2017 NETL Workshop on Multiphase Flow Science

Determination of Flow Patterns by Image Analysis of a Rectangular Spouted Bed

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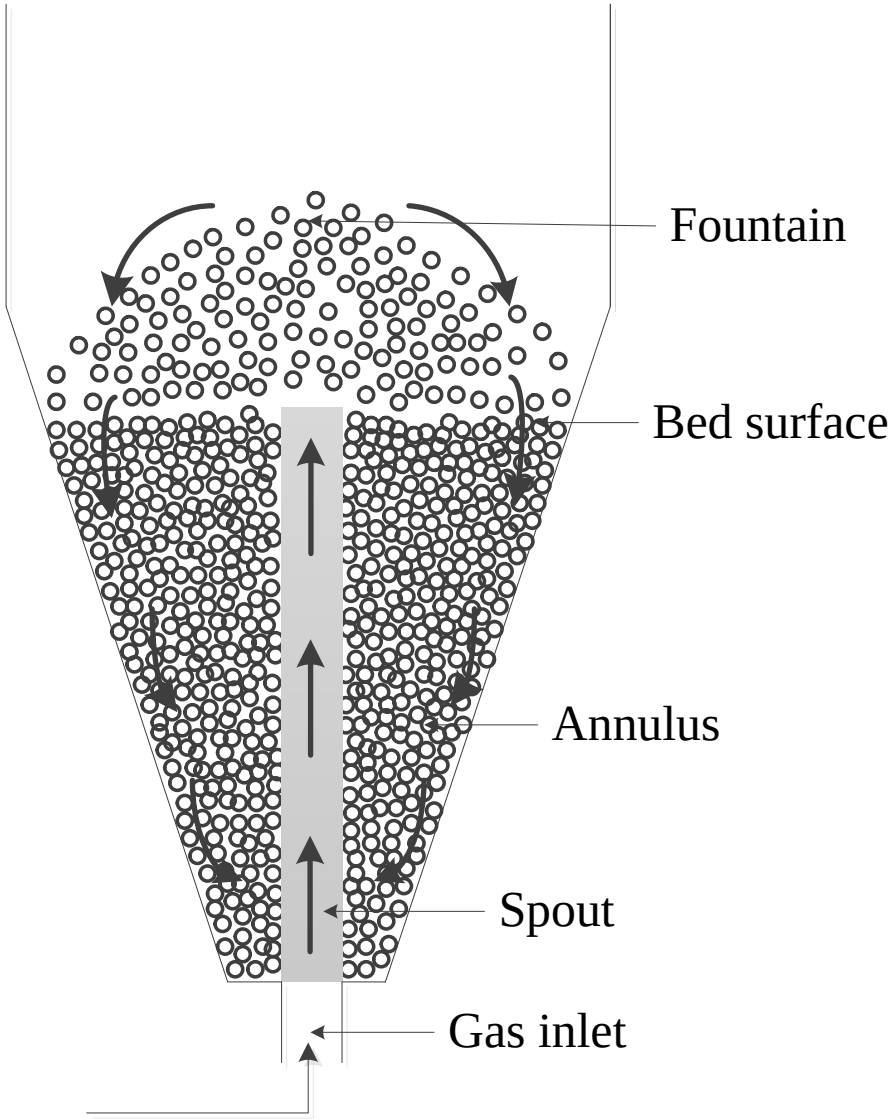
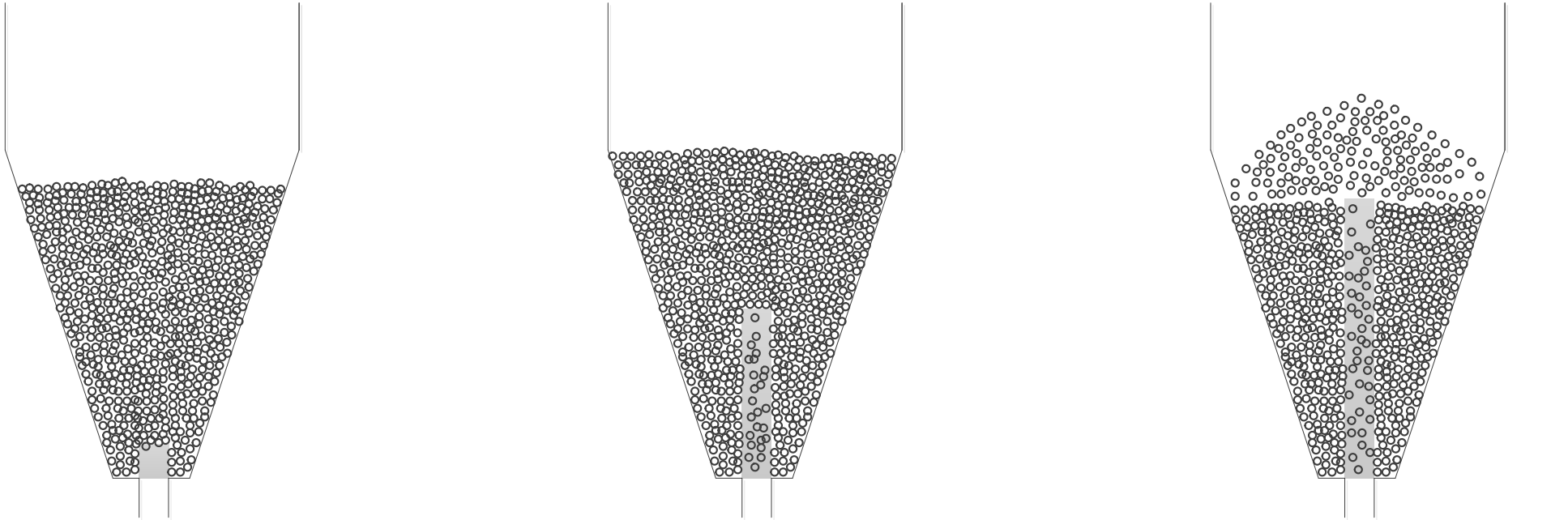
Introduction-*Spouted phenomenon*



For a vessel filled with coarse particles, when the gas is injected vertically through a centrally located opening, the resulting high-velocity jet leads to a stream of particles rising rapidly in a **hollowed central core** within the bed of particles. Particles carried above the bed surface, rain back on the **annular region between the hollowed core and the column wall**.

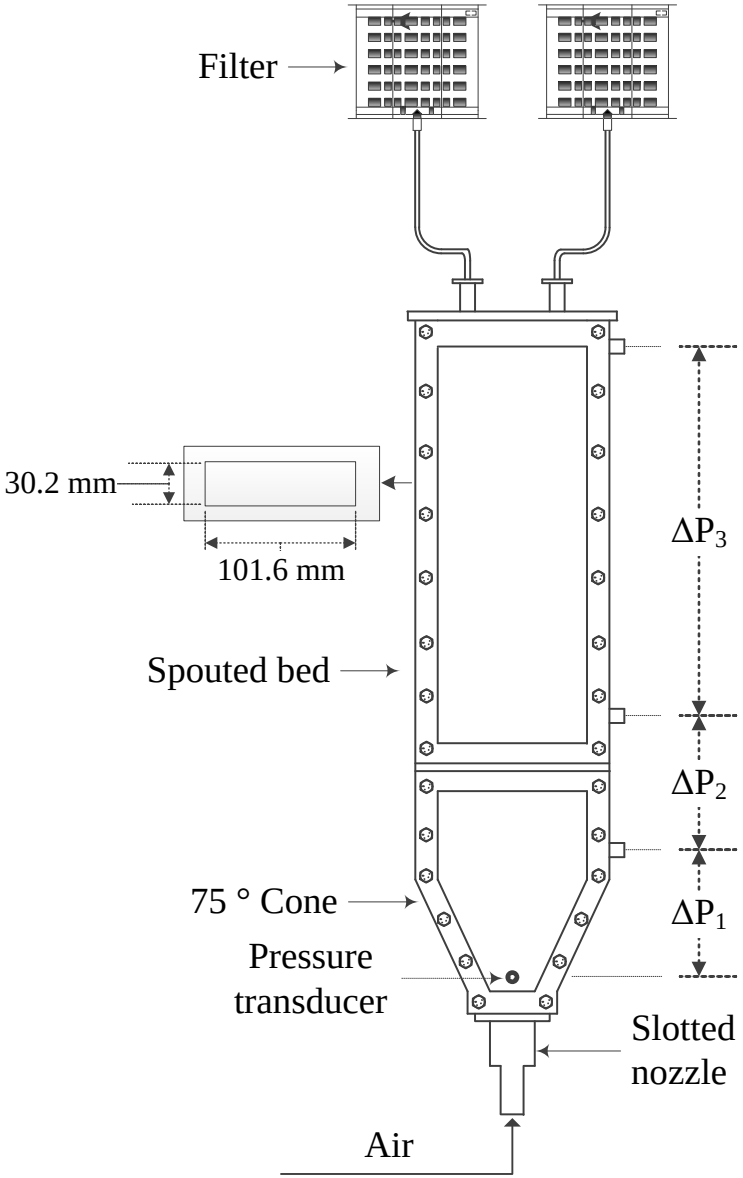
A composite of a **dilute phase central core** with upward-moving solids entrained by a concurrent air flow and a **dense phase surrounding** with downward particle flow.

