IEAGHG/IETS Iron & Steel Industry CCUS & Process Integration Workshop
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Tokyo Institute of Technology, Japan

"Analysis of Low Carbon Blast Furnace by Mathematical Model "

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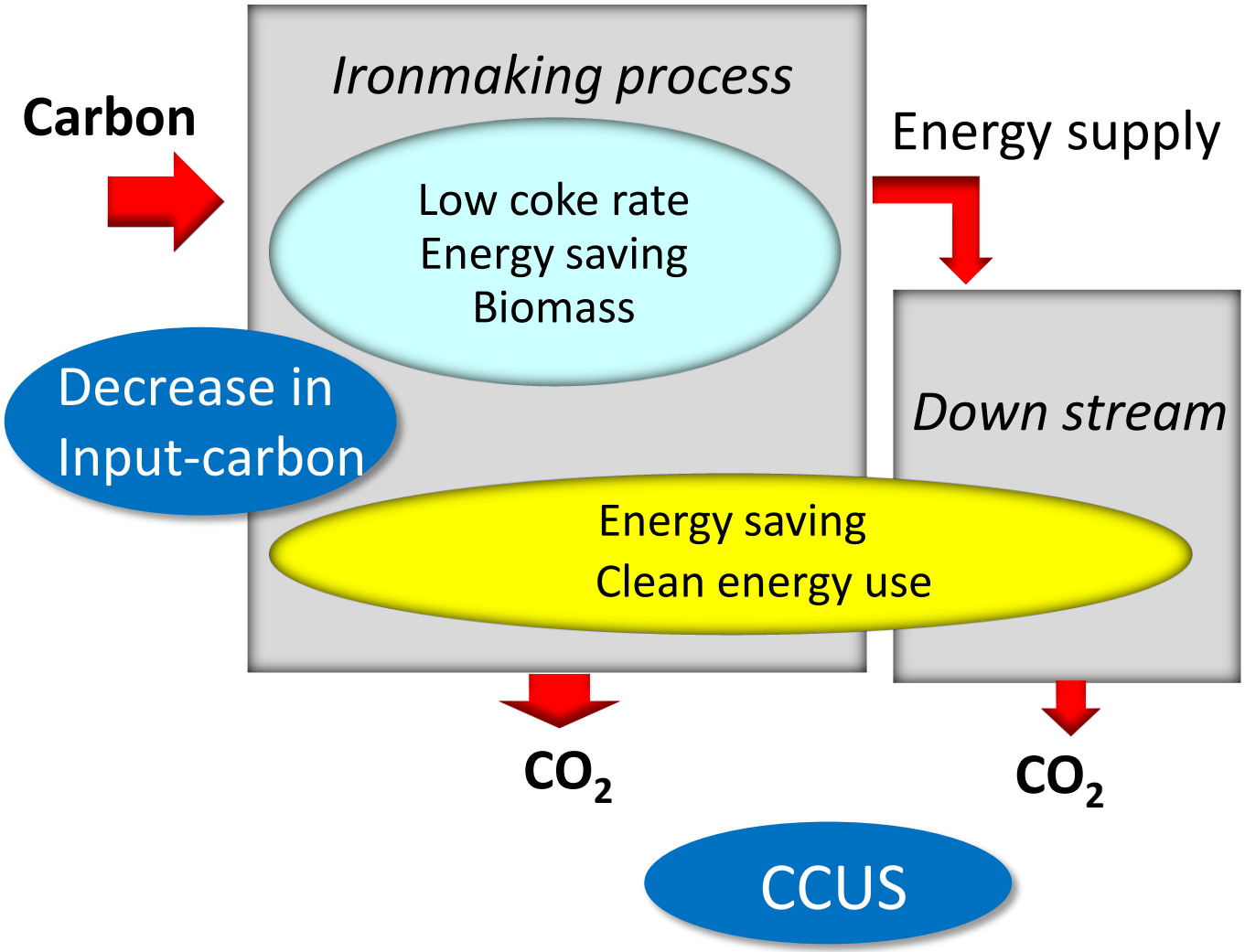
Carbon flow in the integrated steel works

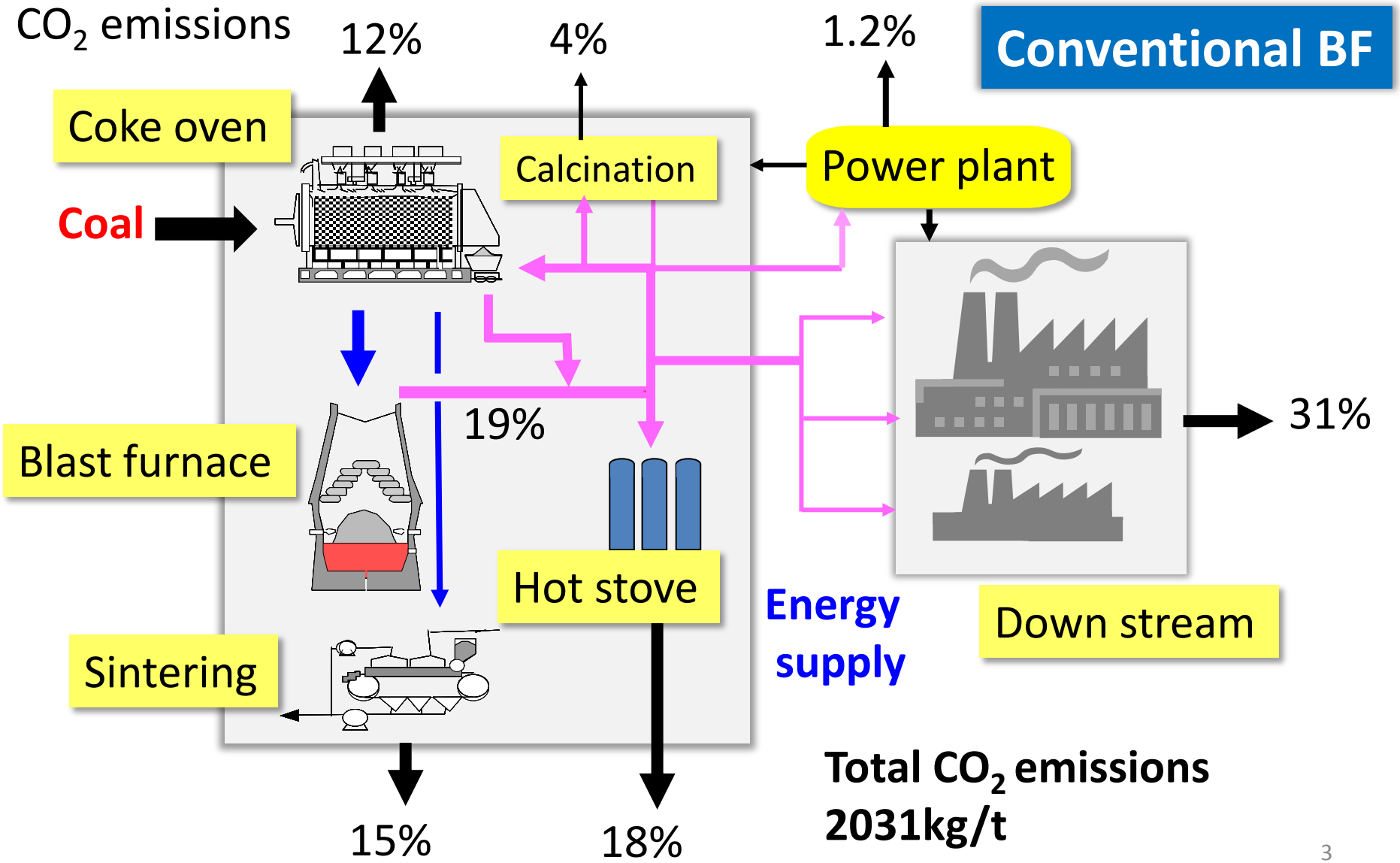
Ca. 20GJ/t



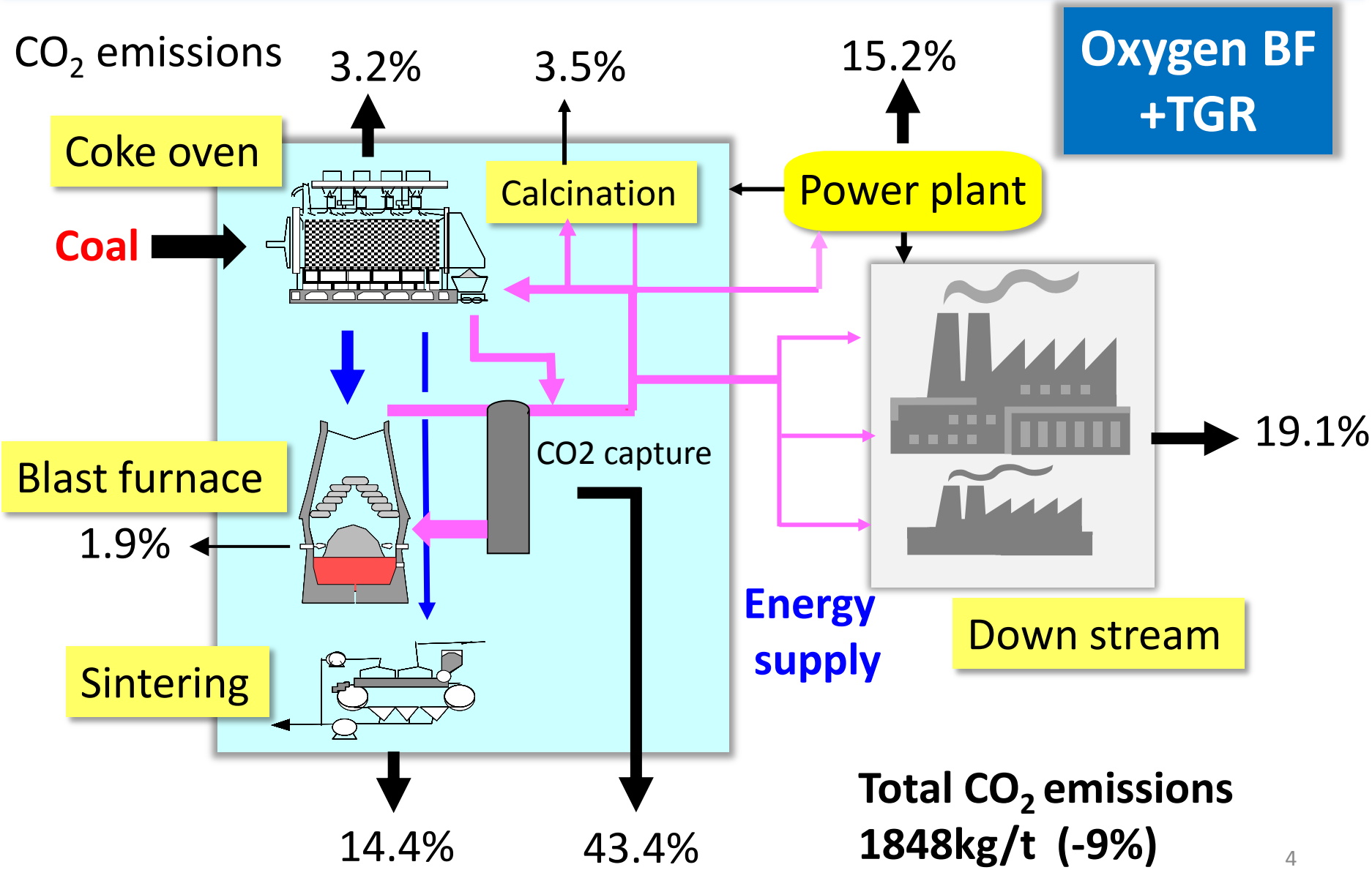
Heat of formation
ΔHf^0 (kJ/mol)

