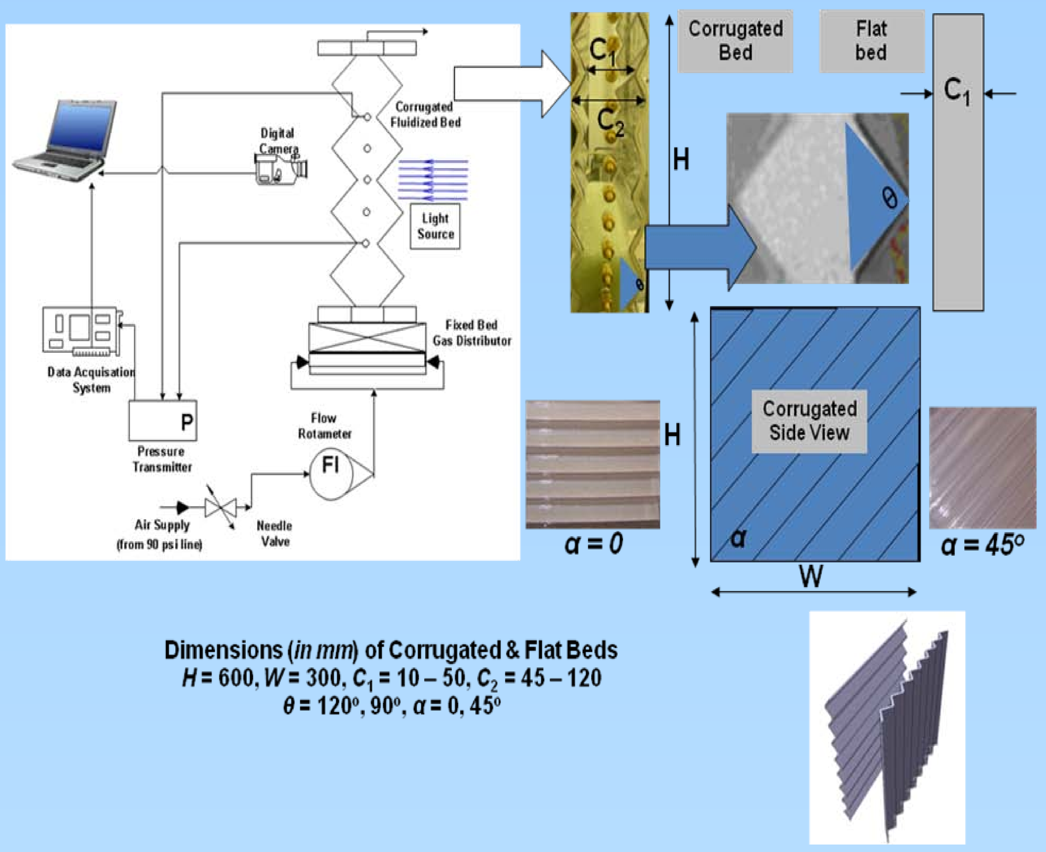
What is Important

Current Objectives

Effect of corrugations on

- **Minimum Fluidization Velocity**
- **Bubble Dynamics (Size, Rise Velocity)**
- **Mixing and/or Segregation of particles**
- **Wall-to-Bed Heat Transfer**

Schematics of Experimental Setup



Dimensions (*in mm*) of Corrugated & Flat Beds
H = 600, *W* = 300, C_1 = 10 – 50, C_2 = 45 – 120
θ = 120°, 90°, *α* = 0, 45°

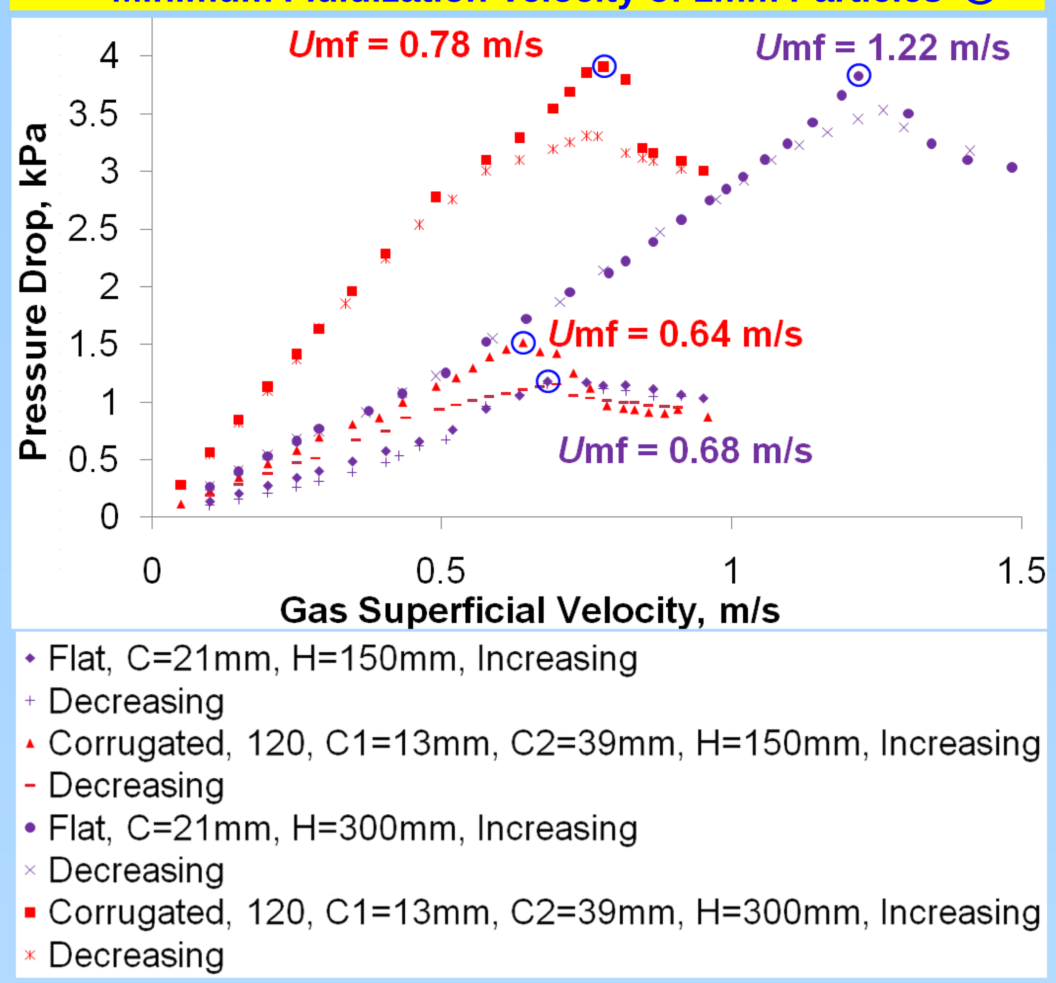
Minimum Fluidization Velocity (U_{mf})

