SIMULATION OF MOVING-BED AND FLUIDIZED-BED REACTORS BY DPM AND MPPIC IN OPENFOAM

KWONWOO JANG, WOOJOO HAN AND KANG Y. HUH
Mechanical Engineering Department, POSTECH, Korea, changfly@postech.ac.kr
Mechanical Engineering Department, POSTECH, Korea, matrix09@postech.ac.kr
Mechanical Engineering Department, POSTECH, Korea, huh@postech.ac.kr

Keywords: DPM(Discrete Particle Method), MP-PIC(Multiphase Particle-In-Cell), rotary kiln, fluidized bed reactor

Many industrial reactors involve a system of many particles interacting with surrounding gas flow in 3D geometry with turbulence, convective and radiative heat transfer and chemical reaction. There are two popular computational methods for handling such a large system of Lagrangian particles in OpenFOAM, DEM (Discrete Element Method) [1] and MPPIC (Multiphase Particle-In-Cell) [2]. The DEM requires large computational resources to track the actual number of particles with all collisions between any pair of particles taken into account. It is practically impossible to apply the DEM to industrial devices with typically over 10^6 particles in the domain. The DPM [1] is a simplified version of DEM with a reduced number of computational parcels composed of the particles of the same characteristics. MPPIC also involves less computational load than DEM by calculating for interaction between the particles on the Eulerian grid. Particle properties are interpolated to the grid and flow field is updated on grid. It is required to assign a sufficient number of parcels in each cell to guarantee smooth spatial variation and computational stability in MPPIC. It was necessary to introduce additional diffusion of particle volume fractions to reduce the computational burden of MPPIC and to compensate for mismatch between Lagrangian parcels and Eulerian grid resolution.

Rotary kilns are a moving-bed reactor employed for a wide range of material processing operations including reduction of iron ore, calcining of limestone, reclamation of hydrated lime and waste incineration. Rotary kilns are essentially heat exchangers in which energy is transferred from hot gas in the freeboard to the packed bed in a long inclined rotating cylinder. In this work simulation is performed for the regime map of particle motion of slipping and rolling in terms of bed depth vs. rotational speed in Henein et al [3] and reduction behavior of iron ore in a pilot scale rotary kiln in Tsuji et al [4].

Table 1: Simulation cases and modes of particle motion

Case #	rpm	h (m)	θ(°)	Mode
1	10	0.035	23.2	Rolling
2	10	0.045	23.0	Rolling
3	10	0.053	23.3	Rolling
4	10	0.07	23.1	Rolling
5	0.5	0.035	21.3 - 27.2	Slumping
6	0.5	0.045	19.4 - 24.4	Slumping
7	0.5	0.053	21.3 - 25.8	Slumping
8	0.5	0.07	30.3	Rolling

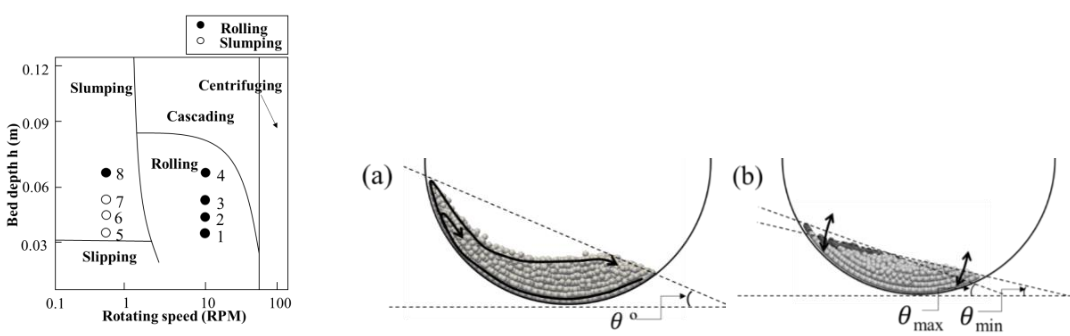

Figure 1: Transverse particle motion in the regime map and Particles in the rolling mode (a) and the slumping mode (b)

