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# AGGLOMERATION OF WET GRANULAR MATERIAL IN ROTATING DRUM

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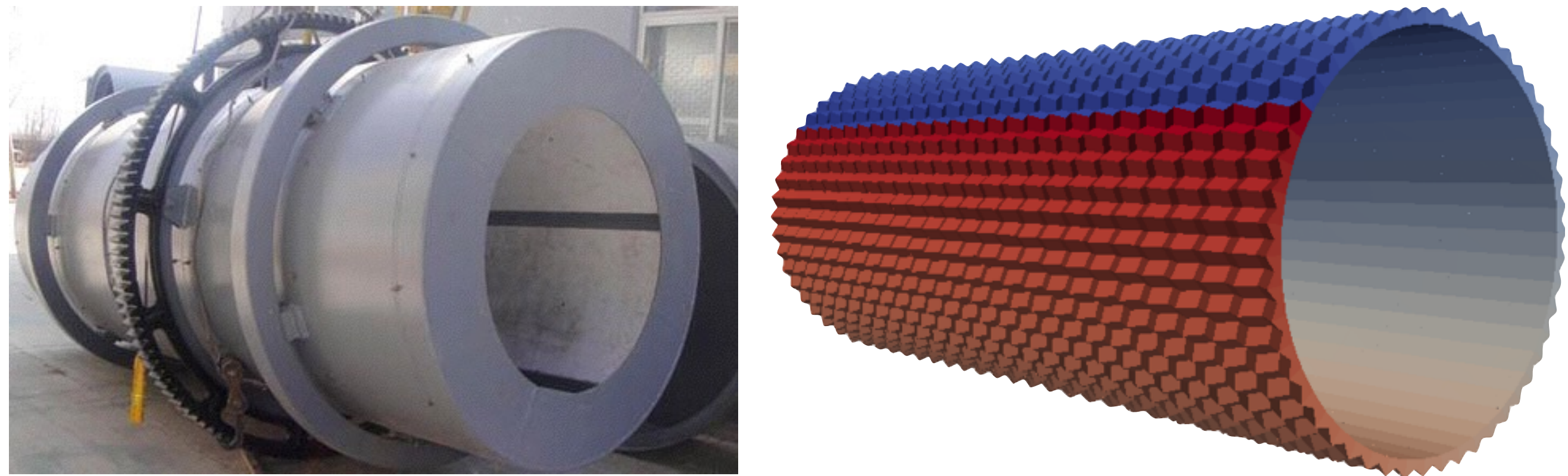
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## OBJECTIVES & METHODOLOGY

Simulation the agglomeration process of solid particles in the presence of a viscous liquid. We are mostly interested in application to iron ore granulation in a horizontal rotating drum. In this work, we use Molecular Dynamics (MD) method to simulate the agglomeration process during the dense granular flows in the rotary drum. In which particles are distributed by an uniform distribution of particle volume fractions.

### INDUSTRIAL PROCESS



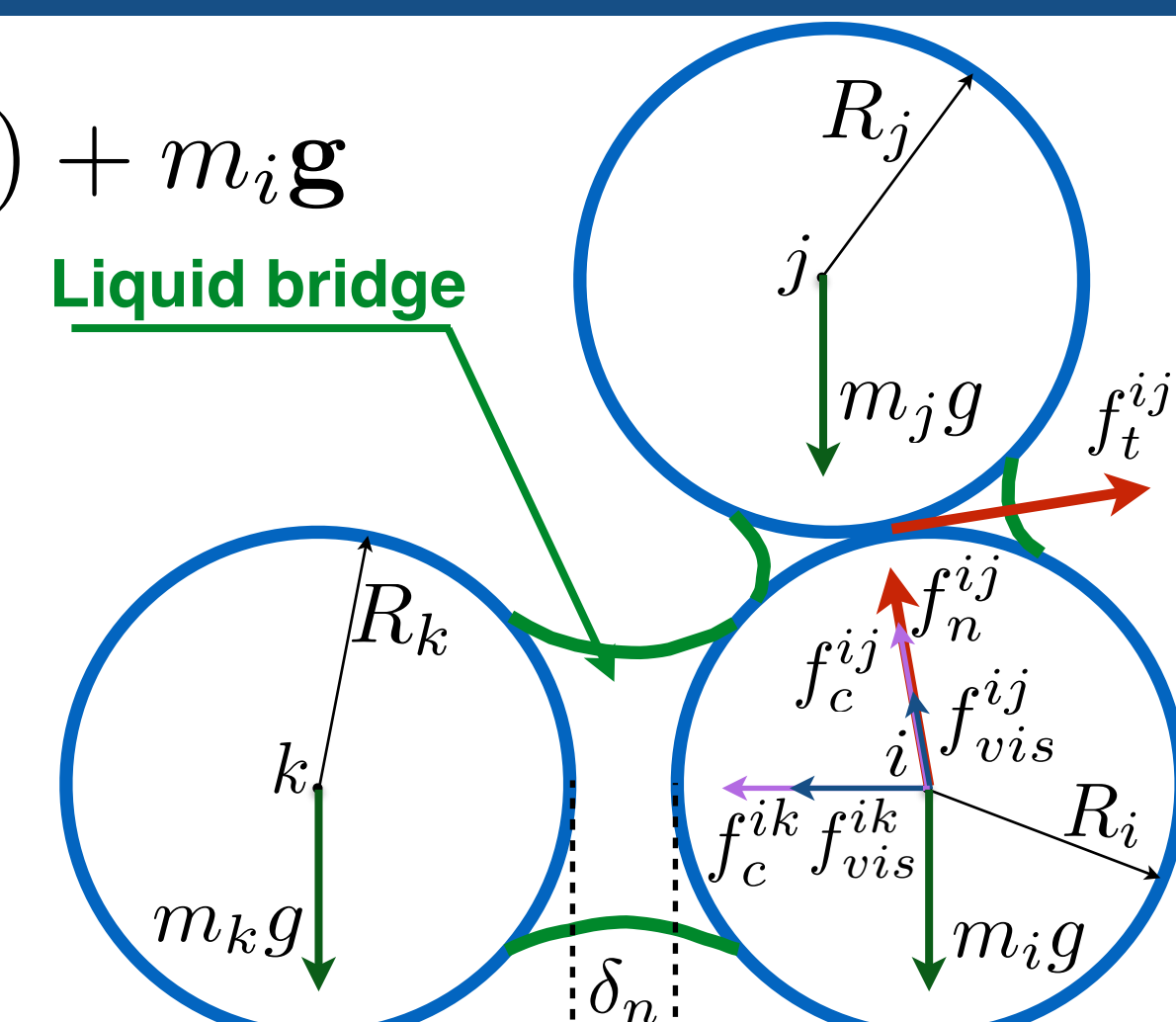
Granulation (balling) Drum

Agglomeration is the process of particles size enlargement and most commonly refers to the upgrading of material fines into larger particles, such as pellets or granules. Iron ore granulation is an important stage in the steel making.