C	0
CH_4	-74
CO	-110
CH_3OH	-239
H_2O	-285
CO_2	-393

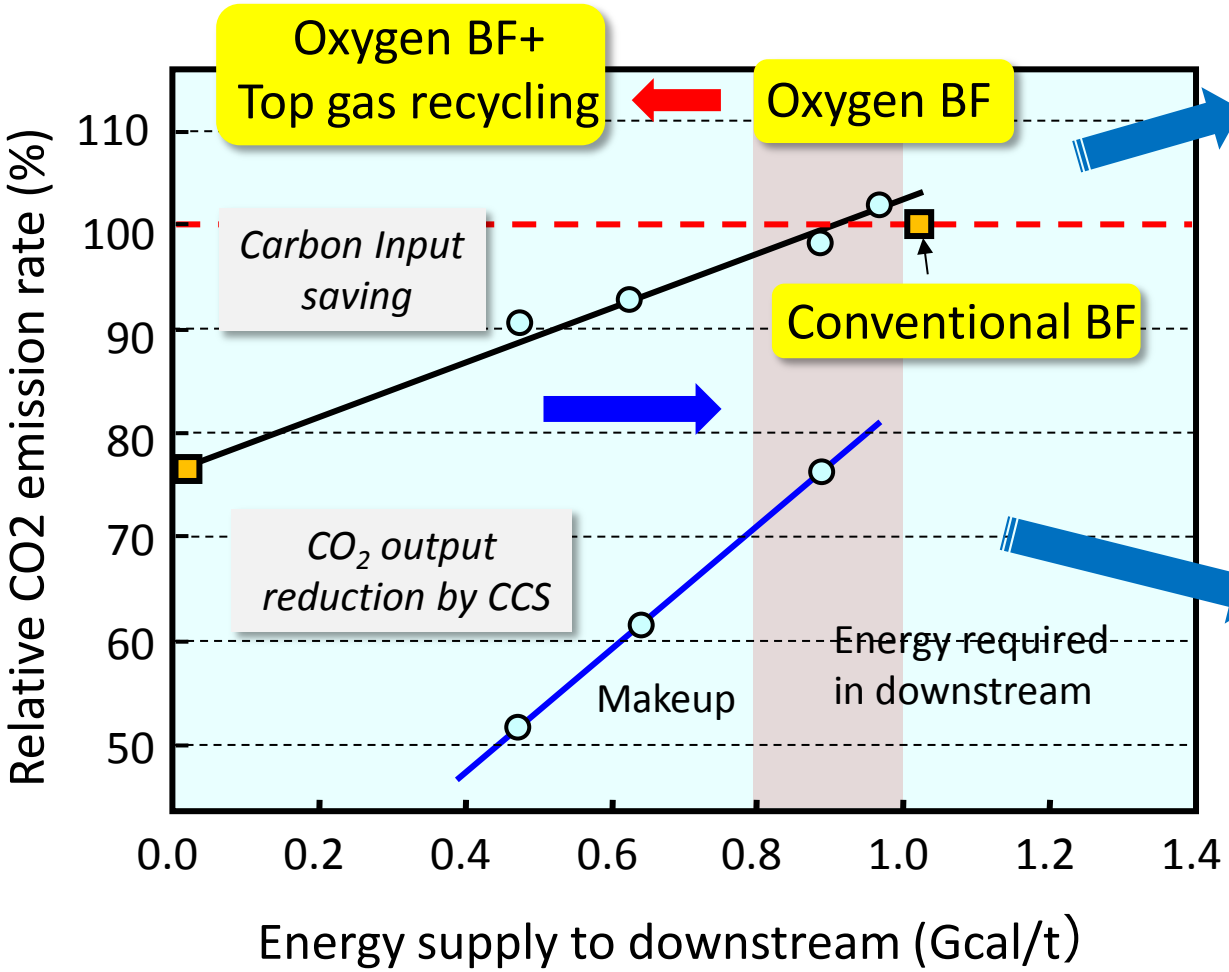
CO_2 emissions from the integrated steel works

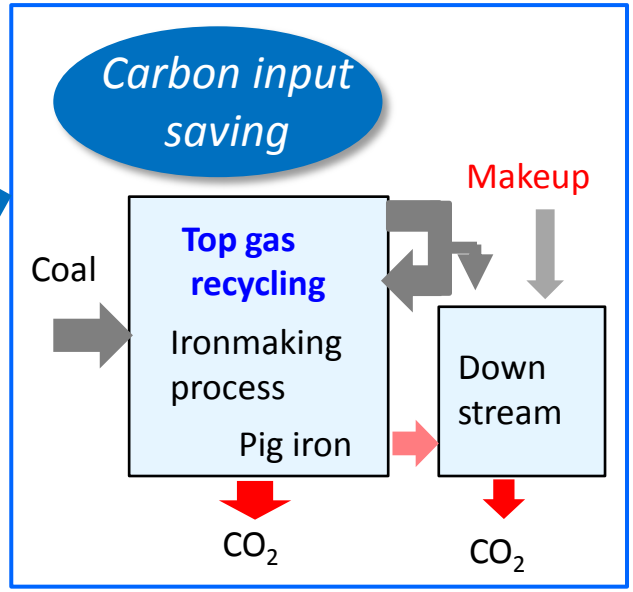


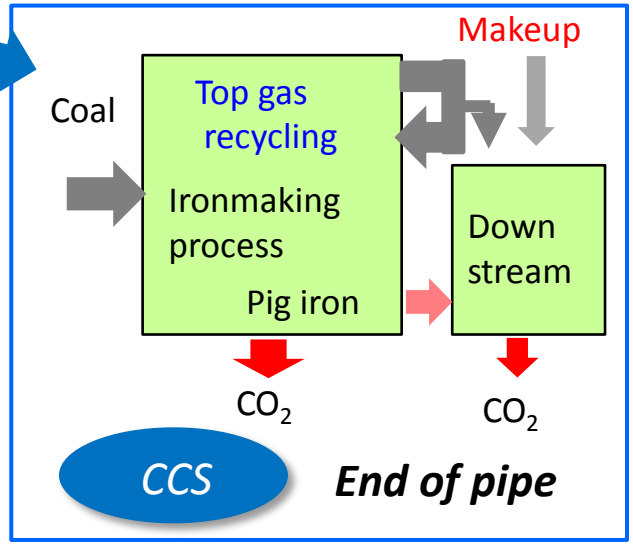
CO_2 emissions from the integrated steel works



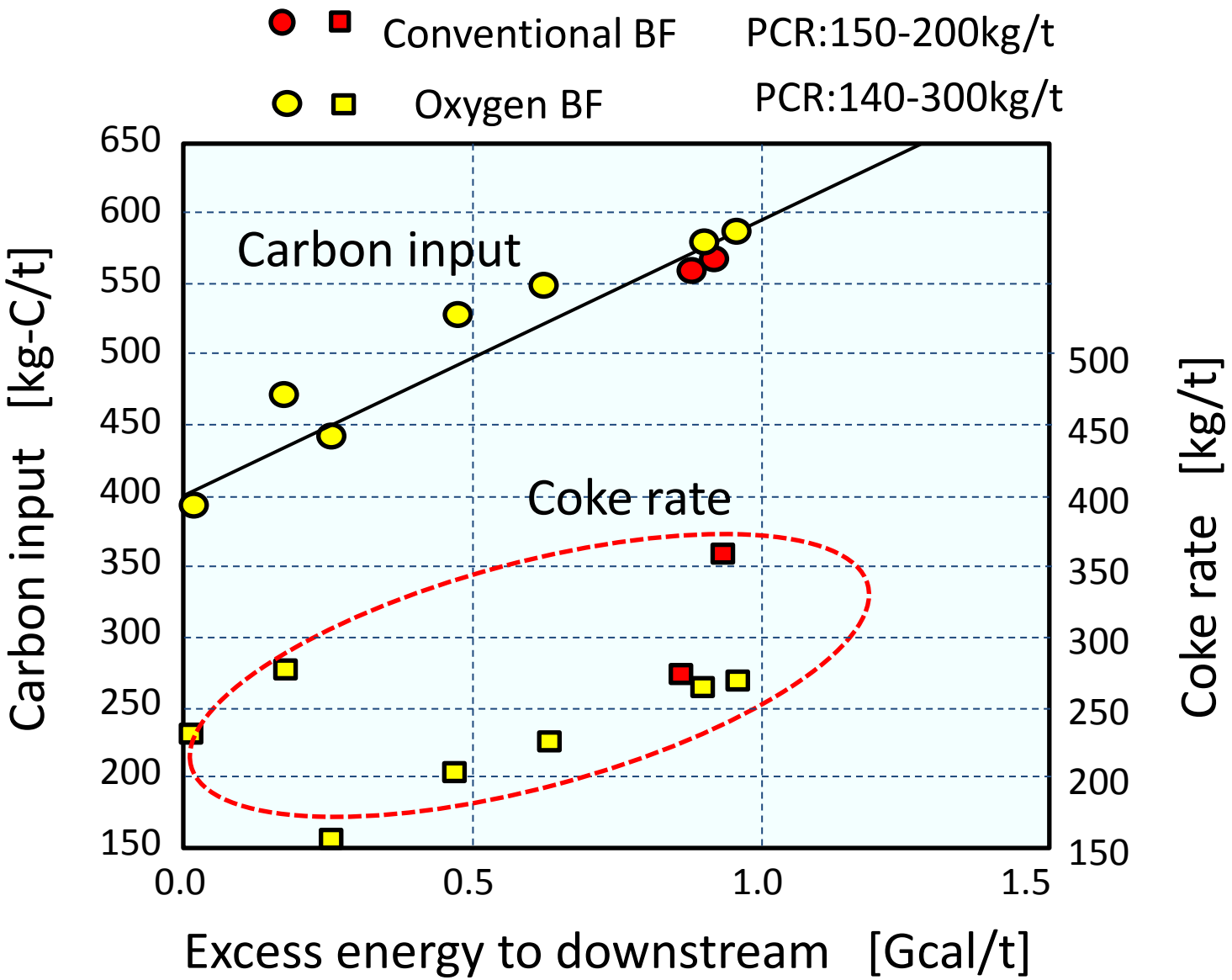
Effect of top gas recycling on CO2 emissions



