Numerical Simulation of Particle Collision and Breakup Behavior by SDPH-FVM Coupling Method

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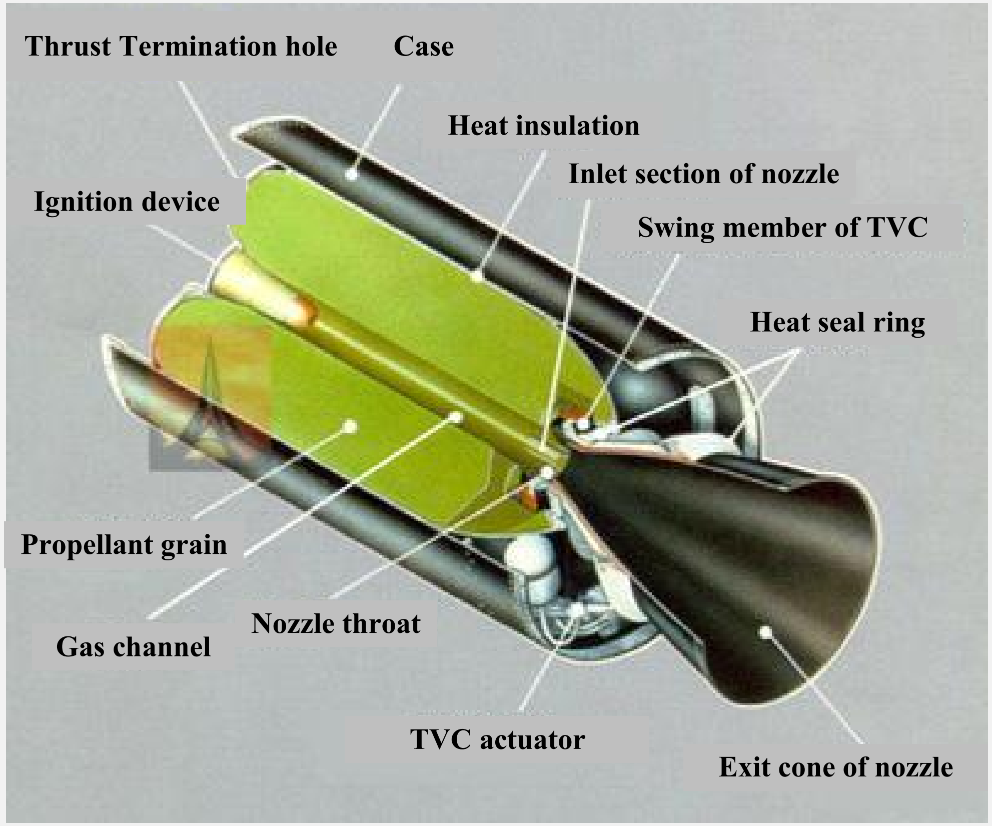
Outline

- Background and Significances
- SDPH–FVM Coupling method
- Particle Collision and Breakup for SDPH–FVM
- Applications in Engineering
- Conclusions and Future works

Background and Significances



Schematic of SRM

Phase transformation of aluminum

↓

Cohesion and broken of aluminum droplets

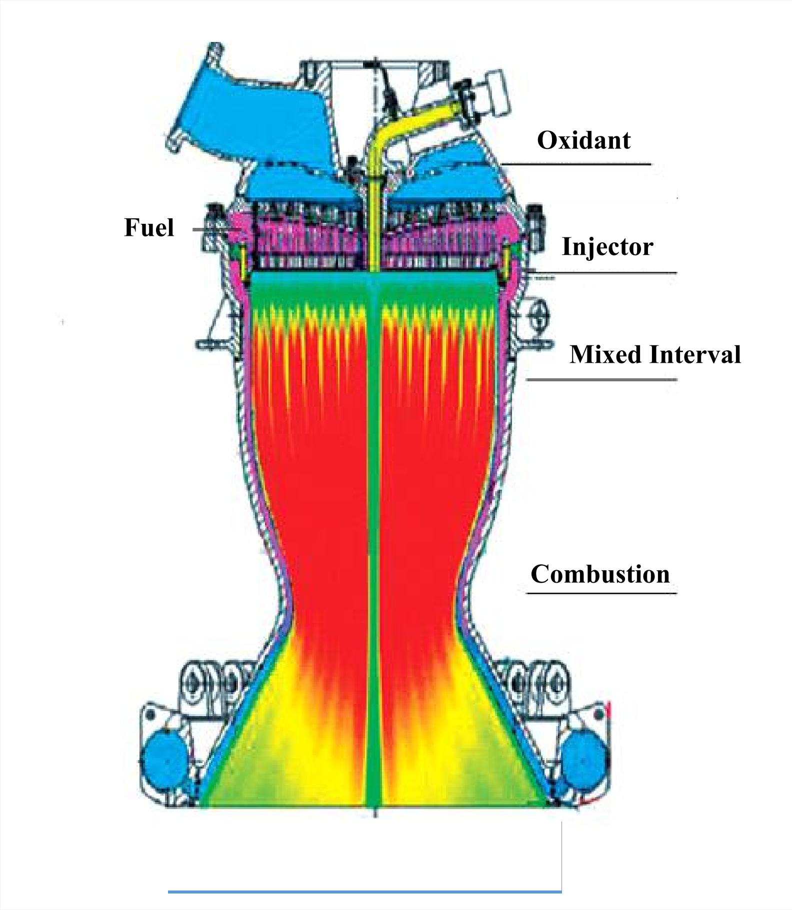
↓

Evaporation and combustion of aluminum droplets

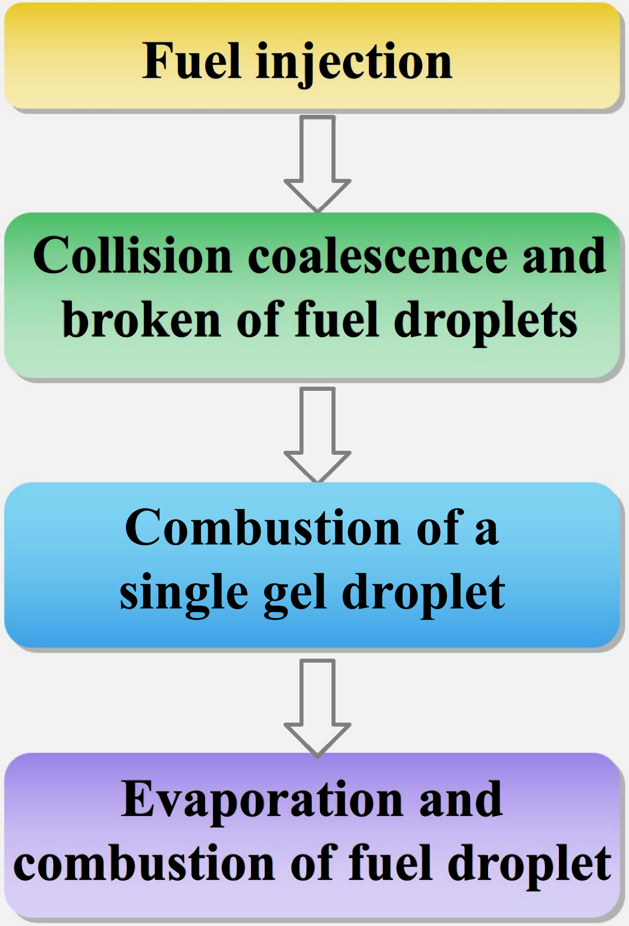
↓

Scouring and deposit to the structure of Al_2O_3

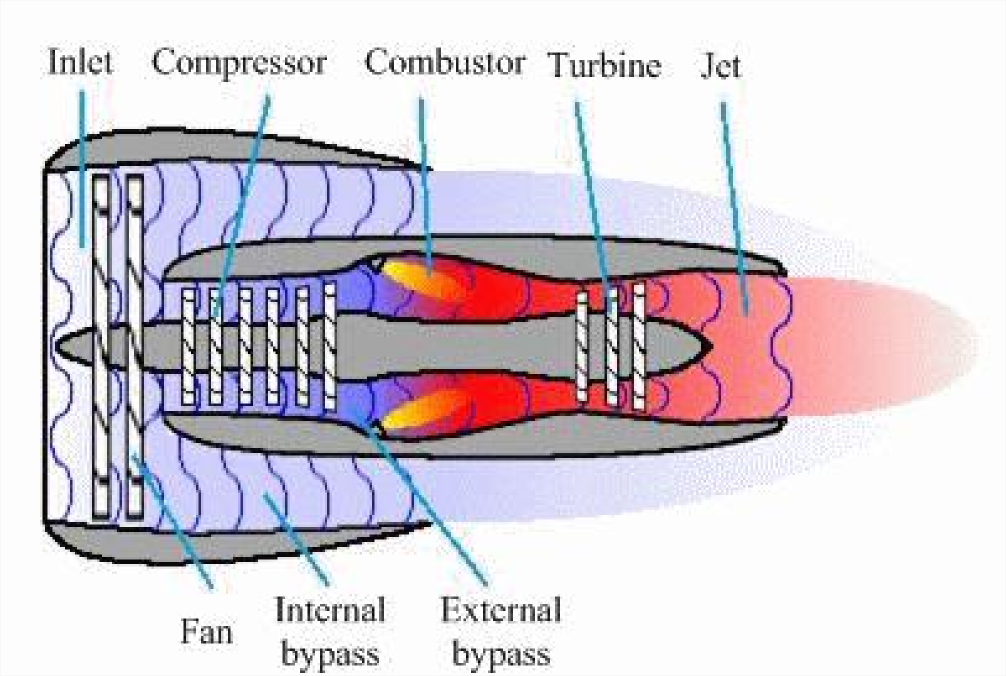
Background and Significances



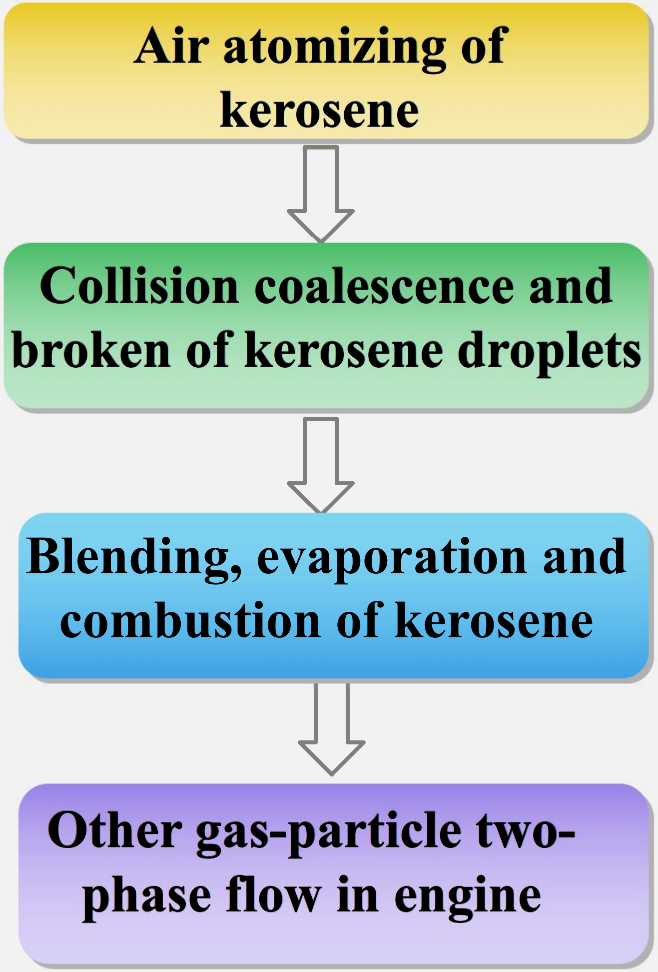
Combustion schematic of liquid rocket engine



Background and Significances



The working process of aircraft engine



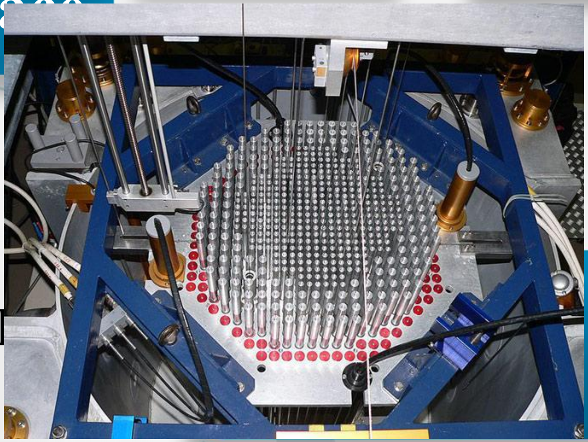
Areas of gas-particle two-phase flow

Aerospace | Environment | Energy | Transport | Chemical engineering

Aerospa

March Rocket Launching

eas of gas-
two-phase



Numerical Reactor

Stand Storm

Utility Boiler

Development and situation of two-phase flow researching

- VOF model
- Mixture model
- Euler -Euler method
- Euler -DPM method
  - Hard sphere
  - Soft sphere

Drawbacks of the current methods

Drawbacks of the current methods

Mixture model
Euler-Euler model

Described by Euler method for particle phase, difficulty in obtaining the discrete properties of particle phase, addition of evaporation and combustion model

Euler-DPM model

Described by Lagrange method for particle phase, can trace the path of individual particles, volume fraction of particles should be lower than 10%, much computational effort.