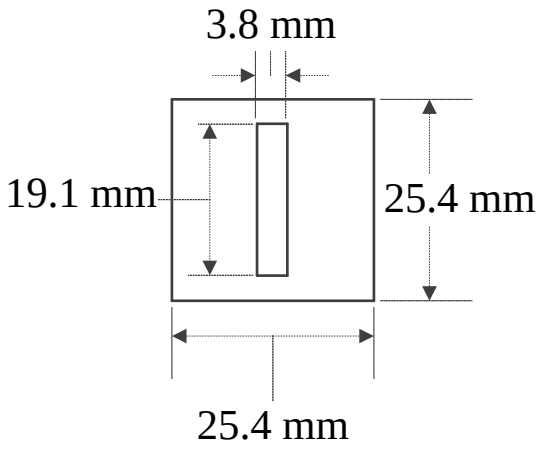
Introduction-*Evolution of typical spouting process*



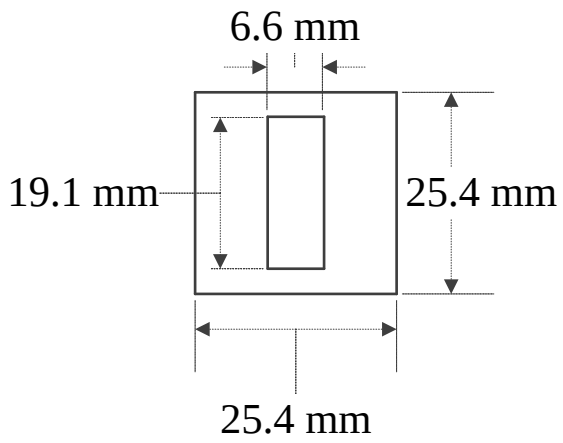
Hydrodynamics in spouted beds have been characterized extensively by optical fiber systems and pressure fluctuation analysis. With the development of high speed video cameras and imaging analysis methods, an alternative method based on image analysis was proposed to study the hydrodynamics in a rectangular spouted bed in this study.

Experimental systems-*Spouted bed & visualization apparatus*

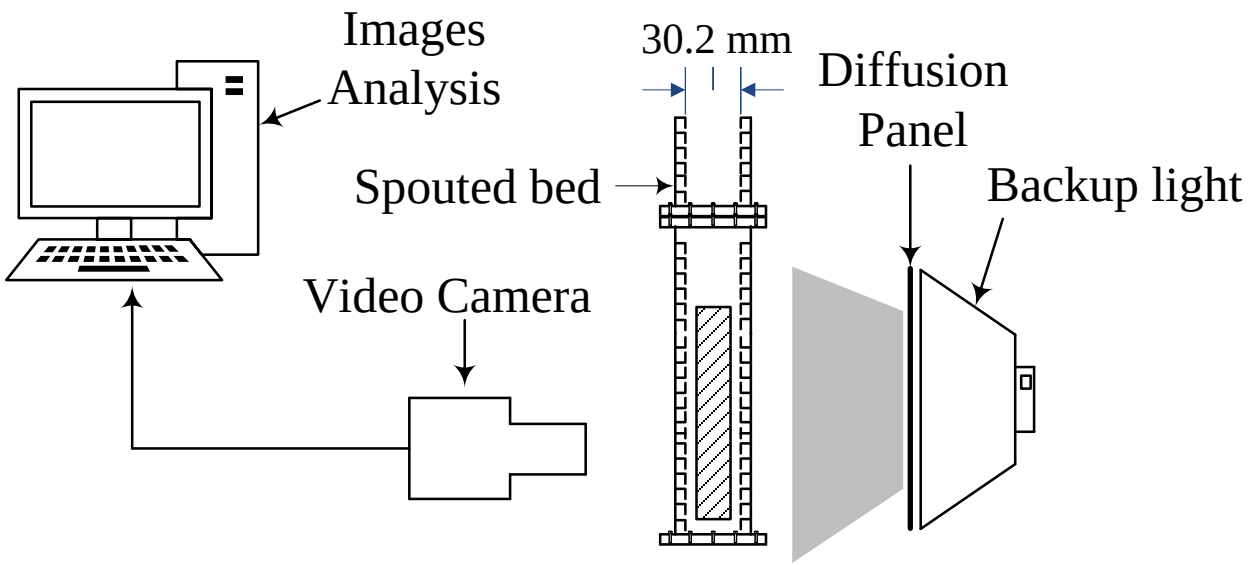




D_{equ} = 9.6 mm

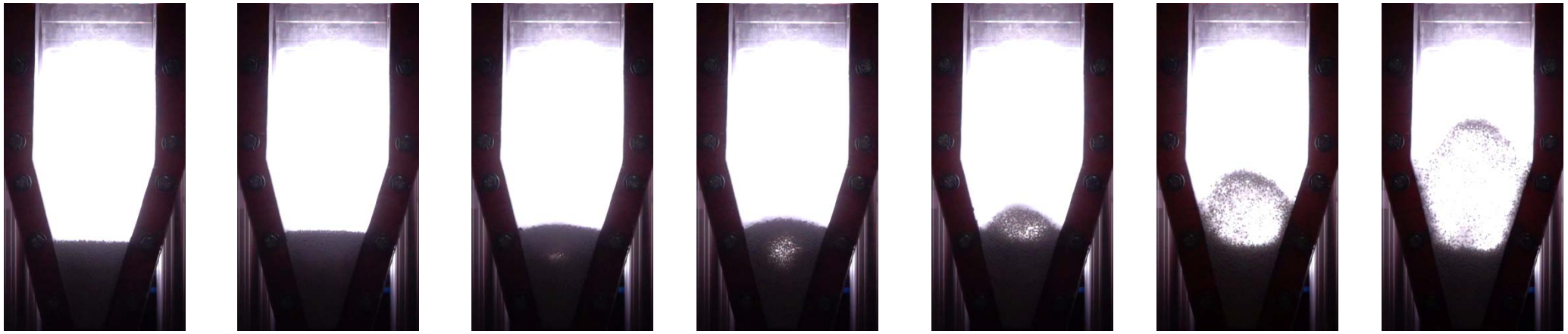


D_{equ} = 12.7 mm



Flow pattern observation

Alumina



Static | Expansion | Bubble development | External spouting

Static | Jet development | External spouting

Increasing gas flow rate

Nylon

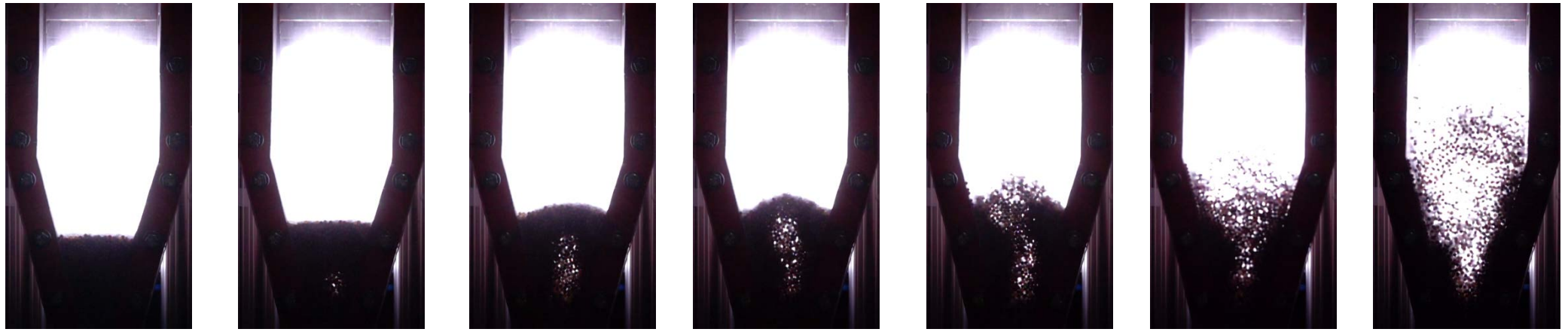
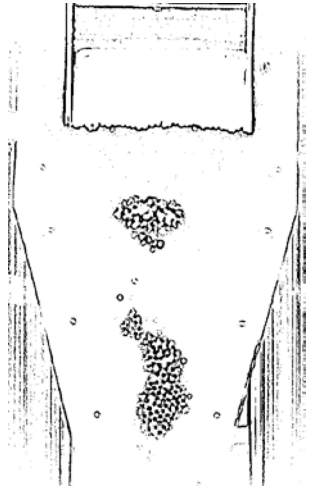


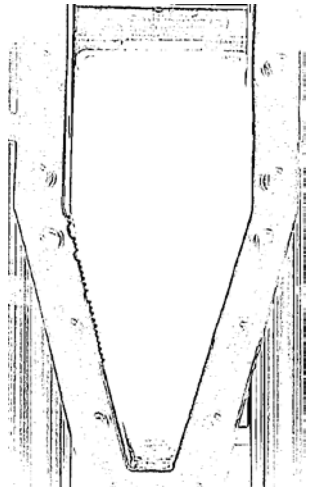
Image preliminary processing

(a)