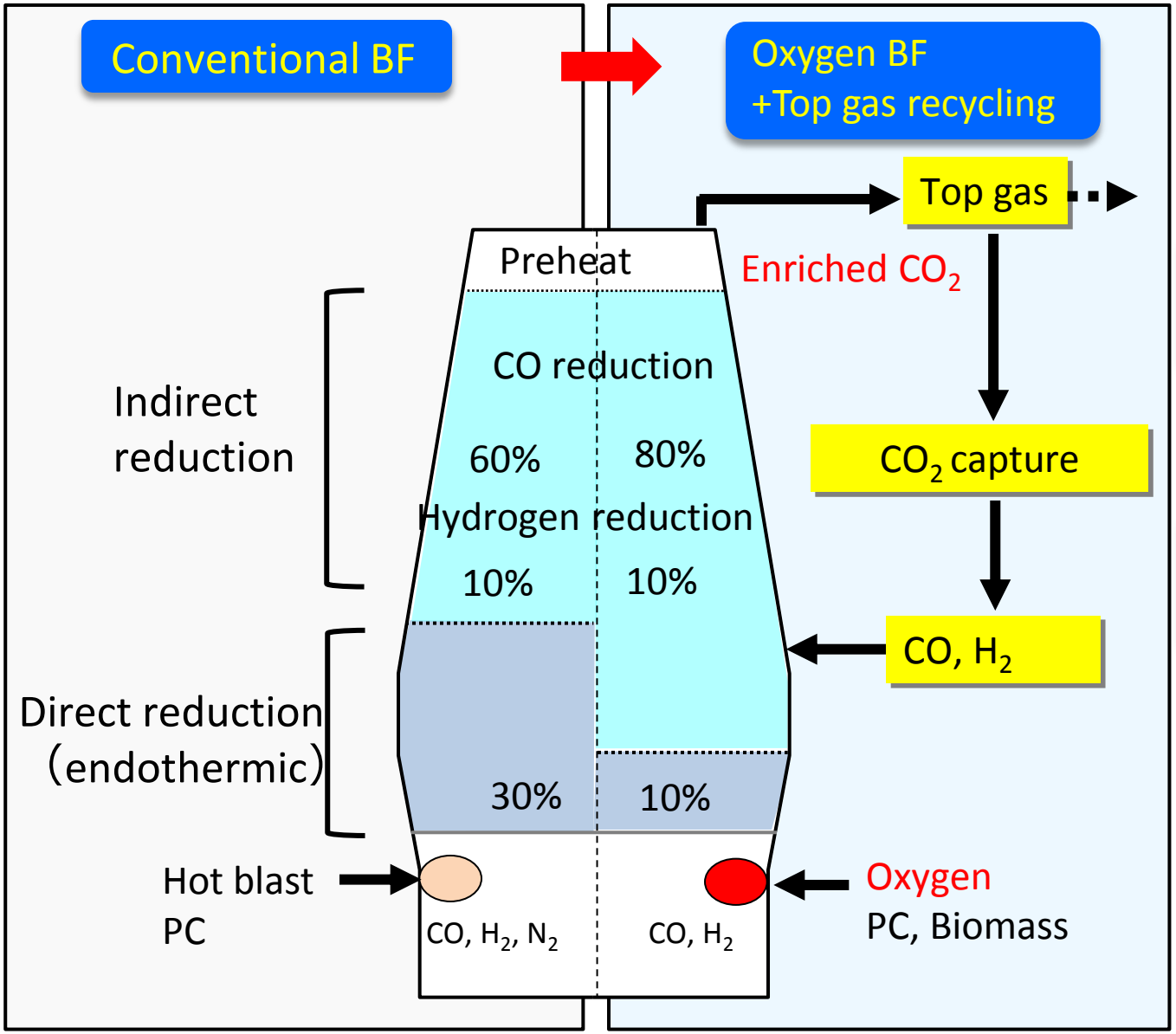




Effect of top gas recycling on coke rate



Low carbon BF by top gas recycling and its subjects

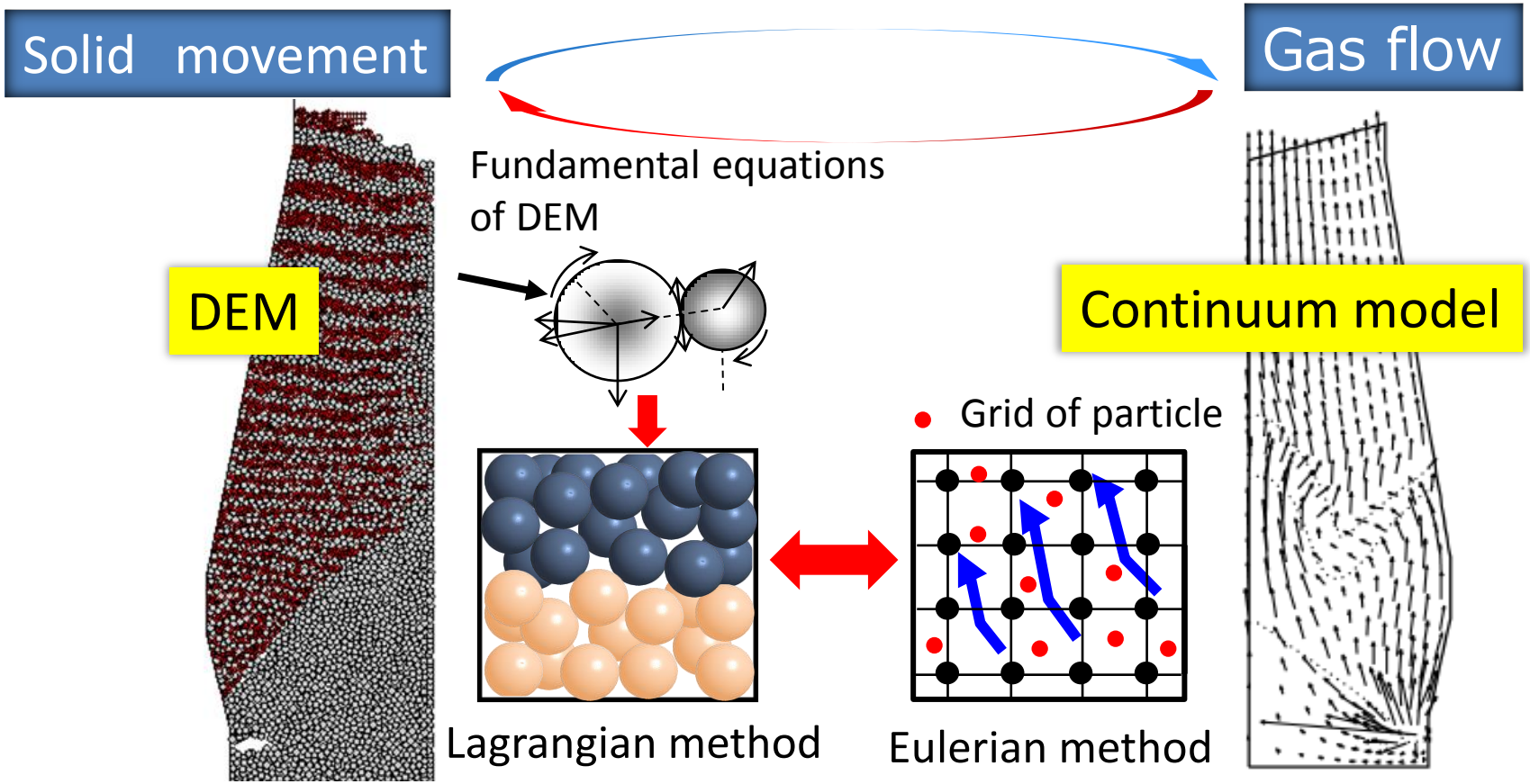


Subjects

Gas penetration of injected gas

Gas permeability at low coke rate

Combination model of DEM and CFD



DEM: Discrete Element Method

Newton's 2nd low

$$m\frac{dv}{dt} = \sum F_n \qquad I\frac{d\omega}{dt} = \sum F_s$$

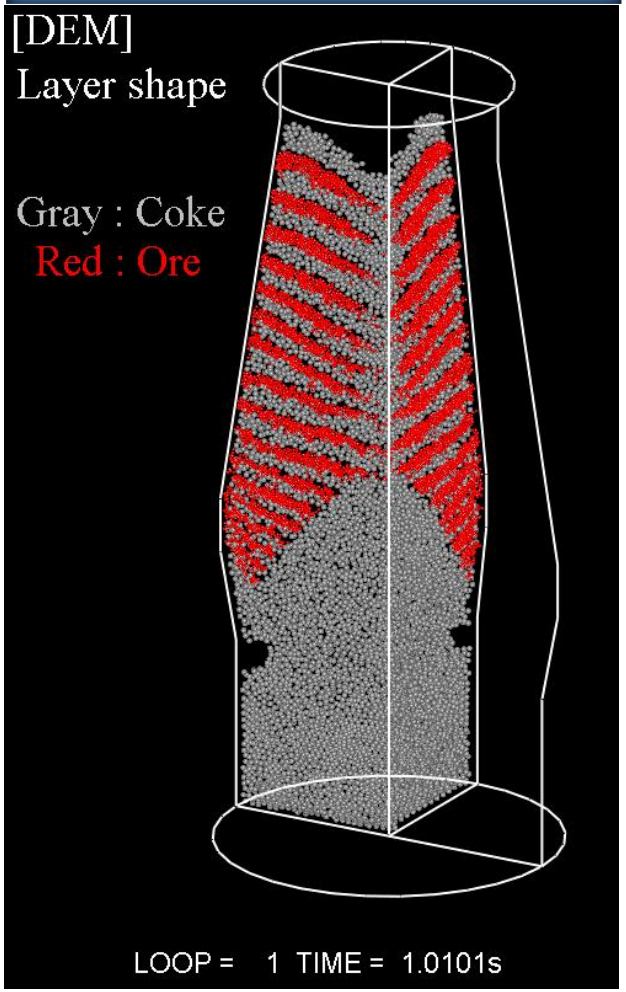
CFD: Computational Fluid Dynamics

General conservation equation

$$\frac{\partial(\varepsilon_i \rho_i \phi_i)}{\partial t} + \mathrm{div}\left(\varepsilon_i \rho_i \vec{U}_i \phi_i\right) = \mathrm{div}\left(\varepsilon_i \Gamma_{\phi_i}\ \mathrm{grad}\ \phi_i\right) + S_{\phi_i}$$

