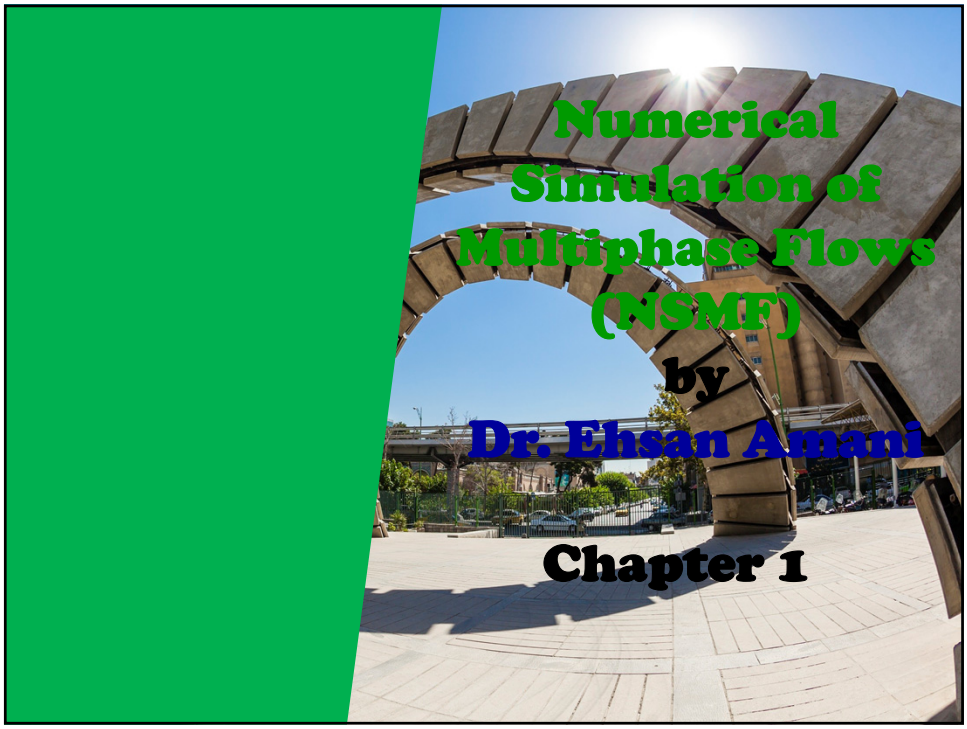
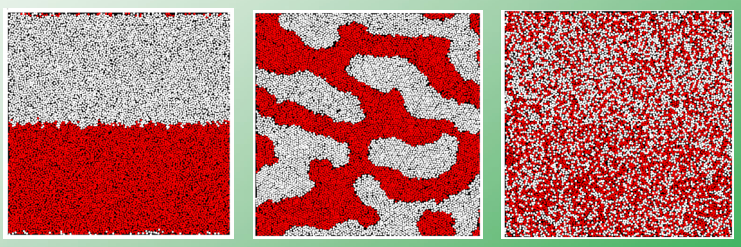


Phase

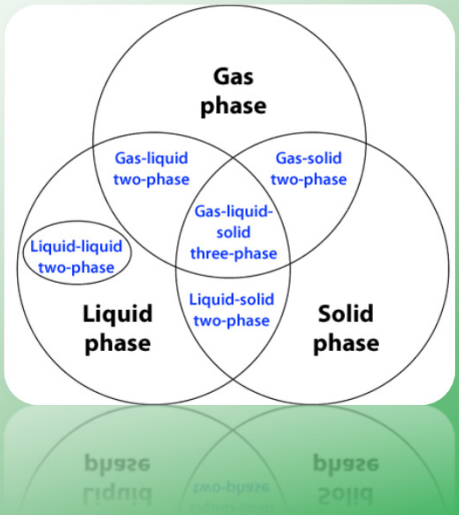
Phase:
Gas – Liquid – Solid

Phase vs. component:
Mixing at the molecular level



Multiphase Flow Classification

Based on phase types:



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Multiphase Flow Examples

Gas-liquid flows

- Gas-liquid flow in ducts
  - The gas-lift technique in oil wells

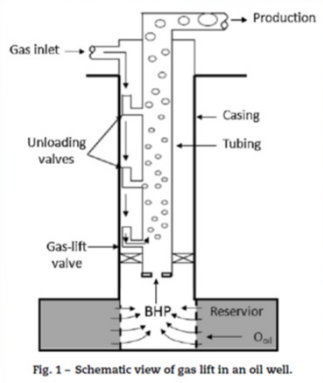

Fig. 1 – Schematic view of gas lift in an oil well.

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Multiphase Flow Examples

Gas-liquid flows

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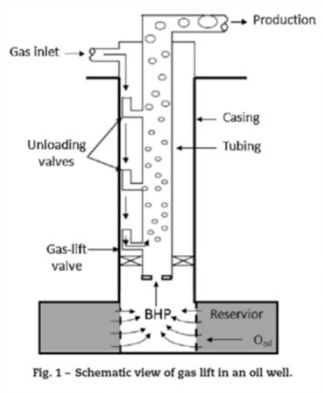
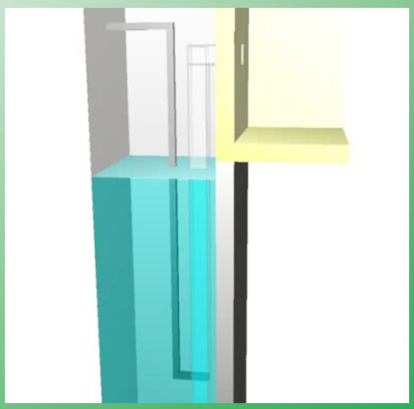


Fig. 1 – Schematic view of gas lift in an oil well.



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Multiphase Flow Examples

Gas-liquid flows

- Gas-liquid flow in ducts
  - Different regimes, different phenomena

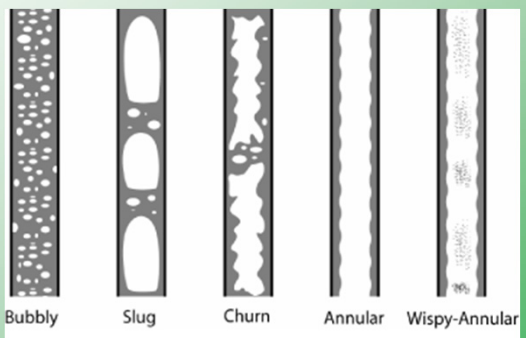

Figure 2. Flow patterns in vertical upward flow in a tube.

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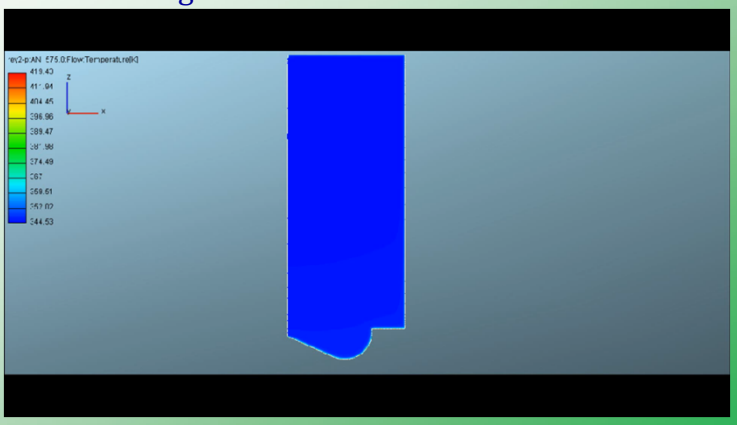
Multiphase Flow Examples