Gas superficial velocity at which, the bed pressure drop exactly balances the net downward forces (gravity minus buoyancy forces) on the bed packing.

$$\frac{\Delta P}{L_{mf}} = (1-\varepsilon_{mf})(\rho_s - \rho_g)g$$

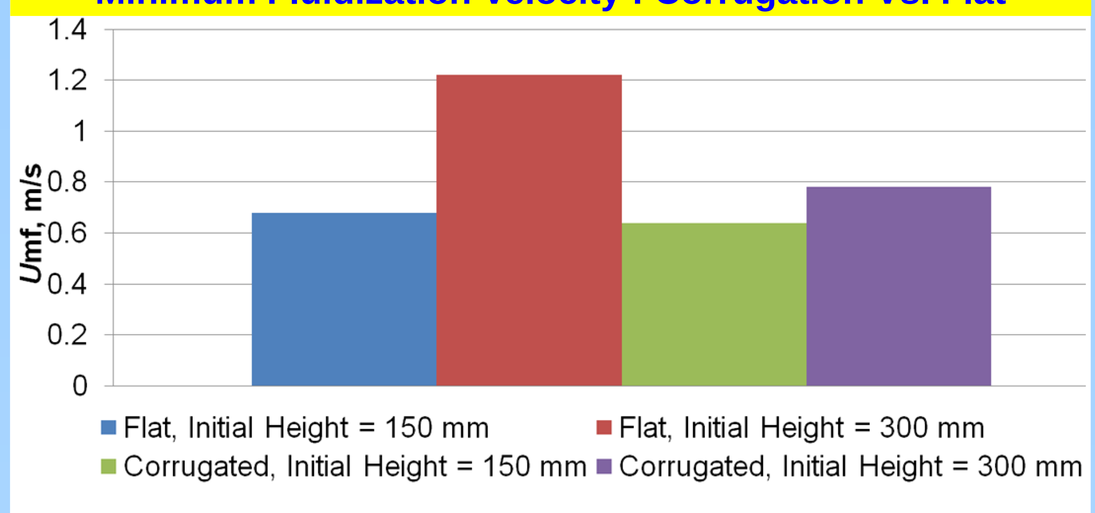
Void fraction at U_{mf} — Density difference at U_{mf} — Bed height at U_{mf} condition

Minimum Fluidization Velocity of 1mm Particles



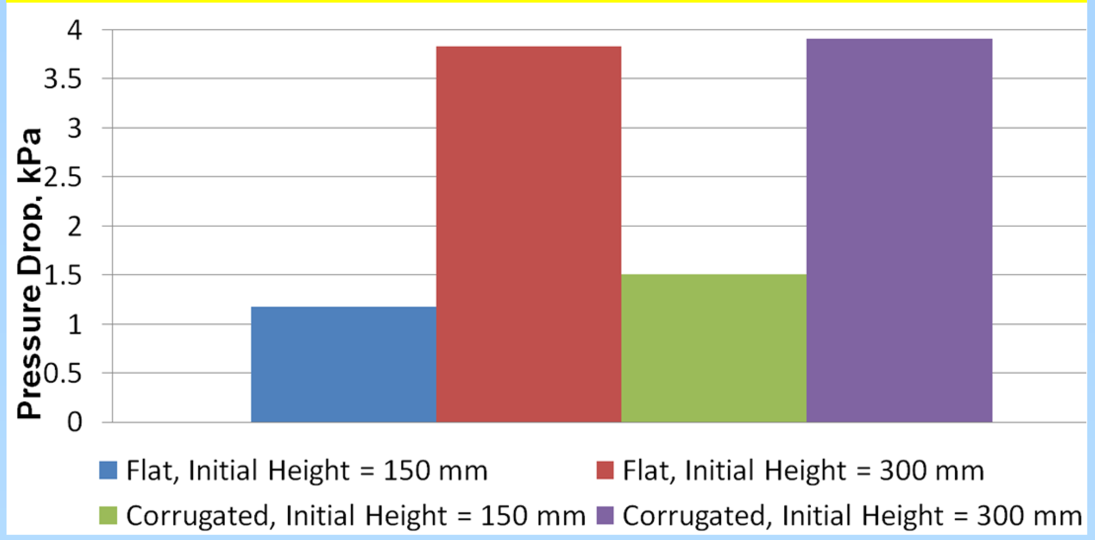
*In case of corrugated beds, gas superficial velocity is calculated on the basis of mean clearance between plates (i.e., 21 mm)