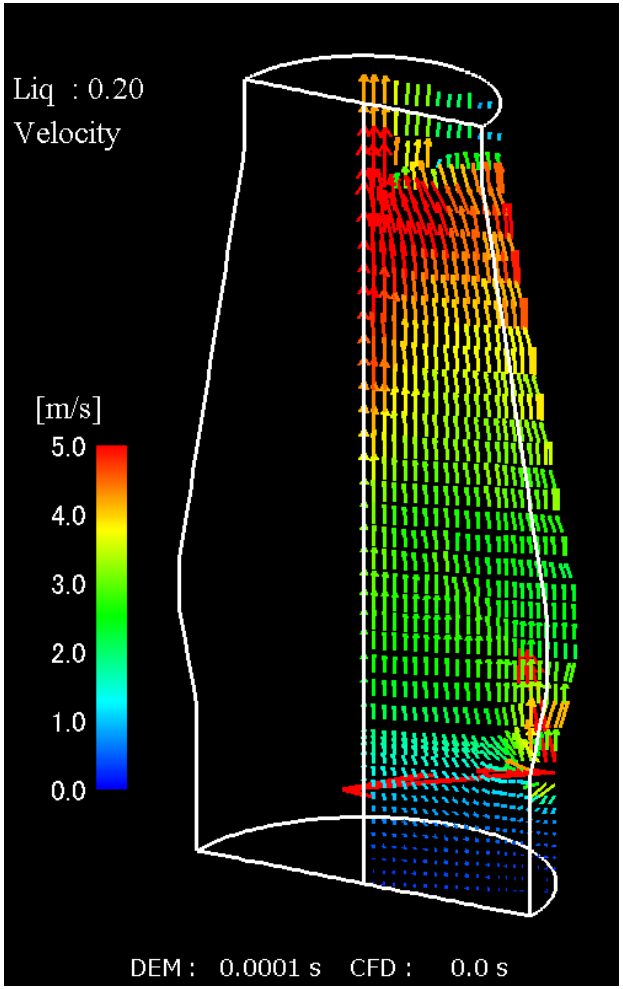
Calculated results by CEM+CFD model

Solid movement



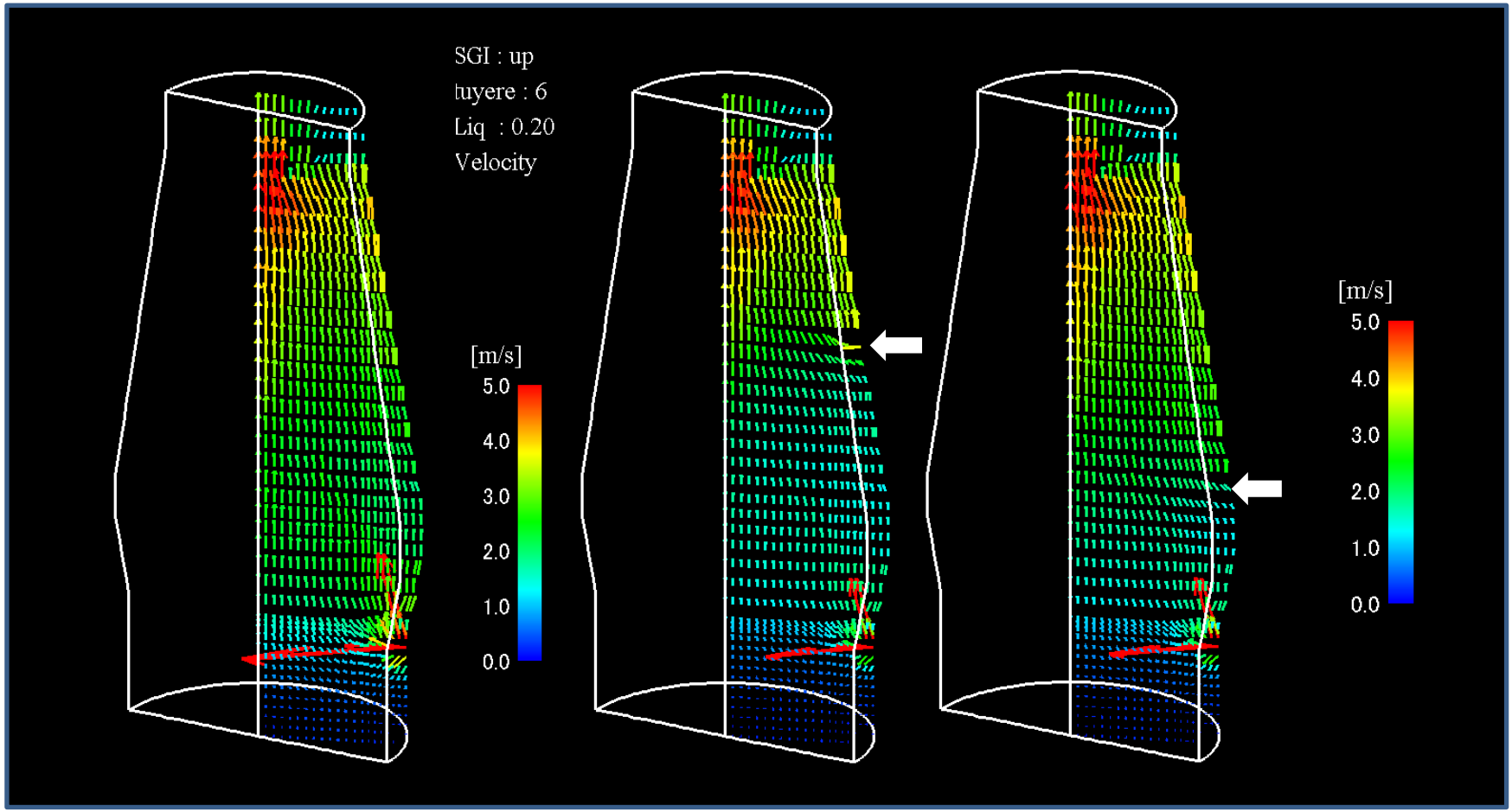
Representation of burden layer

Gas vector



Three-dimensional analysis on gas flow

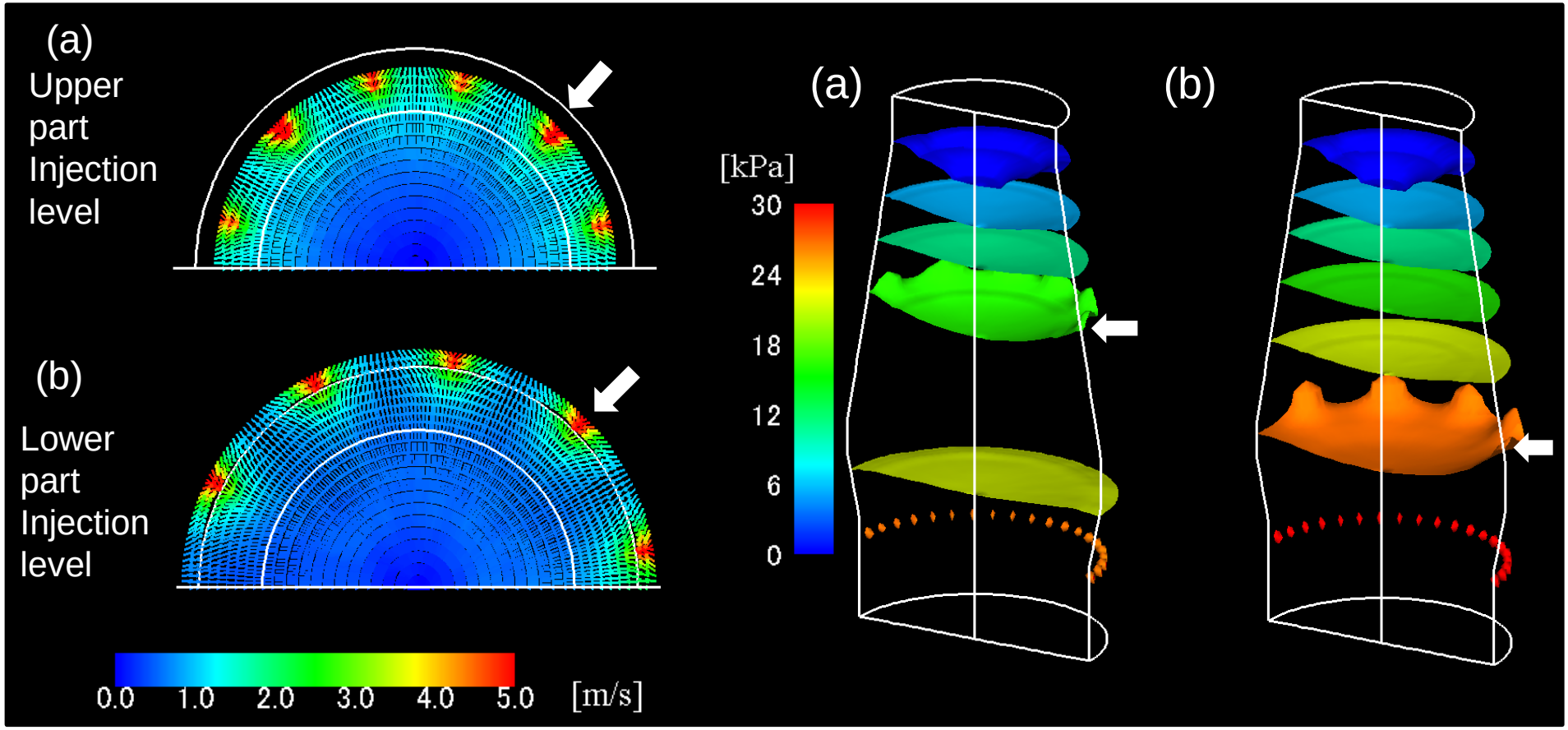
Estimation of gas penetration at shaft gas injection



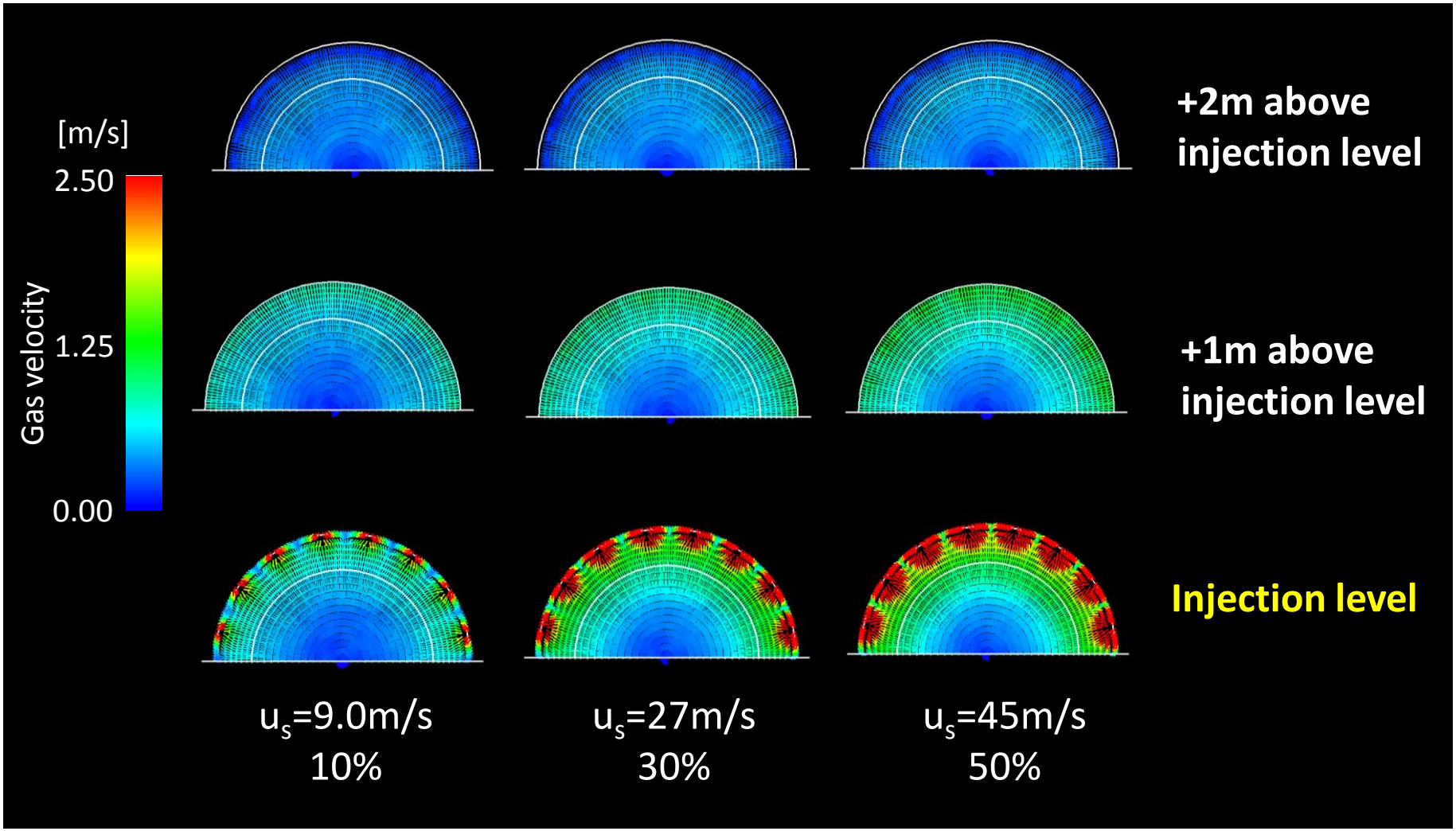
Base condition | **Shaft gas injection at upper part** | **Shaft gas injection at lower part**

