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CFD Application in Process Control of Copper Flash Smelting Process

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Outline

- What is CFD?
- Copper flash smelting process
- Control of copper FS process
- CFD application in process control of FS
- Examples of CFD applications in Engineering

What is CFD ?

- Computational Fluid Dynamics (CFD).
- A branch of fluid mechanics, using numerical analysis and data structures to solve and analyze problems of fluid flows.
- In mid-1960s, Prof. Spalding started to use CFD to simulate problems involving heat transfer, fluid flow and combustion.
- With the rapid development of computers, especially the high-speed computers, CFD has become an effective tool to achieve the numerical solutions of all kinds of processes in engineering.

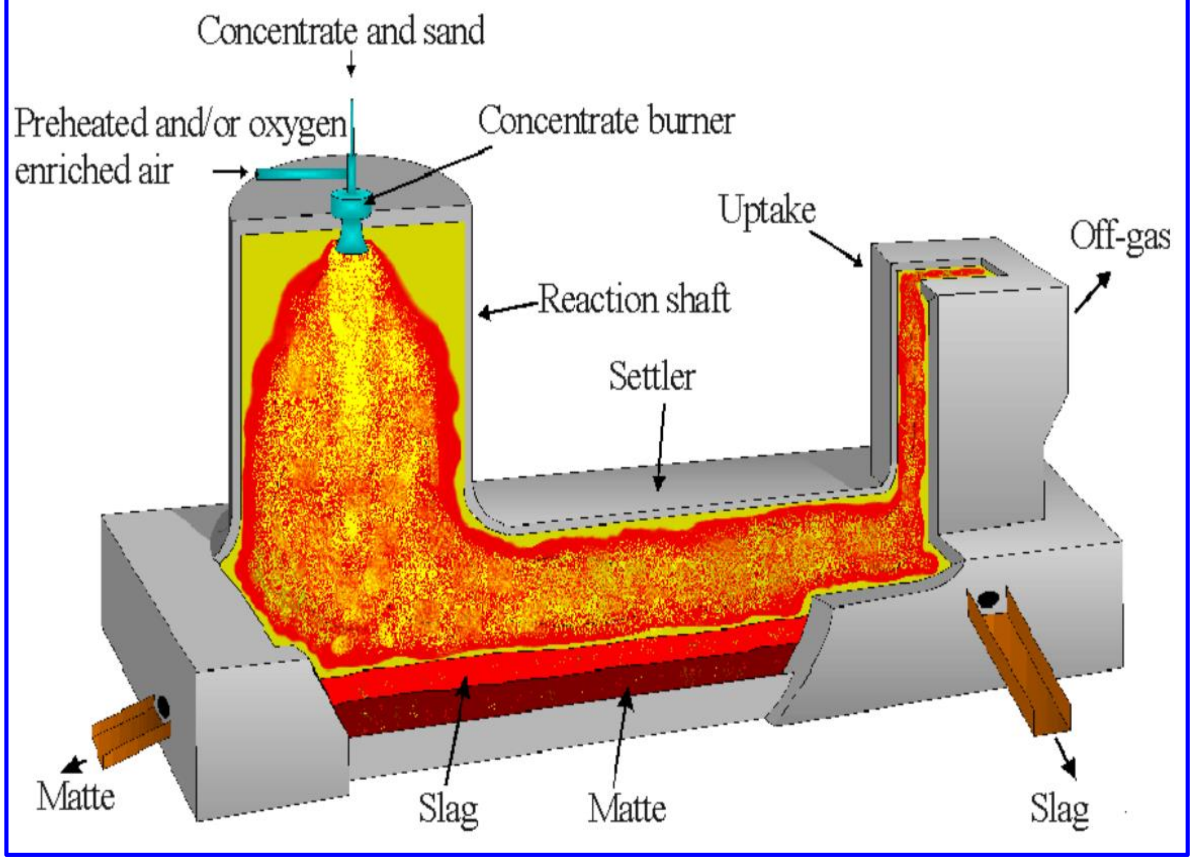
Copper flash smelting process

- **Feeding materials**

  Sulfide concentrate, silicon sand and recycled dust.

- **Products**

  matte and slag.



Picture from : Vaarno J, Jarvi J, Ahokainen T, et al. Development of a mathematical model of flash smelting and converting process[C]. Third International Conference on CFD in the Minerals and Process Industries. Australia, Melbourne: CSIRO, 2003: 147-154..

Control of Copper FS Process

- **Control targets:**

  to achieve the desired matte grade, and keep the matte temperature and the Fe/Si ratio of the slag within a proper range.