Gas-liquid flows

- Liquid sprays
  - Diesel engines



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Multiphase Flow Examples

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Multiphase Flow Examples

Gas-liquid flows

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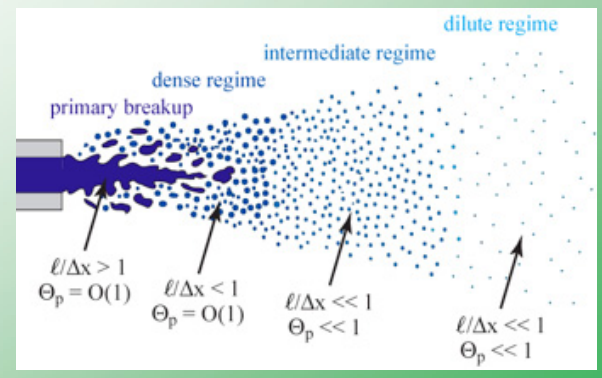

- A better classification?

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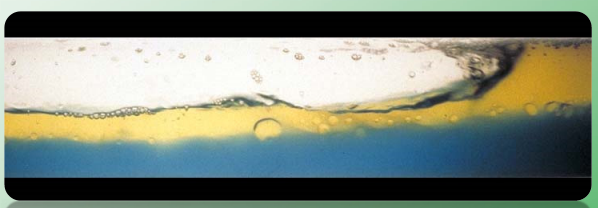
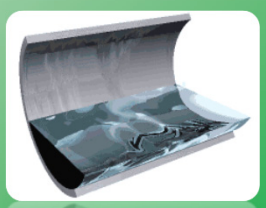
Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

- ***Separated flows***: each phase can be considered as a continuous medium
  - Slug flow
    - Three-phase water-oil-gas flow in oil transport pipelines





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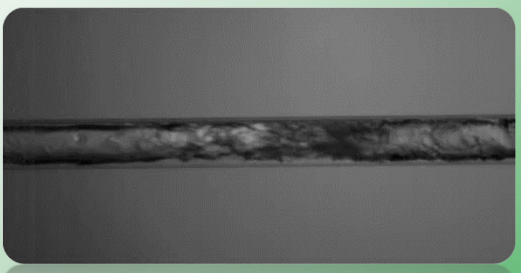
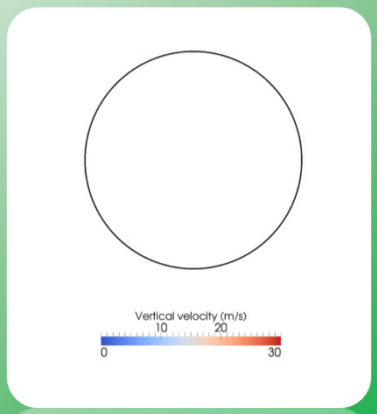
Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

- ***Separated flows***: each phase can be considered as a continuous medium
  - Slug flow
  - Annular flow
    - Condenser tubes





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Multiphase Flow Classification

Separa es

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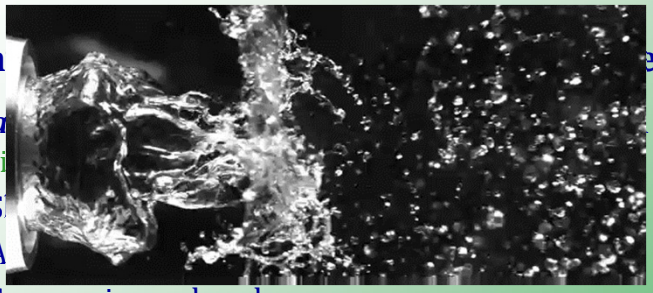
  - S
  - A
  - Spray primary breakup
    - Water or fuel injection



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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