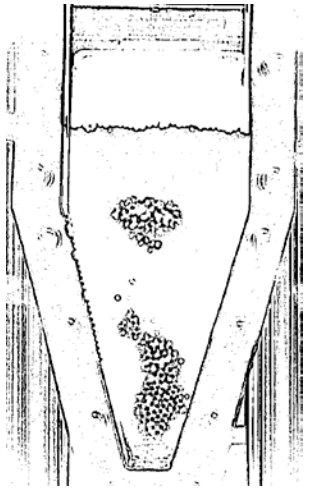


(c)

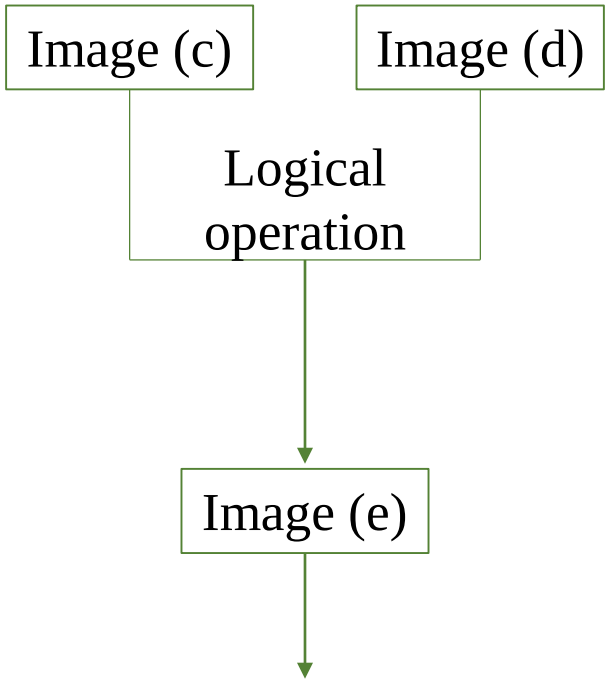
(b)

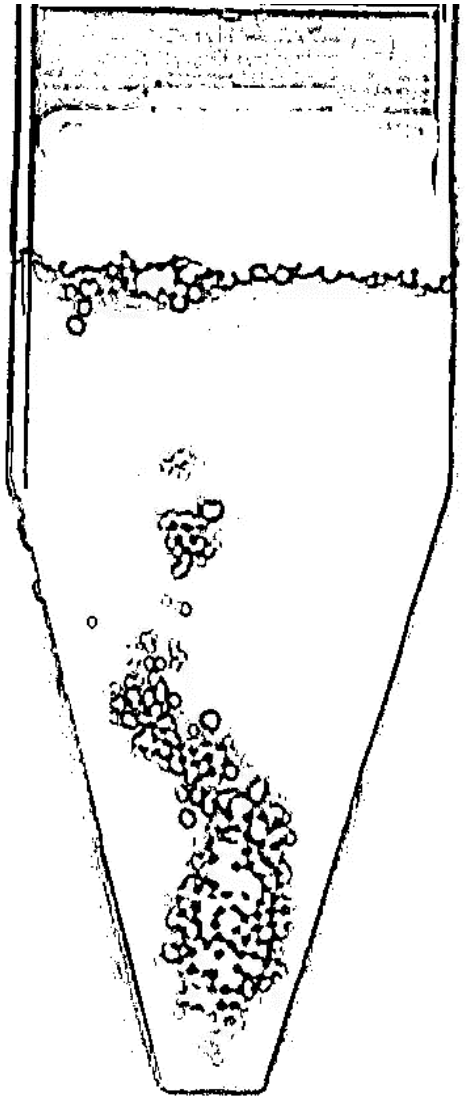


(d)

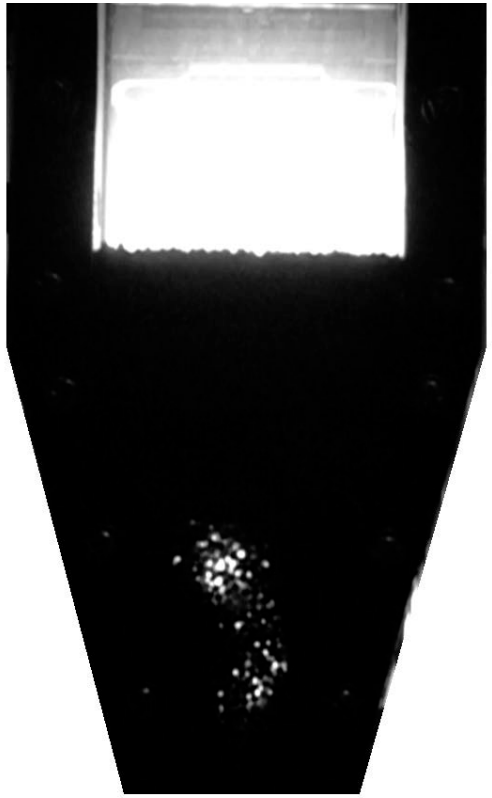


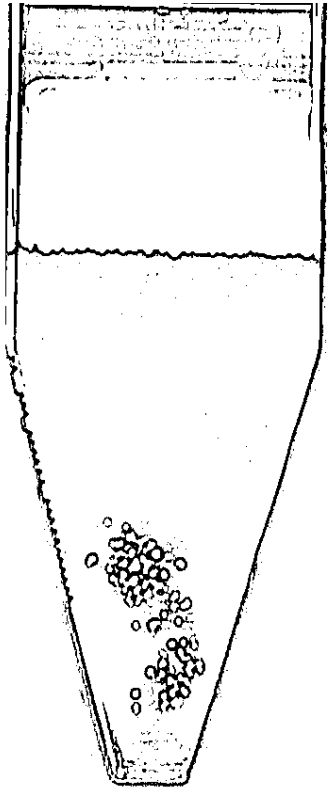
(e)