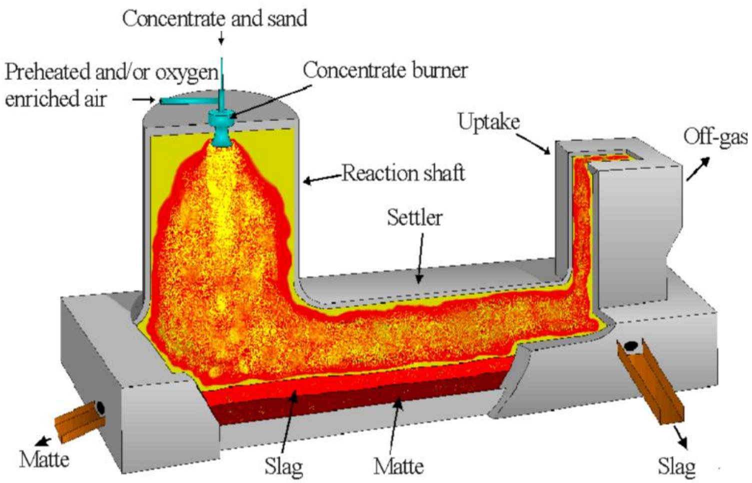
- **Adjustable variables:**

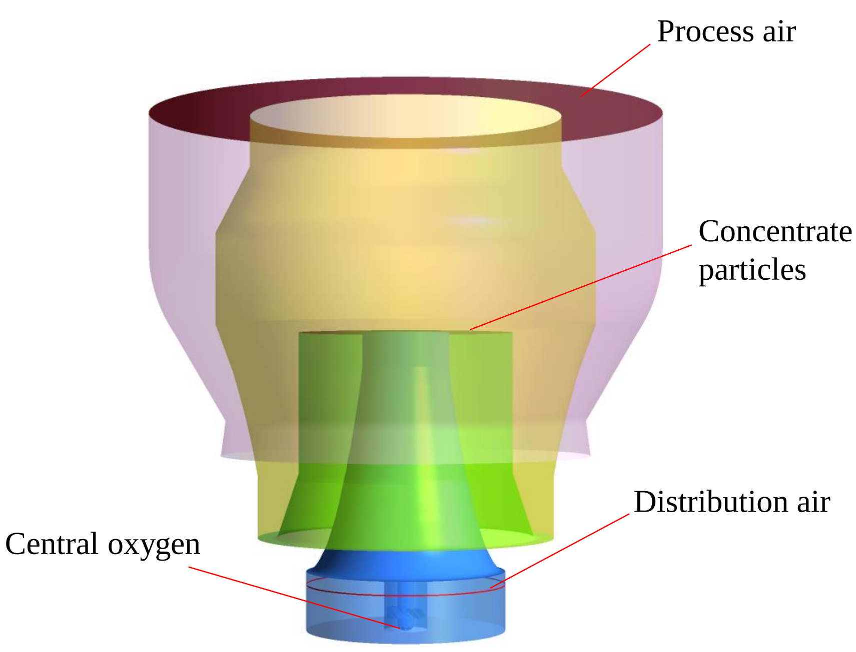
  Concentrate feeding rate

  process air: *Q* & *v*

  distribution air : *Q*

  central oxygen: *Q*





Control of Copper FS Process

- **Features of process control**

 Once the concentrate feeding rate is fixed, the total oxygen necessary for the reactions is determined by the mass and heat balance calculation of the system.

The total flow rate of the air can be adjusted by altering its oxygen-enrichment.

 The flow rate of each gas flow is determined by experience.

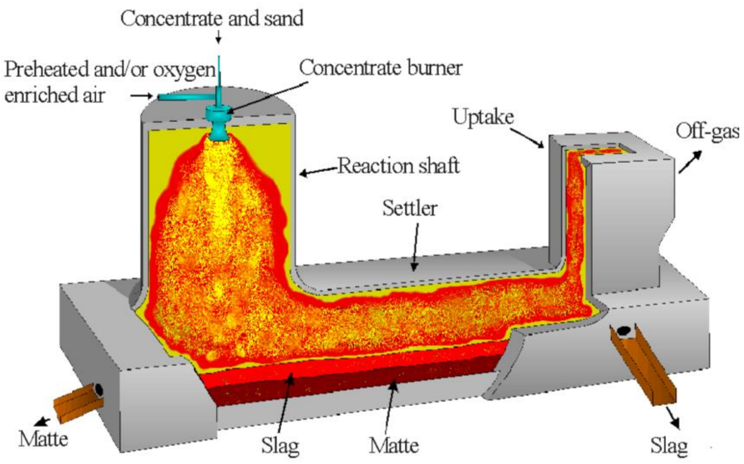
 No intervention can be performed once the gas flows and particles leave the burner. Adjustment is usually delayed for hours until the technicians find abnormal results in operations.