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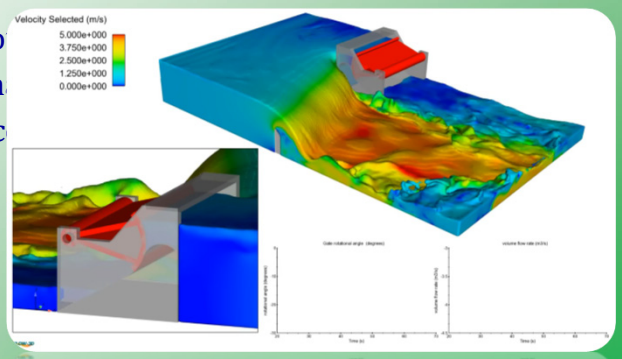
    - Weir



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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

- ***Separated flows***: each phase can be considered as a continuous medium
  - Slug flow
  - Annular flow
  - Spray primary breakup
  - Free surface flows
  - Drop or bubble motion
    - Rising oil droplet

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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

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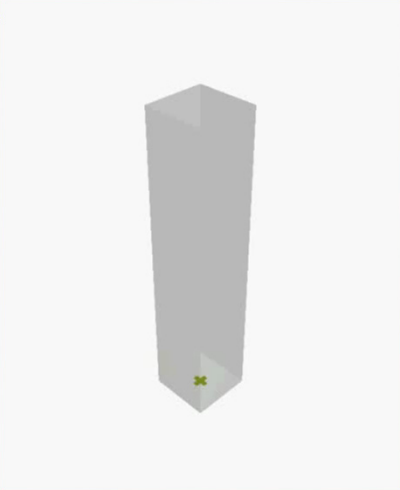

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Multiphase Flow Classification

Separated, dispersed, and mix

- ***Dispersed flows***: some phases ca discrete
  - Gas-solid flows
    - Filters (cyclones, …)
    - Nanofluids
    - Sedimentation
    - Erosion
    - Fluidized beds
    - Aerosol
    - …

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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

- ***Dispersed flows***: some phases can be considered discrete
  - Gas-solid flows
  - Sprays (gas-liquid)
    - Coating

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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

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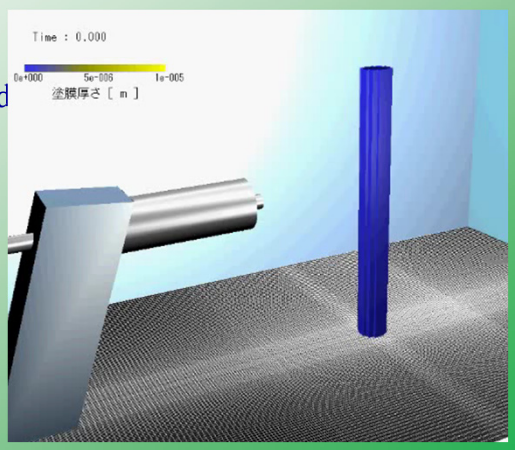

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Multiphase Flow Classification

Separated, dispersed, and mixed flow regimes

- ***Dispersed flows***: some phases can be considered discrete
  - Gas-solid flows
  - Sprays (gas-liquid)
    - Coating
    - Drying
    - Liquid fuel burners
    - Fire extinguishing
    - NOx reduction
    - …

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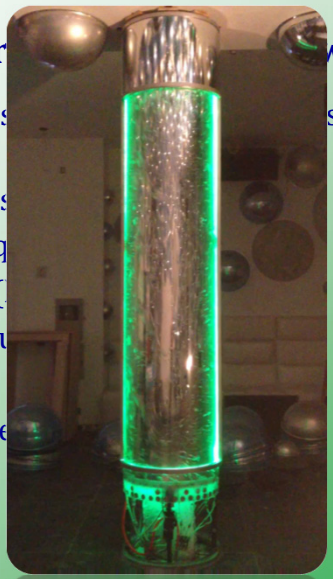
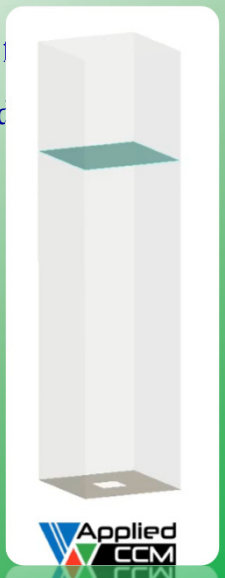
Multiphase Flow Classification