Minimum Fluidization Velocity : Corrugation Vs. Flat



	Flat	Corrugated	
Height (mm)	U_{mf} (m/s)		%increase
150	0.68	0.64	6.3
300	1.22	0.78	56.4
% increase	79.4	21.9	

Pressure Drop: Corrugation Vs. Flat



	Flat	Corrugated	
Height (mm)	Pressure Drop (kPa)		%increase
150	1.18	1.51	28
300	3.83	3.91	2.1
% increase	224.6	158.9	

Properties of Particles & Fluidizing Gas

Property	Description			
Particles	Soda Lime Glass			
Size Ranges (μm)	149-210	210-297	1000	2000
Mean Diameter (μm)	177.9	252.5	-	-
Density (kg/m³)	2500			
Sphericity	≥ 85 % ≈ 1			
Geldart Classification	B	B	D	D
Gas	Air			
Density (kg/m³ @ STP)	1.184			
Viscosity (kg/ m/ s @ STP)	1.983 × 10⁻⁵			

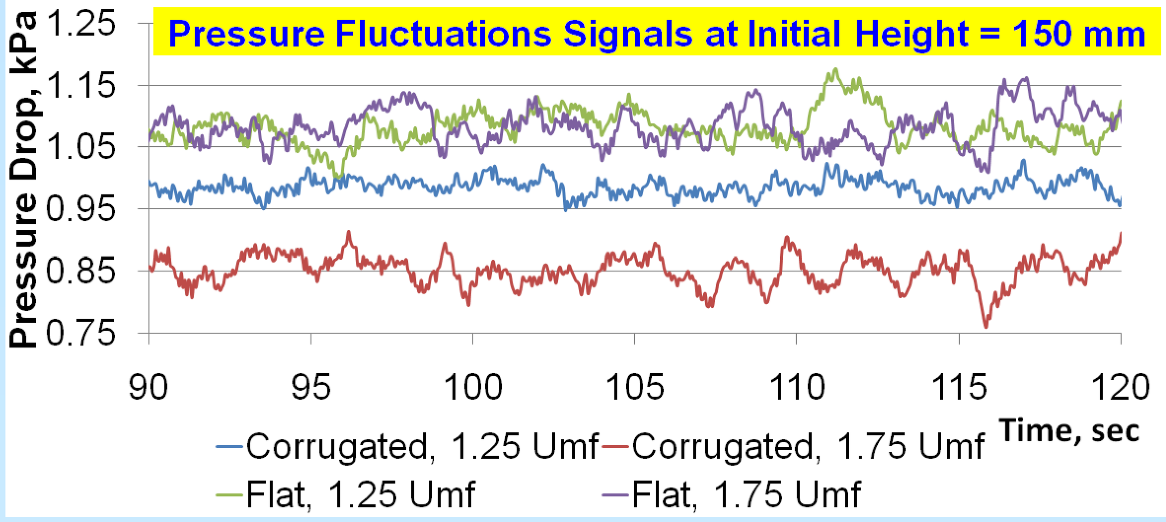
Discussion on U_{mf} & Pressure Drop:

- **Flat walls offer higher U_{mf} at both tested initial bed heights, i.e., 150 mm & 300 mm**
- **U_{mf} is less sensitive to initial bed height for corrugated walls vs. flat walls**
- **At an initial height of 300 mm, % increase in U_{mf} is 56.4 while using flat walls. It shows that corrugated walls are more effective at high a value of initial bed height**
- **Corrugated walls offer high pressure drop especially at low value of initial heights of bed (shallow beds)**
- **% increase in pressure drop due to corrugated walls at 150 mm initial bed height is 28 but it is negligible (2.1 %) at 300 mm. It verifies that corrugated walls are more effective at high bed heights due to its special features of *low U_{mf} and approximately same pressure drop as in flat***
- **Likewise U_{mf}, % increase in pressure drop due to corrugated walls is relatively less sensitive to initial bed height as compared to flat walls (% increase due to flat and corrugated = 224.6 and 158.9 respectivley)**

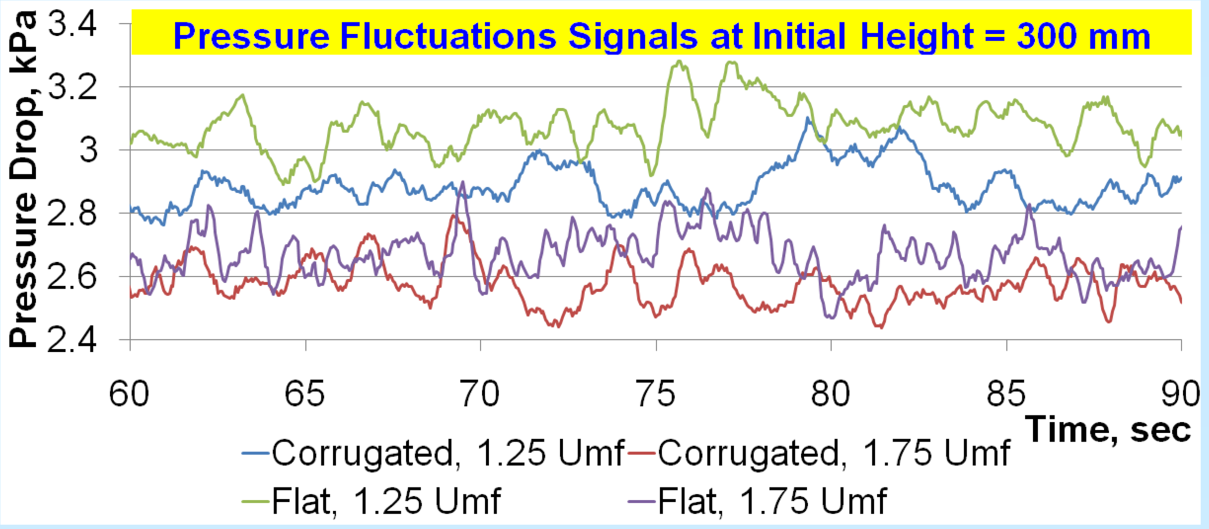
Role of Corrugation in decreasing the U_{mf} of particles