☆**According to analysis, the best method for the problem is：**

- **Continuum phase solved by Euler method** → **FVM**
- **Discrete phase solved by Lagrange method** → **SDPH**

SDPH-FVM coupling method

SDPH for discrete phase

SDPH-------Smoothed Discrete Particle Hydrodynamics

SPH---------Smoothed Particle Hydrodynamics

Kinetic theory of granular flow （KTGF）

Import granular temperature: $\frac{3}{2}m\theta_t = \frac{1}{2}m < C^2 >$ → $\theta_t = \frac{1}{3} < C^2 >$

C is the particle fluctuating velocity

SDPH for discrete phase

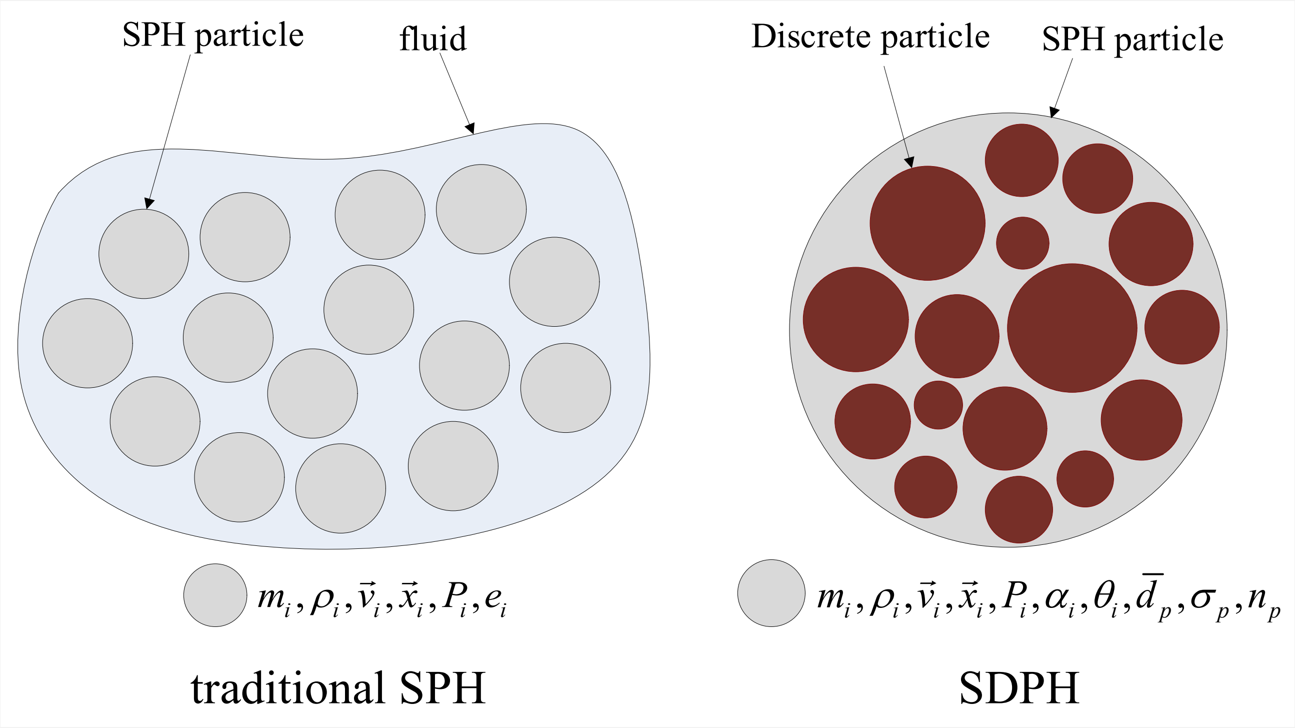
The relationship between the SDPH particles and discrete particles is:

The effective density of q phase is: $\hat{\rho}_q = \alpha_q \rho_q$

Where α_q is the effective volume fraction of q phase

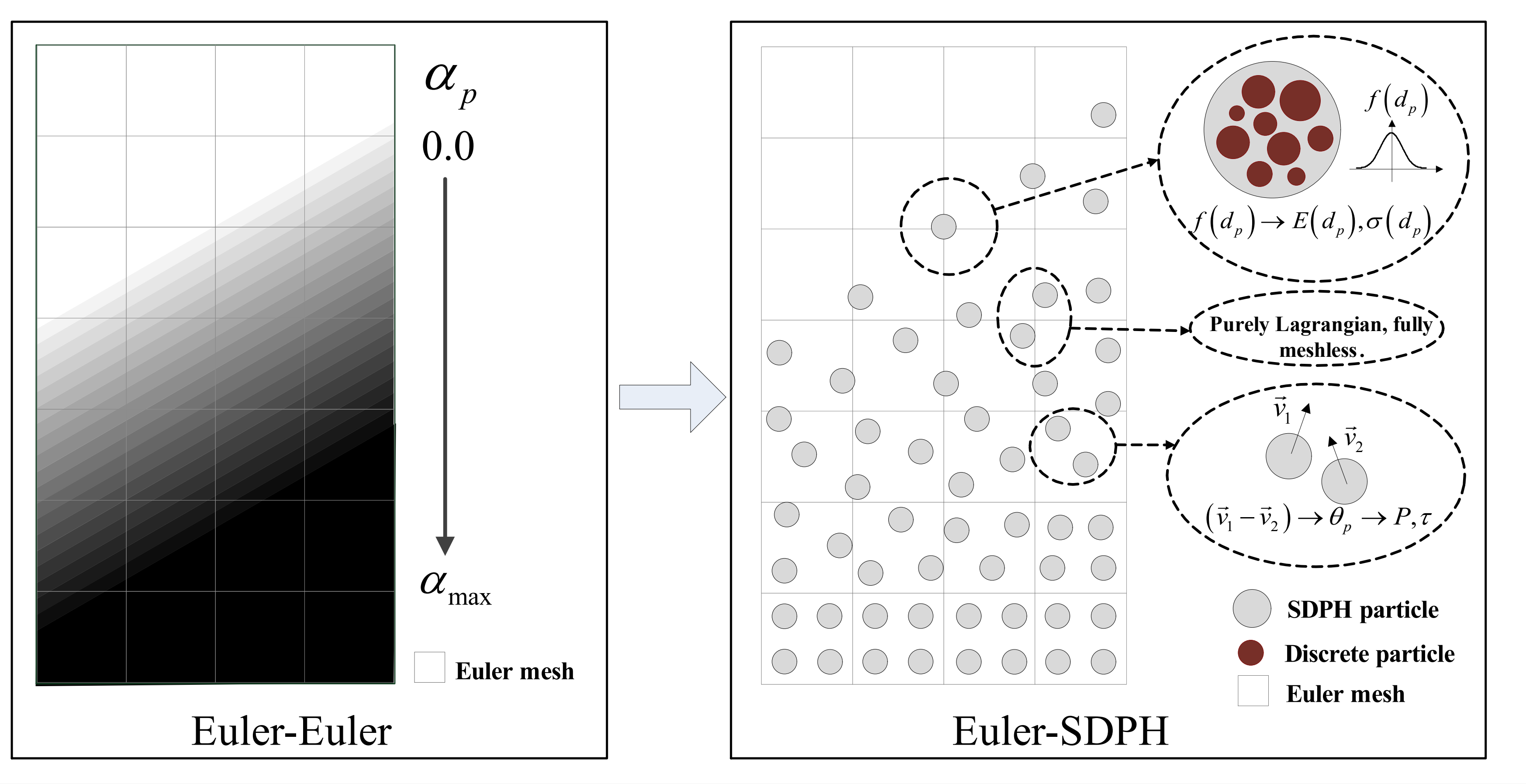
$$\hat{\rho}_q = \alpha_q \rho_q = \frac{V_q}{V_0} \rho_q = \frac{m_q}{V_0} = m_q \sum W \longrightarrow \sum W = \frac{1}{V_{Effect}}$$

SDPH for discrete phase



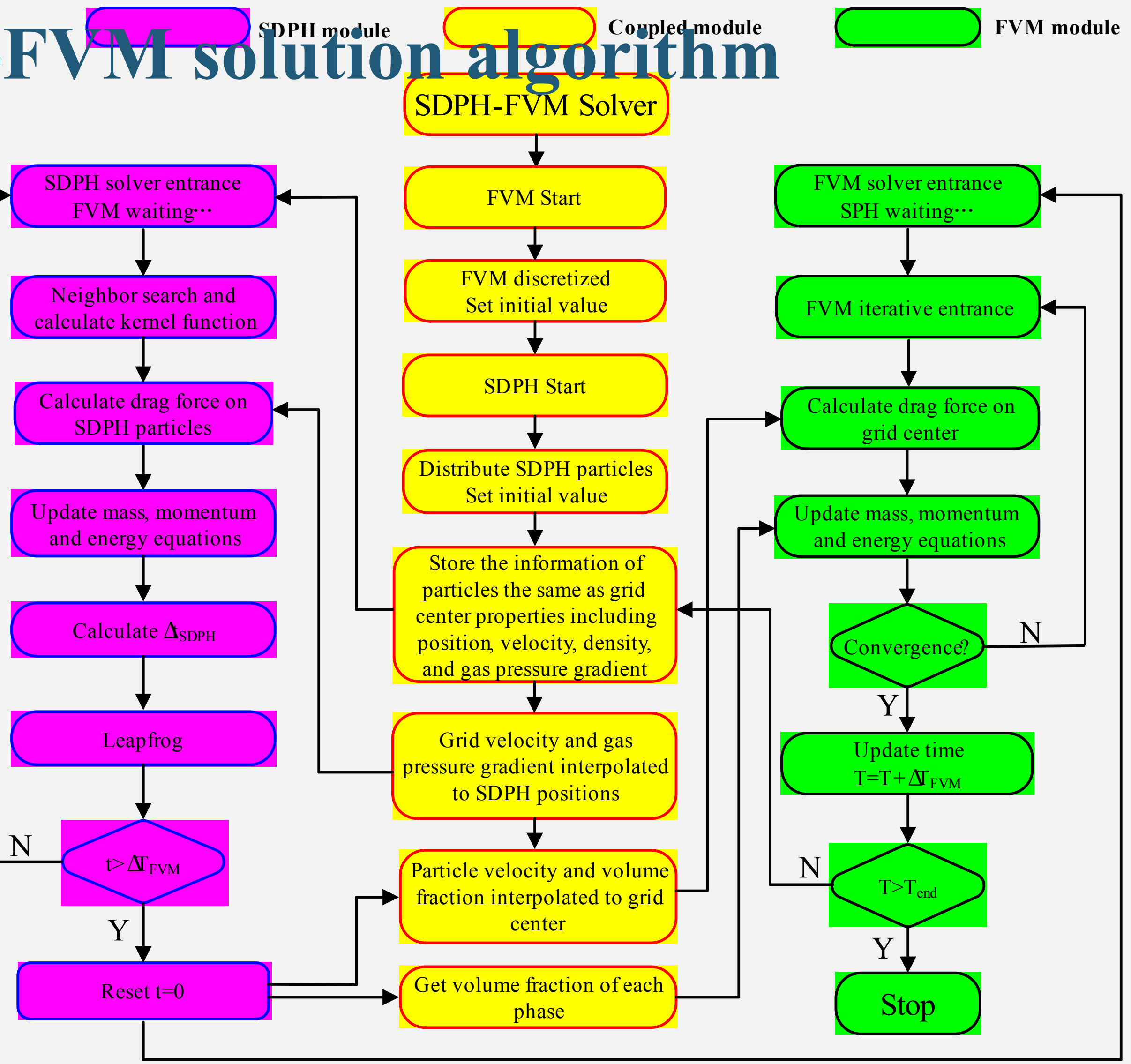
Improved SPH——SDPH

SDPH-FVM coupling framework



Coupling frameworks of different methods

SDPH-FVM solution algorithm



Considering coalescence and breakup of particles

- **Particle coalescence and breakup dealing method**
  - **PBF** Particle Balance Function
    - **Class Method**
    - **Monte Carlo Method**
    - **Moment Method**
  - **BND** Bubble Number Density

Considering coalescence and breakup of particles

Particle Balance Function（PBF）

At point $\mathbf{x}=\left(x_1;x_2;x_3\right)$ $\quad d\mathbf{x}=dx_1dx_2dx_3$

Particle size between $\left(L,L+dL\right)$ $\quad n\left(L;\mathbf{X},t\right)d\mathbf{X}dL$