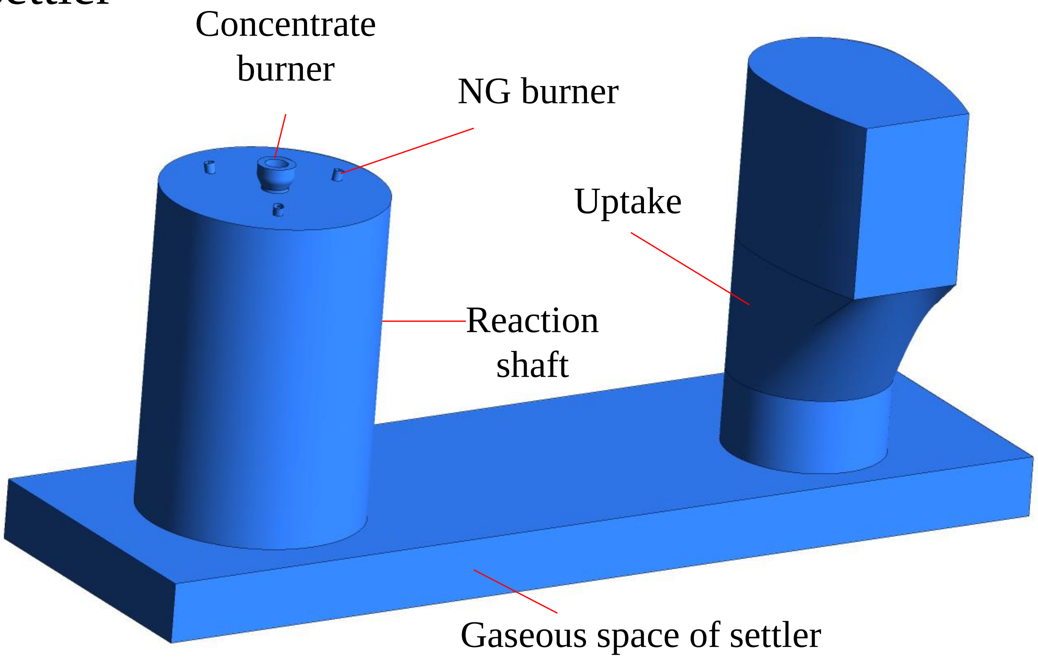
CFD application in process control of FS

- **Purpose of CFD application**
  - To get a better understanding of the smelting process inside the furnace.
  - To understand how the parameters of the gas flow influence the process.
  - To obtain proper ranges for the parameters' adjustment.
  - through analyzing the distribution of physical fields including the flow, temperature and concentration of both the gas and the particles.

CFD application in process control of FS

- **Numerical model of flash smelting Process**
  - Computation domain
    - the concentrate burner,
    - the NG burner,
    - the reaction shaft,
    - the gaseous space of the settler
    - the uptake.





CFD application in process control of FS

- **Numerical model of flash smelting Process**

  - Governing equations
  - General form of equations for the gaseous phase:

$$\nabla \cdot (\rho \vec{v} \phi) = \nabla \cdot \left(\Gamma_{\phi} \nabla \phi\right) + S_{\phi} + S_{\mathrm{P}\phi}$$

  - Governing equations for the particle phase:

$$m \frac{\mathrm{d}\vec{v}_{\mathrm{P}}}{\mathrm{d}t} = F_{\mathrm{D}} + mg \frac{\rho_{\mathrm{P}} - \rho}{\rho_{\mathrm{P}}} + F$$

$$m \frac{\mathrm{d}(C_{\mathrm{P}} T_{\mathrm{P}})}{\mathrm{d}t} = Q_{\mathrm{c}} + Q_{\mathrm{r}} + Q_{\mathrm{rad}}$$

CFD application in process control of FS

- **Numerical model of flash smelting Process**
  - Chemical reactions

Smelting process	Reactions
Decomposition of concentrate	① $2CuFeS_2+O_2 \rightarrow Cu_2S+2FeS+SO_2$ ② $FeS_2+O_2 \rightarrow FeS+SO_2$ ③ $2Cu_5FeS_4+O_2 \rightarrow 5Cu_2S+2FeS+SO_2$
Oxidization and reduction	④ $3FeS+5O_2 \rightarrow Fe_3O_4+3SO_2$ ⑤ $2Cu_2S+3O_2 \rightarrow 2Cu_2O+2SO_2$ ⑥ $FeS+3Fe_3O_4 \rightarrow 10FeO+SO_2$ ⑦ $3Cu_2O+FeS \rightarrow 6Cu+FeO+SO_2$
Slagging reaction	⑧ $2FeO+SiO_2 \rightarrow Fe_2SiO_4$

CFD application in process control of FS

- **Findings in simulation**
  - The gas flow expands greatly and rapidly and forms a gas column in the center of the shaft.