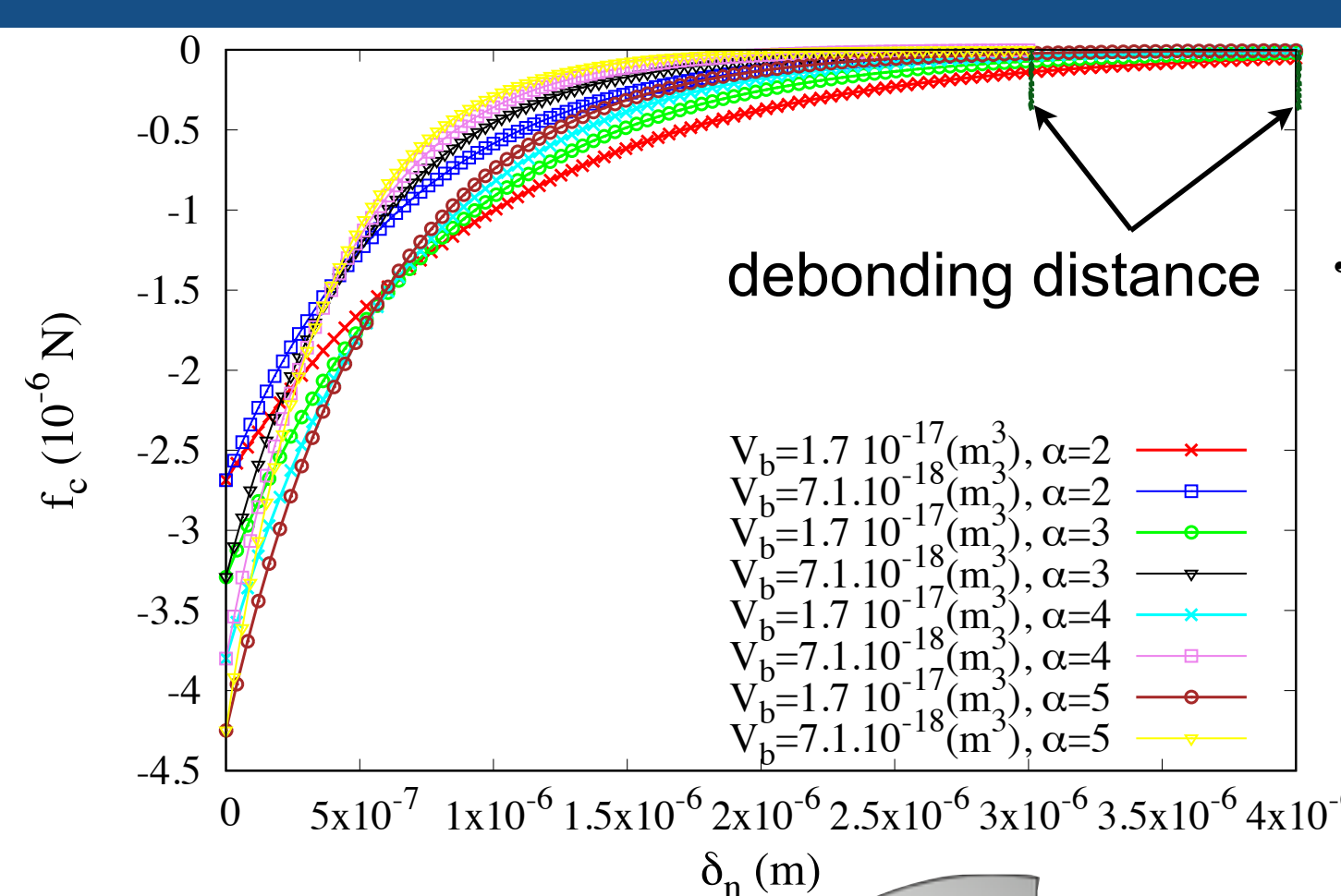
### MOLECULAR DYNAMICS METHOD

$$m_i \frac{d^2 \mathbf{s}_i}{dt^2} = \sum_{(i)} ((f_n + f_c + f_{vis}) \mathbf{n} + f_t \mathbf{t}) + m_i \mathbf{g}$$

$\mathbf{s}_i$  position vector of particle  $i$   
 $\mathbf{g}$  vector gravity  
 $\mathbf{n}$  normal unit vector  
 $\mathbf{t}$  tangential unit vector  
 $m_i$  mass of particle  $i$  (kg)



### CAPILLARY COHESION & VISCOUS FORCE



$$f_c = \begin{cases} -\kappa R, & \text{for } \delta_n < 0 \\ -\kappa R e^{-\frac{\delta_n}{\lambda}}, & \text{for } 0 \leq \delta_n \leq \delta_n^{max} \\ 0, & \text{for } \delta_n \geq \delta_n^{max} \end{cases}$$