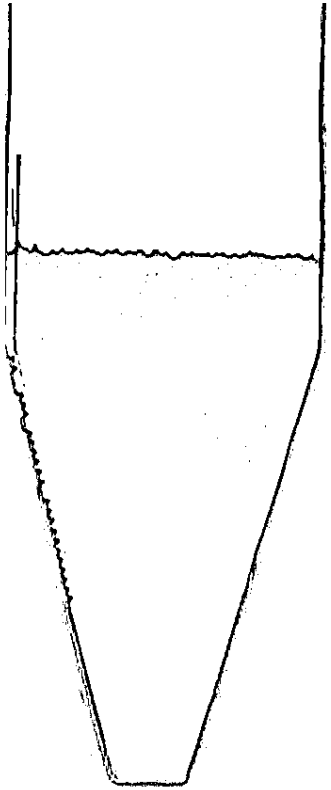




Bed height determination







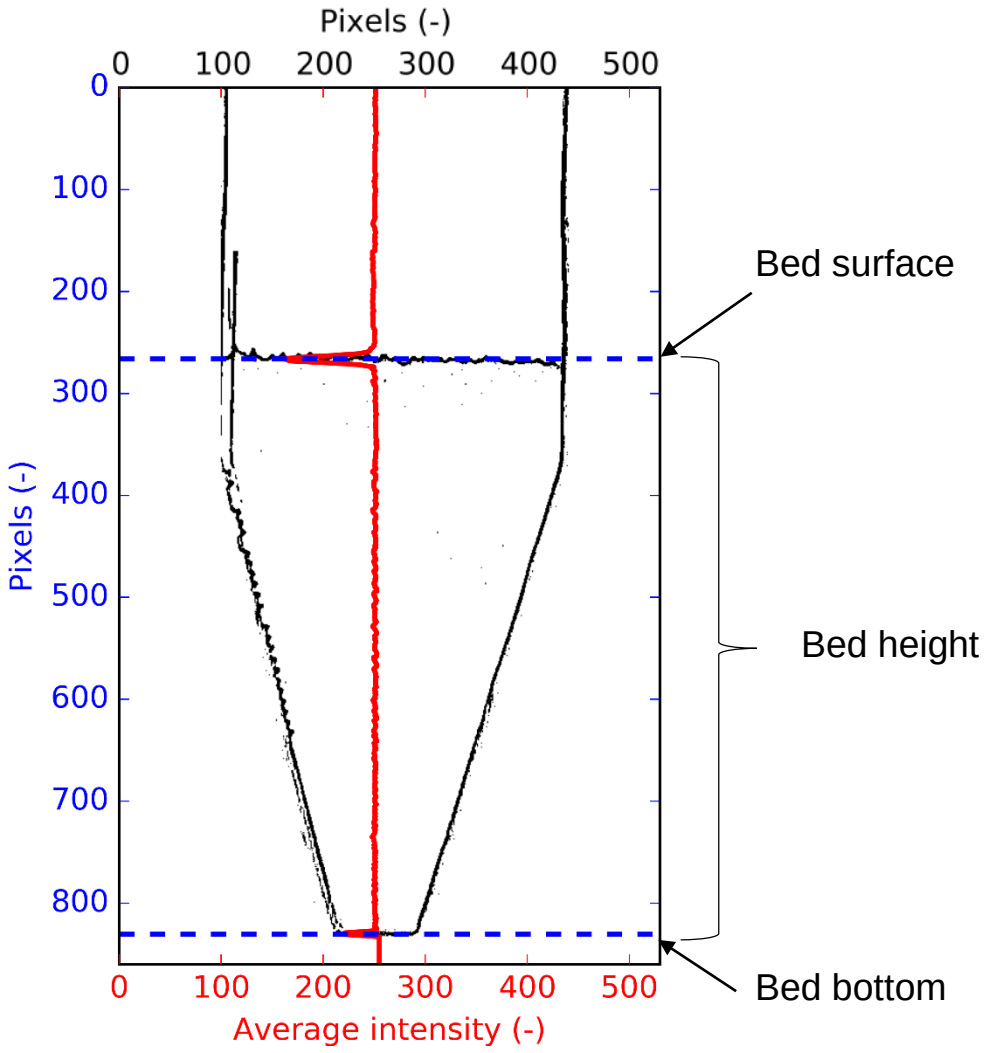
Original

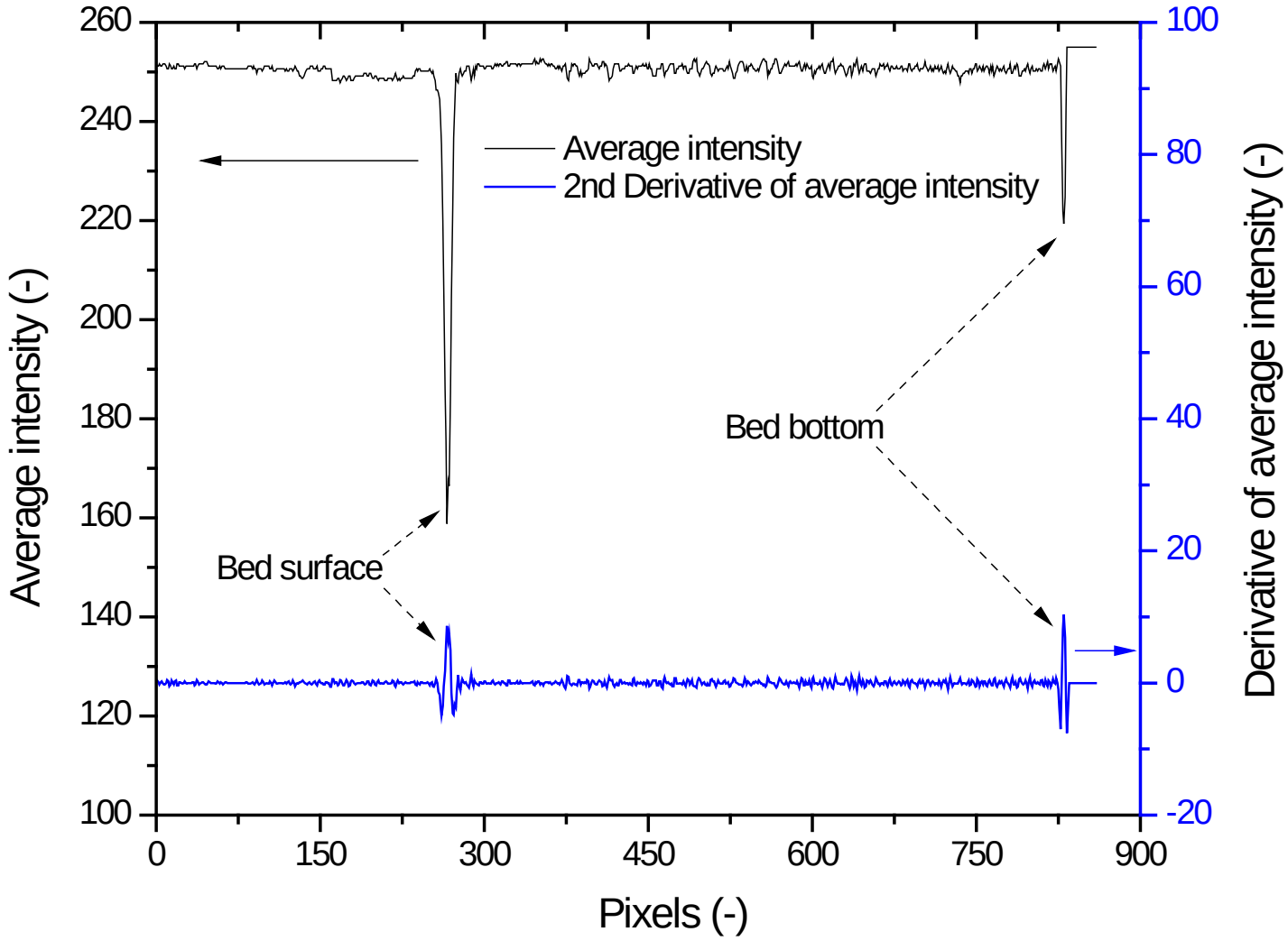
Cropped grayscale

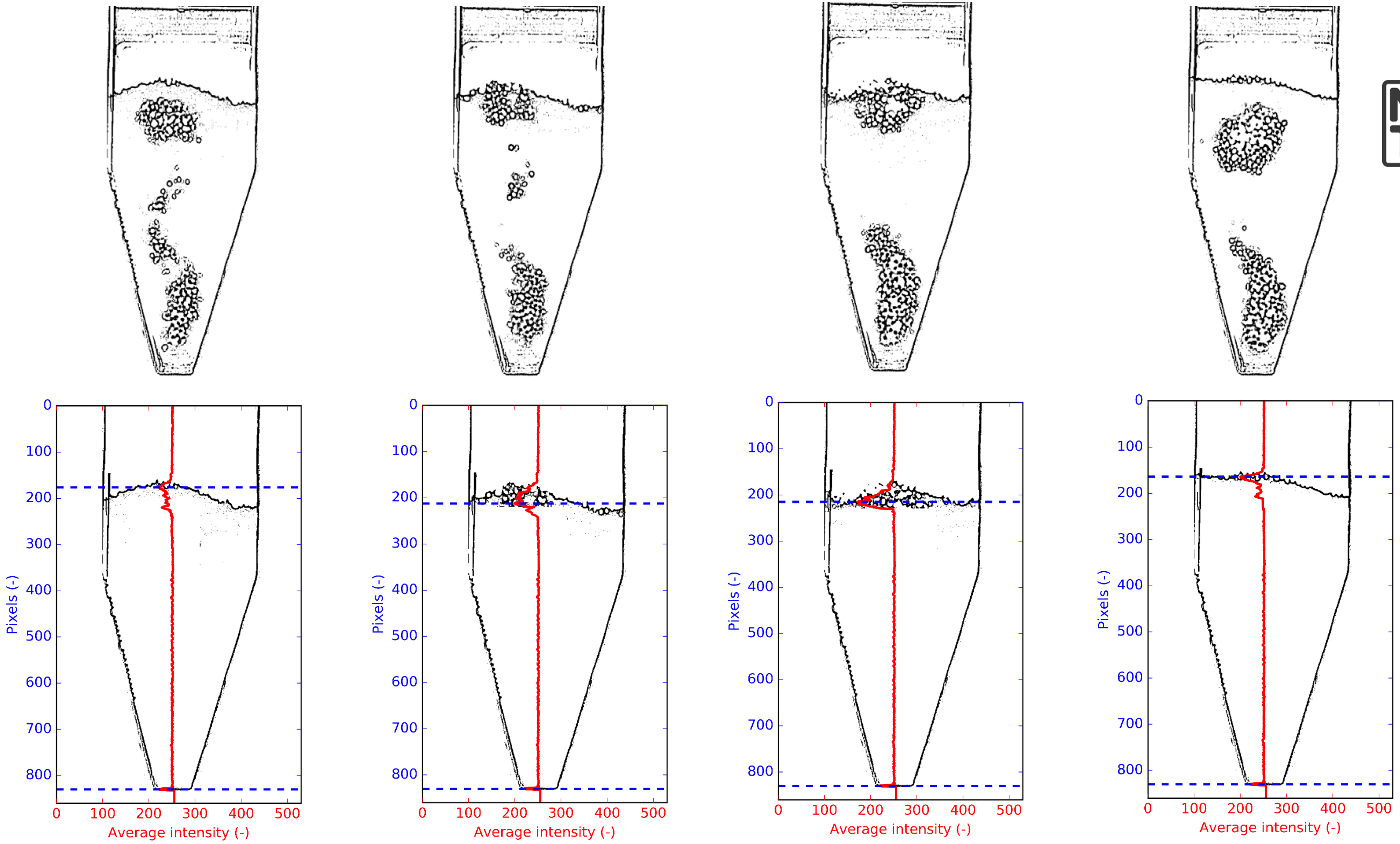
Binary

Extracted binary

Bed height determination-*Demonstration and examples*



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100