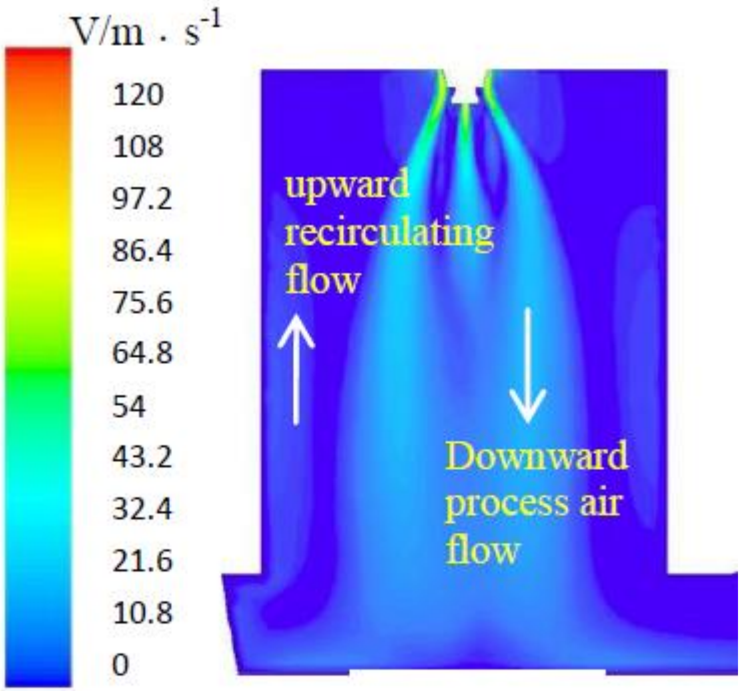


Fig. 1 Gaseous velocity contour

CFD application in process control of FS

- **Findings in simulation**
  - The gaseous flow expands greatly and rapidly and forms a gas column in the center of the shaft.
  - The particle dispersion cone is of a similar size of the gas column .
  - At the bottom of the shaft, the dispersion cone is a little bit larger, because some big particles penetrate the gas column.

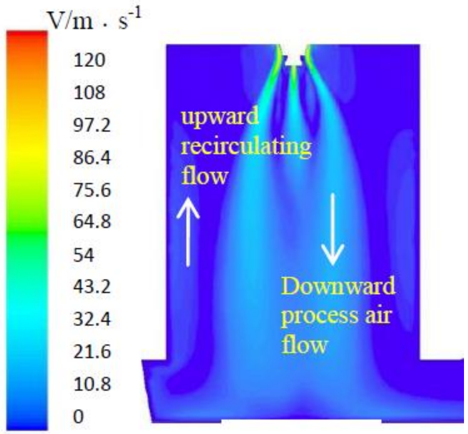


Fig. 1 Gaseous velocity contour

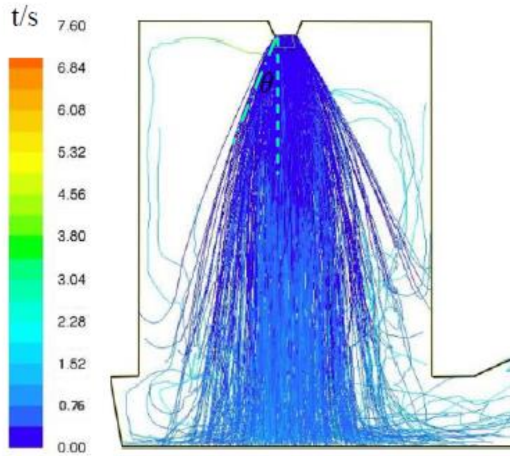


Fig. 2 Particle trajectory

CFD application in process control of FS

- **Findings in simulation**
  - A low temperature zone can be found below the concentrate burner. The temperature then increases gradually and reaches its highest value.
  - The particles are ignited at a height of about 1.3m, instead of burning soon after it enters the shaft. This is referred to as the “ignition delay of particles”.

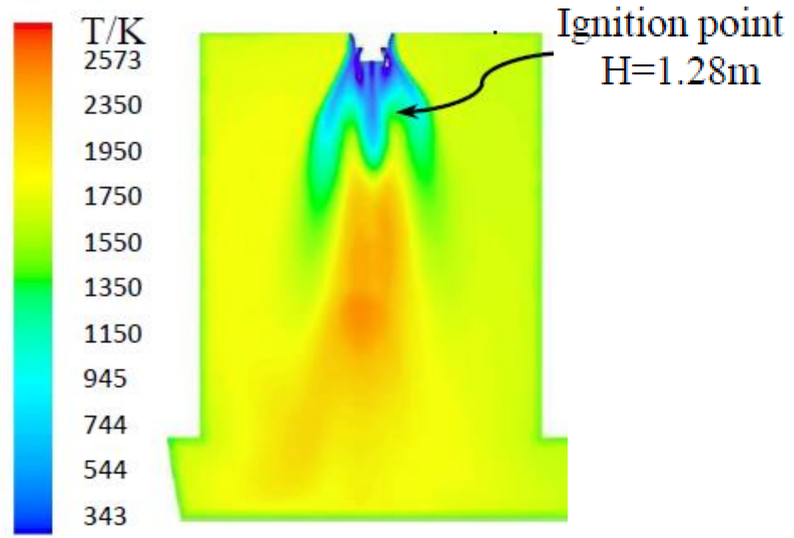


Fig. 3 gaseous temperature contour

—— A severe delay in the particle ignition may cause particles to react incompletely before leaving the shaft, and thereby pile up as raw materials in the settler.