Particle balance function can be wrote

$$\frac{\partial}{\partial t}\left[n\left(L\right)\right]+\nabla\cdot\left[\mathbf{U}_d n\left(L\right)\right]=\left[B\left(L;\mathbf{x},t\right)-D\left(L;\mathbf{x},t\right)\right]$$

$$m_k=\int_0^\infty n\left(L\right)L^k\,dL$$

$$\frac{\partial m_k}{\partial t}+\nabla\cdot\left[\mathbf{U}_d^k m_k\right]=\left[\bar{B}_k-\bar{D}_k\right]$$

Particle Collision and Breakup for SDPH–FVM

- **Considering coalescence and breakup of particles**
  - **PBF solved by moment method**

The Kth moment of particle size distribution function $m_k(t) = \int_0^\infty n(L) L^k dL$

m_0 is the total number of particles

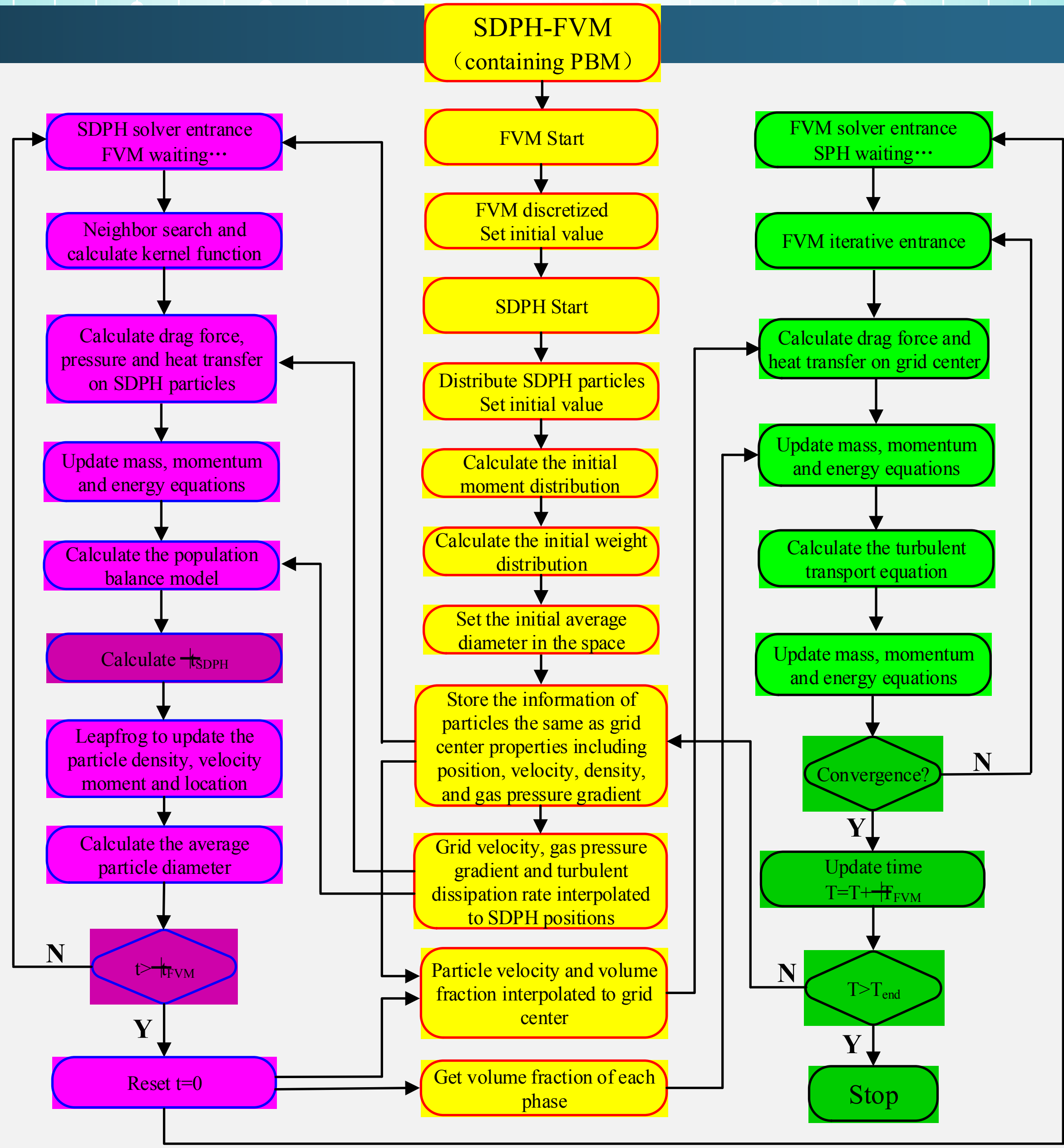
m_2 is related to the specific surface area through the area shape factor K_A

m_3 is related to the volume fraction through the volume shape factor K_V

d_{32} is the surface-averaged mean particle size called Sauter diameter

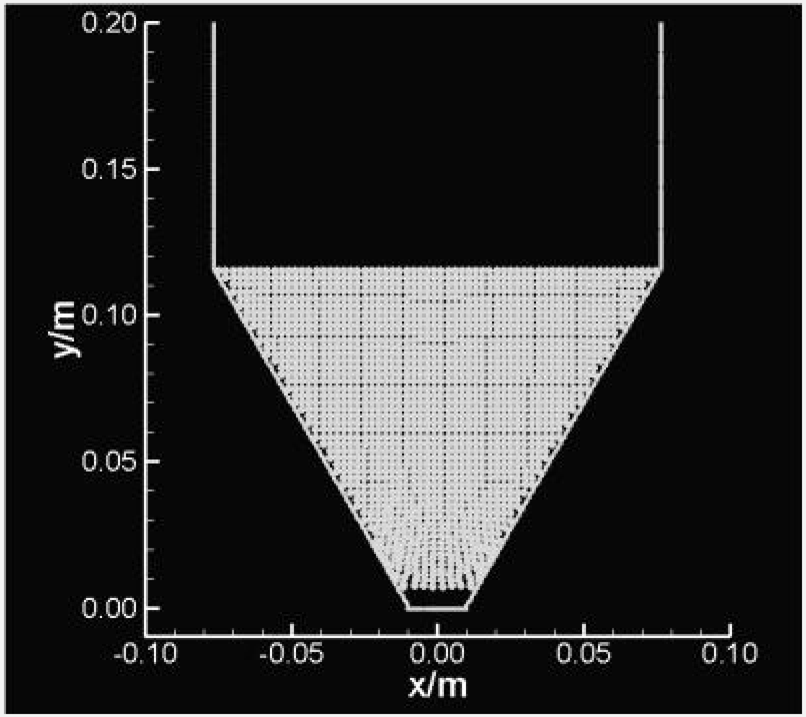
Hence, the relationship between the SDPH particles and discrete particles is established.

Particle Collision and Breakup for SDPH–FVM

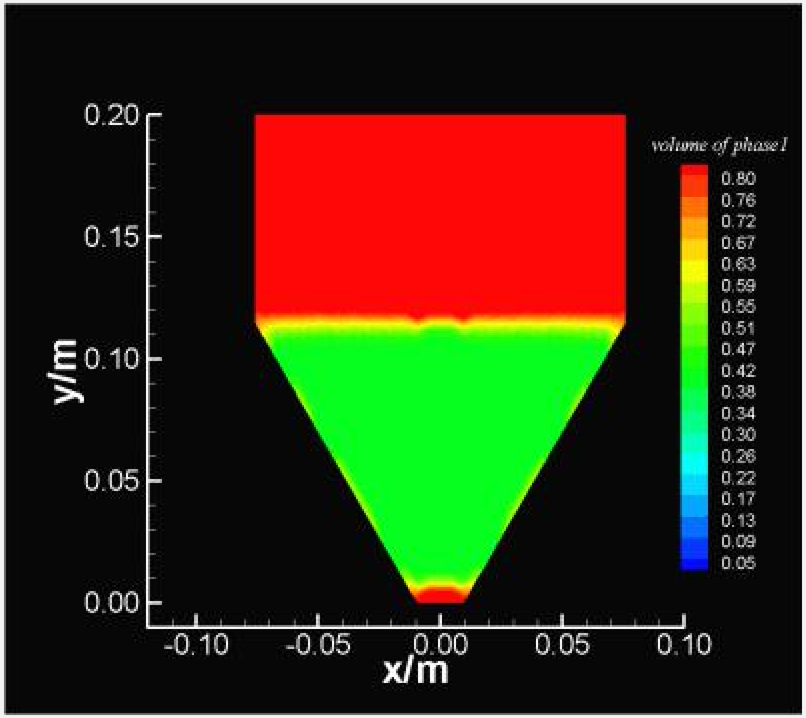


Applications in some engineering fields

➢Two-dimensional conical-based spouted bed



Motions of discrete particles

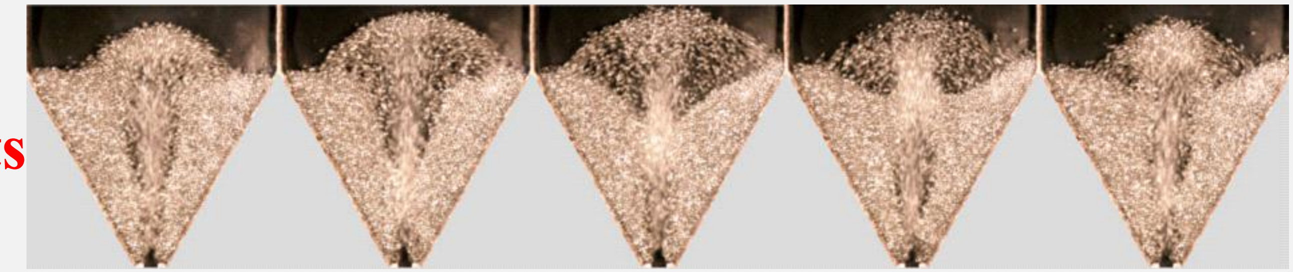


Motions of gas phase

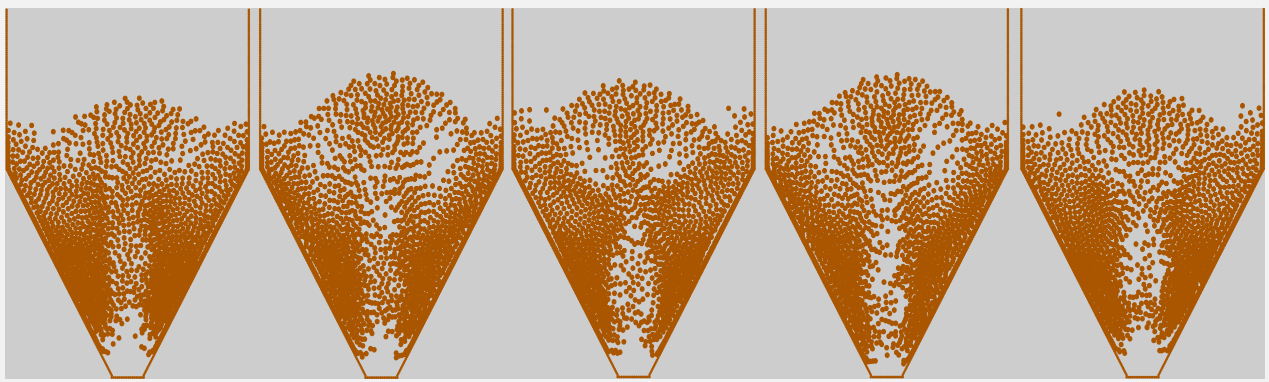
Simulation results of SDPH–FVM coupled method