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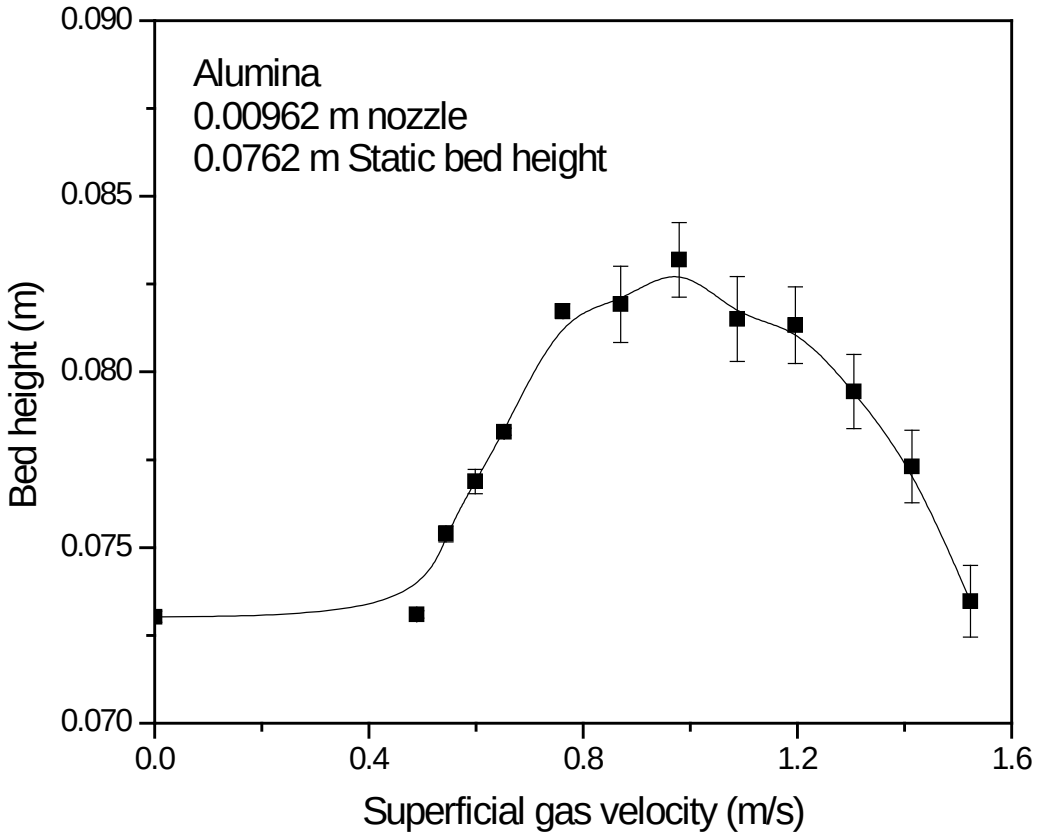
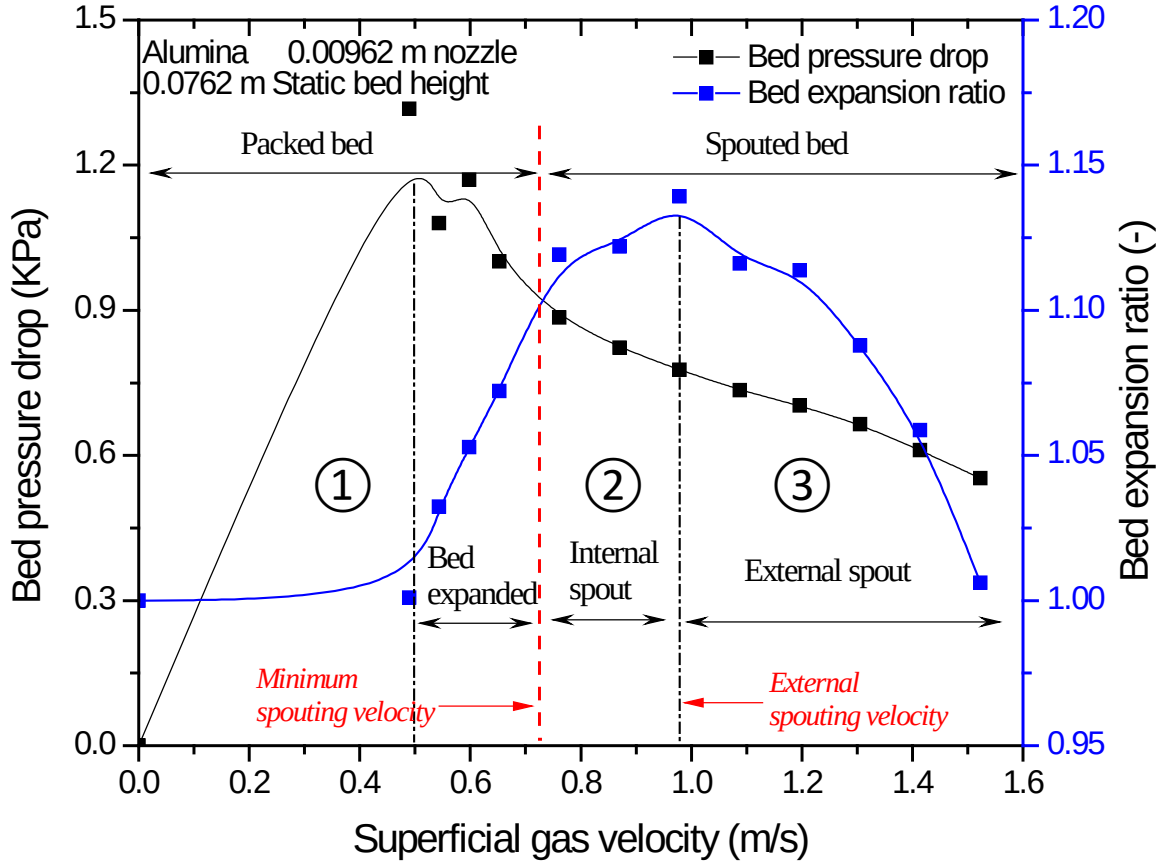
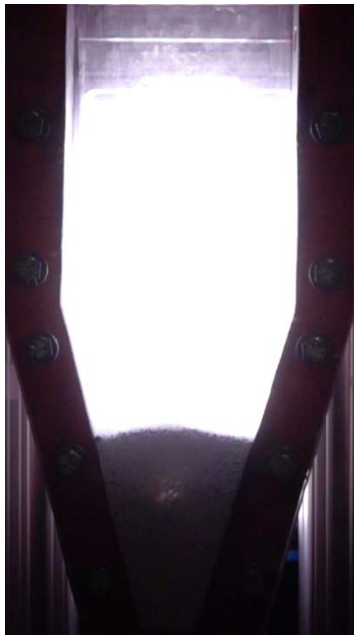
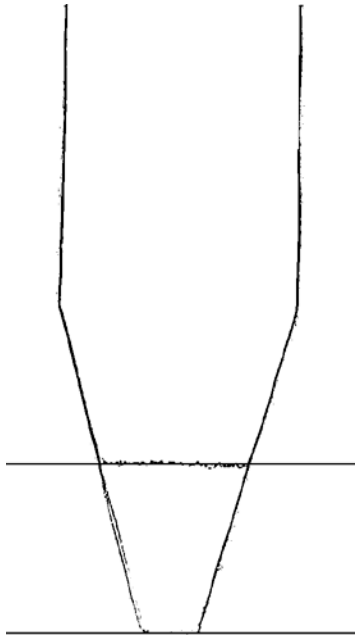
300
400
500

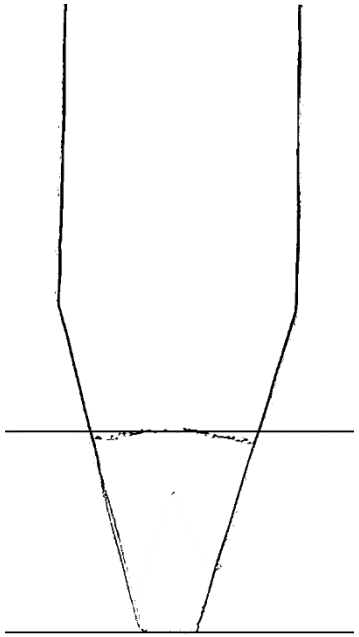
Bed height determination-*Demonstration and examples*