CFD application in process control of FS

- **Optimization of process control**

  - Dispersion angle (θ): half of the conical angle of the dispersion cone.

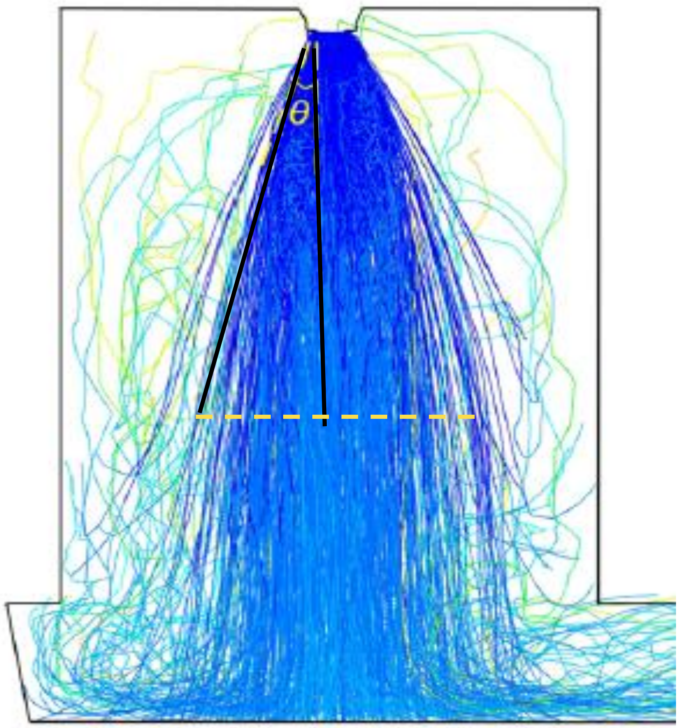


Fig. 5 Definition of dispersion angle

CFD application in process control of FS

- **Optimization of process control**

Table 3 Operational parameters of three cases

	Process air		Distribution air		Central oxygen velocity m/s	$\tan\theta$
	Flow rate m^3/h	velocity m/s	Flow rate m^3/h	Velocity m/s		
Case1	36500	110	2100	215	88	0.937
Case 2	37000	80	1800	184		1.013
Case 3	37500	110	1500	154		0.587

- Both the gaseous flow rate and the velocity may result in the change of the dispersion angle.
- These two factors should be taken into account when considering the influence of the gas flows on the particle dispersion.

CFD application in process control of FS

- **Optimization of process control**

  - By the linear momentum equation, the force that the fluid acts on a particle is determined by the rate of change of its linear momentum rather than the fluid velocity itself:

$$F = \frac{\mathrm{d}}{\mathrm{d}t}\int_{\mathrm{sys}} \vec{v}\,\mathrm{d}m$$

  - Momentum ratio:

$$K = \frac{I_{\mathrm{d}}}{I_{\mathrm{p}}} = \frac{q_{\mathrm{md}} \cdot v_{\mathrm{d}}}{q_{\mathrm{mp}} \cdot v_{\mathrm{p}}}$$

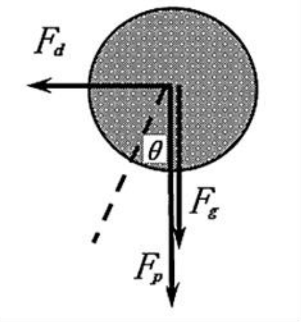


Fig. 6 Force analysis of a single particle

CFD application in process control of FS

- **Optimization in process control**

Table 3 Operational parameters of three cases

	Process air		Distribution air		Central oxygen velocity m/s	Momentum ratio	$\tan\theta$
	Flow rate m^3/h	velocity m/s	Flow rate m^3/h	Velocity m/s			
Case1	36500	110	2100	215	88	0.105	0.937
Case 2	37000	80	1800	184		0.105	1.013
Case 3	37500	110	1500	154		0.052	0.587

- The dispersion angle increases with the momentum ratio.
- The increasing trends are the same for all cases, but the linear relationship differs in cases.