Horizontal gas velocity distribution and isobar planes in blast furnace

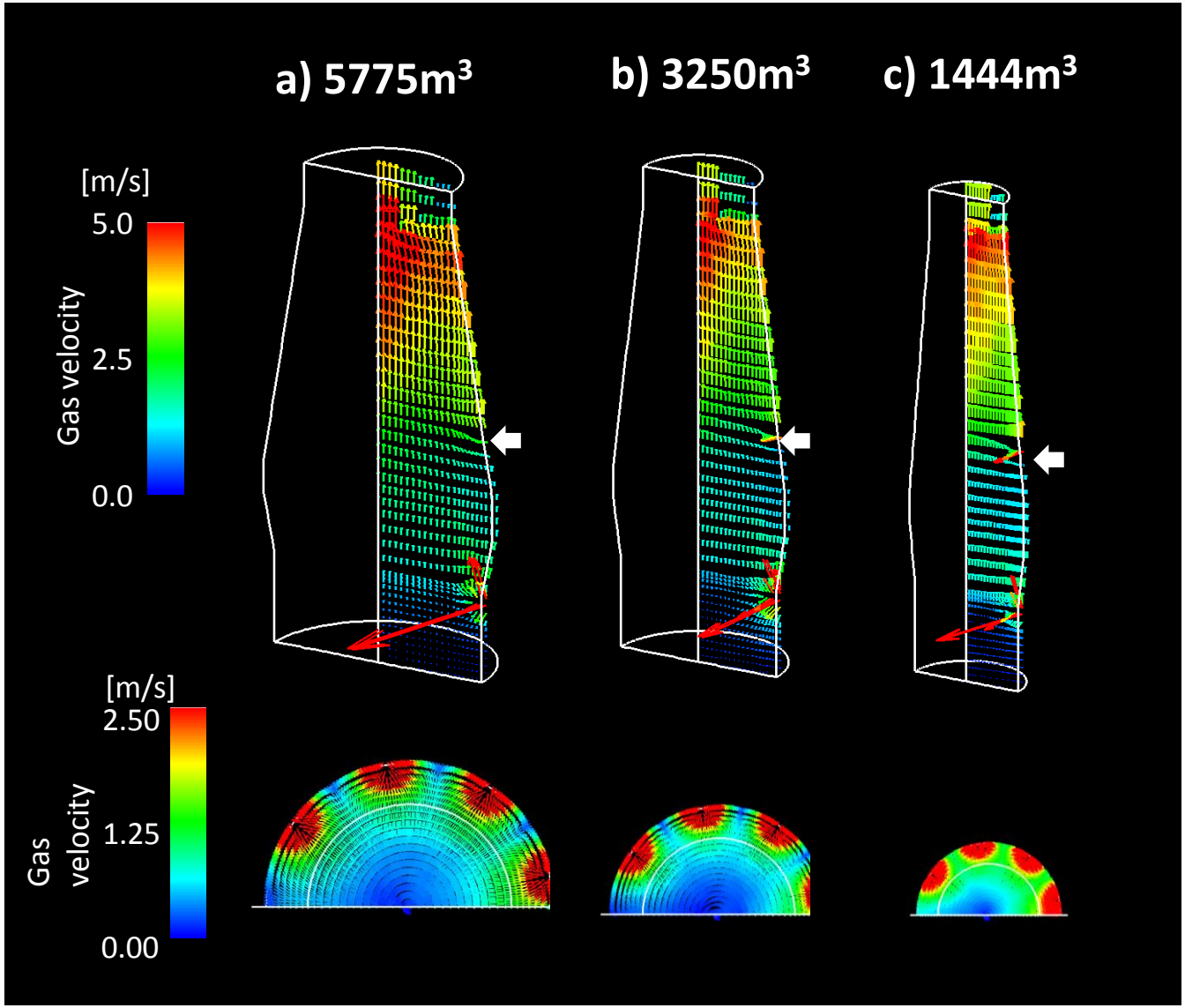
Horizontal gas velocity **Isobar planes**

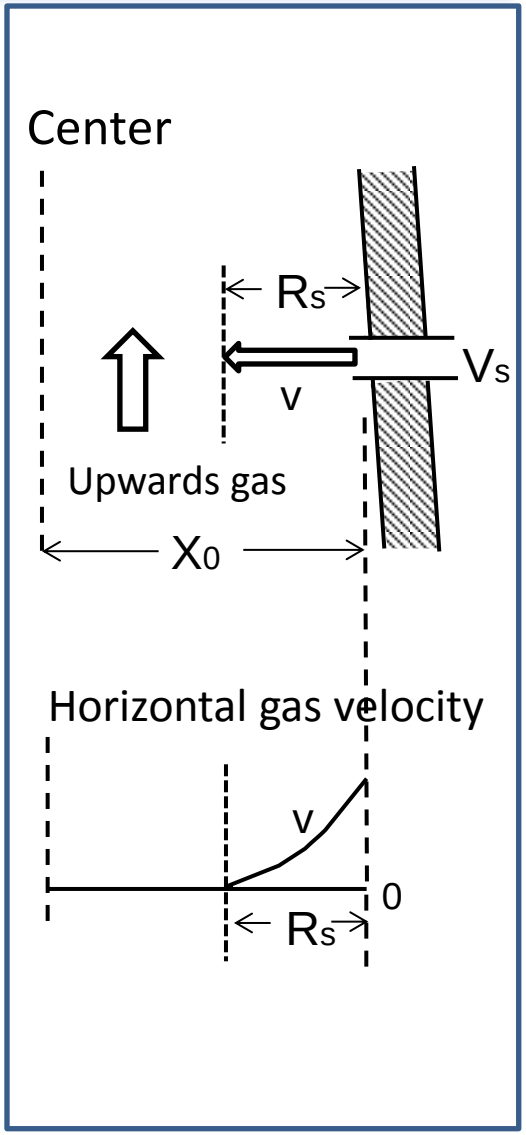


Influence of shaft gas injection velocity on gas penetration in various levels

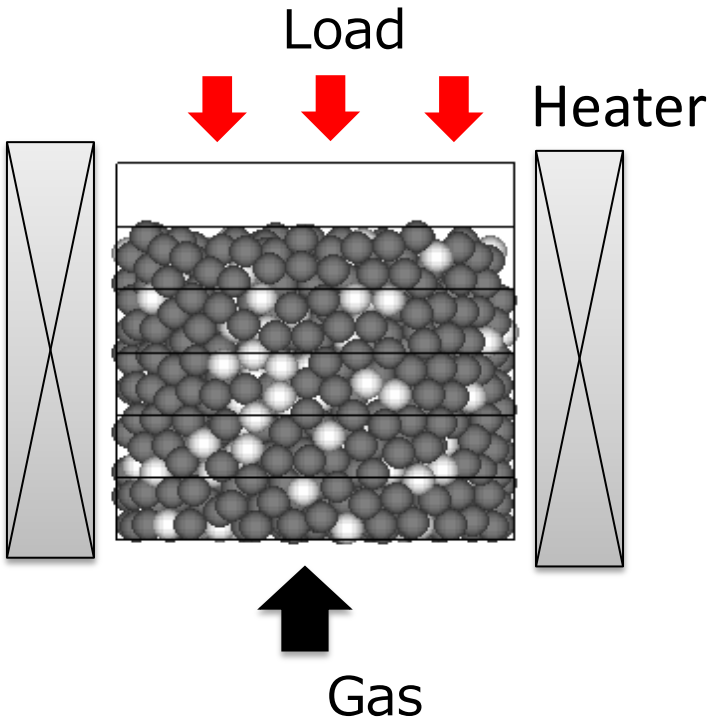


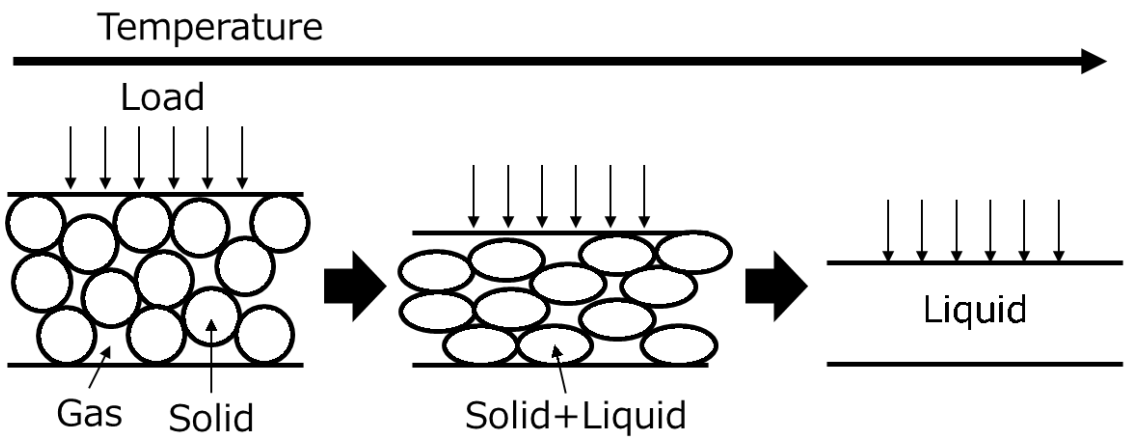
Effect of inner volume of BF on shaft gas penetration

