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Pseudo Three-Dimensional Modeling of Particle Fuel Packing Using Distinct Element Method

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1. INTRODUCTION

FBR cycle system

Low-decontaminated MA fuel is to be used.

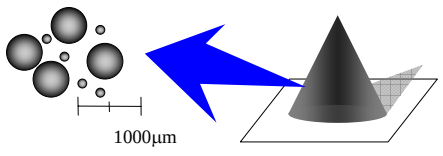
Vibro-filling fuel is suitable.

Because…
1. Simple manufacturing
2. Good remote handling
3. Low cost

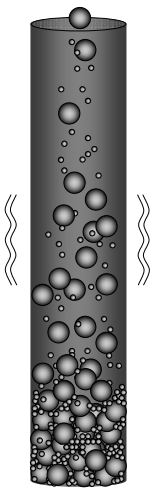
Sphere-pac Fuel
Vipac Fuel

Sphere-pac fuel manufacturing

1. MOX fuel is formed to be spheral. (About 10μm~1000μm)



2. Particle-fuel is filled in a cladding tube under a vibrational motion. Two kind of particle of different diameter are blended and packed.



Challenging of sphere-pac fuel

For achieving { HIGH and UNIFORM } packing density

1. Comprehending the behavior of particles in a vibrating tube
2. Estimating the most effective value

We apply a Distinct Element Method (DEM) to numerical simulation of the vibration-based packing process

In 2-D simulation…
- ○ Low computational cost
- × Infiltration of particles

In 3-D simulation…
- × Significant computational cost
- ○ Infiltration of particles

We propose a pseudo three-dimensional simulation method.
- ○ Practical computational cost
- ○ Infiltration of particles can be expressed

2. COMPUTATIONAL METHOD

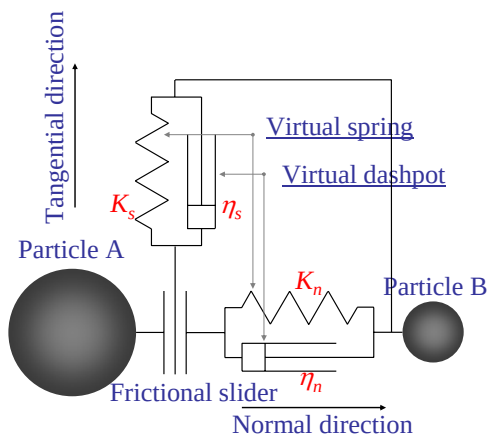
Two-Dimensional Distinct Element Method

To calculate a contact force…

Virtual spring and Virtual dashpot are assumed.

- A repulsion force and A friction force
- An energy dissipation

Contact Force can be expressed.



The Voigt model of contact force between two particles

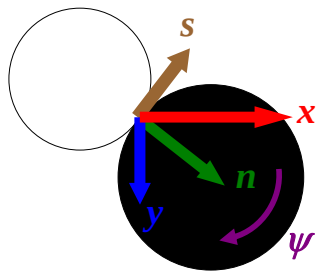
$$F_n = \eta_n \frac{du_n}{dt} + K_n u_n$$

$$F_s = \eta_s \left(\frac{du_s}{dt} + r\frac{d\psi}{dt}\right) + K_s (u_s + r\psi)$$

Normal direction (n)
Tangential direction (s)

Horizontal direction (x)
Vertical direction (y)
Rotational direction (ψ)

Summation of all contact particles force



NOMENCLATURE
- F; contact force
- K; a stiffness coefficient
- η; a damping coefficient
- u; relative displacement
- ψ; displacement of relative rotation
- m; mass of particles
- I; inertia moment
- n; the number of contact particles

Newton's equation of motion

$$m\frac{d^2x}{dt^2} = \sum_{j=1}^{n} F_{xj}$$

$$m\frac{d^2y}{dt^2} = \sum_{j=1}^{n} F_{yj} - mg$$

$$I\frac{d^2\psi}{dt^2} = \sum_{j=1}^{n} rF_{\psi j}$$

Pseudo Three-Dimensional Model

Particles of the same diameter

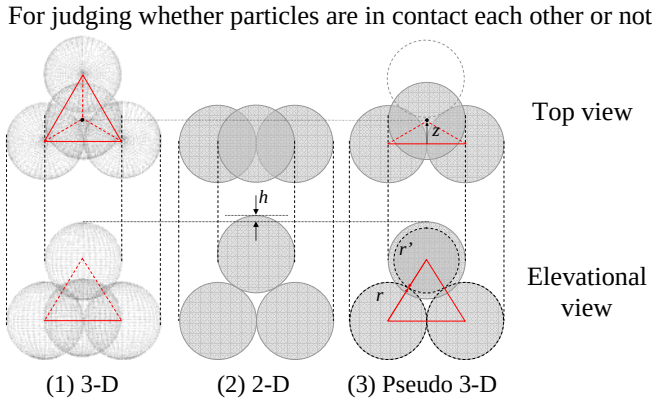
3-D closest packed structure ≠ 2-D closest packed structure