Applications in some engineering fields

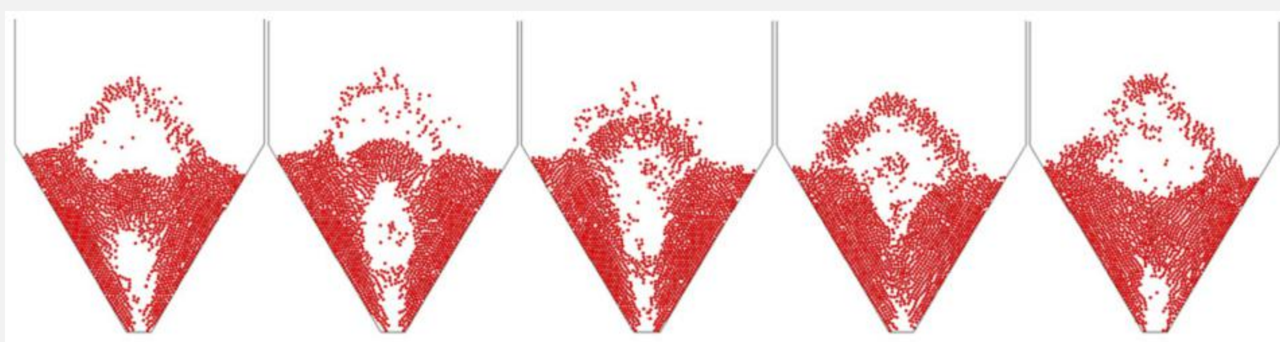
Experiments



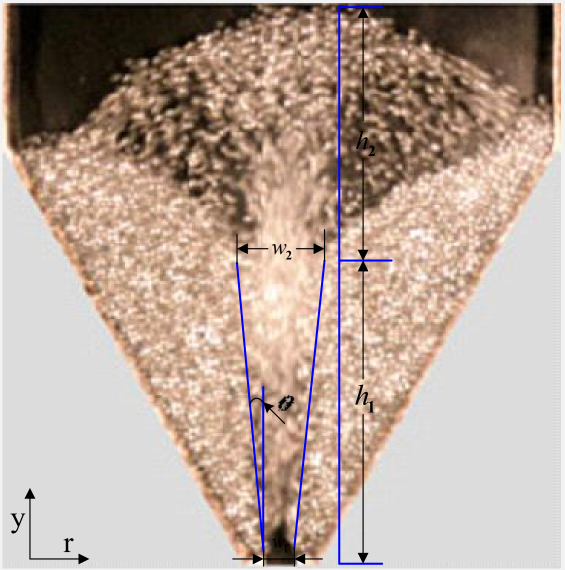
SDPH-FVM



DEM-FVM



Comparison of the results

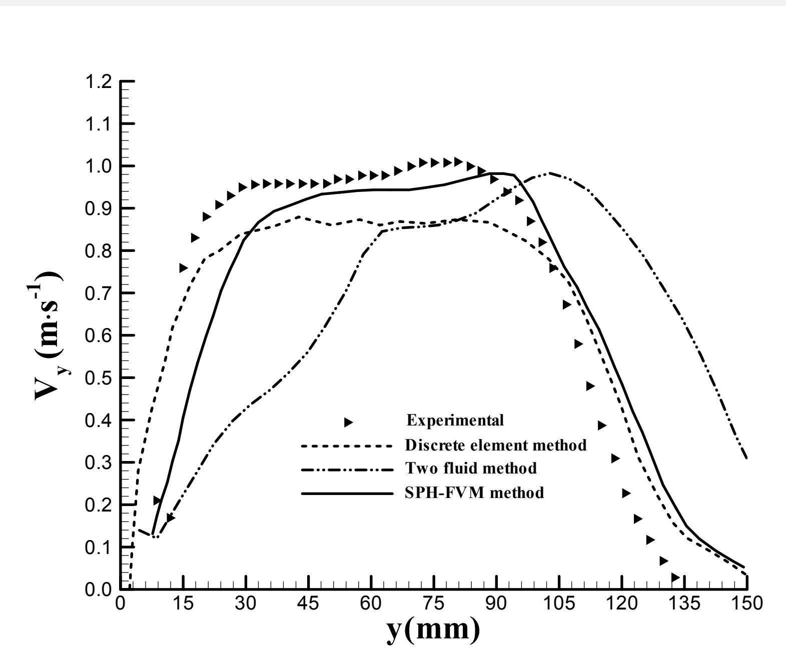


Some parameters definition

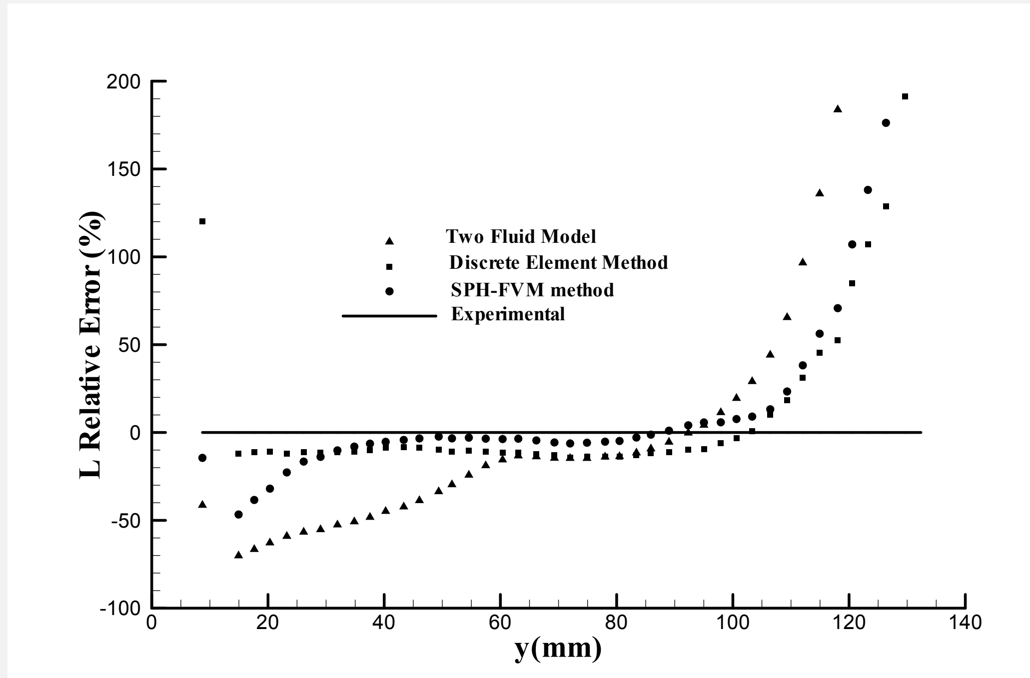
Comparison of some parameters in the spouted bed

	$h_1(mm)$	$h_2(mm)$	$w_1(mm)$	$w_2(mm)$	$\theta(°)$
SDPH-FVM	**99.12**	**53.86**	**10.23**	**40.22**	**8.66**
	（2.83%）	**（5.50%）**	**（4.39%）**	**（5.51%）**	**（6.26%）**
DEM	**96.14**	**55.44**	**12.10**	**36.87**	**7.18**
	（2.73%）	**（8.60%）**	**（23.47%）**	**（3.28%）**	**（11.9%）**
TFM	**103.45**	**66.06**	**11.59**	**45.74**	**9.61**
	（4.66%）	**（29.4%）**	**（18.27%）**	**（19.99%）**	**（17.91%）**
Exp.	**98.84**	**51.05**	**9.8**	**38.12**	**8.15**

Comparison of the results



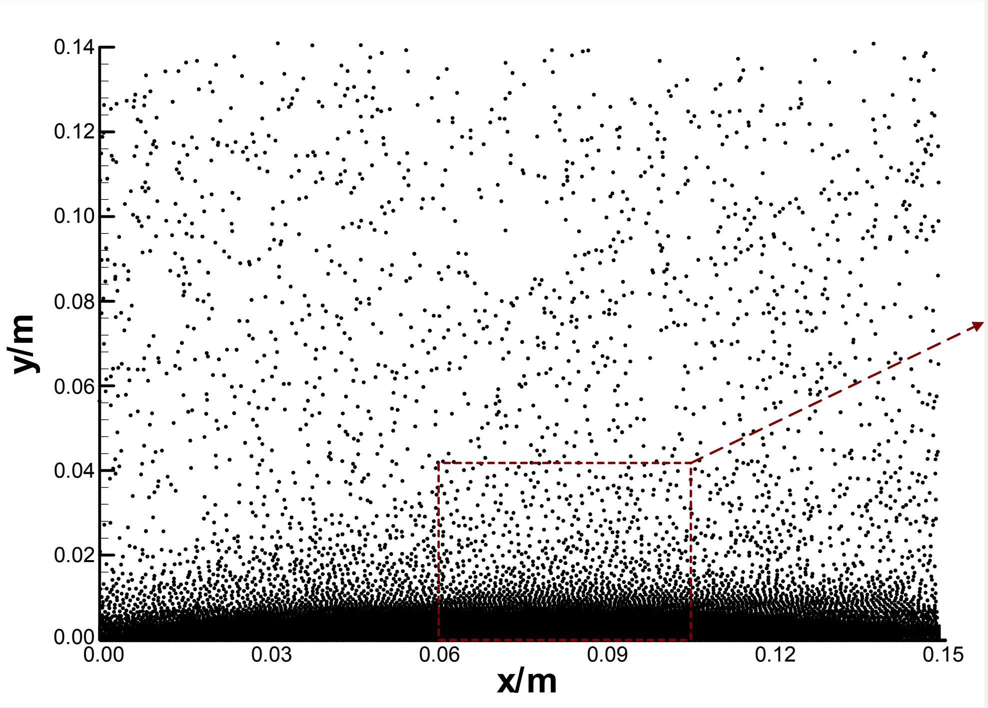
Comparison of vertical velocities along spout axis



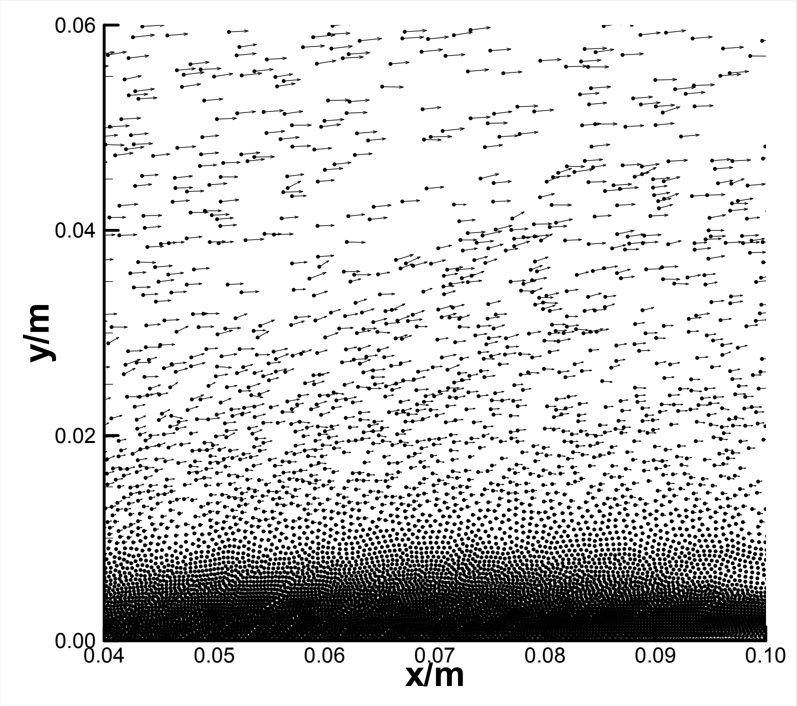
Comparison of relative errors of vertical velocities along spout axis