Pressure Fluctuations

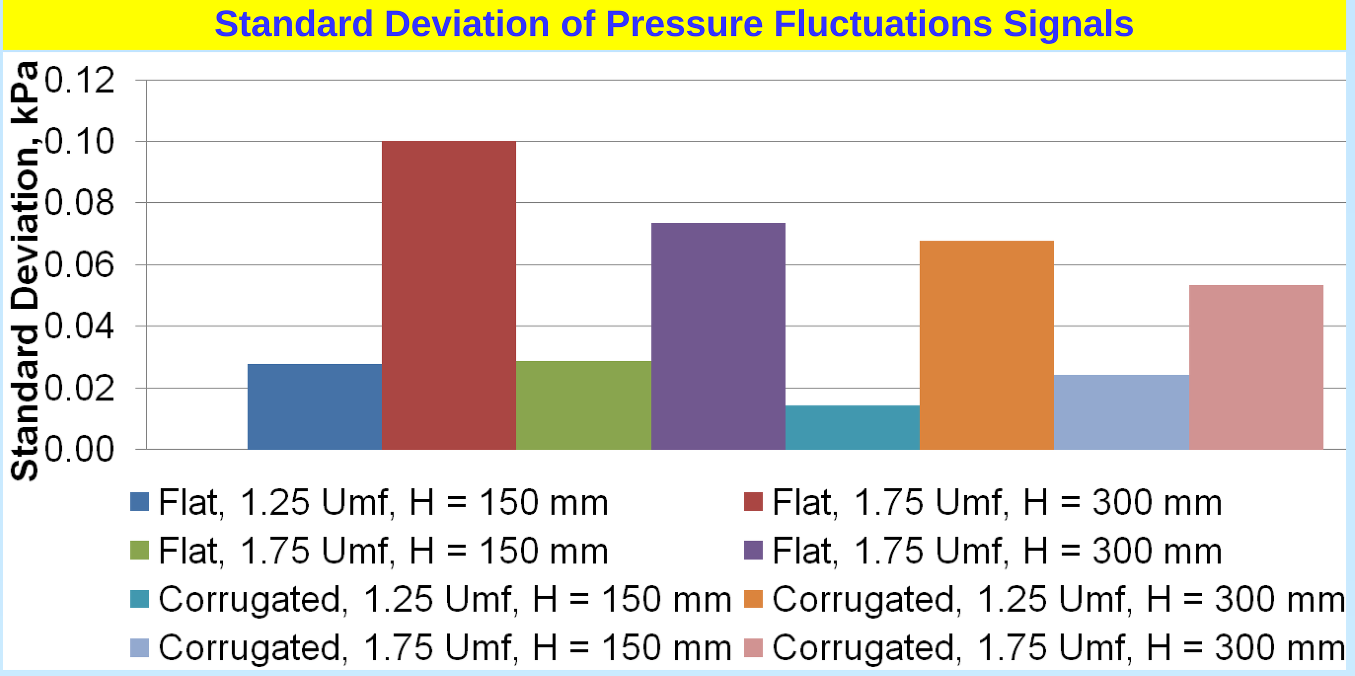
Pressure Fluctuations Signals at Initial Height = 150 mm



Pressure Fluctuations Signals at Initial Height = 300 mm



Standard Deviation of Pressure Fluctuations Signals



	Flat		Corrugated	
Height (mm)	Standard Deviation			
	1.25 Umf	1.75 Umf	1.25 Umf	1.75 Umf
150	0.028	0.029	0.014	0.024
300	0.100	0.074	0.068	0.053

Discussion on Pressure Fluctuations

- **Pressure Fluctuation (PF): shallow beds are stable at both gas superficial velocities (1.25 U_{mf} & 1.75 U_{mf}): Low PF Standard Deviation of shallow beds**
- **PF Standard Deviation shows that corrugated beds are more stable than flat beds**
- **Increase in standard deviation due to initial bed height is relatively lower for corrugated beds, especially at high gas flowrates**