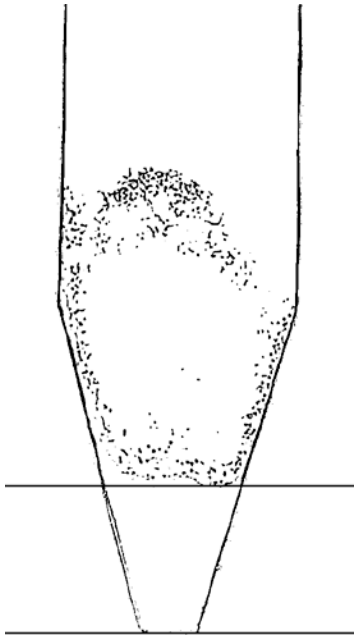




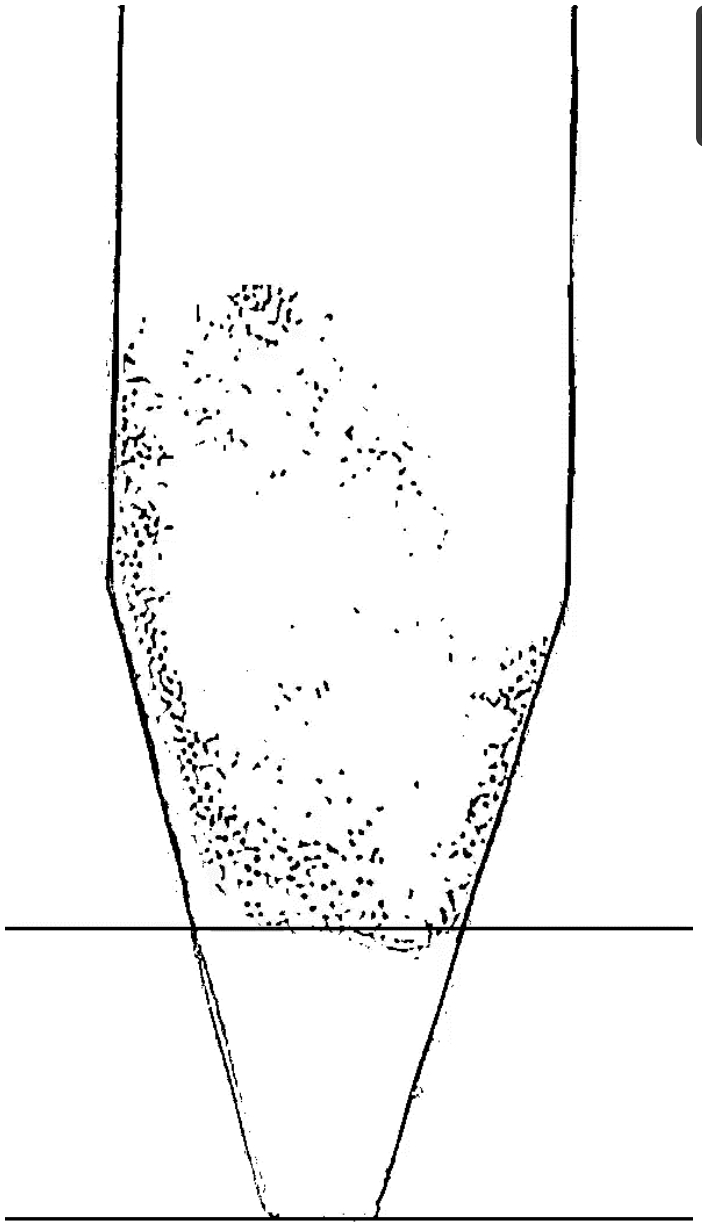




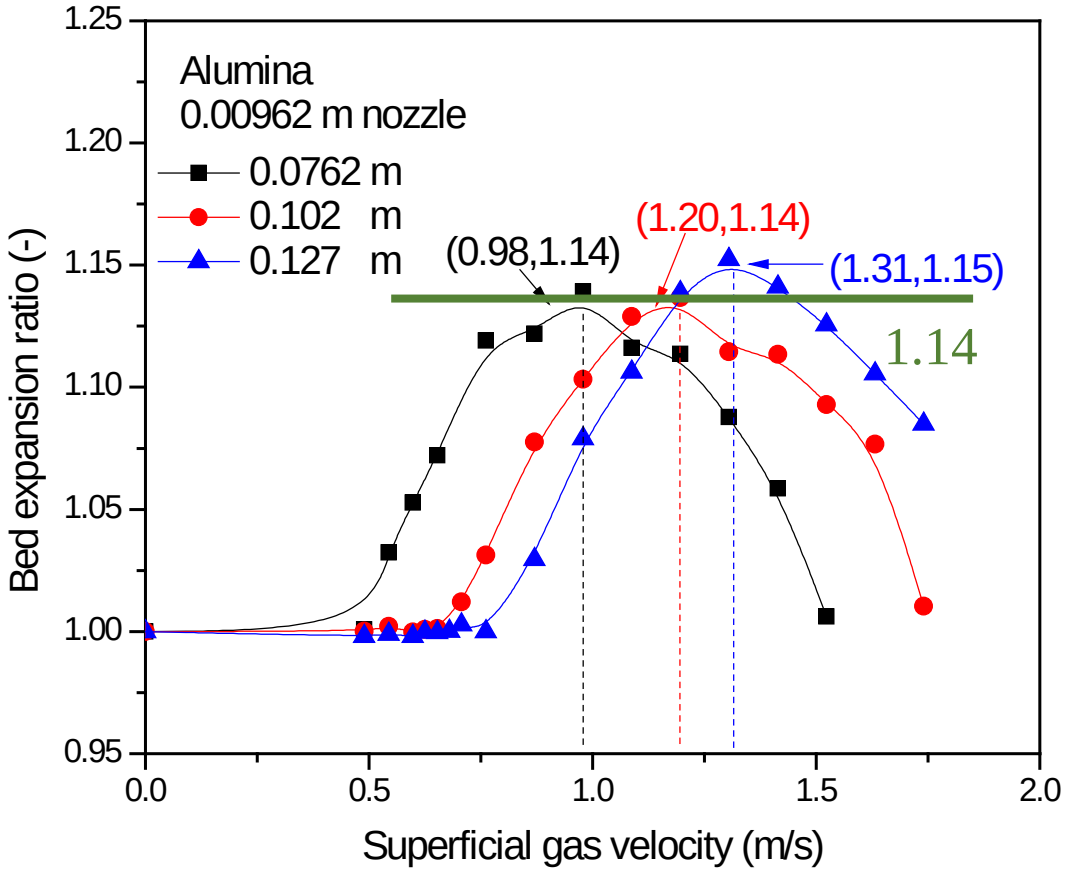


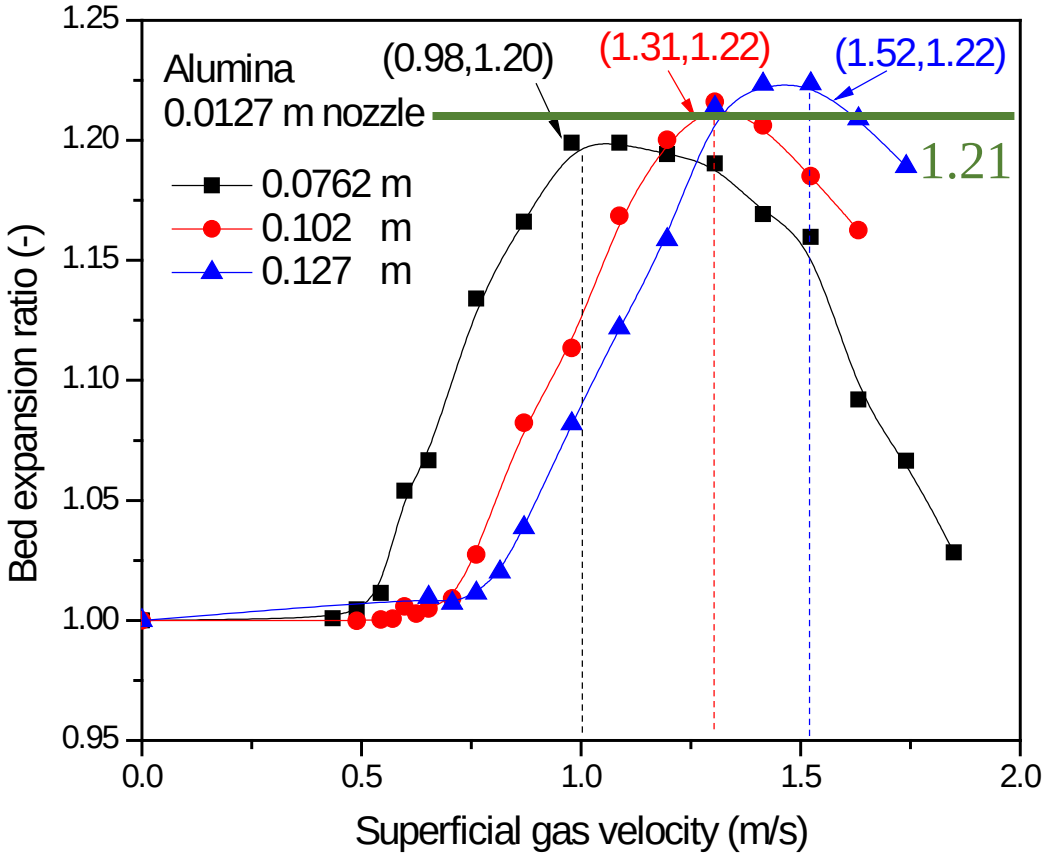


① ② ③



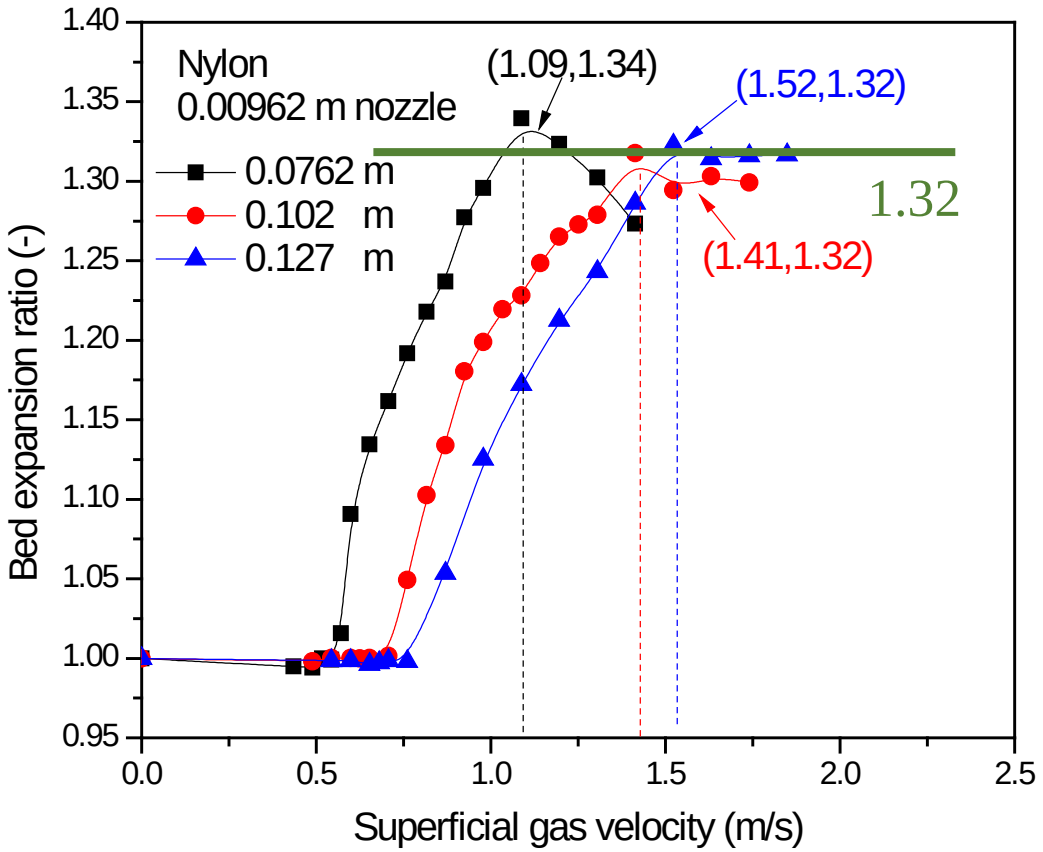
Bed expansion ratio-*Alumina*

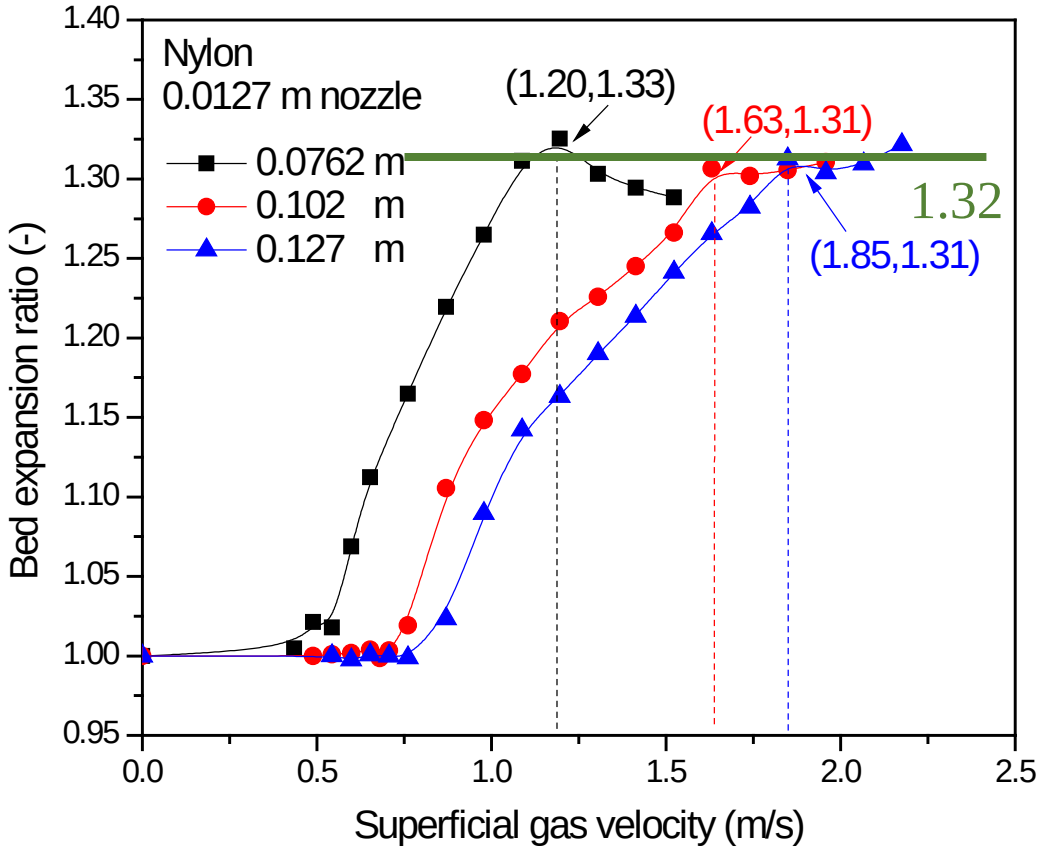