➢Environment

——Aeolian sand transport



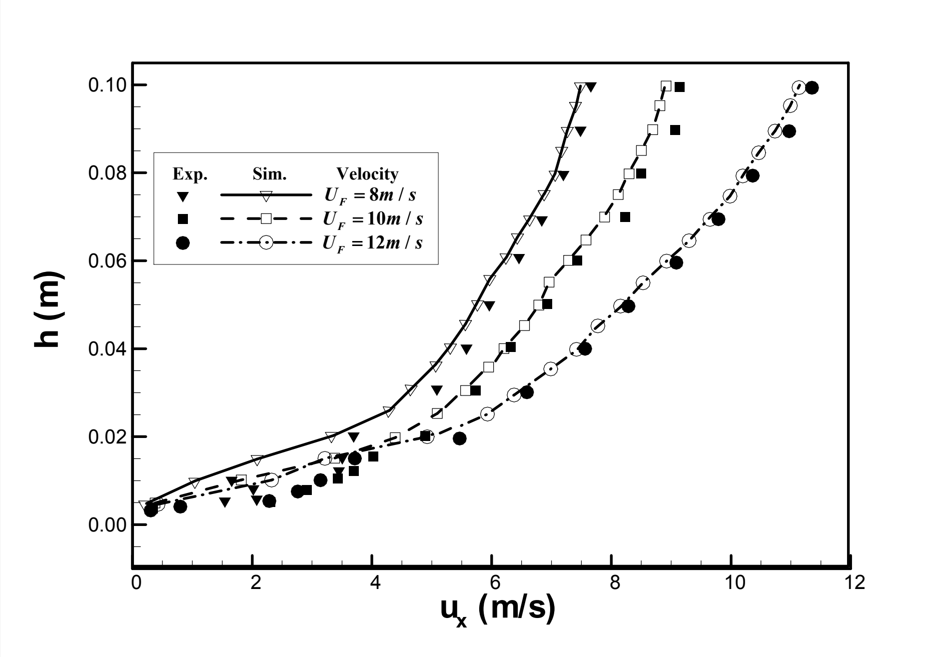
The particle spatial distribution



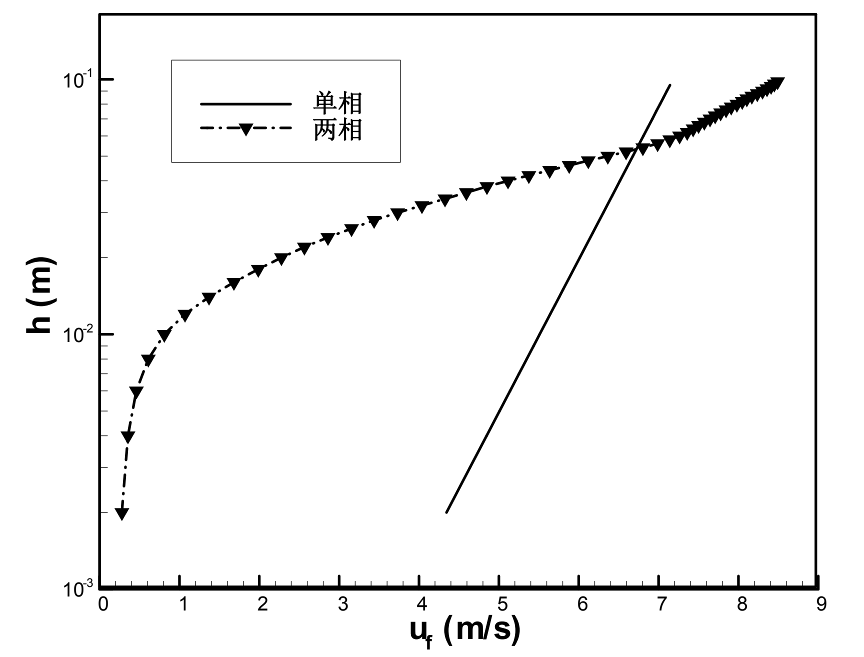
The particle velocity distribution

➢Environment

———Aeolian sand transport



Comparisons of mean downwind sand velocity

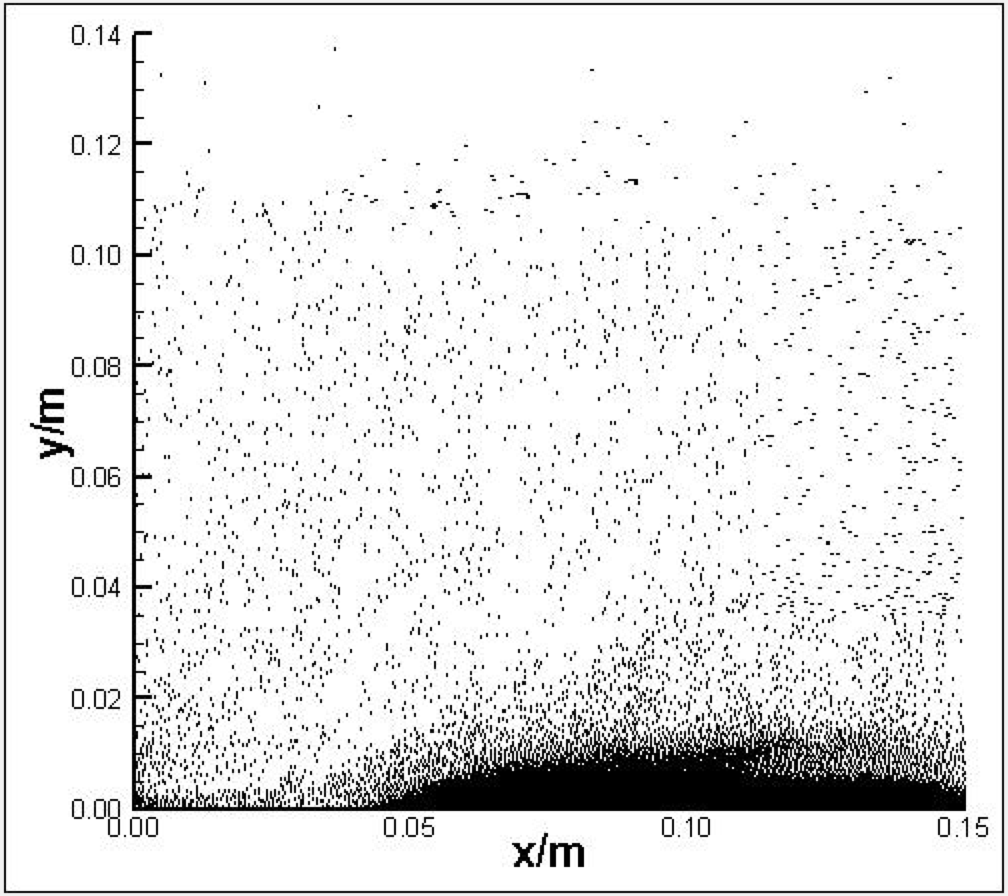


Horizontal velocity distribution of gas

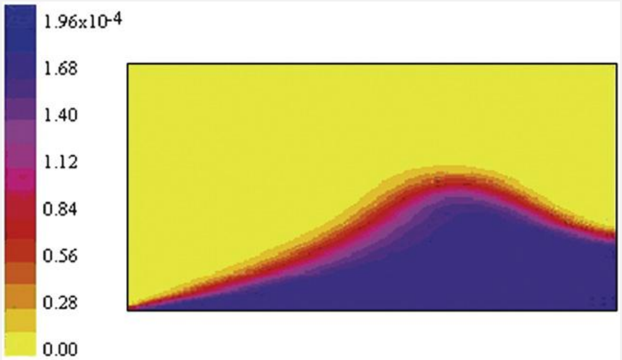
u_x

Applications in some engineering fields

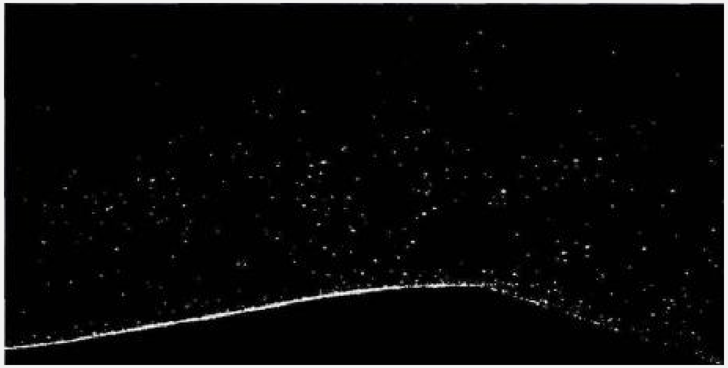
➢Environment——Aeolian sand transport



The motion of sand dune



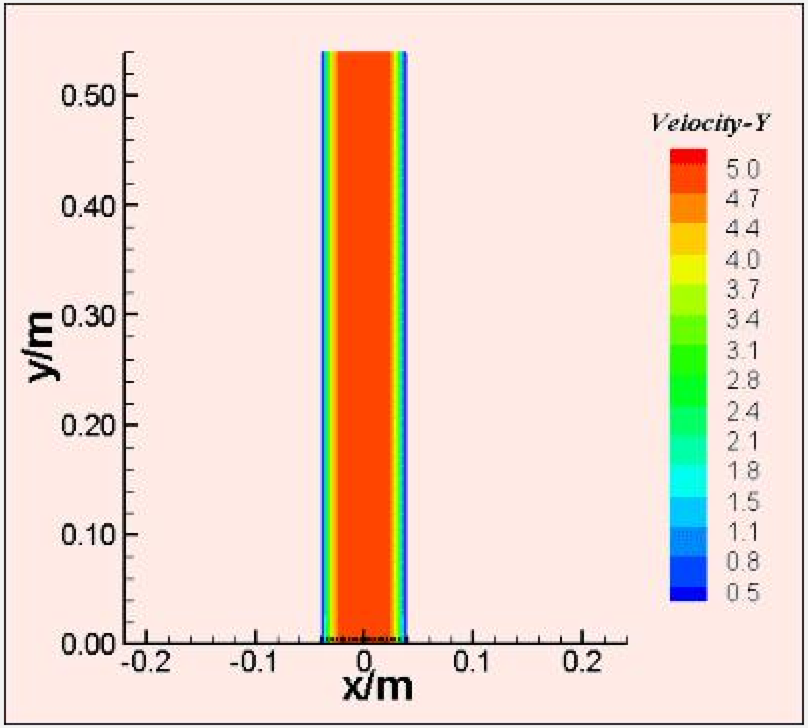
The sand dune in literature



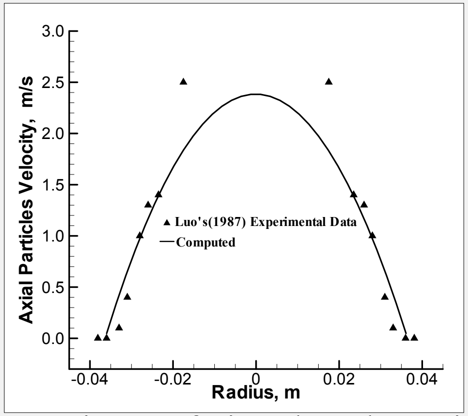
The motion of sand dune in experiments

Applications in some engineering fields

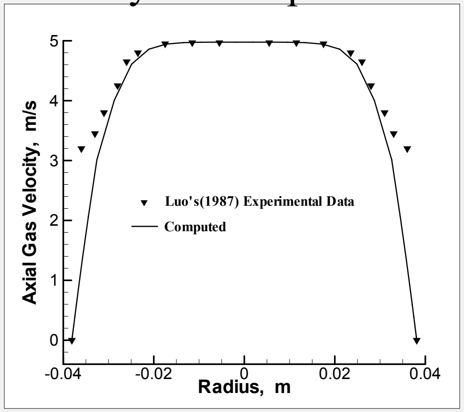
➢Transport ——Pneumatic transportation of particles



Vertical pneumatic transport



Comparison of simulated particle velocity with experiments

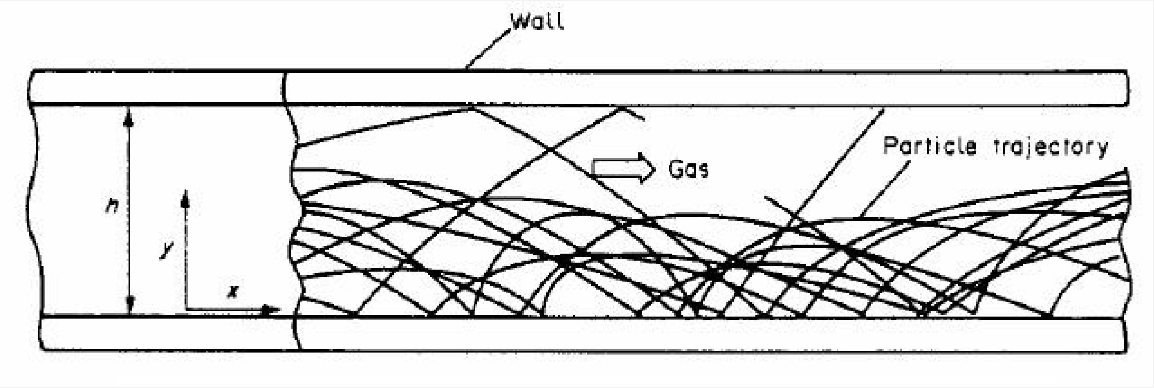


Comparison of simulated gas velocity with experiments

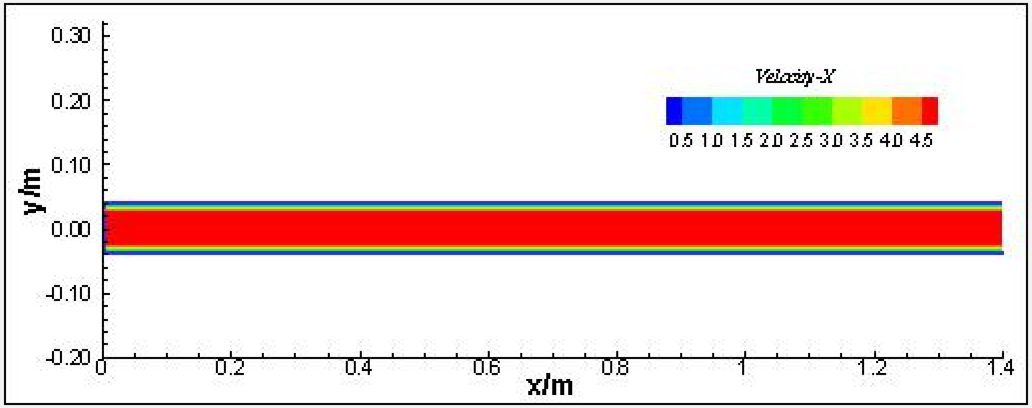
Applications in some engineering fields

➢Transport ——Pneumatic transportation of particles

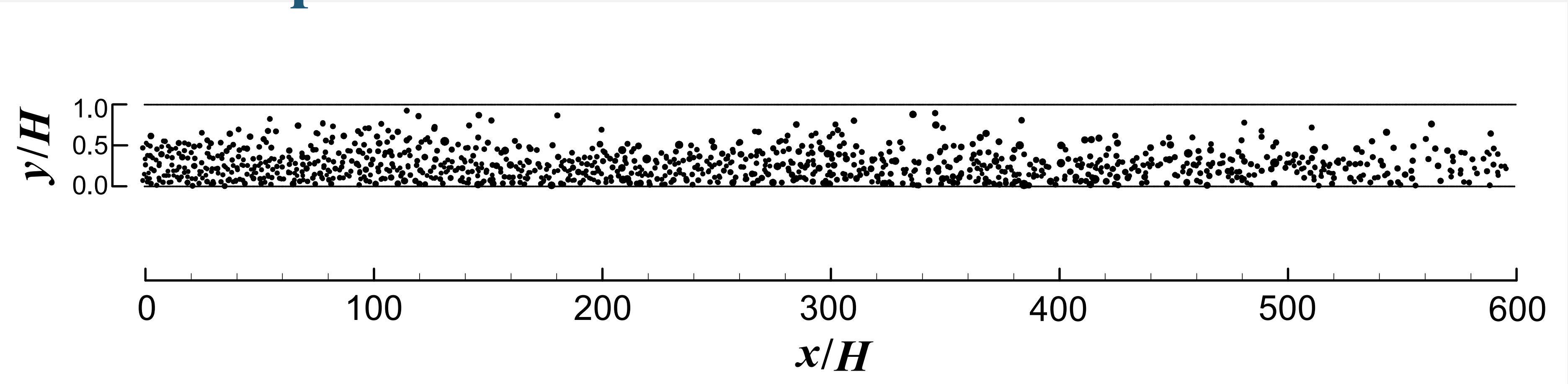
Schematic diagram of particle trajectory