Separated, disper

- ***Dispersed flows***: s
  discrete
  - Gas-solid flows
  - Sprays (gas-liq
  - Bubbly flows (
    - Bubble colu
    - Gas-lift
    - Thee-phase
    - …





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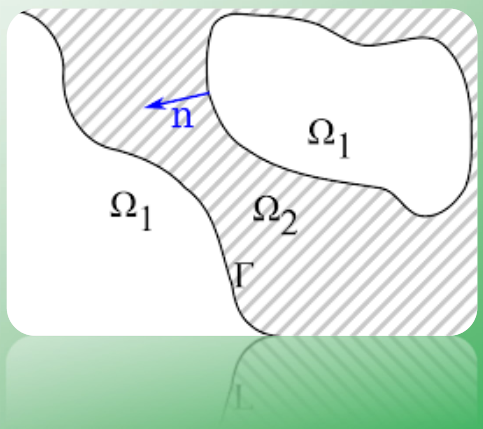
Multiphase Flow Computation

Part II

DNS of multiphase flows

Capturing the location of the interface between phases



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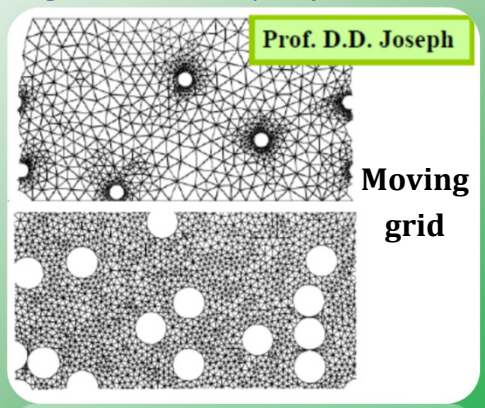
Multiphase Flow Computation

DNS of multiphase flows

(Navier-Stokes + proper treatment of the interface)

- ***Arbitrary Lagrangian Eulerian (ALE)***



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Multiphase Flow Computation

DNS of multiphase flows

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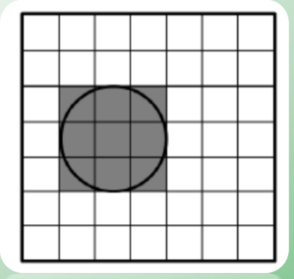
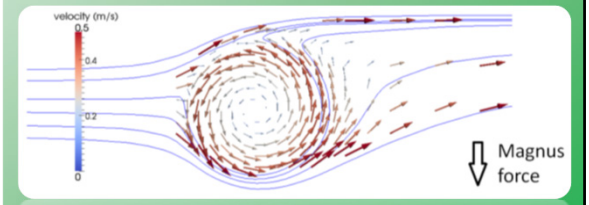
- ***Arbitrary Lagrangian Eulerian (ALE)***
- ***Immersed Boundary Method (IBM)***





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Multiphase Flow Computation

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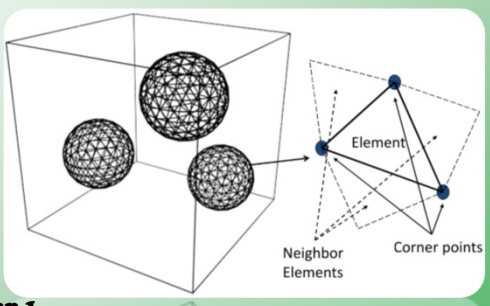
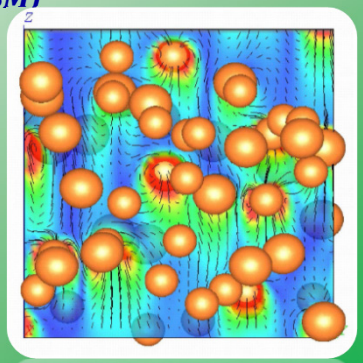
- ***Front Tracking Method (FTM)***