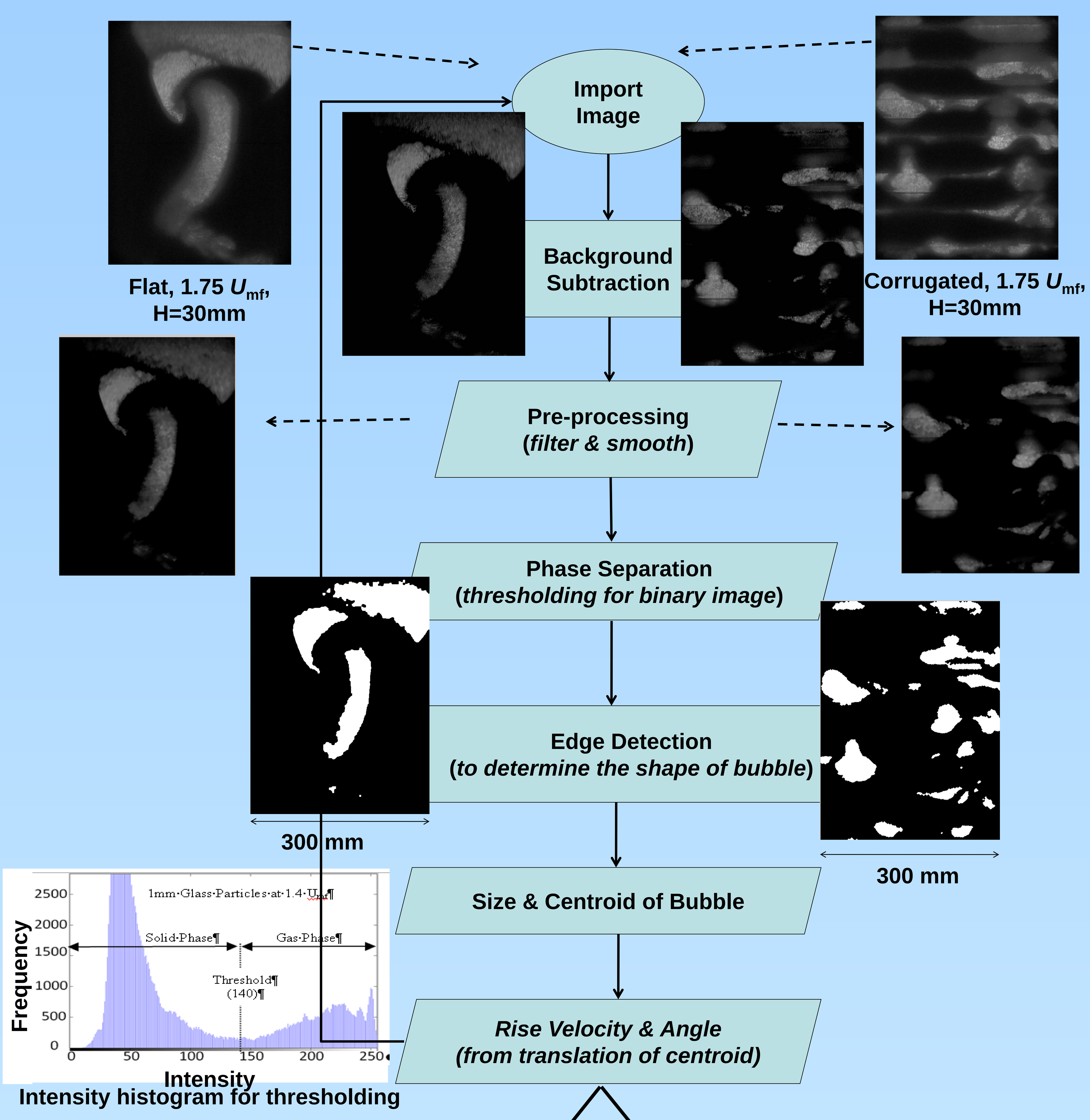
Introduction

- **Mixing of particles** in gas-solid fluidized beds: as an important parameter influencing both heat and mass transfer rates and therefore the apparent reaction rates of catalytic/non-catalytic reactions
- In the case of endothermic gasification, those **transfer performances** can deeply influence the reactor temperature, thus the syngas composition and overall thermal efficiency of the process
- In allothermal/autothermal gasification process, combustion of residues is delocalized in an adjacent fluidized bed and heat is then brought to the gasifier by a **circulating solid carrier or through a separating wall**
- In both cases, ***High heat losses and/or a poor heat transfer*** through the separating wall

Bubble Dynamics by Using Digital Image Analysis Technique

Principle: Use of pixel intensity to discriminate between bubble & emulsion phases. Backlight is used in Bubble Dynamics Study with a high speed camera* (Images capture at 205 frames per s over 30 s period with 200 μsec exposure time).