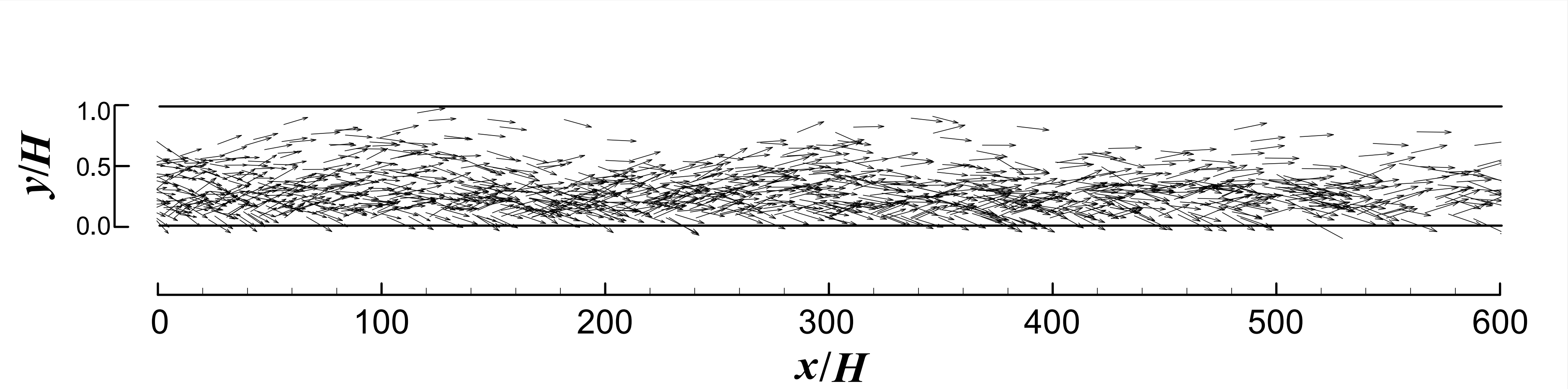
Lateral flow of particles



➢Transport ——Pneumatic transportation of particles



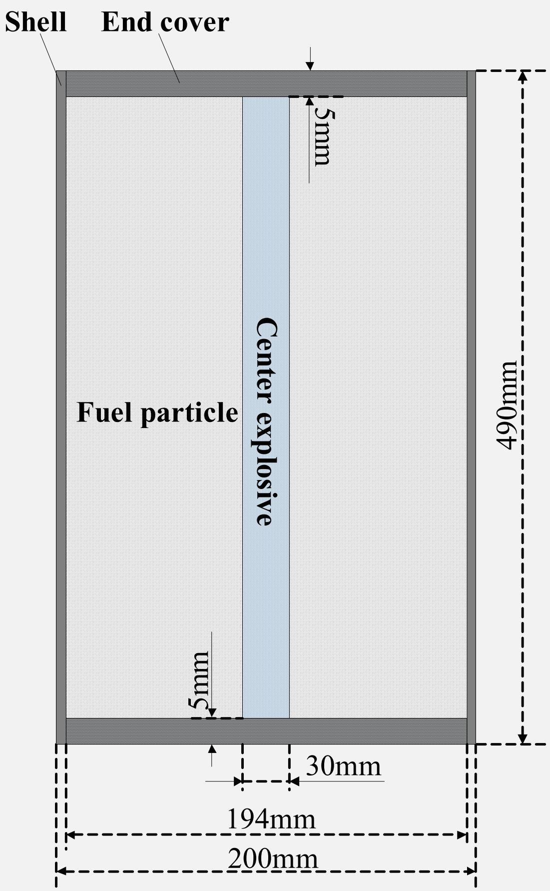
The particle distribution after computation reaching the steady state