tan θ

CFD application in process control of FS

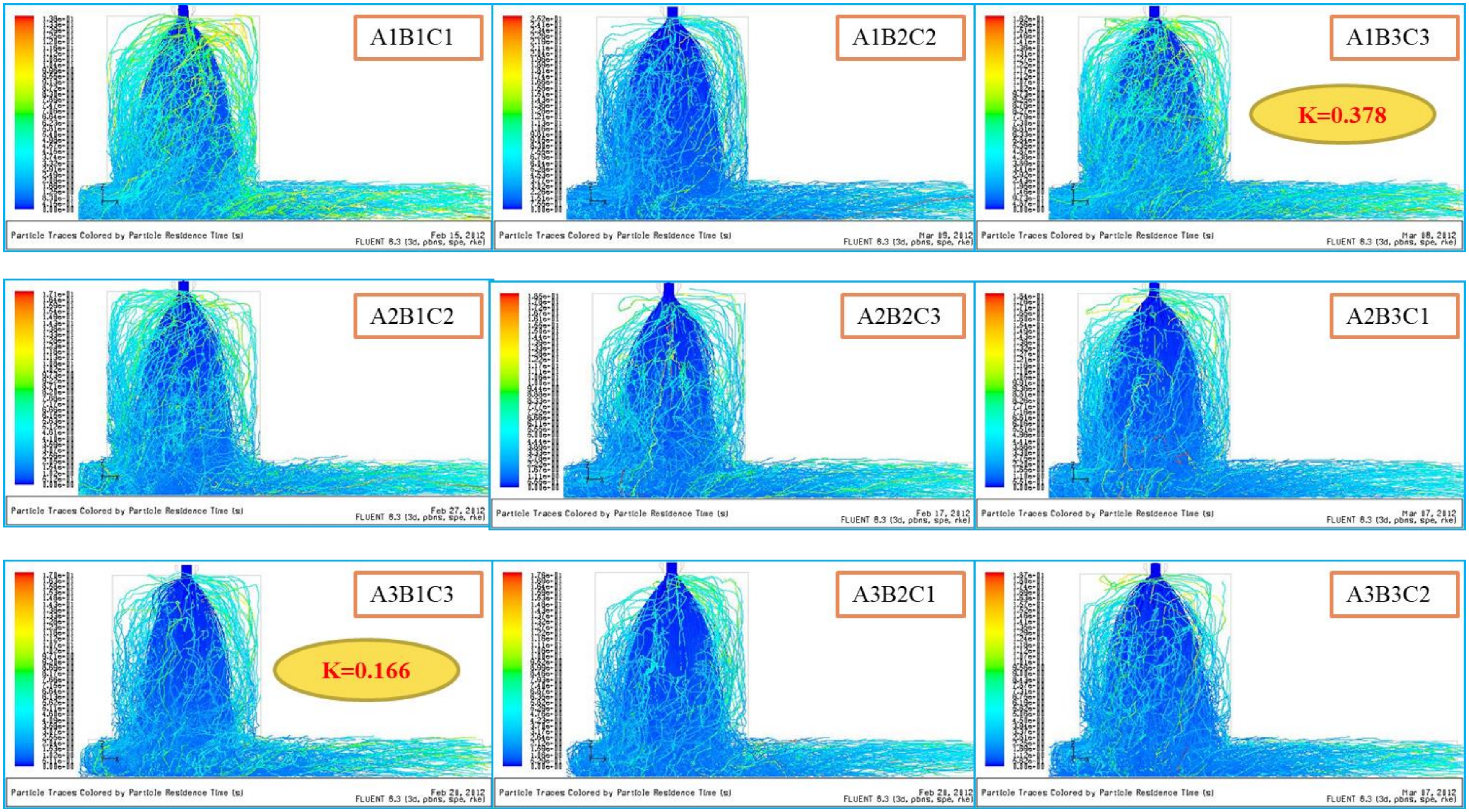
- **Optimization in process control**

  - The numerical simulation and the orthogonal experiments were combined to investigate the of influences of each gas flow on the process, and the distribution air and the process air are found to the first and second significant factors affecting the particle dispersion.
  - Series numerical computations were also carried out for cases at different concentrate feeding rates, and adjustment ranges for the momentum ration and the control parameters for different productivity levels.

CFD application in process control of FS

- **Optimization in process control**

  ✓ Results of cases with a concentrate feeding rate of 100t/h.