At the onset of the external spout, the bed expanded the same ratio regardless of the static bed height. The expansion ratio varies with the size of nozzles.

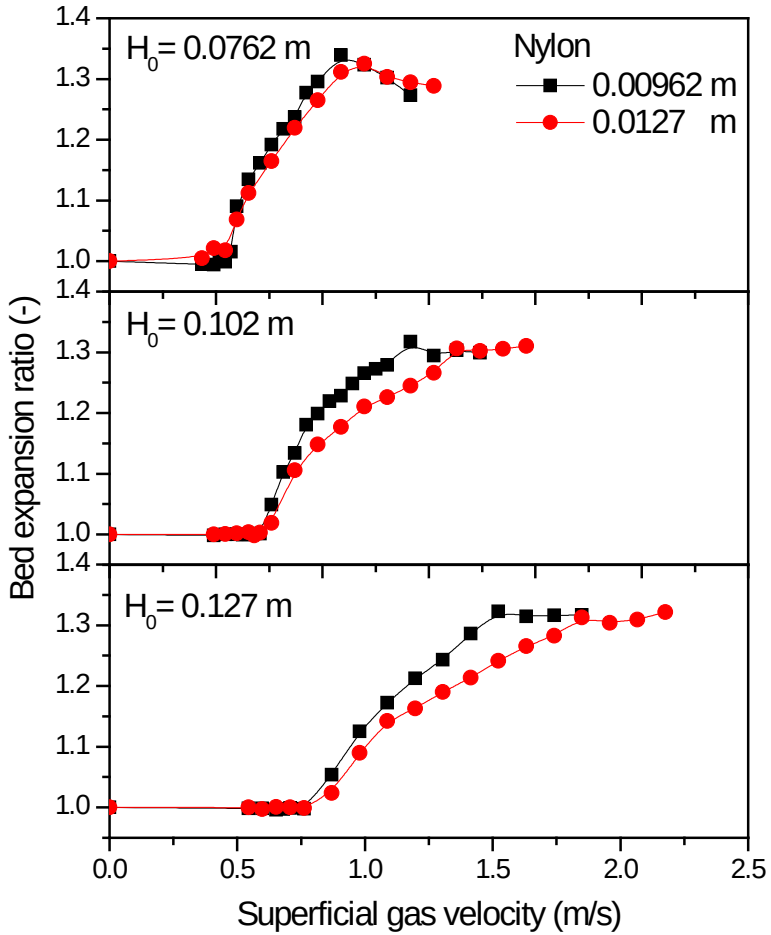
Bed expansion ratio-*Nylon*

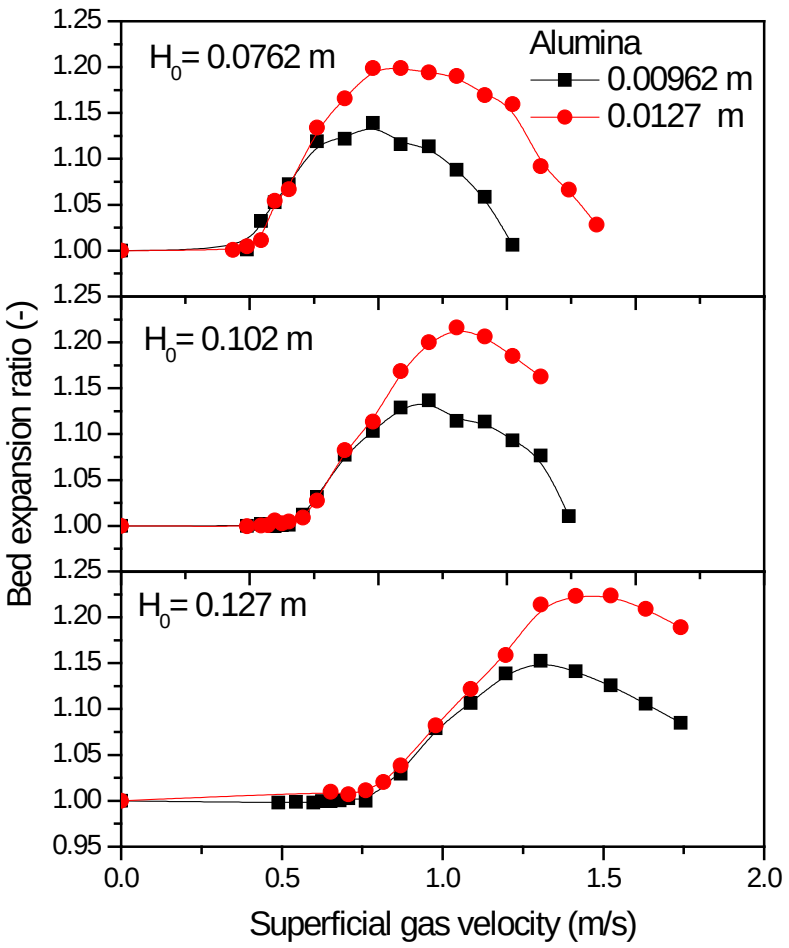




At the onset of the external spout, the bed expanded the same ratio regardless of the static bed heights and nozzle sizes.