$$f_{vis} = \frac{3}{2} \pi R^2 \eta \frac{1}{\delta_n} \frac{d\delta_n}{dt}$$

$$\kappa = 2\pi \gamma_s \cos \theta$$

$$\delta_n^{max} = (1 + \frac{1}{2}\theta) V_b^{1/3}$$

$$\alpha = \frac{R_{max}}{R_{min}}$$

$$\lambda = c h(\alpha) (\frac{V_b}{R'})^{\frac{1}{2}}$$

$$R = \sqrt{R_i R_j}$$

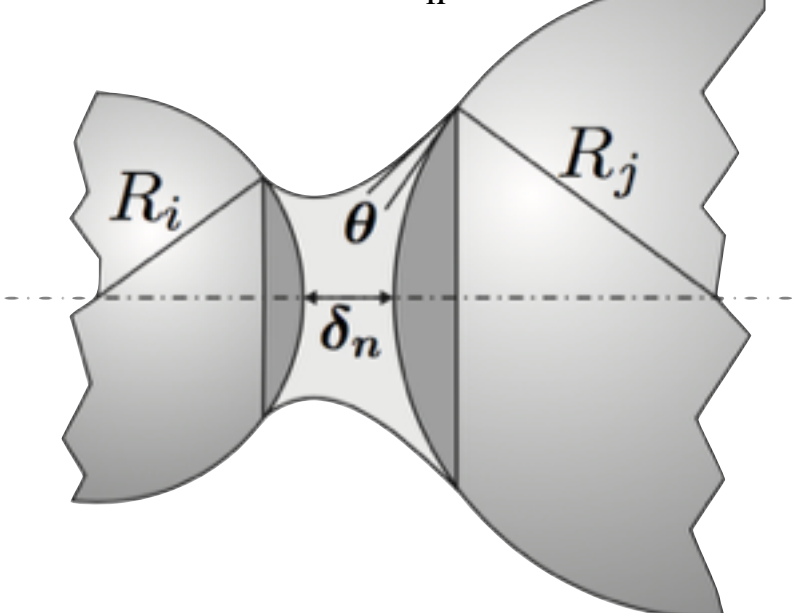
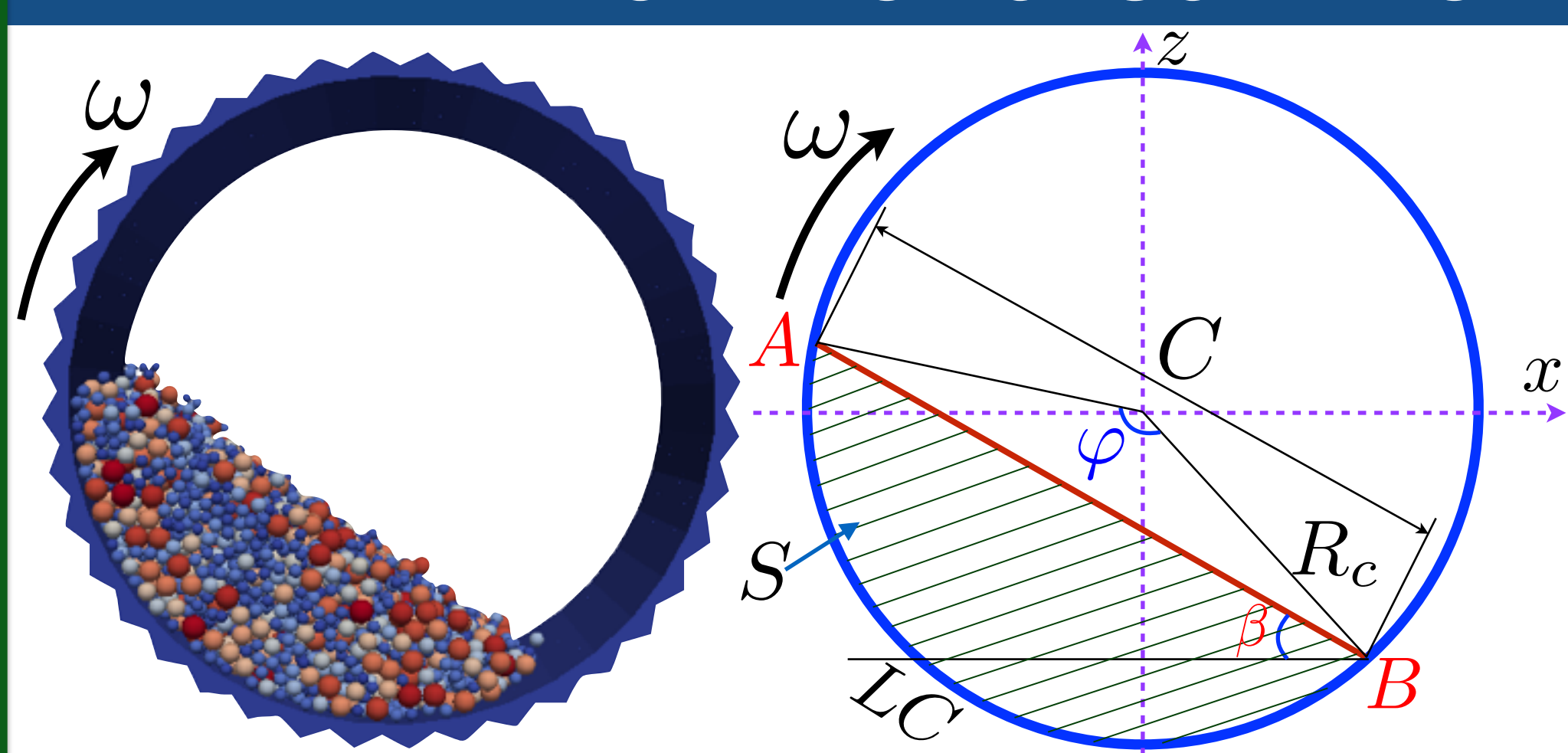


Diagram of capillary bridge

### ROLLING - CASCADING MODEL



$$C = AB = 2R_c \sin \frac{\varphi}{2}$$

$$S = \frac{R_c^2}{2} (\varphi - \sin \varphi)$$

$$LC = \widehat{AB} = \varphi R_c$$

$\omega$  Rotational speed (rad/s)

$\beta$  Free surface angle

$\varphi$  Filling angle (degree)

Packing fraction:

$$\Phi = \frac{V_s}{S * L} = \frac{\Sigma(\frac{4}{3} \pi R_i^3)}{S * L}$$

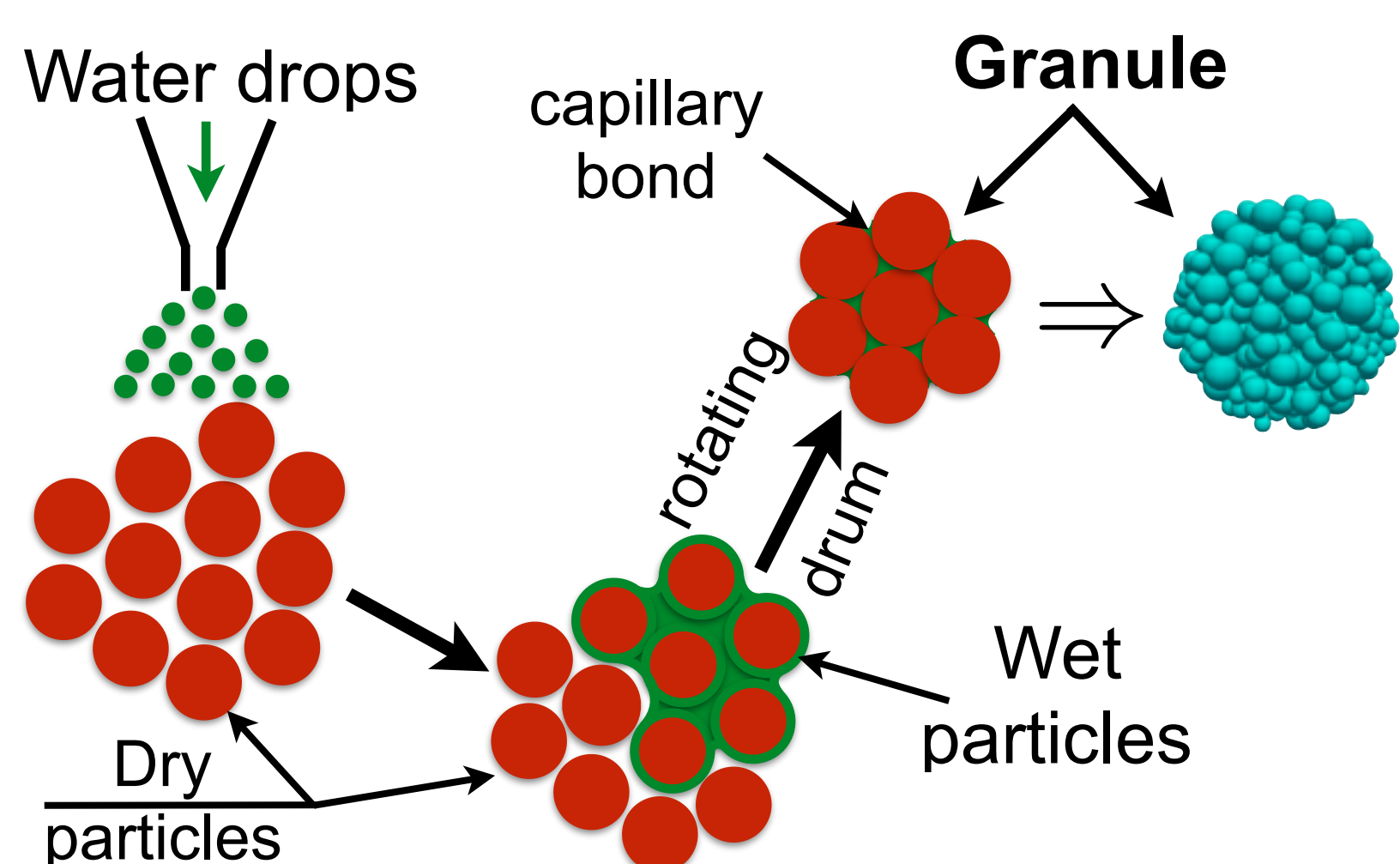
Filling level:

$$f = \frac{S}{\pi R_c^2} = \frac{\varphi - \sin \varphi}{2\pi}$$

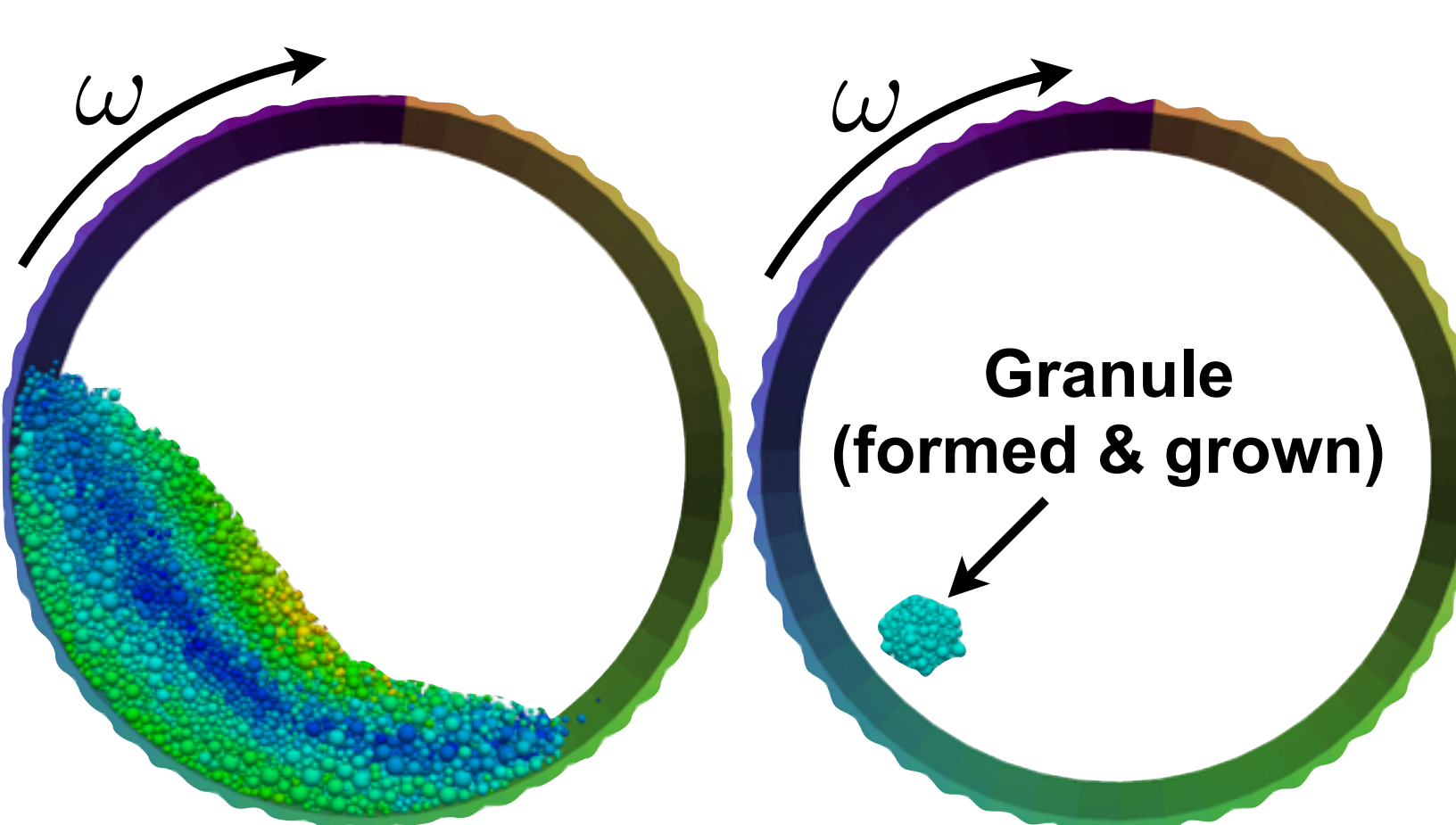
Froude number:

$$Fr = \frac{\omega^2 R_c}{g}$$

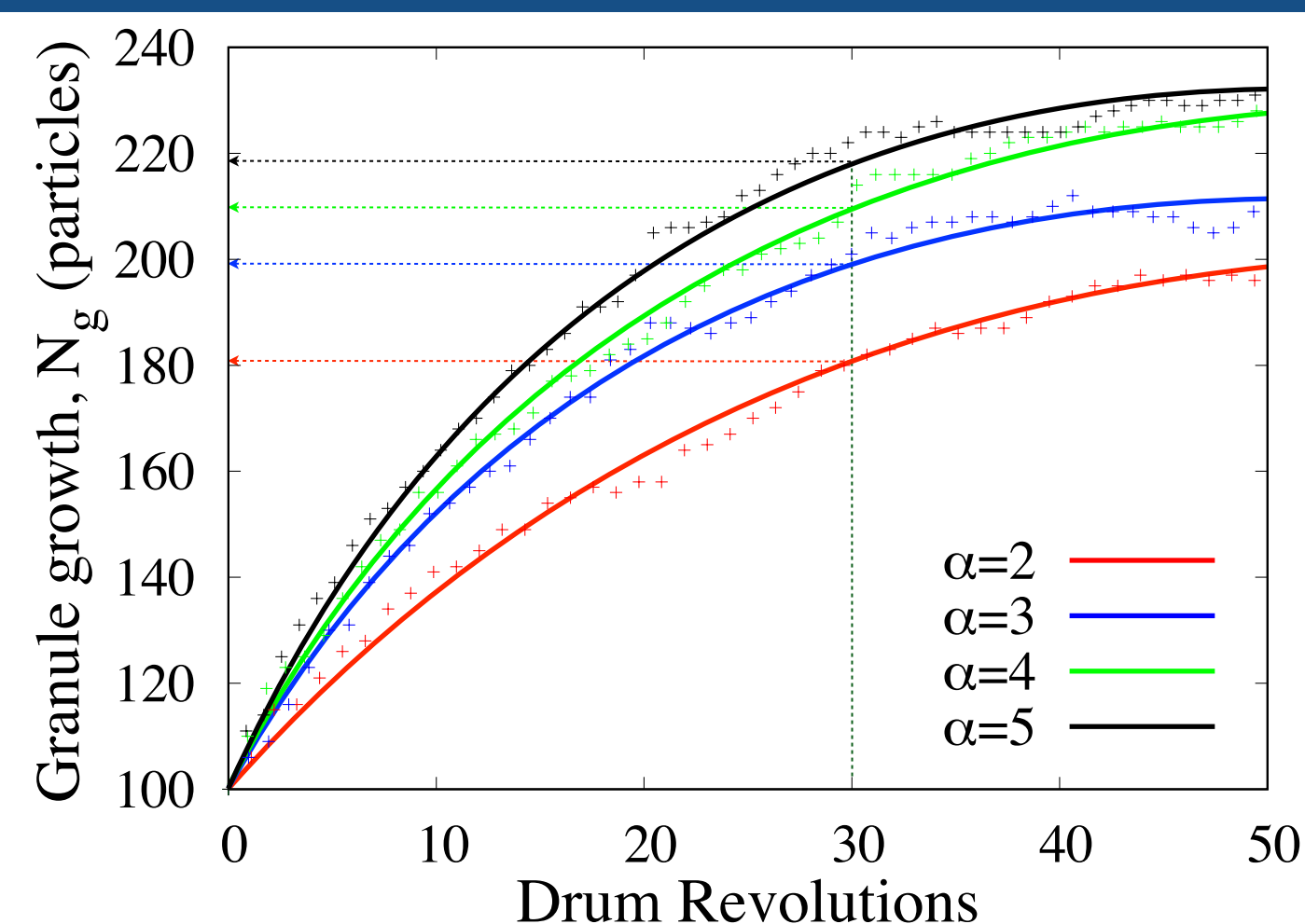
## AGGLOMERATION RESULTS



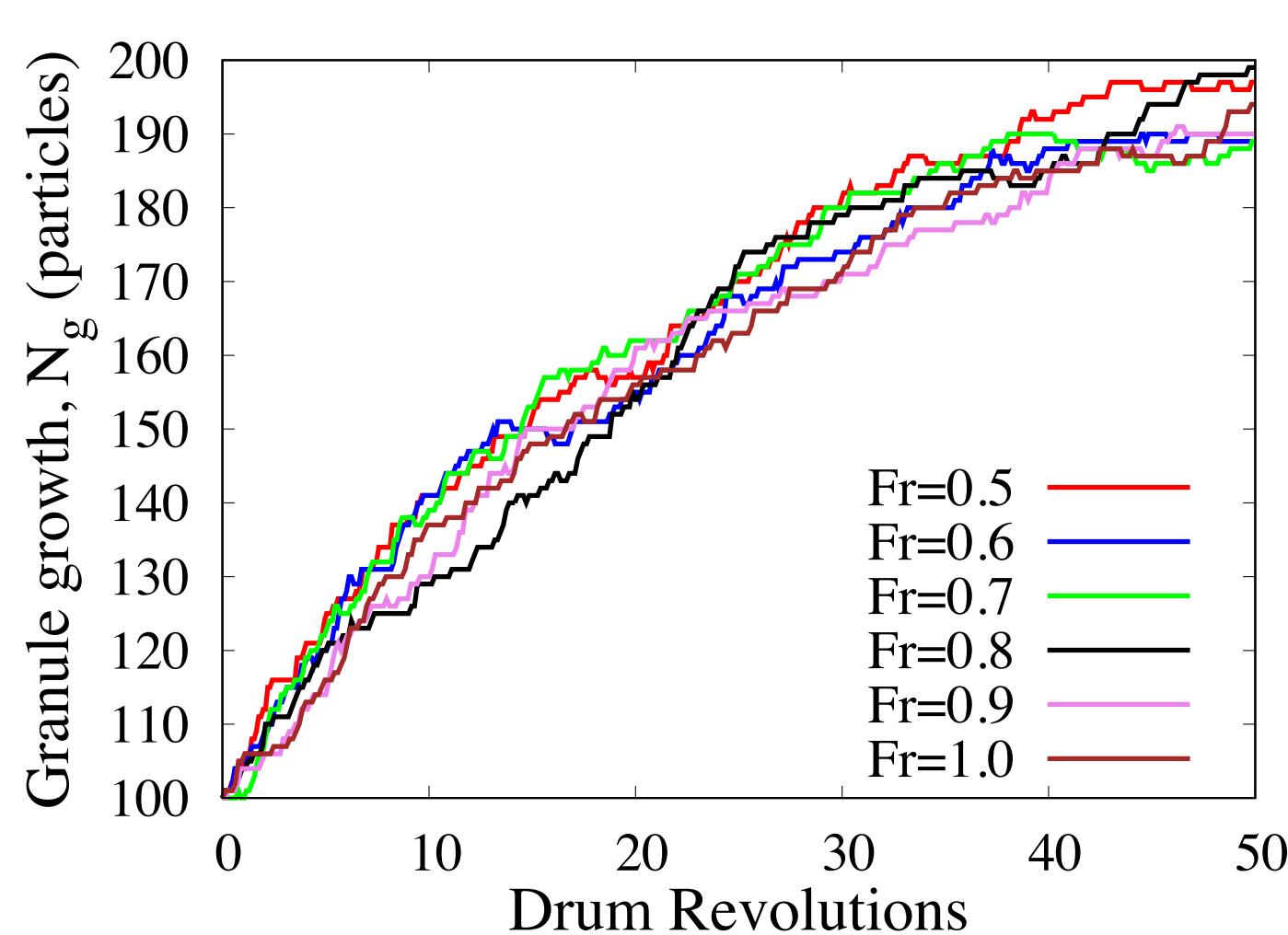
Mechanism of granule formation



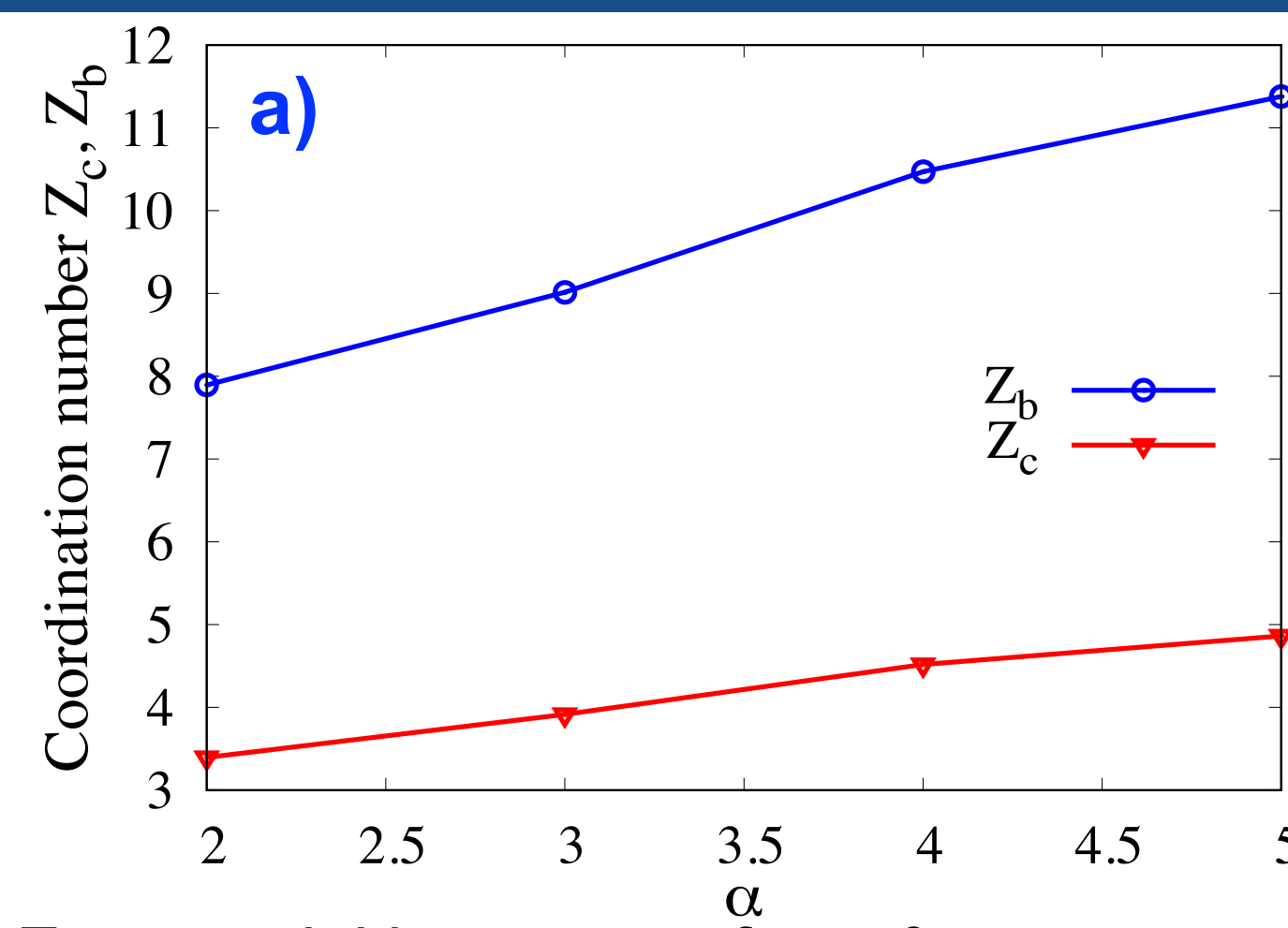