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Multiphase Flow Computation

DNS of multiphase flows

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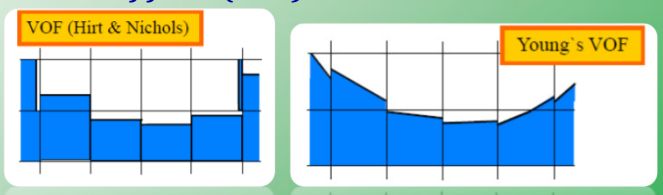
- ***Arbitrary Lagrangian Eulerian (ALE)***
- ***Immersed Boundary Method (IBM)***
- ***Front Tracking Method (FTM)***
- ***Level Set (LS)***
- ***Volume of fluid (VOF)***



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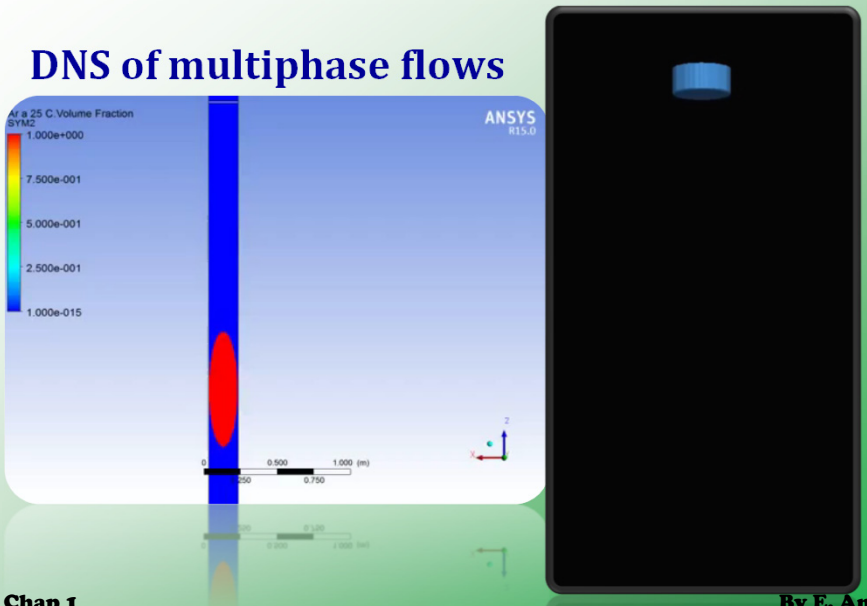
Multiphase Flow Computation

DNS of multiphase flows



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Multiphase Flow Computation

DNS of multiphase flows

(Navier-Stokes + proper treatment of the interface)

- *Arbitrary Lagrangian Eulerian (ALE)*
- *Immersed Boundary Method (IBM)*
- *Front Tracking Method (FTM)*
- *Level Set (LS)*
- *Volume of fluid (VOF)*
- *Phase-Field (PF)*
- *Lattice-Boltzmann Method (LBM)*
- *…*

Multiphase Flow Computation

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- *Volume of fluid (VOF)*
- *Phase-Field (PF)*
- *Lattice-Boltzmann Method (LBM)*
- *…*

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Multiphase Flow Modelling

Part III

Eulerian averaged (statistical) approaches

- ***Multi-fluid model***

$$\frac{\partial}{\partial t}(\alpha_f \rho_f)+\frac{\partial}{\partial x_i}(\alpha_f \rho_f U_i)=0$$

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Multiphase Flow Modelling

Eulerian averaged (statistical) approaches

- ***Multi-fluid model***
- ***Population balance model***
- ***Mixture (drift-flux) model***
- ***Homogeneous model***

Higher levels of simplification

Simpler coding

- ***Advantage: practical engineering usage***
- ***Disadvantage: closure problem***