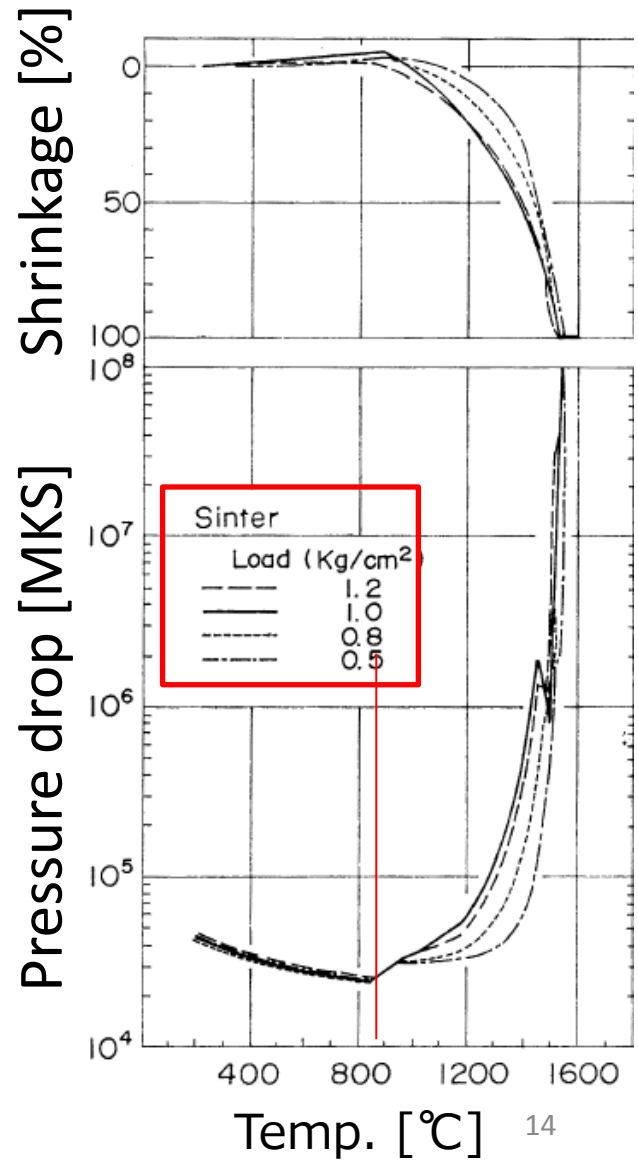




Simulation of softening test under load by DEM

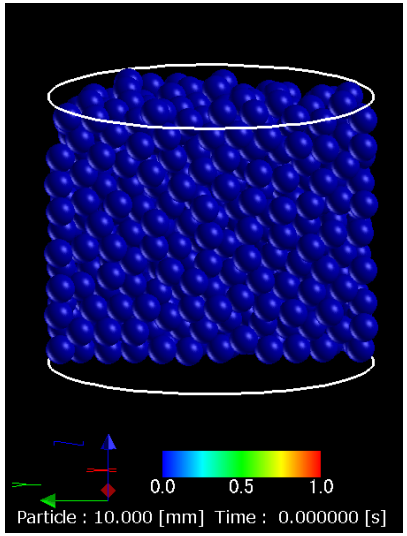
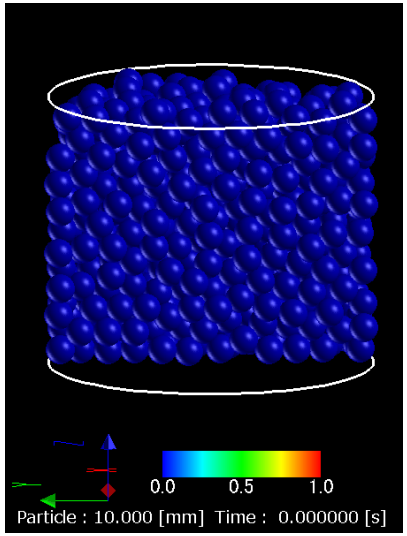
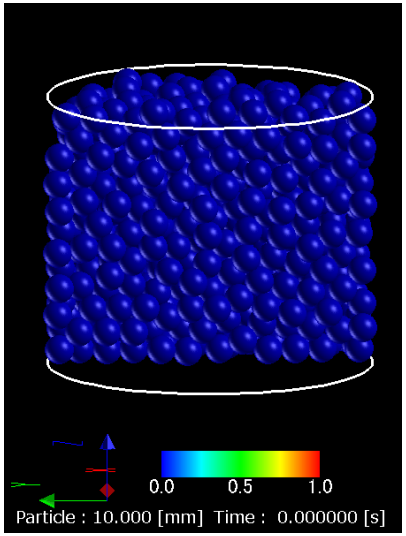
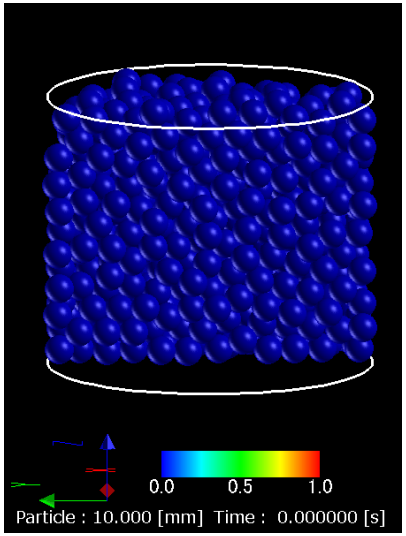
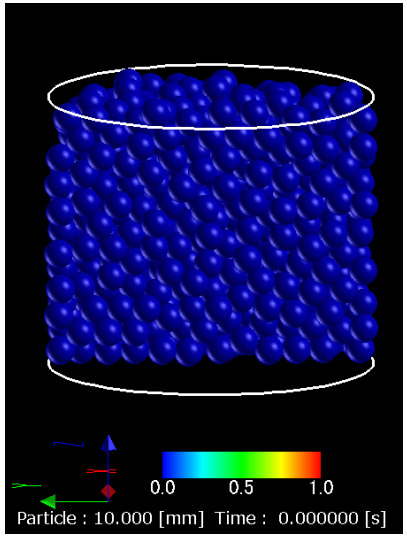
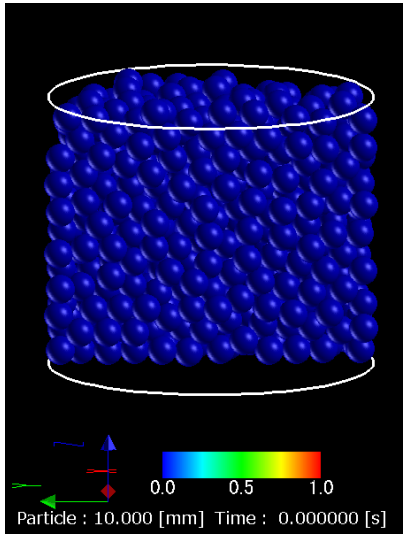
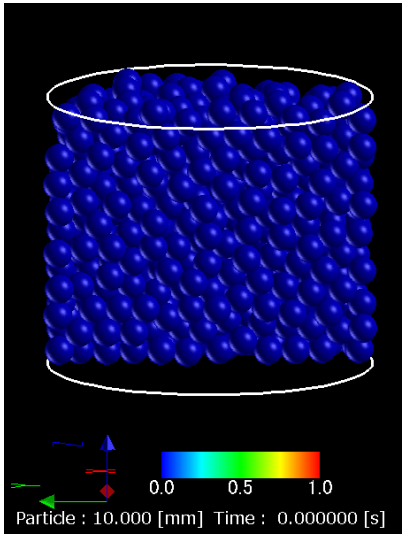
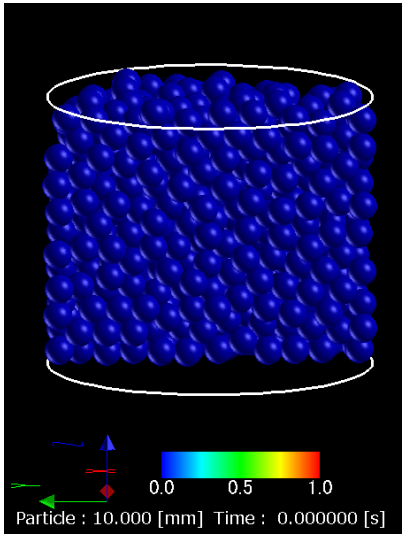