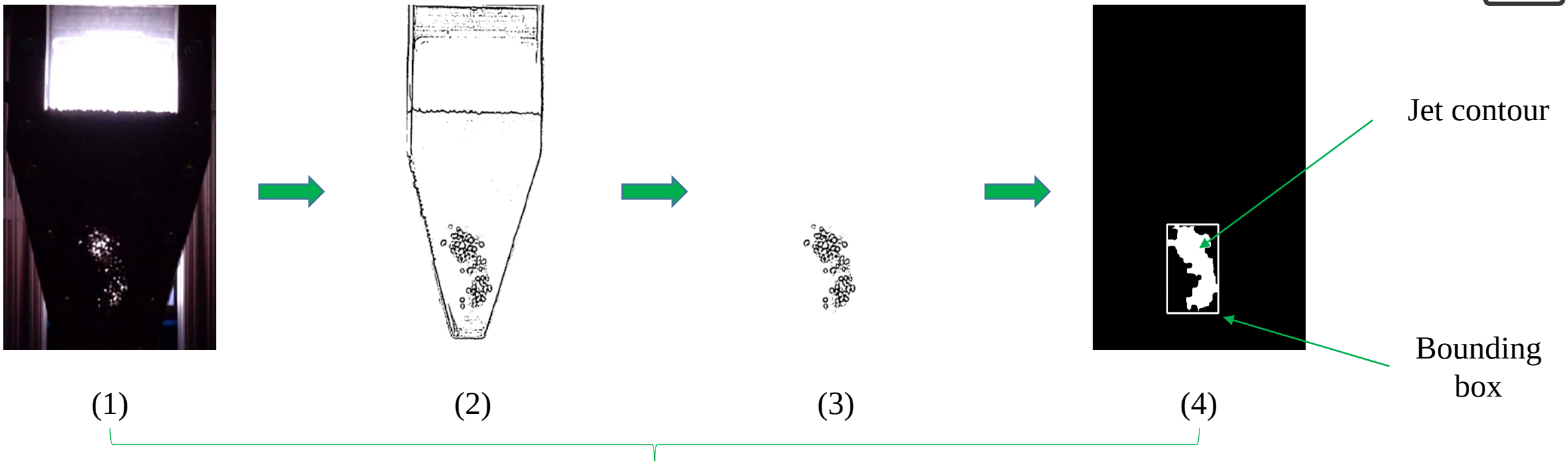
Bed expansion ratio-*The effect of nozzle size*





The effect of nozzle size on the bed expansion ratio of Alumina is more significantly than that of Nylon.

Future focuses- *Jet size & voidage determination*



The jet with a certain **geometrical shape** and a relatively **clear boundary** can be determined.

Jet contour (particles & air) → Jet area, S_{jet}; Bounding box (Jet heights & width, H_{jet} & W_{jet}) → Jet area equivalent diameter, D_{jet}

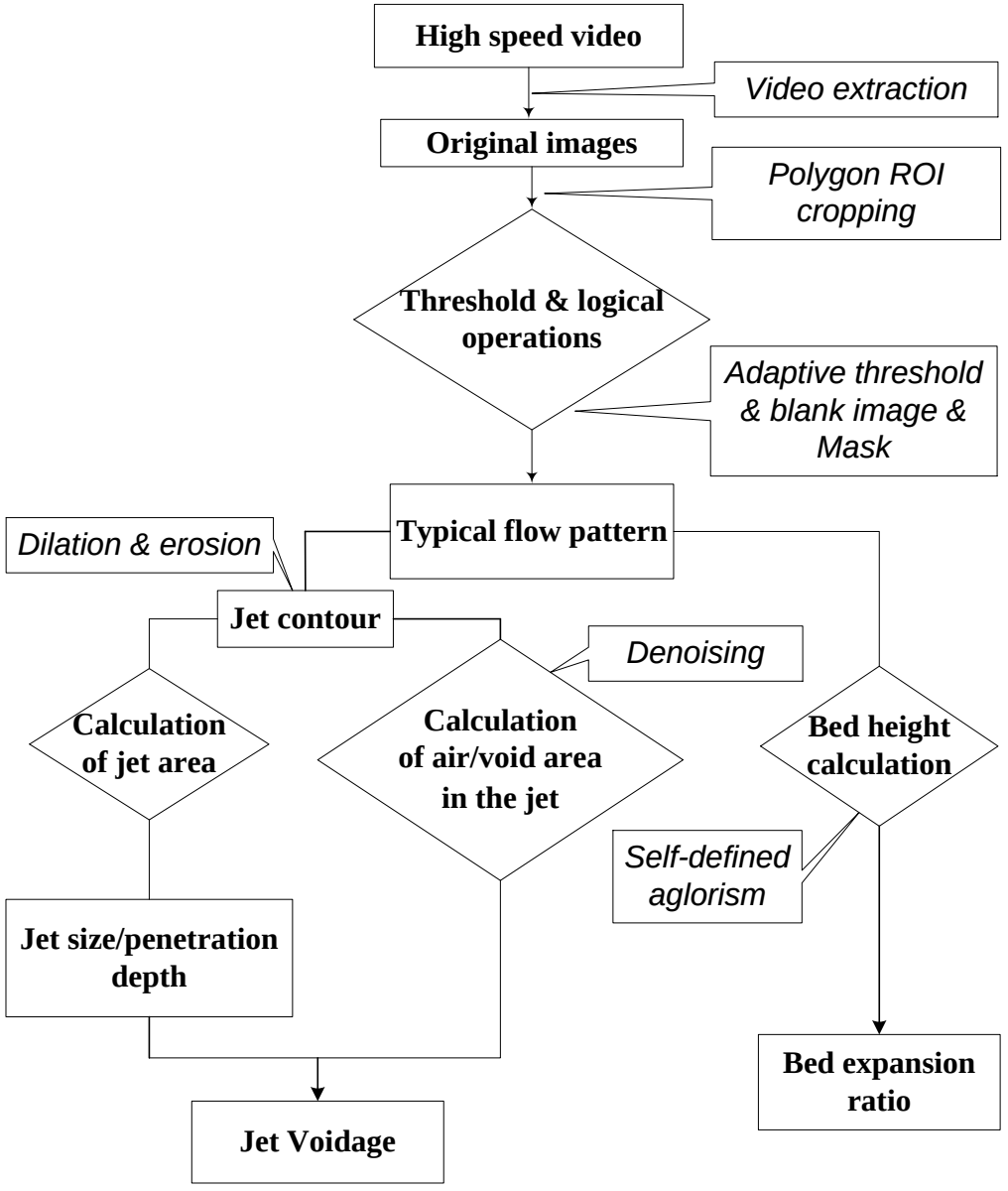
$$D_{jet} = 2s * \sqrt{\frac{N}{\pi}}$$

Void area ratio, $R_v = \frac{S_{air}}{S_{jet}}$ → Equivalent jet voidage, $\varepsilon_v = \frac{D_{air}^3}{D_{jet}^3} = \frac{S_{air}\sqrt{S_{air}}}{S_{jet}\sqrt{S_{jet}}}$

where N is the pixel number occupied by the jet; s is ratio of m/pixel.

Conclusions

- Based on a systematic of image processing procedures, an alternative method was proposed to study the hydrodynamics in a rectangular spouted bed.
- Different flow patterns were observed:
  - Flow regime transformation was complicated;
  - Under the same static bed height, the flow regime was changed with the increase of superficial gas velocity.
- Bed expansion ratio indicated the external spout velocity, which was helpful to determine flow regime.



Conclusions

- The variation of bed expansion ratios with superficial gas velocity were shown for Alumina and Nylon particles using two different nozzle sizes (0.00962 m and 0.0127 m):
  - At the onset of the external spout, the bed expanded the same ratio regardless of the static bed heights under the same nozzle size for both particles;
  - Comparing to Nylon, the bed expansion ratio of Alumina at the onset of the external spout was influenced more significantly by the nozzle size.
- Future focuses:
  - Determination of jet sizes and voidage, and fountain height by applying image analysis;
  - Different parameters such as cone angle, property of bed materials;
  - Flow regime map construction.

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- Justin Weber (Research Advisor);
- Steve Rowan;
- Michael Bobek;
- Nicholas Hillen;
- Sam Bayham;

Questions and Comments are very welcome !