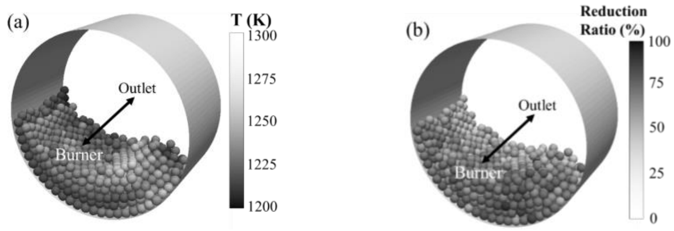

Figure 2: Temperature (a) and reduction ratio (b) of particles at 57minutes in the pilot scale rotary kiln

FINEX is an iron making technology developed by POSCO. Different from traditional blast furnace technology, iron ore is used to directly for making molten iron. The FINEX is an environmentally friendly process in the sense that it produces less CO_2 and requires low cost coal with no pollution from a cokes plant as in a blast furnace process. FINEX is consist of three fluidized bed reactor. The major roles of fluidized bed reactors are reduction and heating up of iron ore fines. R2 reactor is intended primarily for heating of fine iron ore with pure oxygen burners installed around the periphery. Both DEM and MPPIC are applied to simulate particle motion in the fluidized bed R2 reactor in the FINEX process. Validation is performed for the computational models in OpenFOAM in terms of the distributions of the void fraction and development of rising bubbles for the well documented case [5]. Results show that DPM requires larger computational resources than MPPIC to consider collision between all possible pairs of Lagrangian parcels for a much smaller number of parcels for R2 reactor. The flames from the lower burners showed strong interaction with jet flow from the bottom plate with possibility of unwanted excessive heating and melting in some operating conditions.

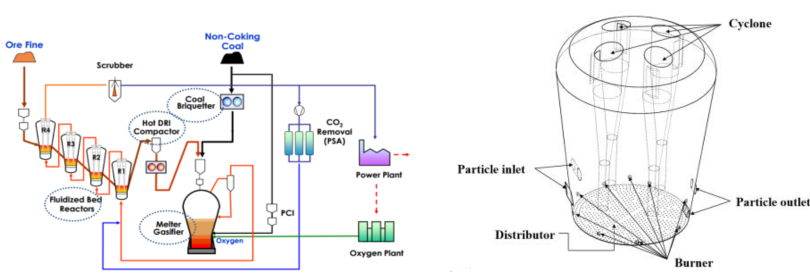

Figure 3: Schematic diagram of FINEX [6] and geometry of fluidized bed reactor

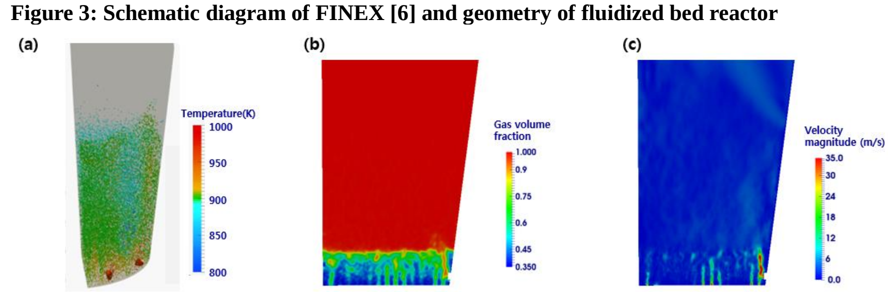

Figure 4: Particle motion (a), gas volume fraction (b) and velocity magnitude (c) in FINEX fluidized bed reactor

References

[1] C. Kloss, C. Goiva, G. Aichinger, S. Pirker, Proceedings Seventh International Conference on CFD in the Minerals and Process Industries, CSIRO, Melbourne, Australia, 2009

[2] M. J. Anderews and P.J. O'Rourke, the multiphase particle-in-cell (MP-PIC) method for dense particulate flows, Int. J. Multiphase Flow 22. 1996.

[3] H.Henein, J.K. Brimacombe and A.P Watkinson, Experimental Study of Transverse Bed Motion in Rotary Kilns, Metallurgical Transactions B, Vol 8, 1997

[4] H. Tsuji, Behaviour of Reduction and Growth of Metal in Smelting of Saprolite Ni-ore in a Rotary Kiln for Production of Ferro-nickel Alloy, ISIJ International, Vol. 52, 2012

[5] Christoph R.Muller, et al, Validation of a discrete element model using magnetic resonance measurements, Particuology 7, 2009

[6] Satyendra, FINEX process for liquid iron production, www.ispatguru.com, 2013