Algorithm for Digital Image Analysis



Equivalent Diameter

$$d_b = \sqrt{\frac{4S_b}{\pi}}$$

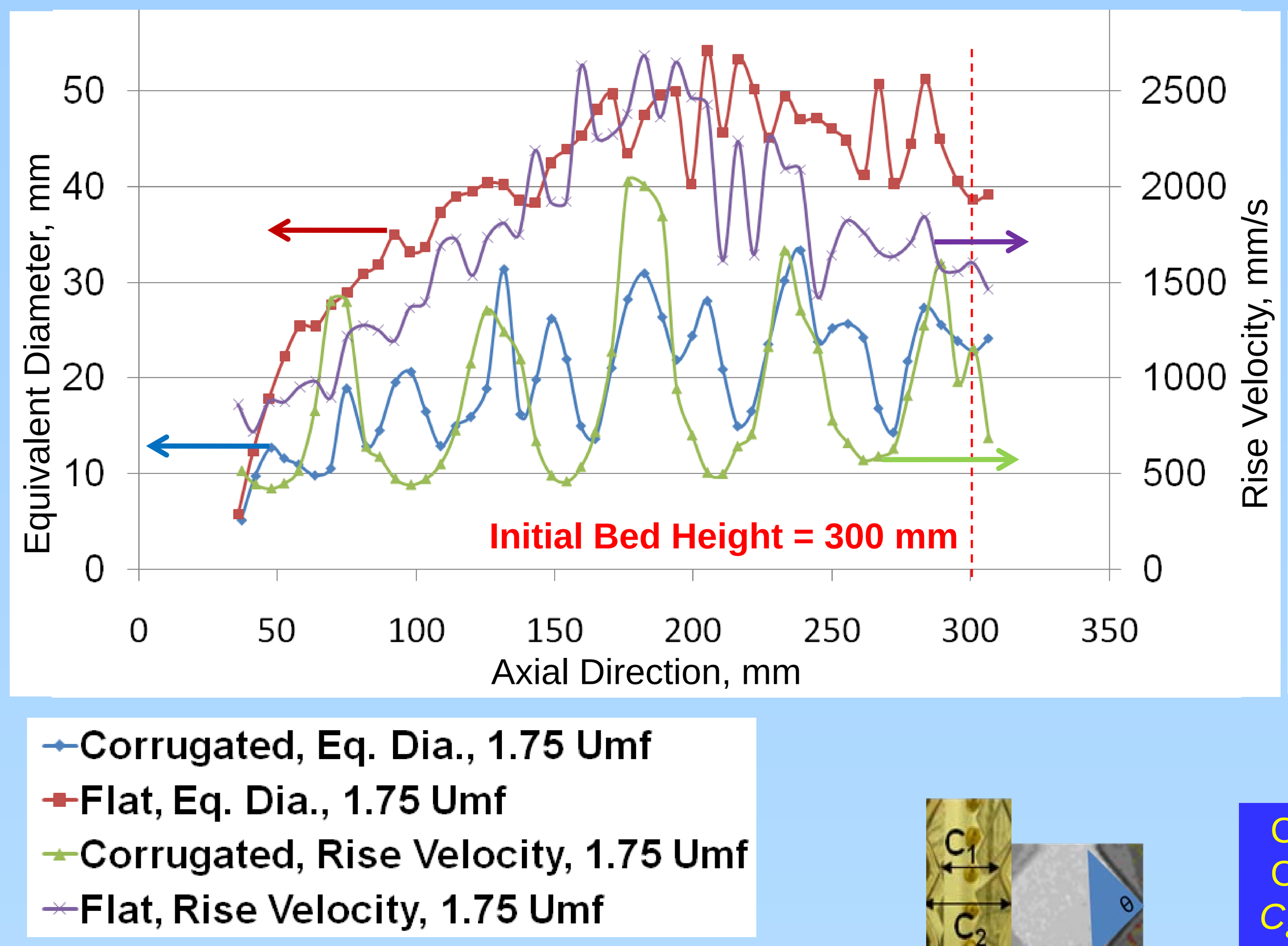
Rise Velocity

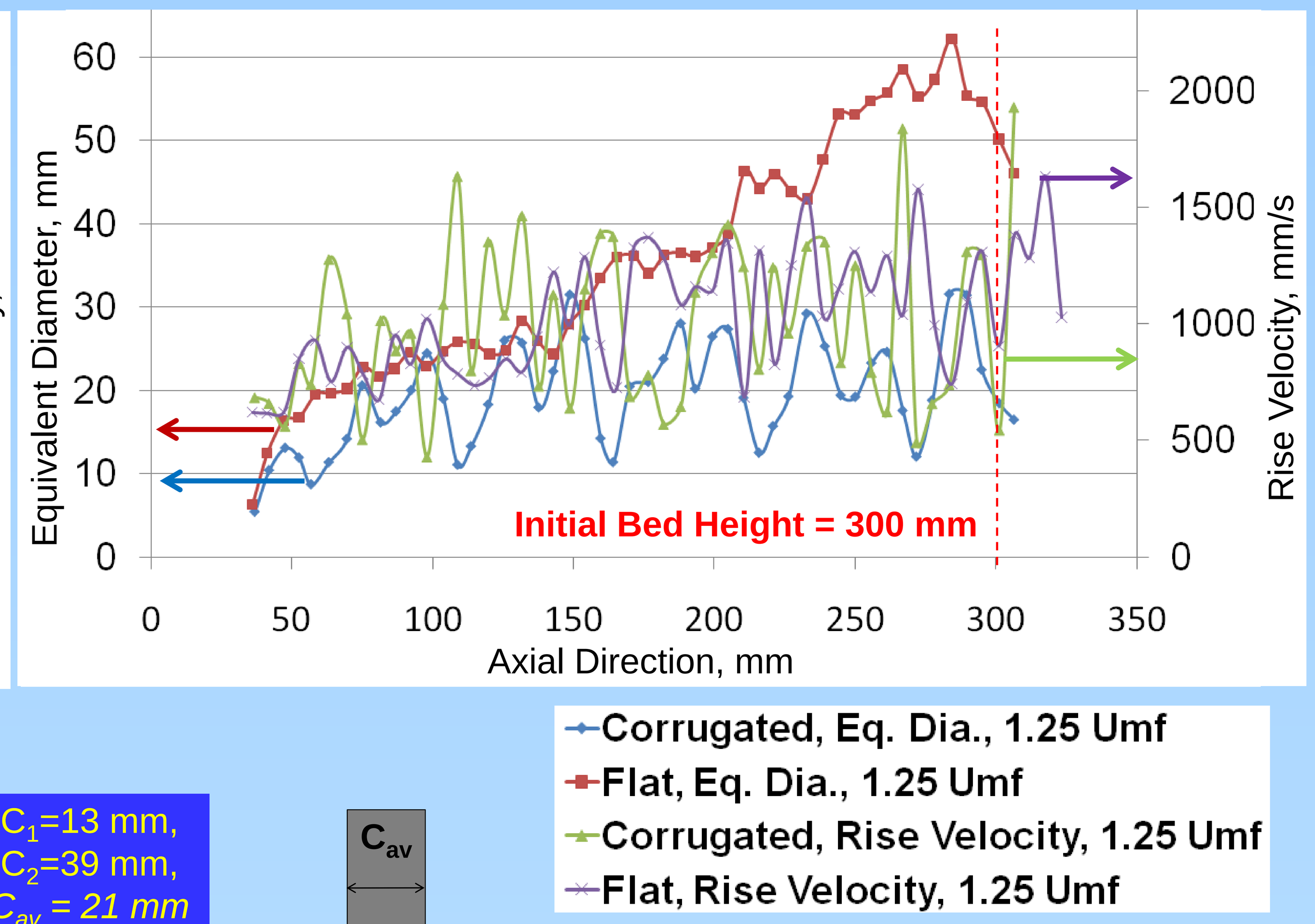
$$\frac{Translation\ of\ Centroid}{\left(\frac{1}{fps} + Exposure\ time\right)}$$