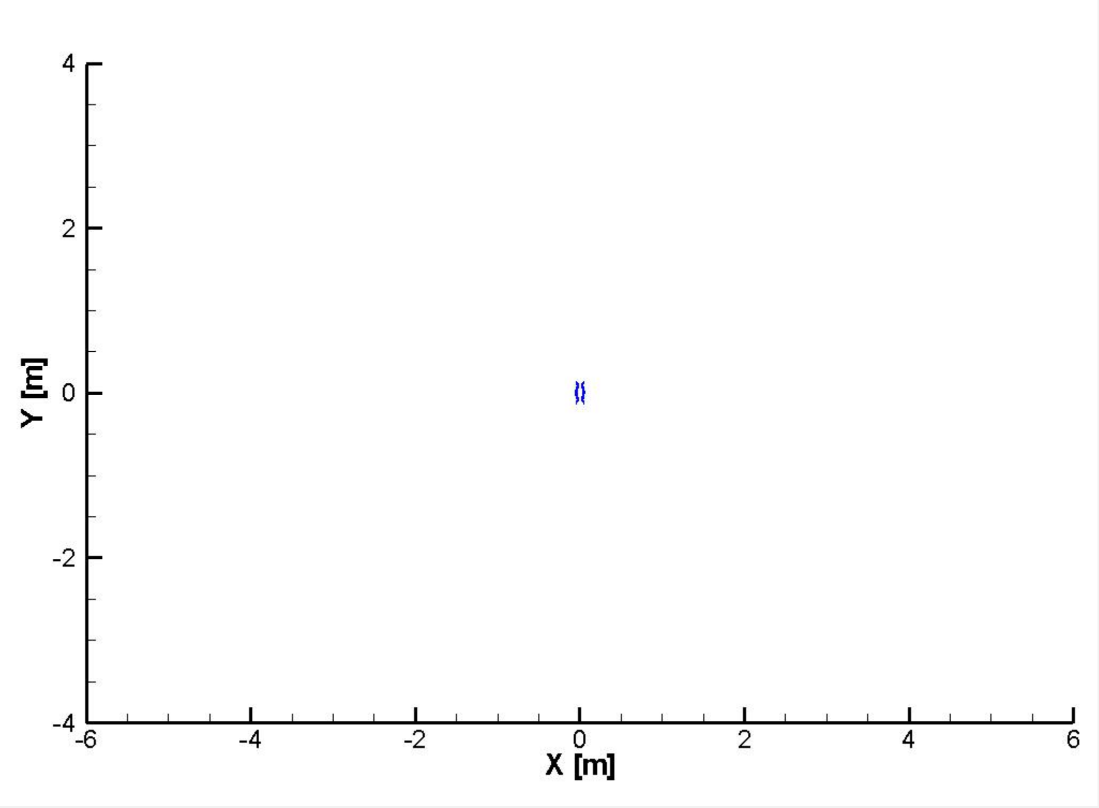


The particle velocity distribution after computation reaching the steady state

➢Explosion and Shock

——Fuel dispersal into cloud and its combustion and explosion

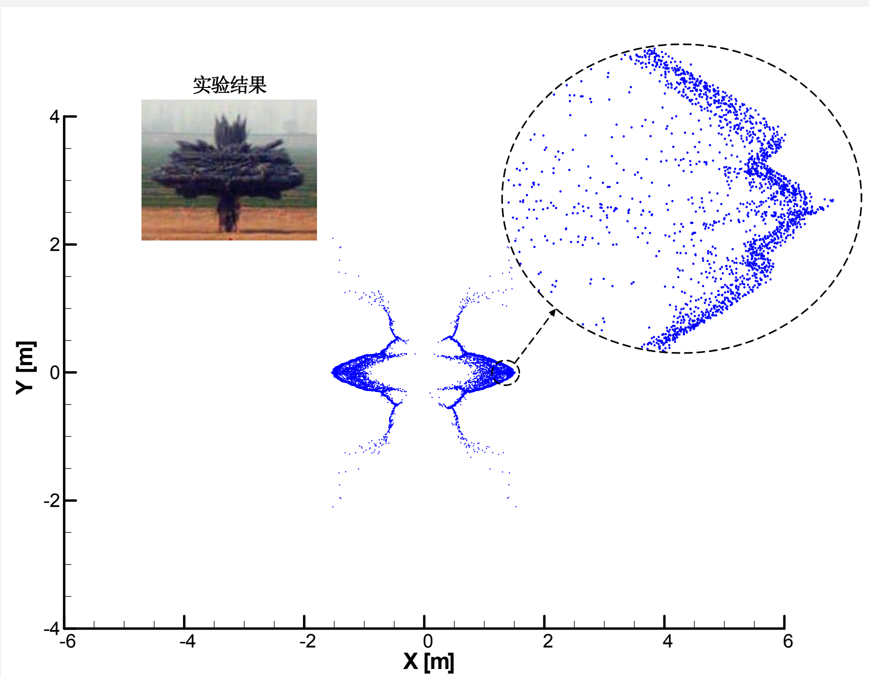




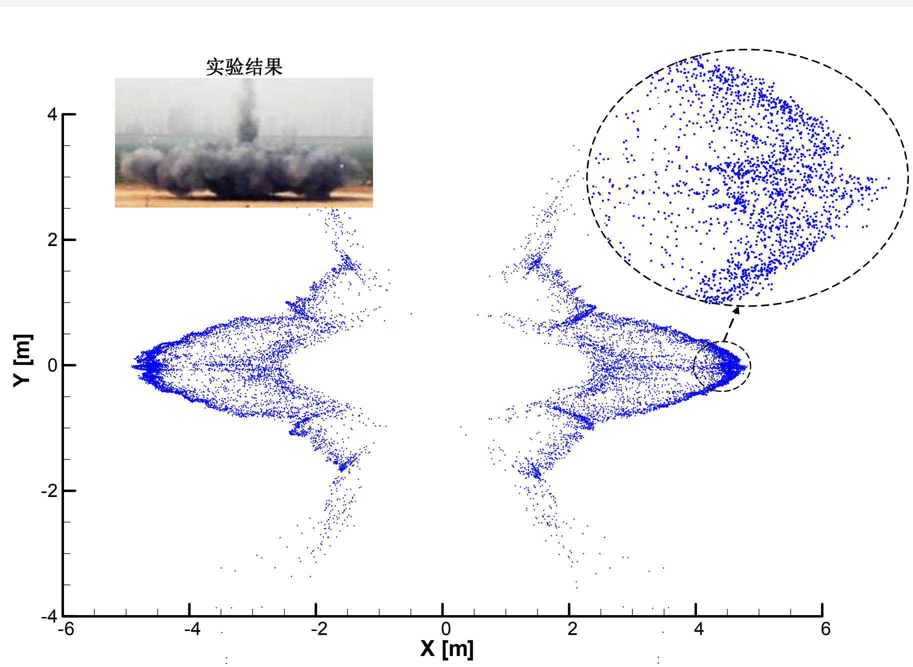
Line initiation

➢Explosion and Shock

——Fuel dispersal into cloud and its combustion and explosion



(a) 4ms

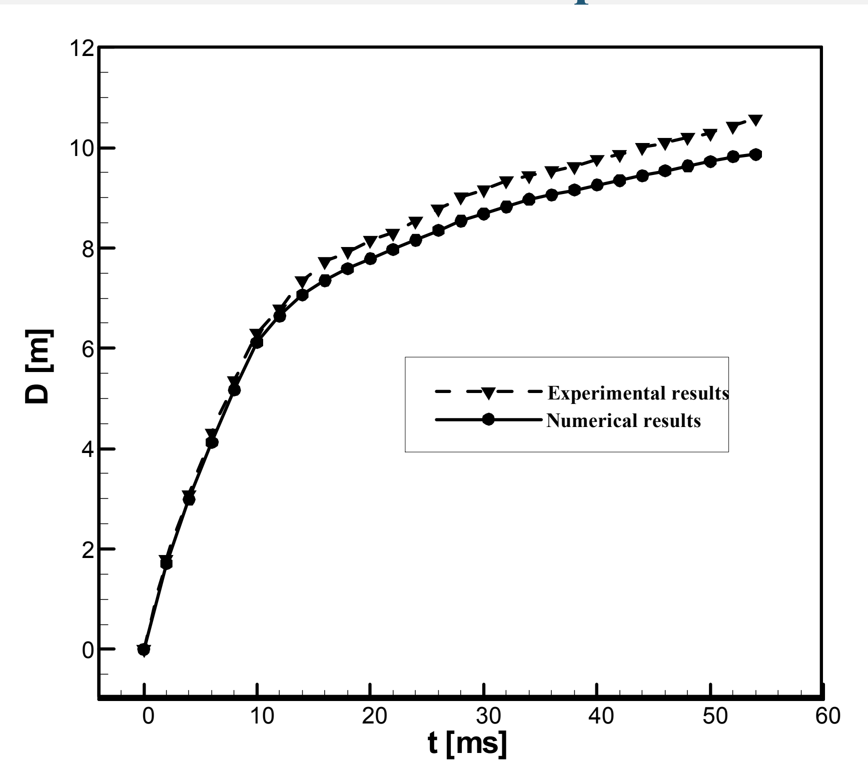


(b) 50ms

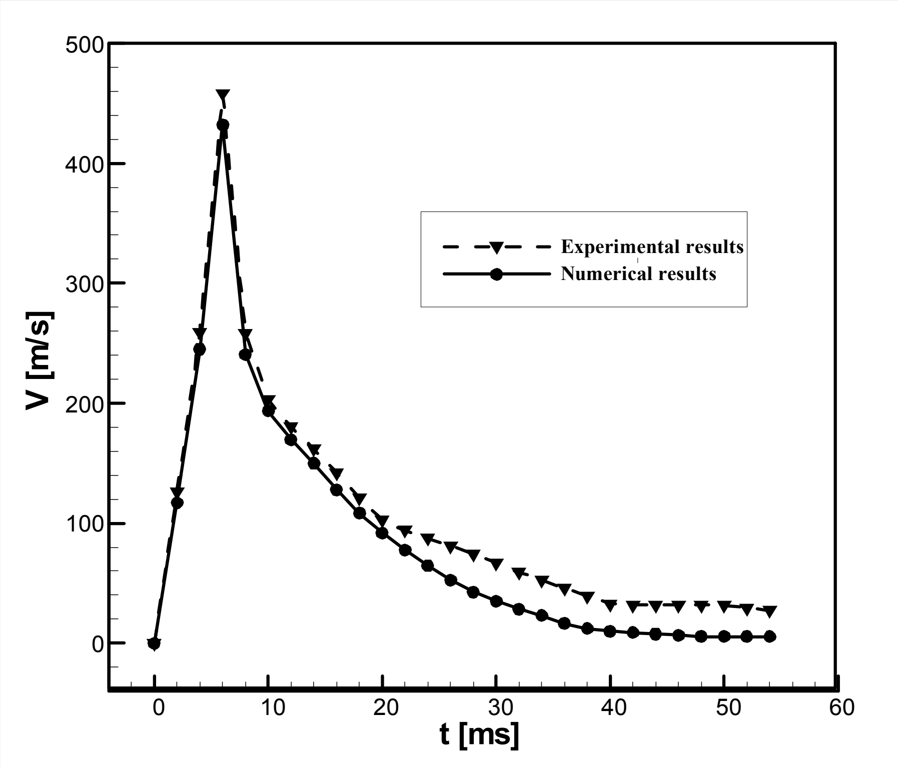
Line initiation

➢Explosion and Shock

——Fuel dispersal into cloud and its combustion and explosion



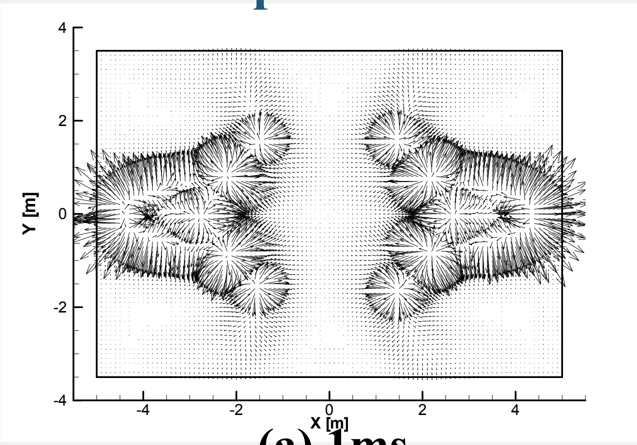
Fuel dispersal diameters versus time



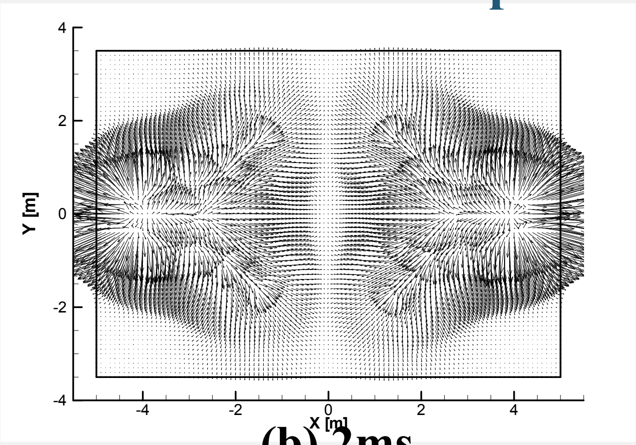
Fuel dispersal velocity versus time at boundary

➢Explosion and Shock

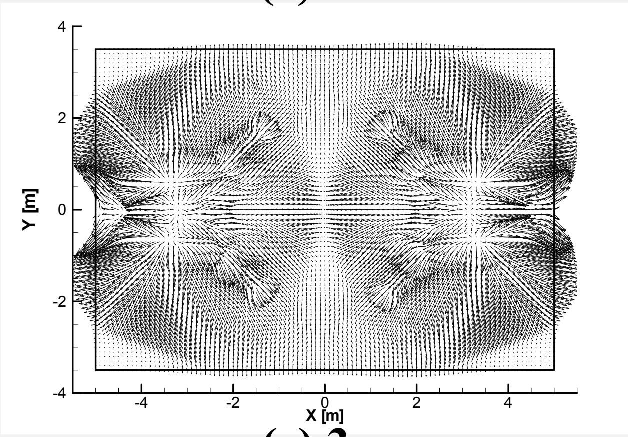
——Fuel dispersal into cloud and its combustion and explosion



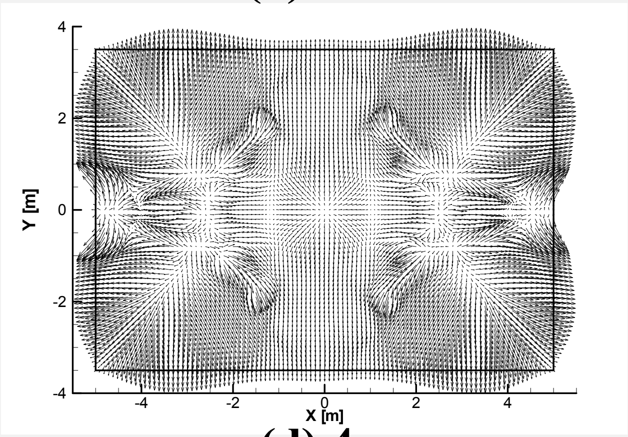
(a) 1ms



(b) 2ms



(c) 3ms



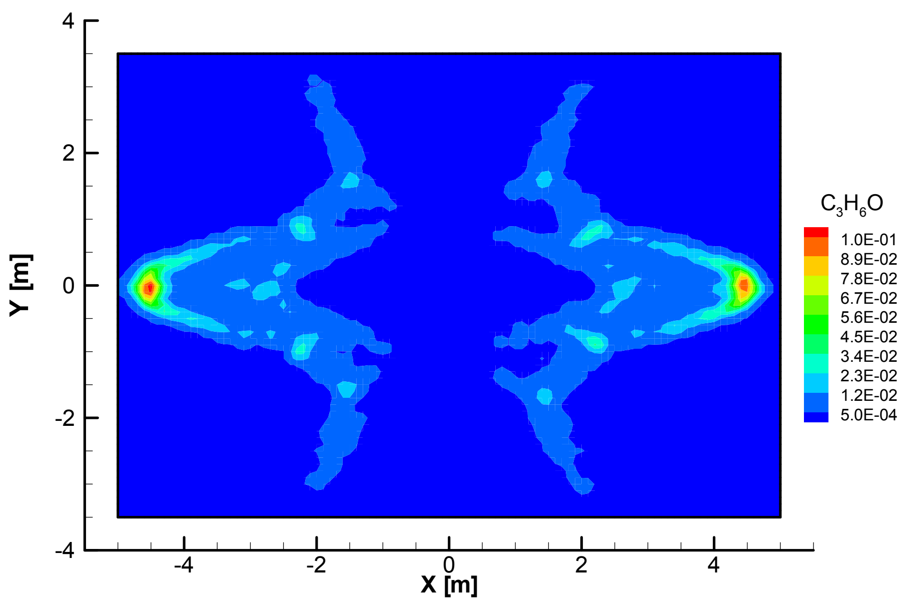
(d) 4ms

Velocity field variation in the explosion of fuel gas

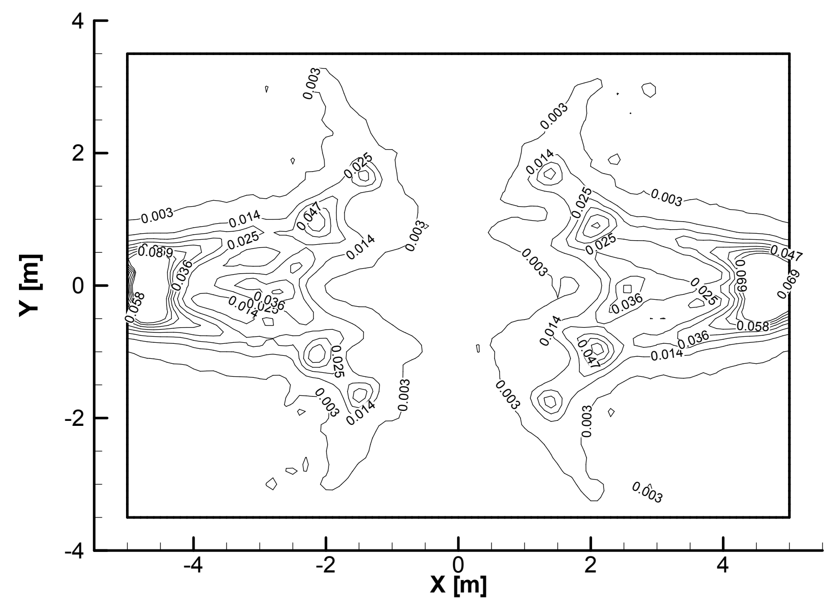
Applications in some engineering fields

➢Explosion and Shock

——Fuel dispersal into cloud and its combustion and explosion



C_3H_6O concentration distribution after fuel evaporation

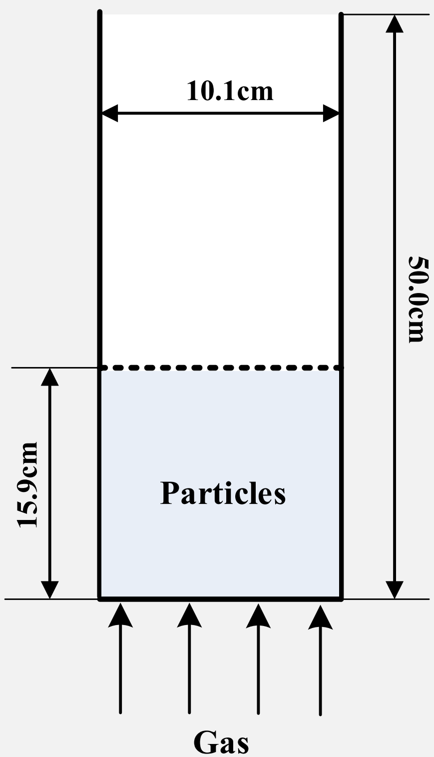


Contour lines of carbon dioxide concentration at 4 ms

Applications in some engineering fields

➢Chemical Engineering

—— particle size distribution in fluidized bed gasifier



Particle diameter $d_p = 174\mu m$

Particle density $\rho_p = 2530 kg/m^3$

Gas density $\rho_g = 1.225 kg/m^3$

Gas viscosity $\mu_g = 1.7985\times10^{-5} Pa\cdot s$

Initial gas velocity $V_{g,0} = 0.2 m/s$

Particle volume fraction $\alpha_p = 0.196$

The maximum Packing fraction $\alpha_p^c = 0.38$

Grid distance along X $\Delta x_{FVM} = 0.0067m$

Grid distance along Y $\Delta y_{FVM} = 0.0067m$

SDPH particle distance $\Delta r_{SDPH} = 0.00335m$

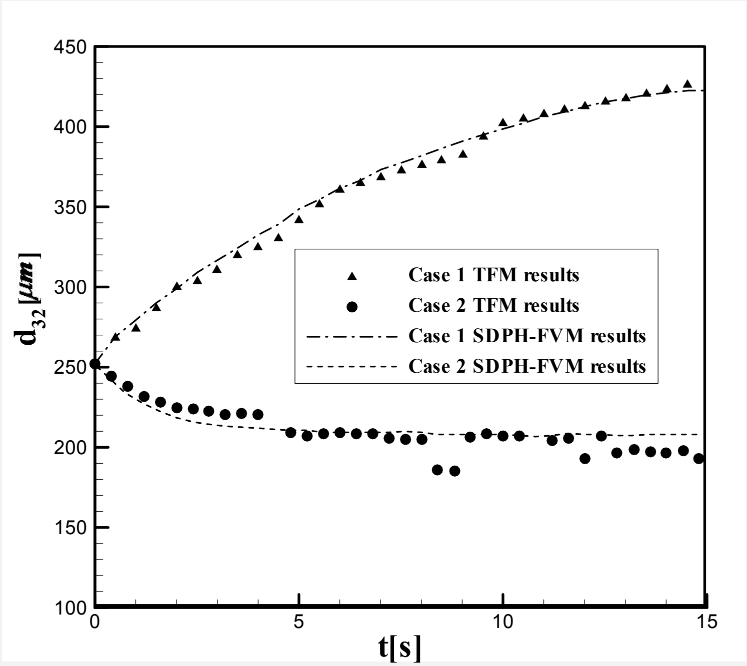
SDPH density $\rho_{SDPH} = 495.88 kg/m^3$