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Multiphase Flow Modelling

Eulerian averaged (statistical) approaches

- *Multi-fluid model*
- *Population balance model*
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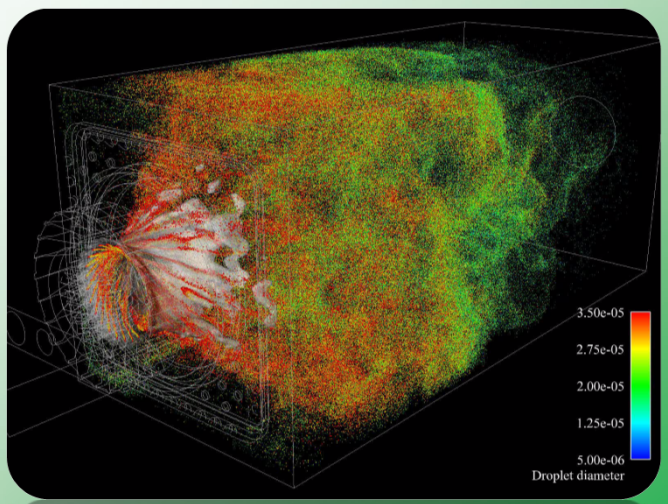
Multiphase Flow Modelling

Part IV

Eulerian-Lagrangian point-particle approaches



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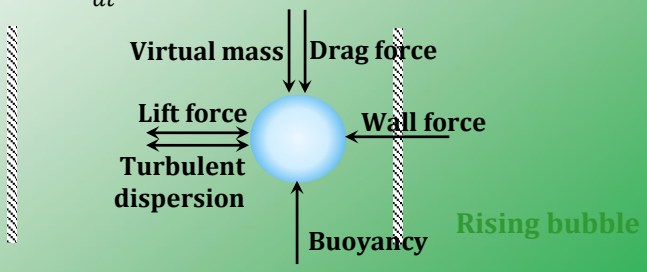
Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

- *Eulerian continuous phase + Lagrangian particles*
  - *Lagrangian particle tracking algorithm*

$$\frac{dx_{p,i}}{dt} = U_{p,i}$$

$$m_p \frac{dU_{p,i}}{dt} = F_{\text{fluid-particle,i}} + F_{\text{particle-particle},i} + F_{\text{body,i}}$$



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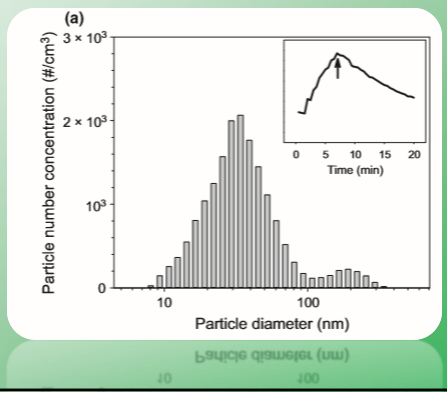
Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

- *Eulerian continuous phase + Lagrangian particles*
  - *Lagrangian particle tracking algorithm*
  - *Statistical representation of particles (DDF)*



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Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

- *Eulerian continuous phase + Lagrangian particles*
- *Fluid-particle interactions*
  - *Force closures*
  - *Energy transfer closures*
  - *Mass Transfer closures*
  - *Dispersion*
  - *Two-way coupling*

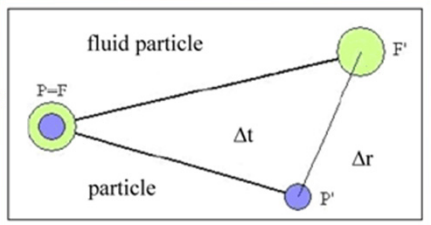

Figure 1: Solid and fluid particle trajectories

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Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

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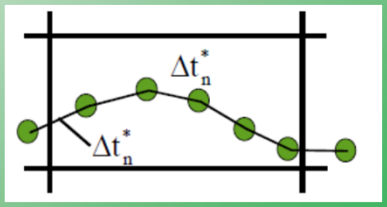