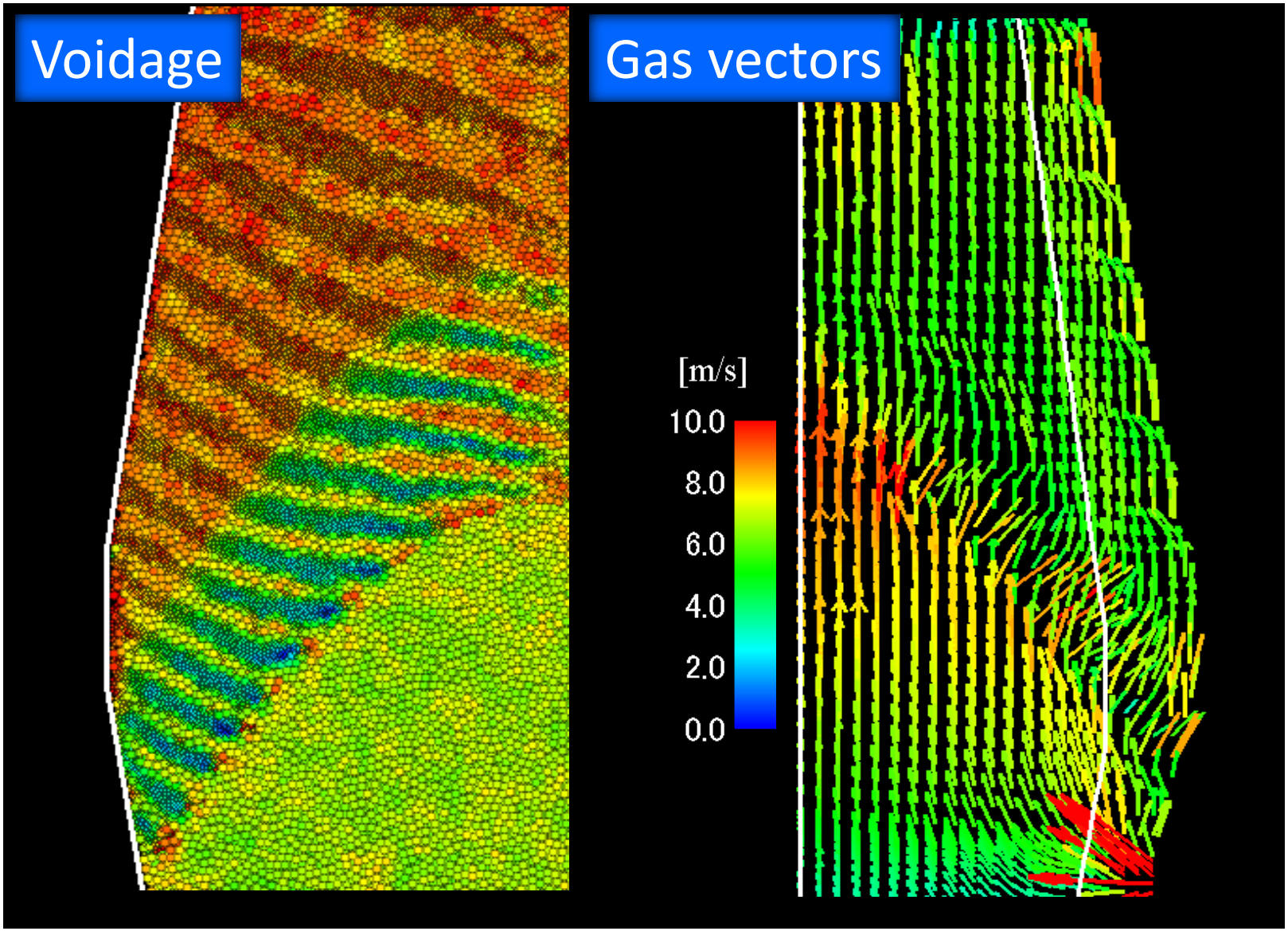


Simulation of softening behavior of ore by DEM

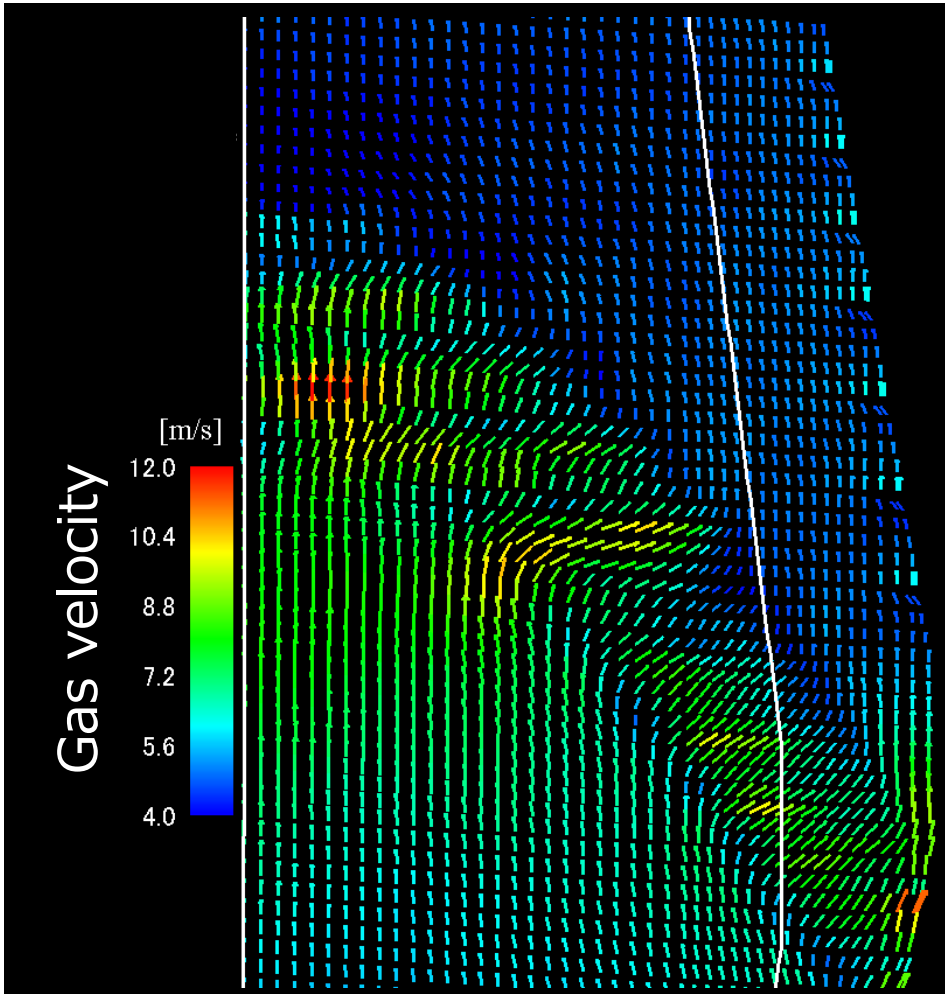
Young's modulus

	3.5 GPa	0.35 GPa	0.035 GPa	0.0035MPa
Shrinkage				
Normal stress				

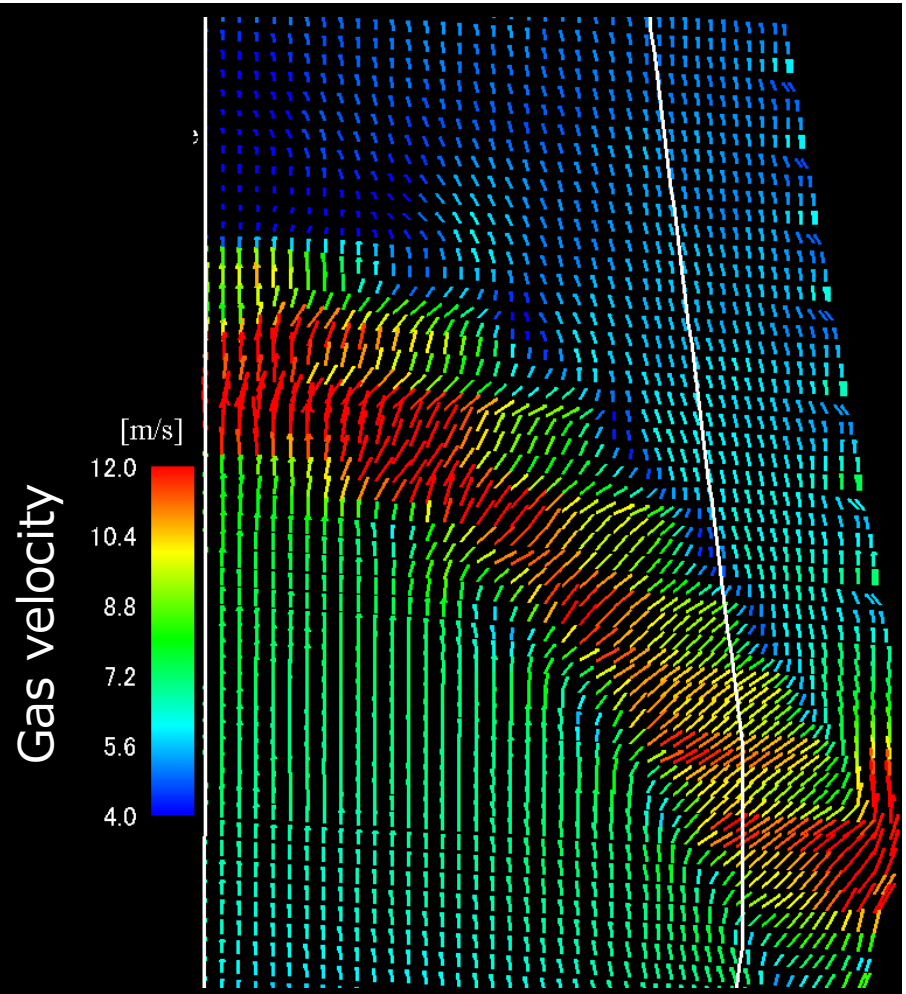
Gas flow in cohesive zone calculated by DEM-CFD