SDPH represent particle number $n = 72.65$

SDPH smoothing length $h_s = 1.5\Delta r_{SDPH}$

FVM time step $\Delta t = 10^{-5} s$

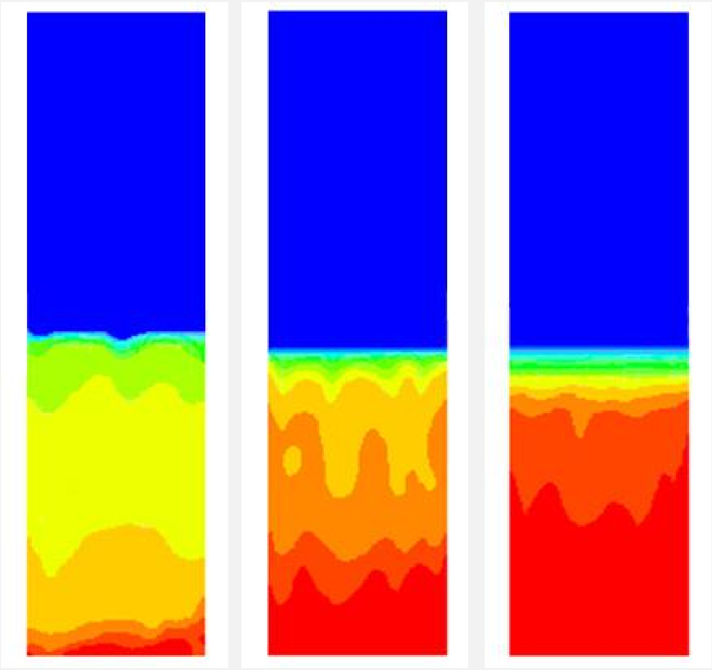
Schematic diagram and parameter setting



Curves of sauter diameter over time

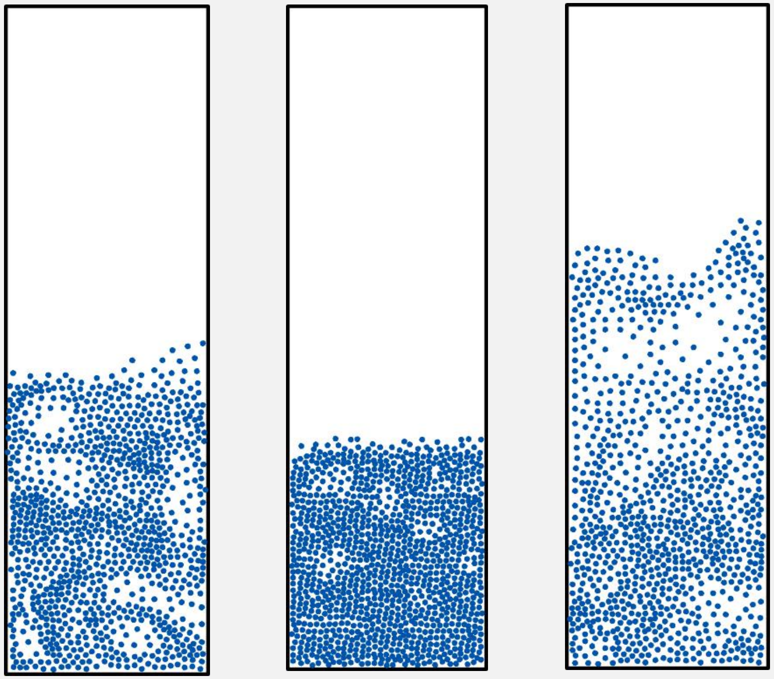
➢Chemical Engineering

—— particle size distribution in fluidized bed gasifier



(a)5s (b)10s (b)15s

Sauter diameter distribution at different time in case 2



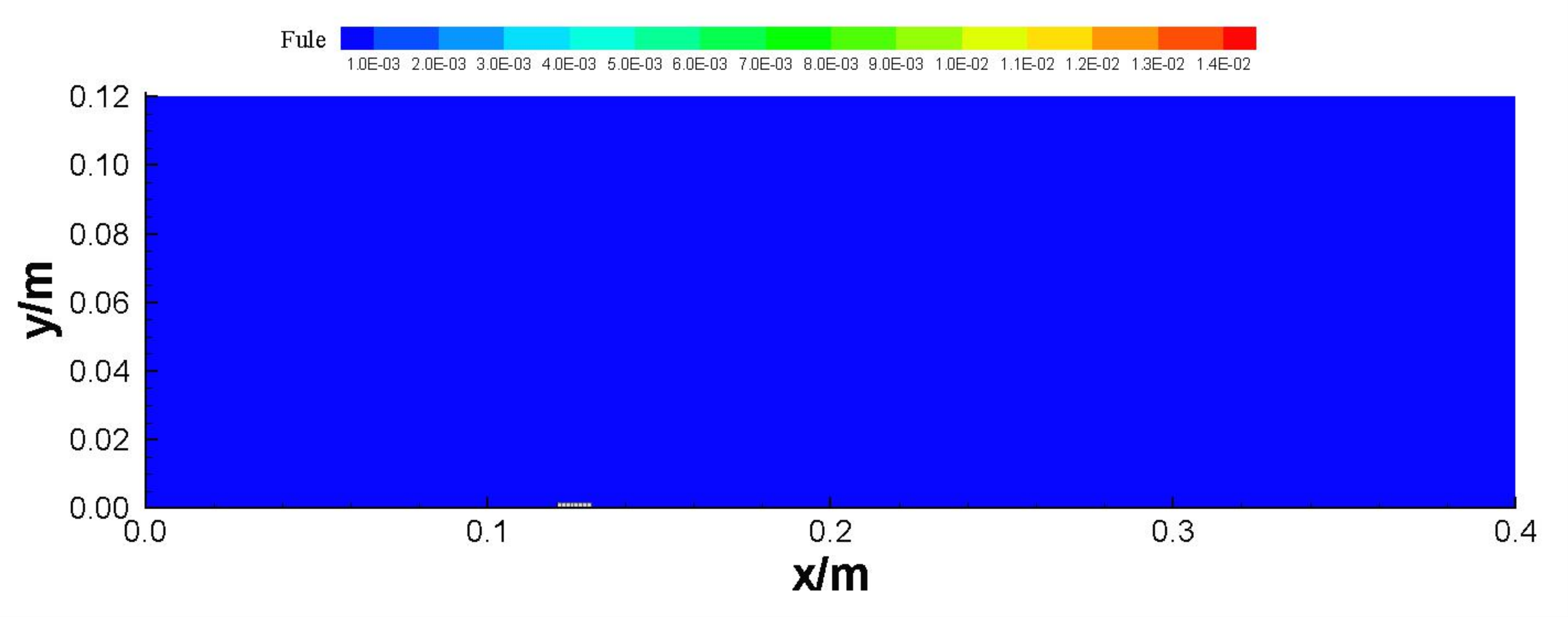
No polymerization and breakup Case 3 Case 4

The spatial distribution of particles under different conditions

➢ Aerospace ——Fuel spray and evaporation under horizontal airflow

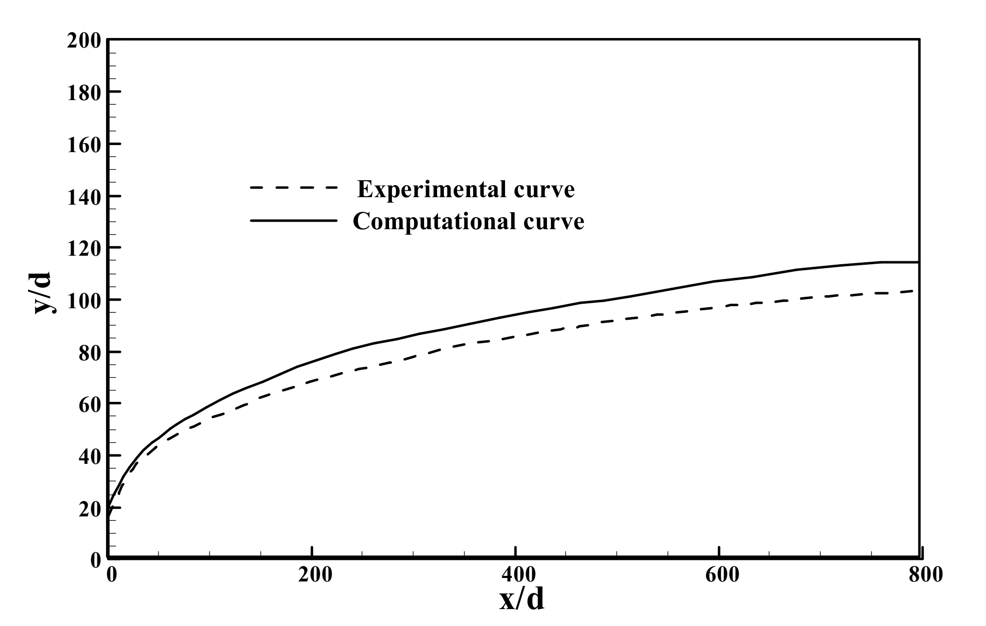
$L_1 \times L_2 = 400\text{mm} \times 120\text{mm}$ $d_0 = 10\text{mm}$ $v_{gas} = 103m/s$ $v_{jet} = 9.3m/s$

$P_0 = 140KPa$ $T_{gas,0} = 350K$ $T_{jet,0} = 300K$ $T_{vap} = 341K$ $C_p = 2090J \cdot kg^{-1} \cdot K^{-1}$

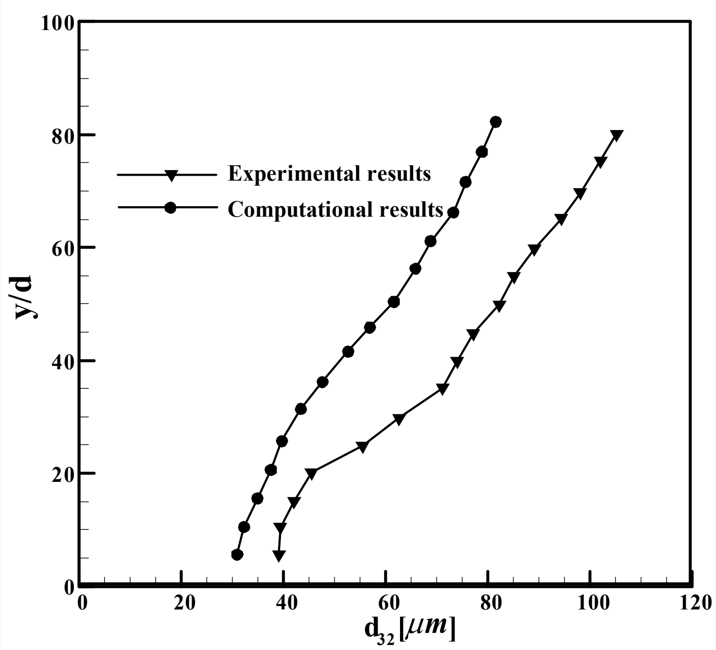


Applications in some engineering fields

➢Aerospace ——Fuel spray and evaporation under horizontal airflow



Liquid droplets penetration comparison



Liquid droplets SMD distribution

Conclusions:

（1）The SDPH concept solving the discrete phase is presented.

（2）SDPH-FVM coupling framework is established.

（3） SDPH-FVM coupling method considering particle collision polymerization and breaking is built through importing the population balance equation.

（4）The series of the new methods established are applied to simulate the gas-particle two-phase flow in many areas and current results shown above is successful.

Thanks!

Sincerely wish for critiques!