Granular material flow & granule growth in the cascading regime



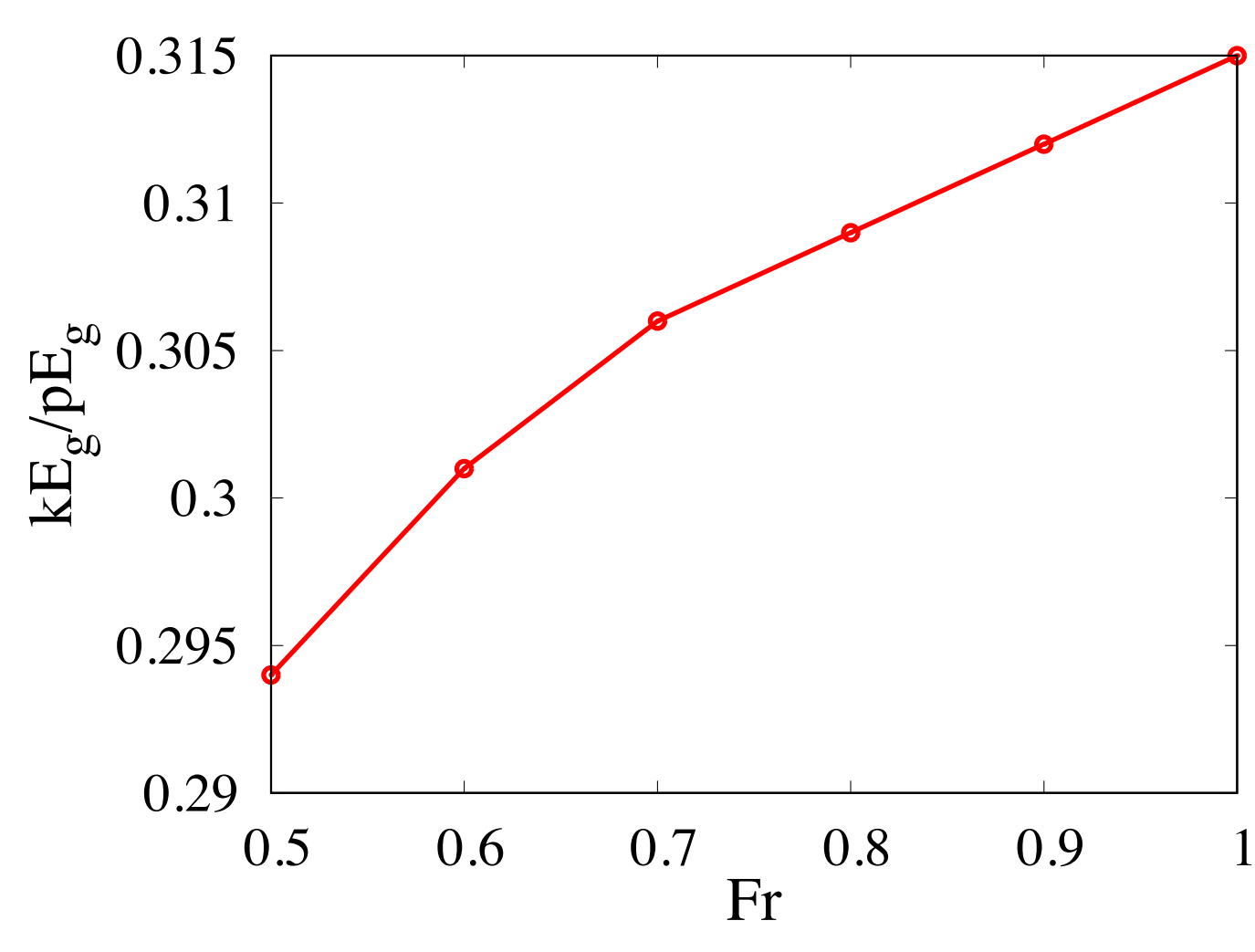
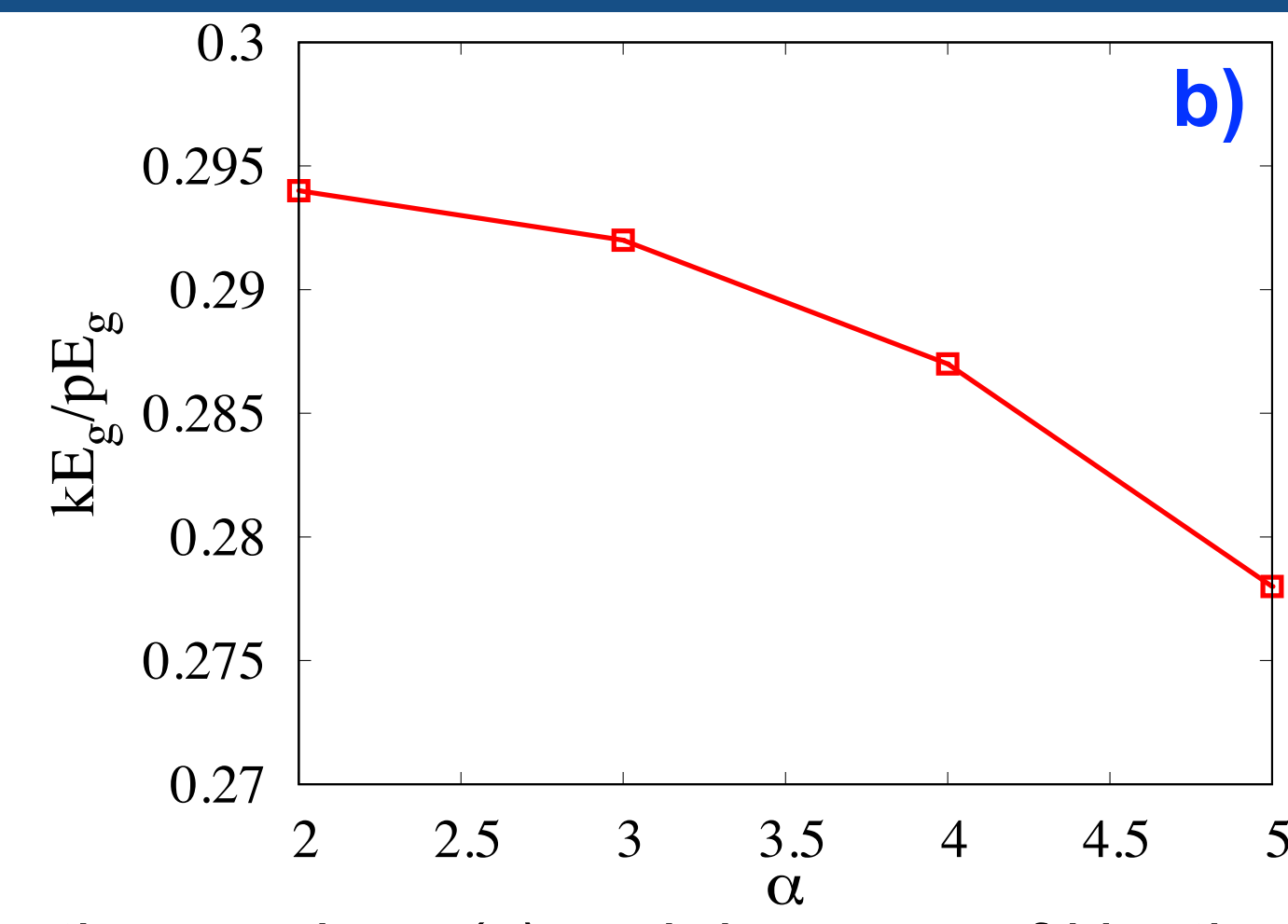
Exponential increase of granule for different size ratios