Gas velocity vectors at various coke rate conditions

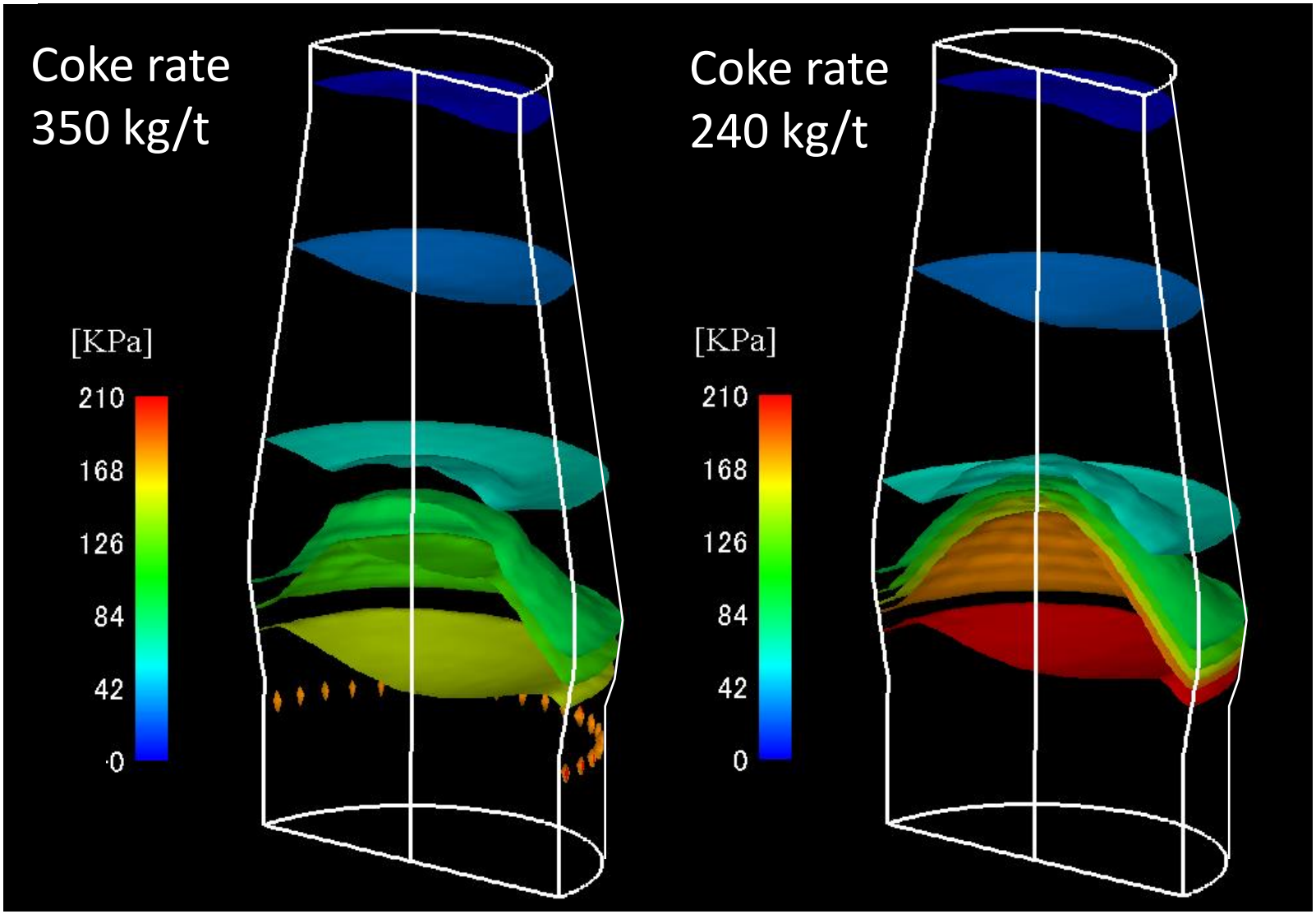


Coke rate 350 kg/t

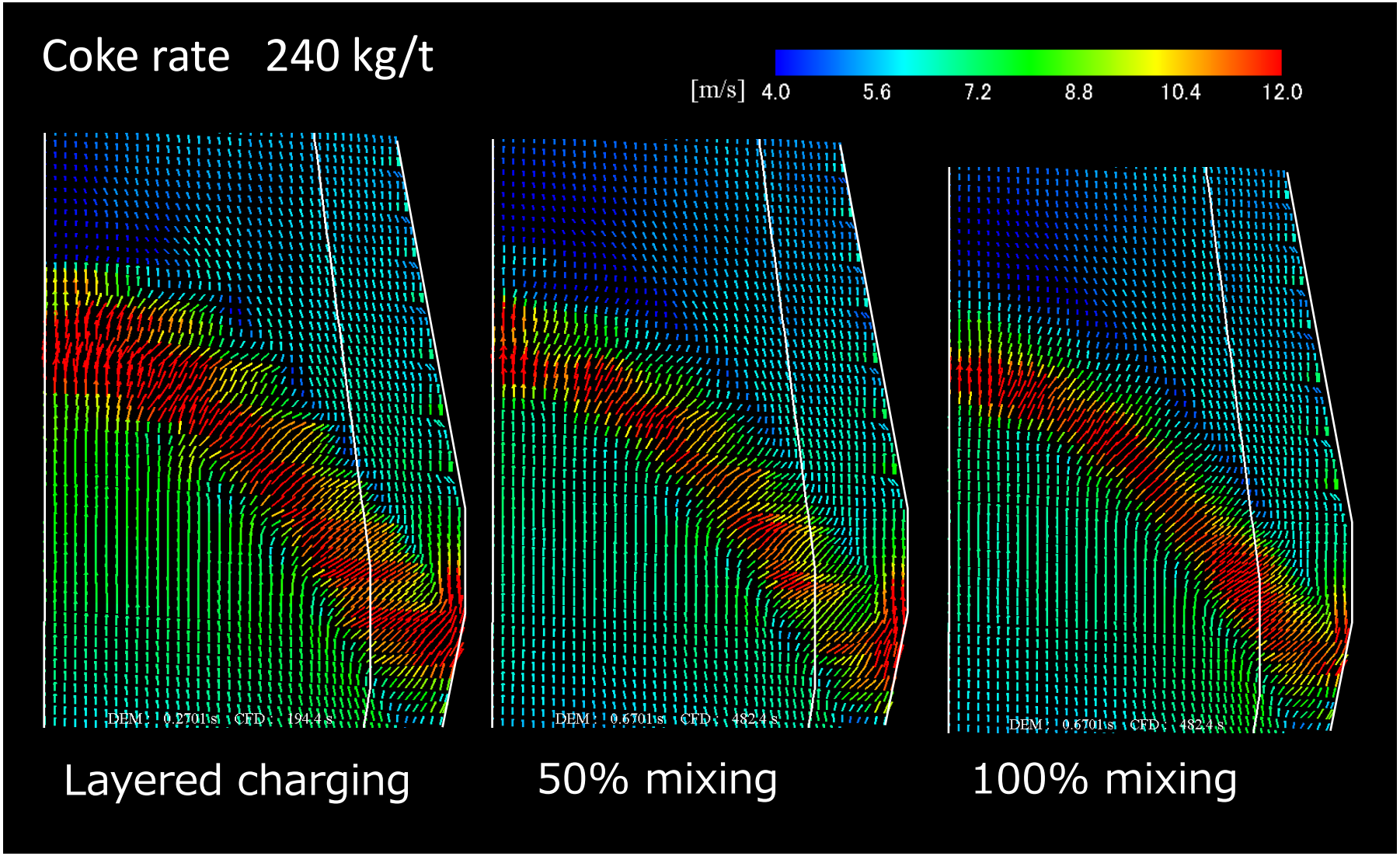


Coke rate 240 kg/t

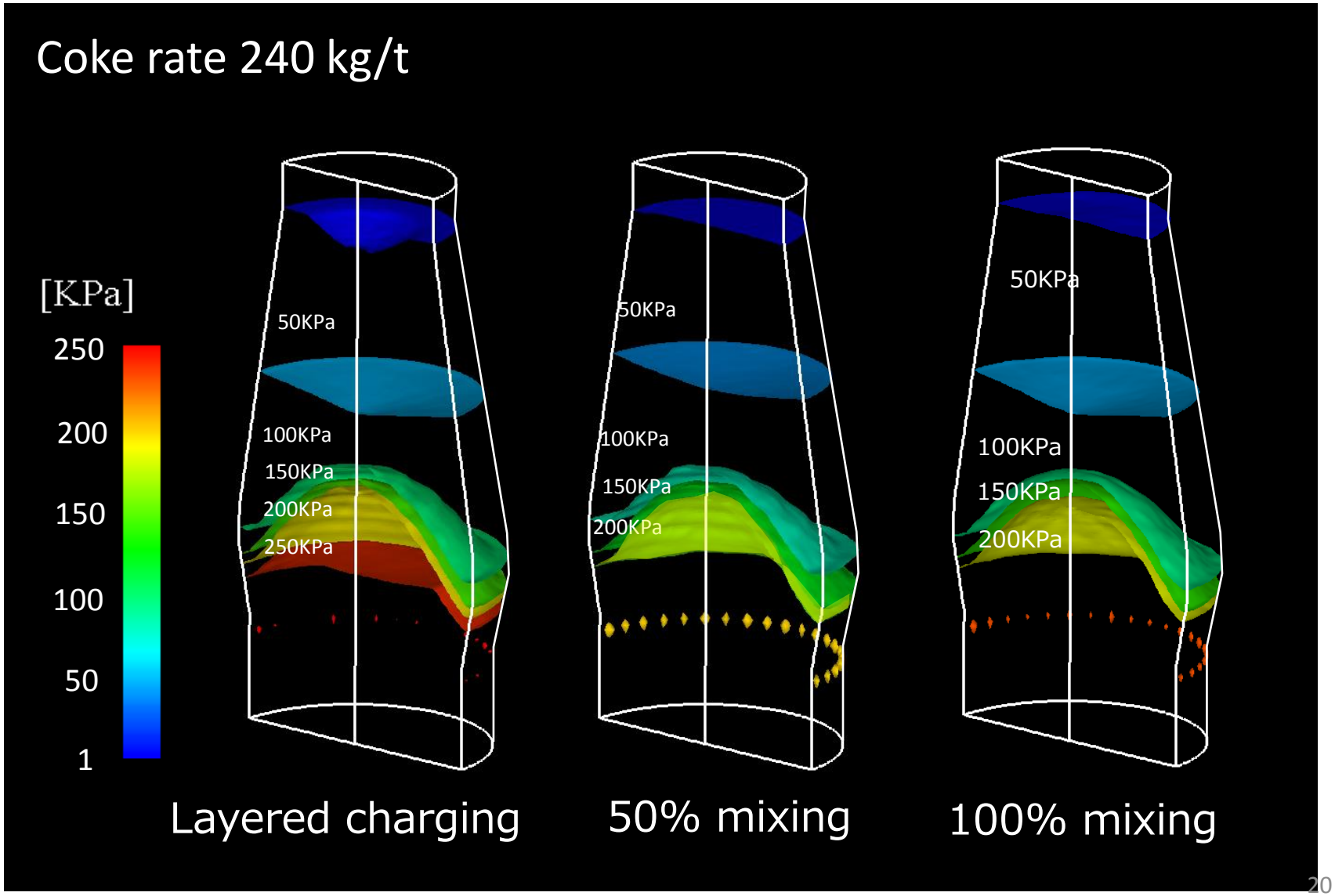
Isobars planes at various coke rate conditions



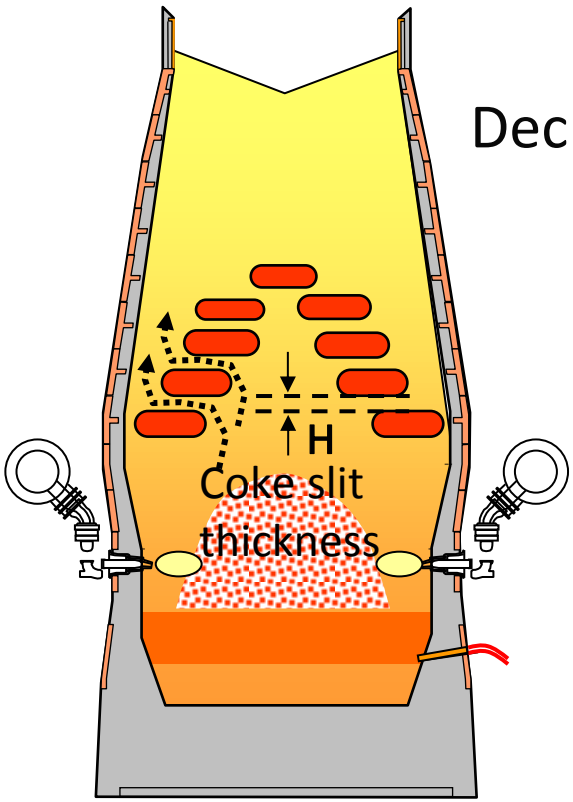
Effect of charging mode on gas flow



Effect of charging mode on isobars planes



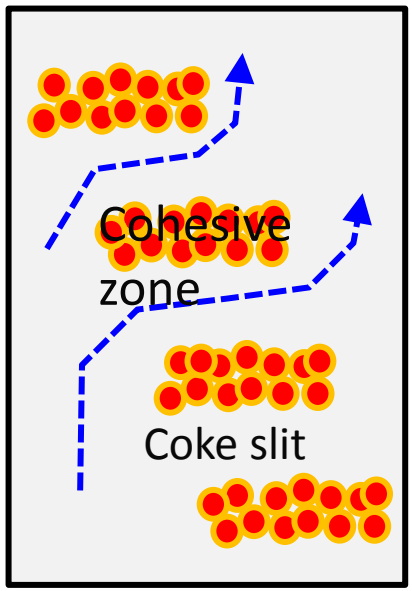
Effect of coke mixed charge in low coke rate

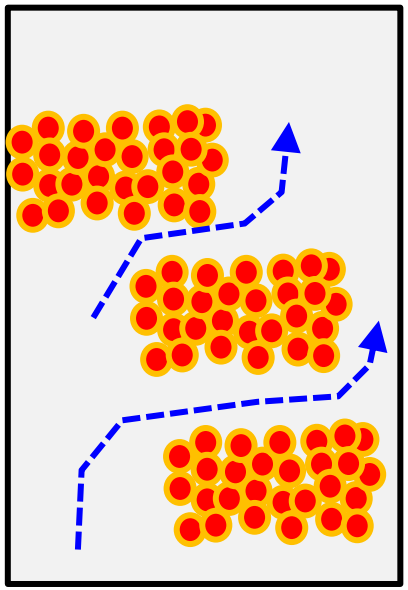


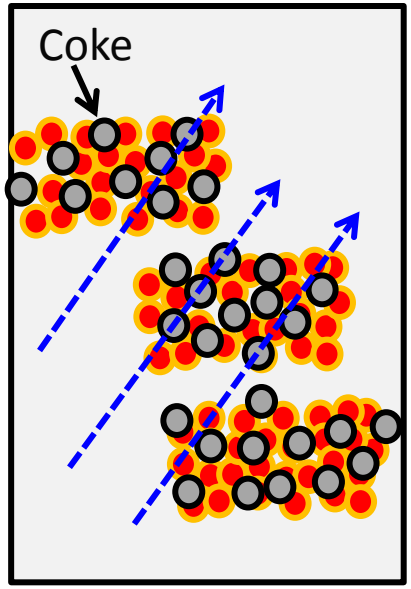
Layered charge

Coke mixed charge

Decrease in coke rate







Increase in pressure drop due to narrow coke slit

Conclusions

- The gas flow and solid motion with shaft gas injection and low coke rate conditions were three-dimensionally analyzed by a hybrid model of DEM and CFD.
- The influence of shaft gas injection is restricted to the peripheral zone.
- In smaller blast furnace, the injected gas can easily reach the central part.
- At low coke rate conditions, charging mode must be improved to keep permeability in the cohesive zone. Coke mixed charge has a favorable effect .

Thank you for your attention