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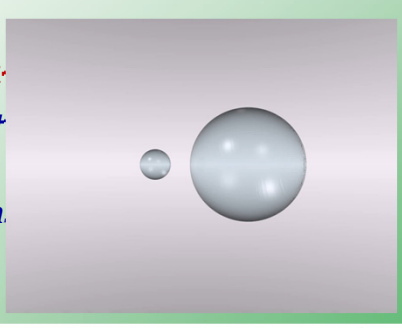
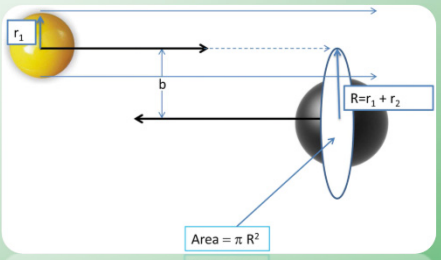
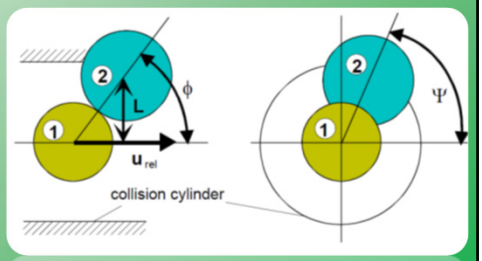
Multiphase Flow Modelling

Eulerian-Lagrangian point-

- *Eulerian continuous phase +*
- *Fluid-particle interactions*
- *Particle-particle interaction*
  - *Collision models*







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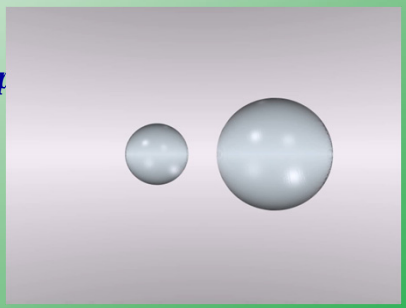
Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

- *Eulerian continuous phase + Lagrangian particles*
- *Fluid-particle interactions*
- *Particle-particle interactions*
  - *Collision models*
  - *Coalescence and breakup*



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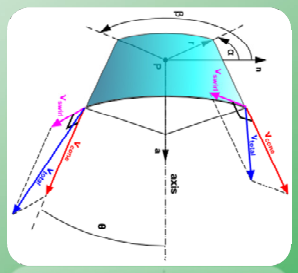
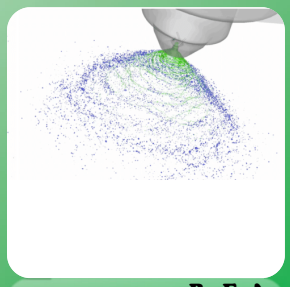
Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

- *Eulerian continuous phase + Lagrangian particles*
- *Fluid-particle interactions*
- *Particle-particle interactions*
- *Boundary conditions*
  - *Injection models*





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Multiphase Flow Modelling

Eulerian-Lagrangian point-particle approaches

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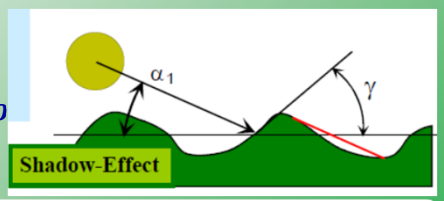
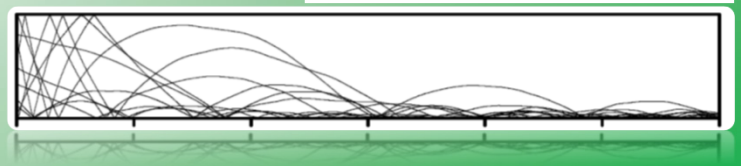
- *Particle-particle interactions*
- *Boundary conditions*
  - *Injection models*
  - *Particle-wall interactio*
  - *...*





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