Exponential increase of granule for different Froude numbers.



Exponential increases of wet & contact coordination numbers (a) and decrease of kinetic energy normalized by potential energy of granule (b), as functions of size ratio  $\alpha$ .

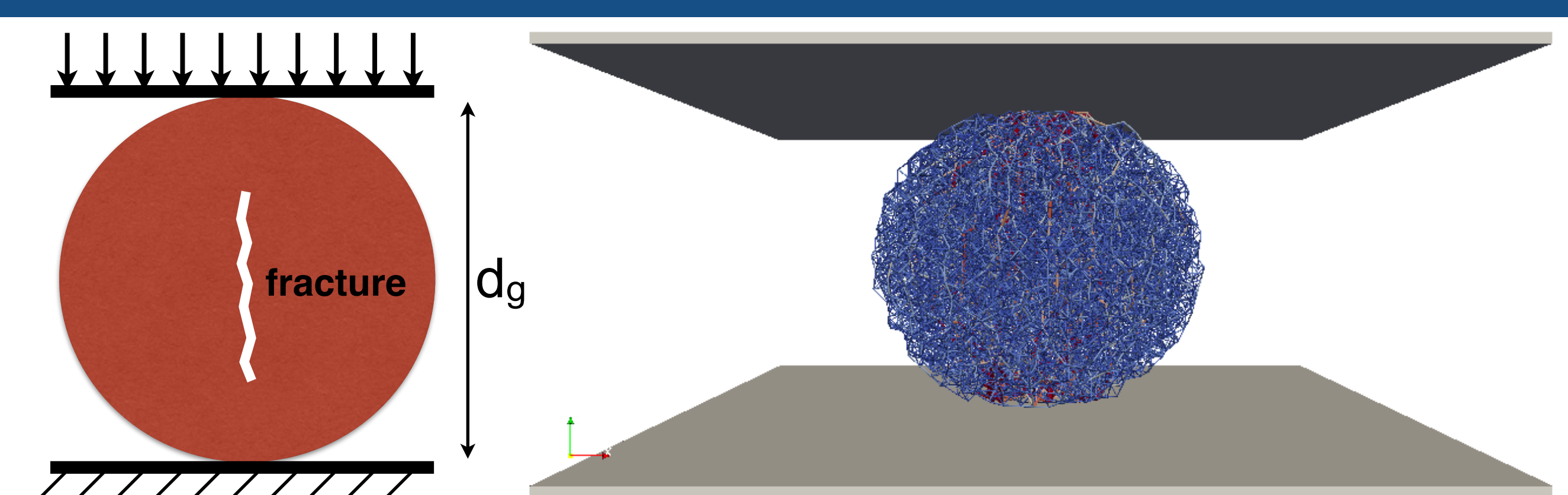


Exponential increase of kinetic energy normalized by potential energy of granule as function of  $Fr$ .