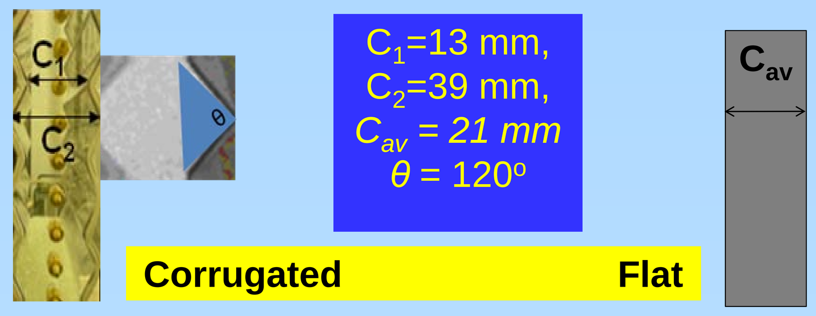
S_b = bubble projected area, *fps* = frames per s

*Specifications of Camera: HS-200 TSI Inc., USA.
Frames per second = 205.
Software: Insight 3G

Axial Variation in Bubble Equivalent Diameter & Rise Velocity
(Corrugatied vs. Flat at Initial Bed Height = 300 mm)



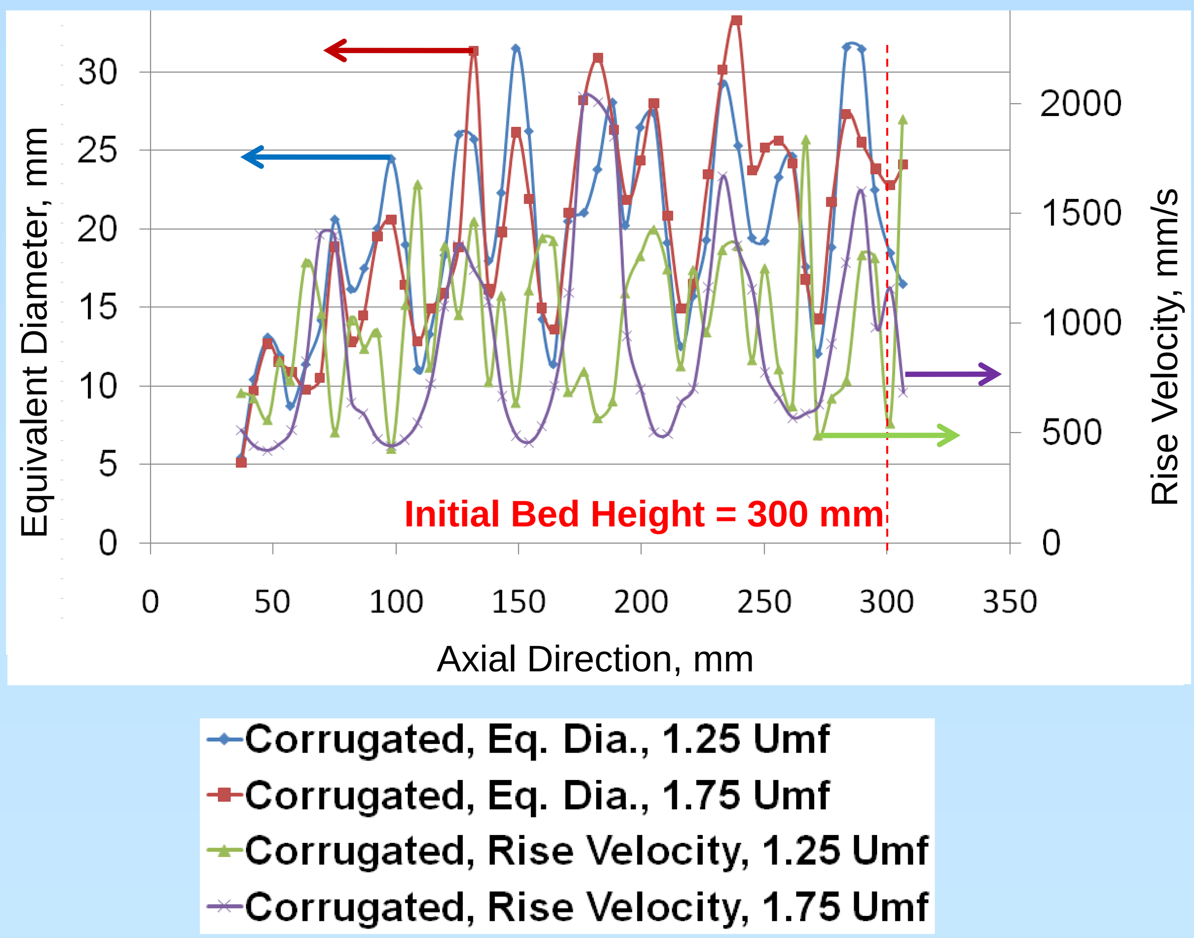


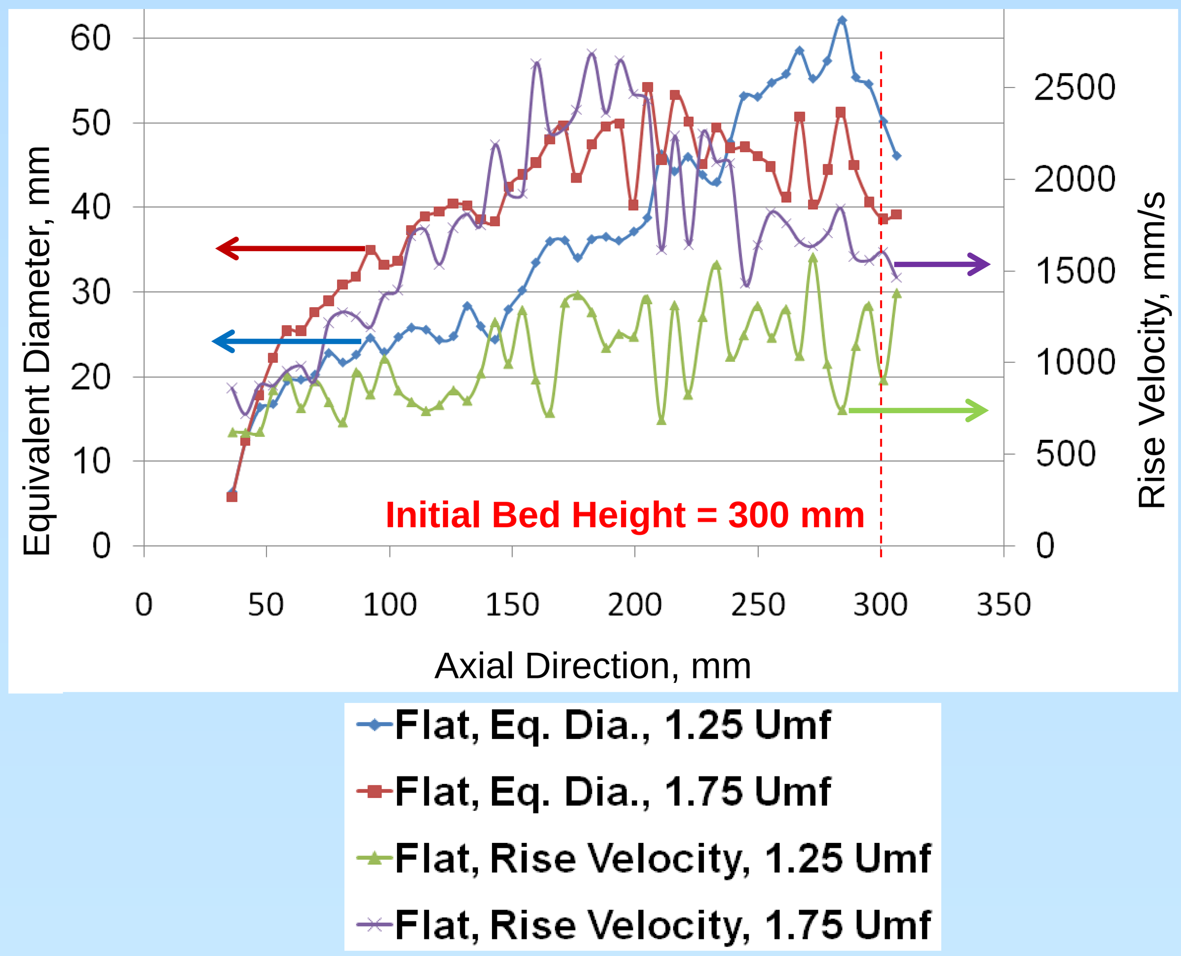


C_1=13 mm,
C_2=39 mm,
C_{av} = 21 mm
θ = 120°

Corrugated Flat

Axial Variation in Bubble Equivalent Diameter & Rise Velocity
(Effect of Gas superficial velocity at Initial Bed Height = 300 mm)





Discussion on Bubble Equivalent Diameter and Rise Velocity:

- **Corrugated walls offer significant continuous bubble breakup as compared to flat walls**
- **Bubble breakup happens at the neck (*minimum clearance*) between the corrugated walls**
- **Size of bubbles in case of flat walls is higher than for corrugated walls at same gas velocity**
- **Bigger bubbles move with higher velocities in both the cases (corrugated and flat)**

Conclusion: New design of gas-solid fluidized bed with corrugated walls has shown significant decrease in U_{mf} and Bubble Size due to enhanced bubble breakup at the neck between two plates. Further research is needed on various configurations and modeling of such systems.

Ongoing and Future Work : Study the effect of different configurations of corrugated walls on:

- **Minimum fluidization velocity of particles**
- **Bubble Dynamics (Bubble Size and Rise Velocity) by using Digital Image Analysis Technique**
- **Mixing & Segregation of binary mixture by using Digital Image Analysis and Fluorescence Particle Image Velocimetry Techniques**
- **Experimental investigation of heat transfer in the vicinity of corrugated walls by using fast response heat flux probes**
- **CFD modeling and simulatiosn of experiemtnal results by using FLUENT 6.3.26 software**