Natasia Naudé, University of Pretoria

Computational modelling for mineral processing processes
OVERVIEW

- Introduction
- Scope of Modelling
- What is CFD?
- What is DEM?
- Multi-Phase Model
- Limitations in Modelling
- Future of modelling
INTRODUCTION

- Mineral processing models in theory – Empirical Approach

- Design techniques
  - Analytical and continuum (2-D) methods
  - Trial and error
  - Experience and know-how
  - Simulation/Modelling
Scope of Modelling

Application of modelling can address the following issues:

- Design modification and performance evaluation
  - Reduce cycle time in design and prototype building
  - Parametric studies
  - Retro-fit and re-design analysis
  - Enhance quality and productivity achievements

- Troubleshooting and knowledge building
  - Identify and resolve process/equipment specific problems
  - Obtain data in systems not easily tested or measured
  - Operator training
Scope of Modelling

- Process dynamics and logistics matching
  - Evaluate implications of changes in process variables on plant
  - Identify and resolve non-matching process steps

- Environmental impact analysis and control
  - Monitor and improve release of polluting gases and waste/tramp elements
  - Waste recovery system analysis and improvement
What is CFD?

- **Computational Fluid Dynamics (CFD)** – predicting fluid flow, heat and mass transfer, chemical reactions and related phenomena by solving numerically the set of governing equations (conservation of mass, momentum, energy).

- The partial differential equations are discretised into a system of algebraic equations and are then solved numerically to render the solution field.

\[
\frac{\partial}{\partial t} \int_V \rho \phi \, dV + \int_A \rho \phi \mathbf{V} \cdot dA = \int_A \Gamma V \phi \cdot dA + \int_V S \phi \, dV
\]
Advantages of CFD

- **Low Cost**
  - Using physical experiments and tests to get essential engineering data for design can be expensive
  - Computational simulations are relatively inexpensive
  - No equipment downtime during testing

- **Speed**
  - CFD simulations can be executed in a short period of time.
  - Quick turnaround means engineering data can be introduced early in the design process

- **Comprehensive Information**
  - Experiments only permit data to be extracted at a limited number of locations in the system (e.g. pressure and temperature probes, heat flux gauges, LDV, etc.)
  - CFD allows the analyst to examine a large number of locations in the region of interest, and yields a comprehensive set of flow parameters for examination
  - Both numerical and graphical output available
Cyclone Separators

- Pressure
- Radial velocity
- Axial velocity

CFD Examples
Examples CFD modelling – Fluidised bed effect of bed thickness

Q. Zhou, Y.Q. Feng, et al. 2011
What is DEM?

- **Discrete Element Method (DEM)** – simulating the movement of discrete matter

- DEM simulations produce valuable data including:
  - Internal behaviour of a granular bulk interacting with machine surfaces
  - Magnitude, frequency and distribution of collisions between system components
  - Velocity and location of each particle
  - Energy associated with impact, abrasion, cohesion and de-bonding of particles within a bulk flow
  - Force chains and structural integrity of meta-particle structures
Challenges of applying DEM to Industrial Applications

- Large number of particles
- Wide variety of shapes
- Fine particles
- Deformation/Breakage
- Cohesion/Adhesion present
- Inputs at a particle level

DEM is an approximation of material flow in the real world
DEM Example: Chute design
Multi-Phase Model

- **Coupled CFD-DEM** – Multi-phase modelling – accounts for particle-particle interaction and particle-fluid interaction forces

- Typical objectives of multi-phase modeling analysis
  - Maximize the contact between the different phases, typically different chemical compounds
  - Flow dynamics
EDEM-FLUENT Process Flow

- **DEM timestep(s)** started at end of fluid simulation timestep
  - Calls EDEM
  - Fluid iterated to convergence
    - Forces on fluid from particles are introduced into fluid through a series of momentum sinks
  - Drag forces on particles calculated using data extracted from fluid mesh cells
    - Particle positions input into FLUENT
    - Particle positions updated
Examples of Multi-phase modelling – batch jig

Xia et al., (2006)
Examples of Multi-phase modelling – Hydro-Cyclone

DEM Solutions, 2008
Examples of Multi-phase modelling – Pulsation Profile in Jigs

S. M. Viduka, Y.Q. Feng, et al, 2011

Sinusoidal

Sawtooth-backward
Case Study: Mineral Density Separator
Schematic Representation of MDS

- Cylindrical chamber with rings
- T3 - Exhaust
- T1 - Inlet
- Air
- Change of water level in the hutch during operation
- Water chamber - Hutch

Water
MDS Test Work
Different Shapes of the Base Particles

- Spherical (D = 2 mm)
- Triangular (3.5mm x 4mm)
- Elongated (3mm x 2mm)
Particles Created

Random size distribution of 6mm to 8mm

Total number of particles created:
Brown $< 3.2 \text{ g/cm}^3$
White $> 4.0 \text{ g/cm}^3$

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<td>TOTAL NUMBER</td>
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EDEM-CFD COUPLED MODELS

- EDEM-CFD coupling method
  - Eulerian coupling

- Drag Model
  - Free-stream drag model

- EDEM Contact Model
  - Hertz Mindlin
Fully Coupled Multiphase Model
Starting Position
Consolidated Bed For The First Pulse
Consolidated Bed For The Third Pulse
Consolidated Bed After Seven Pulses
Pressure Profile At Starting Position

[Image of pressure profile diagram]
Velocity Profile At The Starting Position
Limitations in Modelling

- Material Properties are not always known
- Transient analyses are time consuming
- CFD and DEM solutions rely upon physical models of real world processes - the solution can only be as accurate as the physical model
- Uncertainty and variation in boundary conditions due to process variations
- Validation is difficult
Future of modelling

- A logical approach is required to create calibrated simulations to reproduce real life flows to obtain financial benefits
- Simulations is an excellent tool to analyse and trouble-shoot complex systems
- More complex flows in minerals processing
- Validation of empirical equations with the aid of simulations
- Hardware constraints? – Future
EDEM EXAMPLES