CFD application in process control of FS

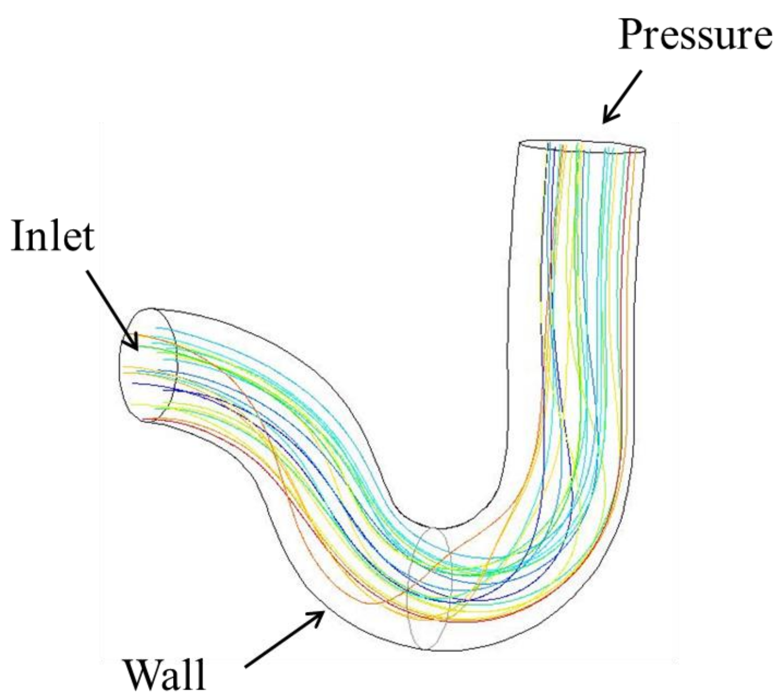
- **Optimization in process control**

  - The results of the momentum ration and the control parameters obtained by simulation were combined into the offline model, to provide suggestions to the settings of the flow rate/velocity of each gas flow.

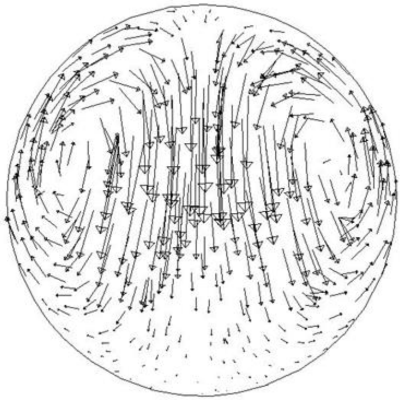
  - With the optimization in the process control, the concentrate loading rate the furnace increased from 172t/h to 185t/h. As a result, the system productivity increased about 7.5%.