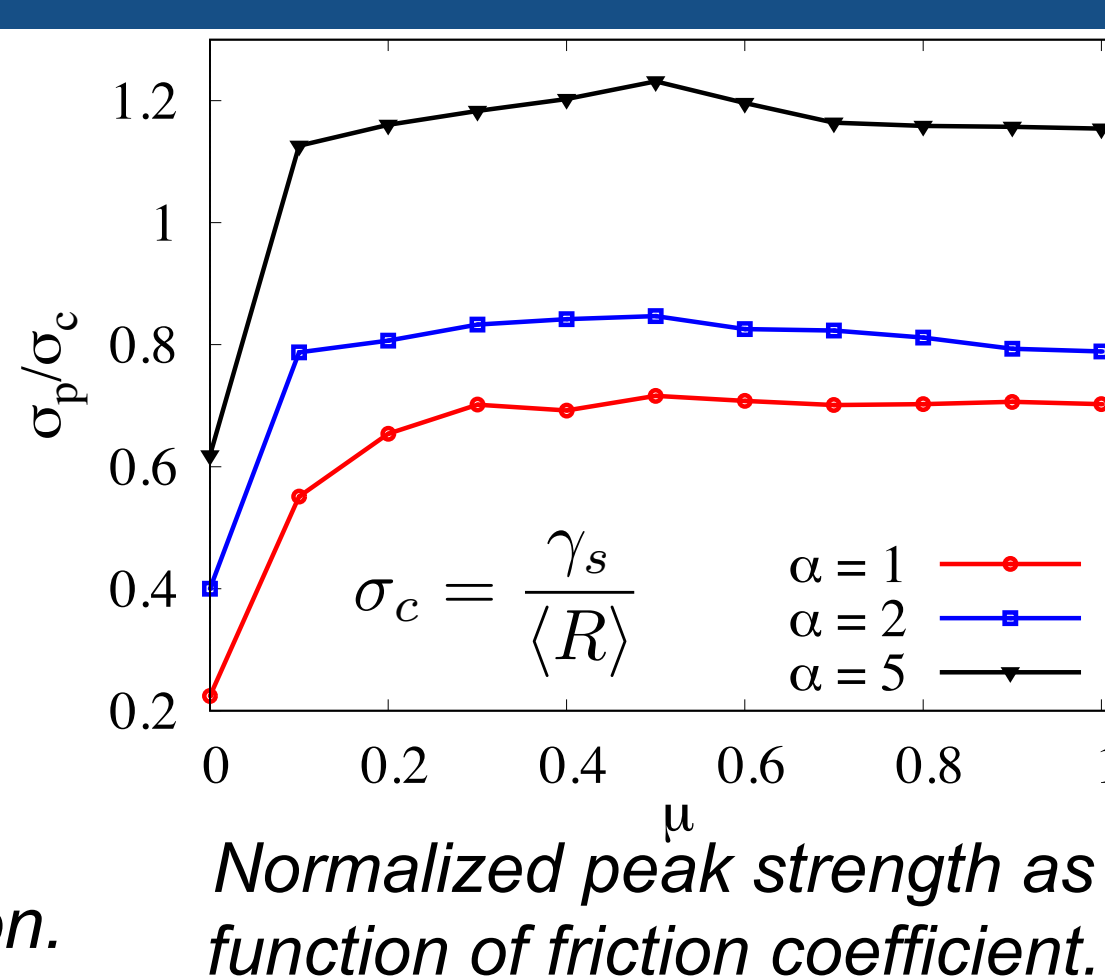
### Conclusions

- 1) The effect of size ratio on the granule growth is more crucial than that of rotational speed.
- 2) Granule growth is an exponential function of size ratio and rotational speed of drum.
- 3) Kinetic energy normalized by potential energy increases proportional to the rotational speed, but inversely proportional to the size ratio.
- 4) The wet and contact coordination numbers of agglomerate grains are proportional to size ratio.

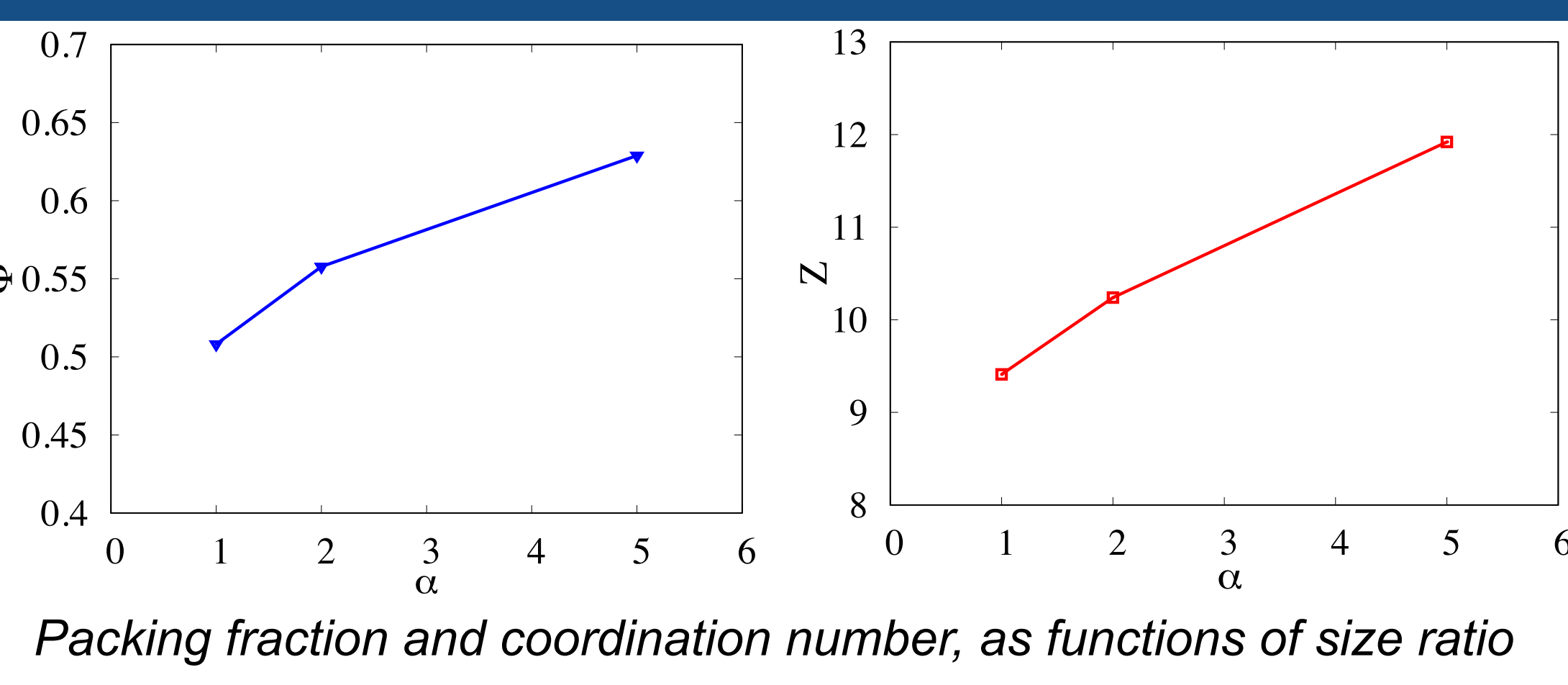
## GRANULE COMPRESSION STRENGTH



The snapshots of model and force chains of a granule under diametrical compression.



Normalized peak strength as function of friction coefficient.



Packing fraction and coordination number, as functions of size ratio

## FURTHER RESEARCHES

- Investigation the agglomeration process of a huge number of particles.
- Comparison between experiment and simulation of agglomeration processes in rotating drum.

8<sup>th</sup> International Conference on  
 Micromechanics of Granular Media  
 Powders & Grains 2017