In Pseudo 3-D model…

Equivalent diameter ***r'*** is defined

$$\begin{cases} r' = \left(\sqrt{\frac{11}{3}} - 1\right) r \\ h = \left(\sqrt{3} - \sqrt{\frac{8}{3}}\right) r \\ z = \frac{1}{\sqrt{3}} r \end{cases}$$

For judging whether particles are in contact each other or not



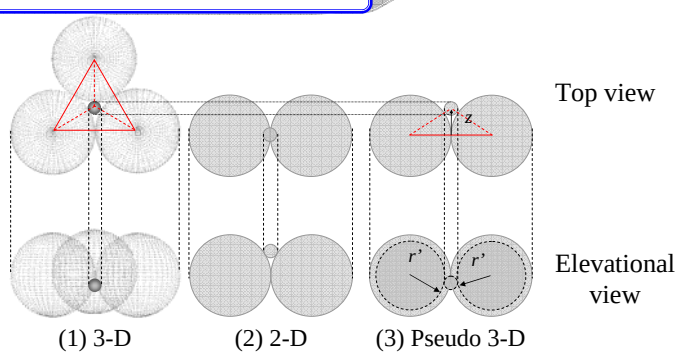
Particles of different diameter

In 3-D simulation…
A fine particle ***can*** pass through the opening space between coarse particles.

In 2-D simulation…
A fine particle ***cannot*** pass through the opening space between coarse particles.

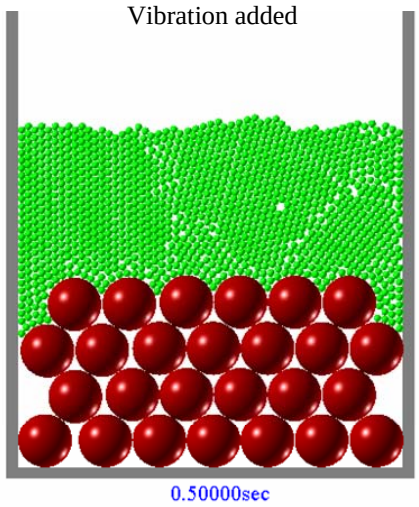
In Pseudo 3-D model… Equivalent diameter ***r'*** is defined

$$\begin{cases} r' = \left(1 - \frac{2\sqrt{3}-3}{6}\right) r \\ z = \frac{1}{\sqrt{3}} r \end{cases}$$



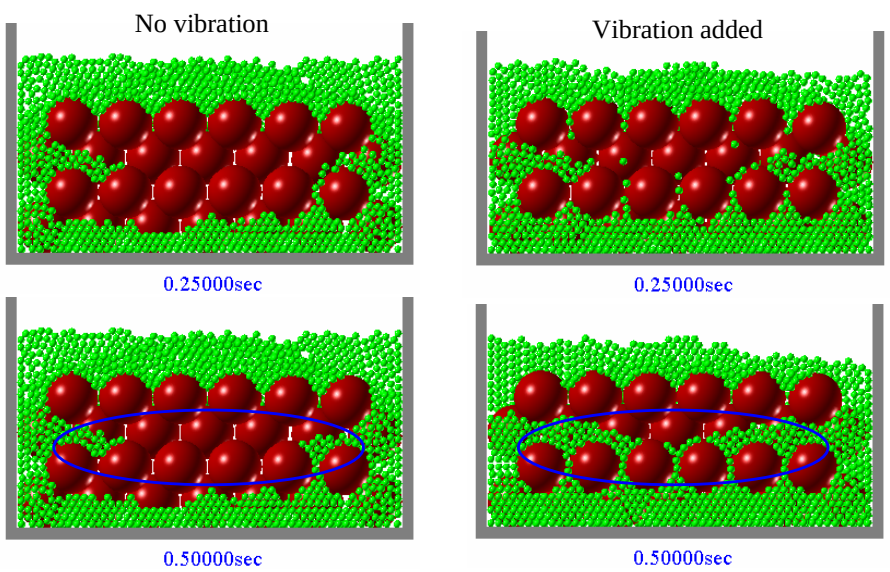
3. NUMERICAL SIMULATION

Two-dimensional simulation



No infiltration of particles due to 2-D simulation

Pseudo three-dimensional simulation



Realistic analysis of fuel packing phenomenon
Enhancement of the infiltration due to external vibration

The condition of analysis

particles	
coarse particles diameter	1.40E-3 [m]
fine particles diameter	2.00E-4 [m]
density	1.10E+4 [kg/m^3]
Young's modules	1.00E+10 [Pa]
Poisson's ratio	0.28 [-]
coefficient of friction	0.25 [-]
number of coarse particles	26
number of fine particles	1200
container	
width	1.00E-2 [m]
height	2.00E-2 [m]
Young's modules	3.90E+9
Poisson's ratio	0.25
coefficient of friction	0.17
calculation	
time step size	1.0E-7 [sec]
duration time	0.5 [sec]
vibration	
amplitude	2.50E-5 [m]
frequency	200 [Hz]

The dynamic behavior of particles in the manufacturing process of the sphere-pac fuel can be simulated with the present methodology.