CFD applications in Engineering

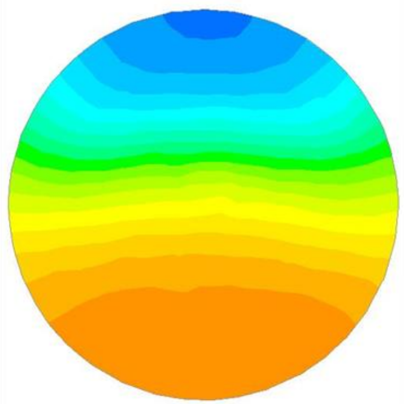
- **Internal flow in a curving pipe**



Pathline plot



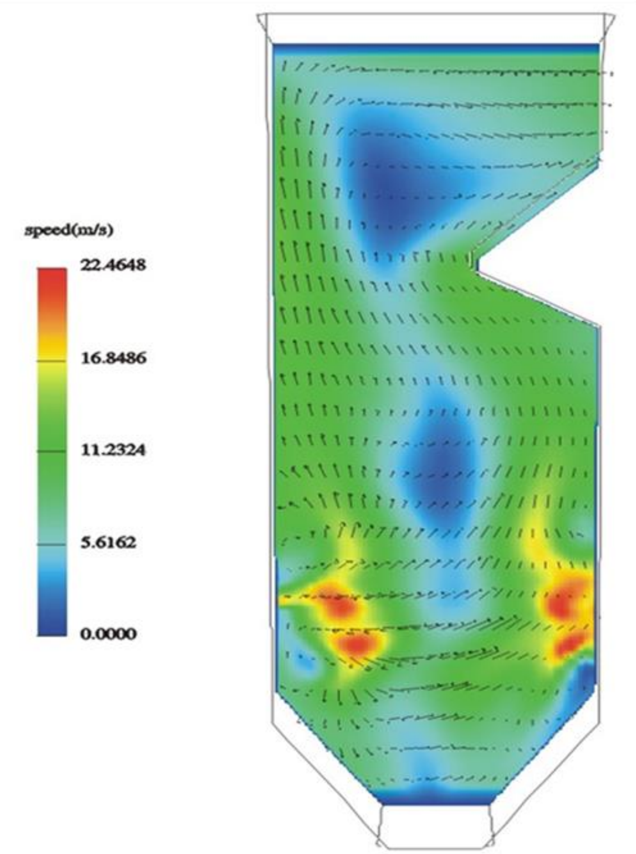
Velocity vector plot



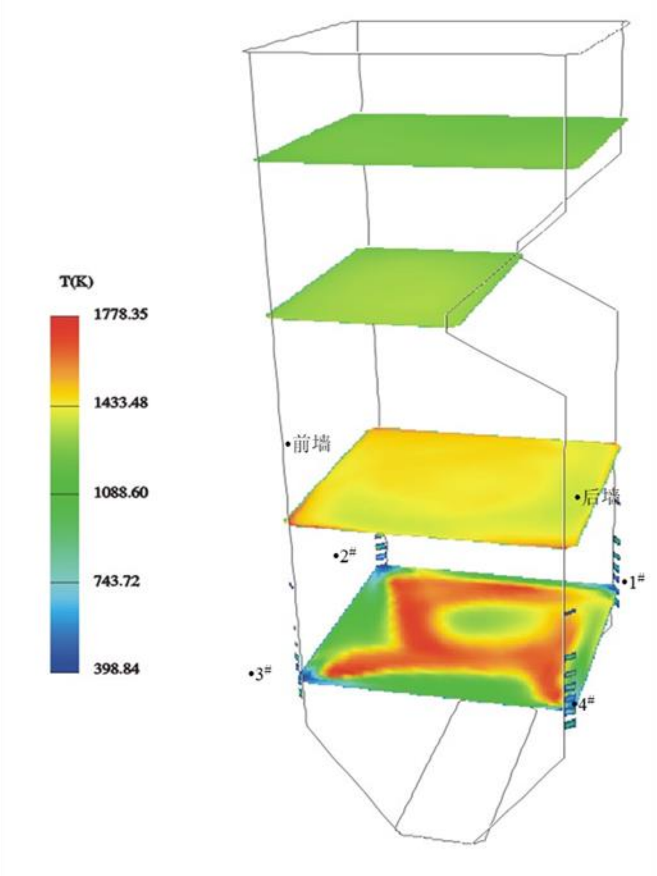
Pressure contour plot

CFD applications in Engineering

- **Combustion process in a pulverized coal boiler**



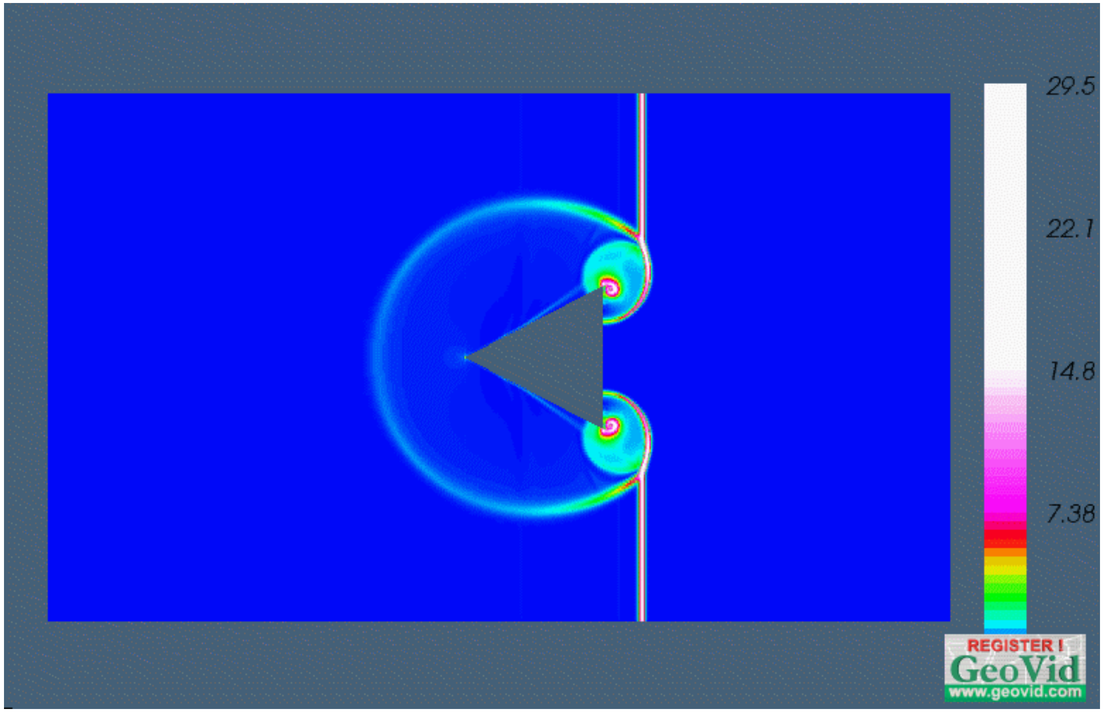
Velocity of primary air in the shaft section of the boiler



Temperature in cross-sections of different heights in the boiler

CFD applications in Engineering

- **Reflection of High Pressure Shock Wave in a box**



Many thanks for your attention.