KITECH 한국생산기술연구원

FEP 융합연구단 Future Energy Plant Convergence Research Center

Strategies to improve 3D simulation accuracy using 1D simulation for CFB boilers

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Barracuda Virtual Reactor Users' Conference 2022

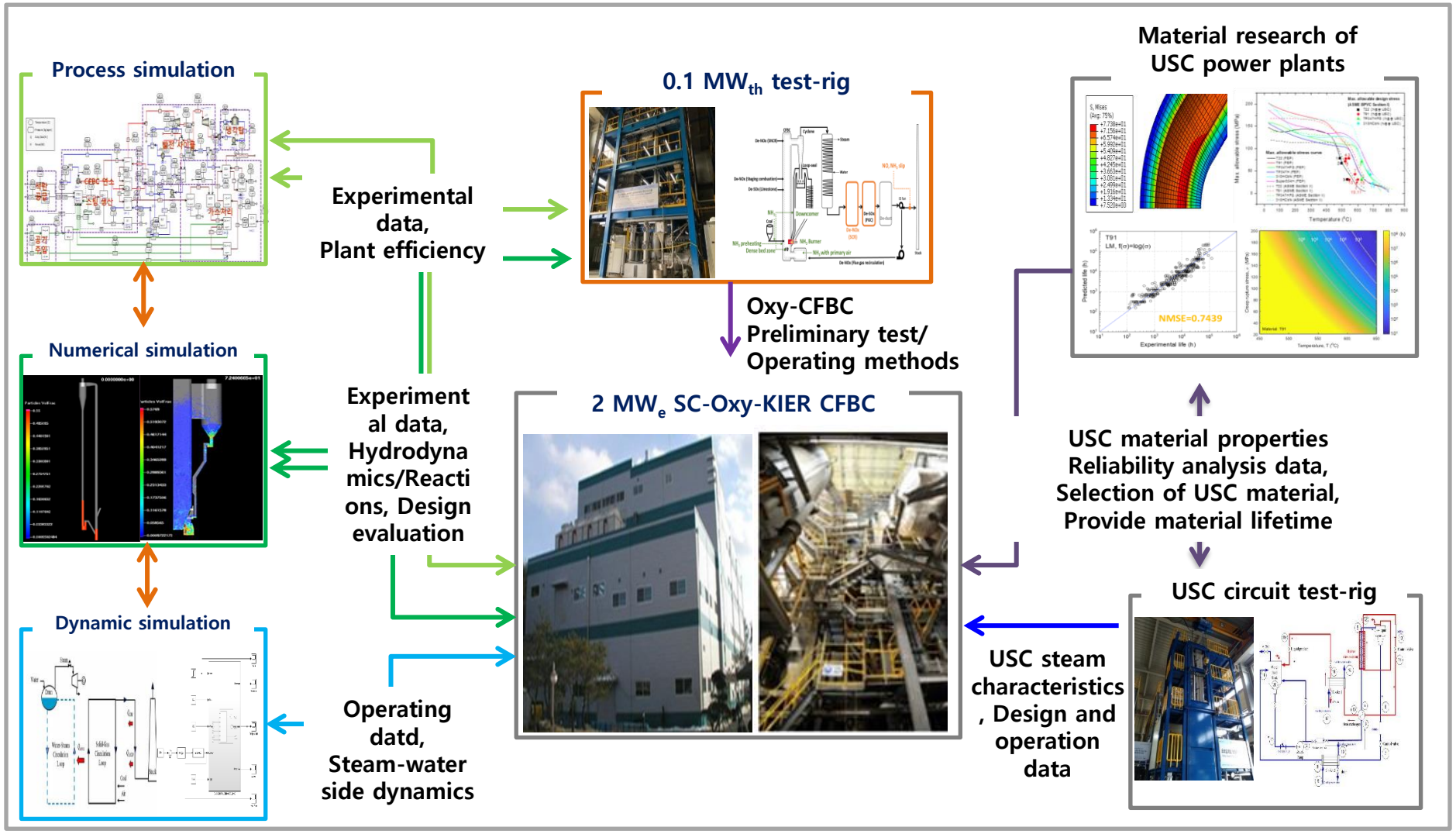
Hyunmin Kwon[1,2] , Byeongryeol Bang[1,2], Uendo Lee[1,2,3]

[1] Carbon Neutral Technology R&D Department, Korea Institute of Industrial Technology

[2] Future Energy Plant Convergence Research Center, Korea Institute of Energy Research

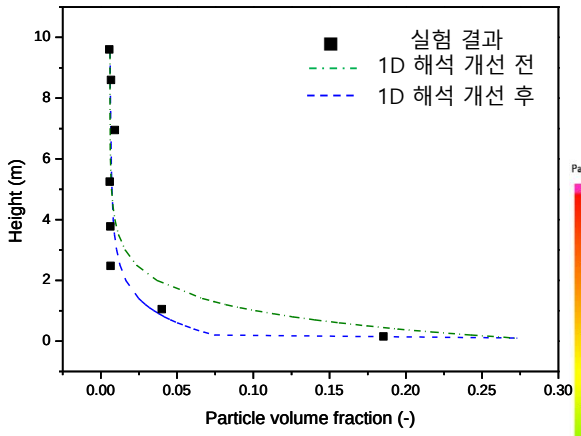
[3] Green Process and Energy System Engineering, University of Science and Technology

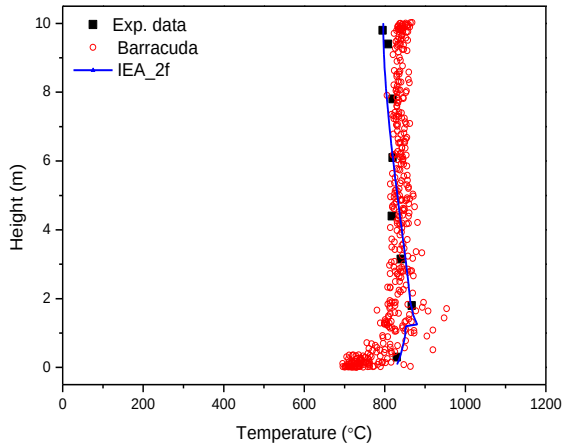
CFBC research activities at FEP CRC



Numerical simulation of 0.1 MW_{th} CFB combustor

0.1 MW_{th} Test-rig (FEP CRC)





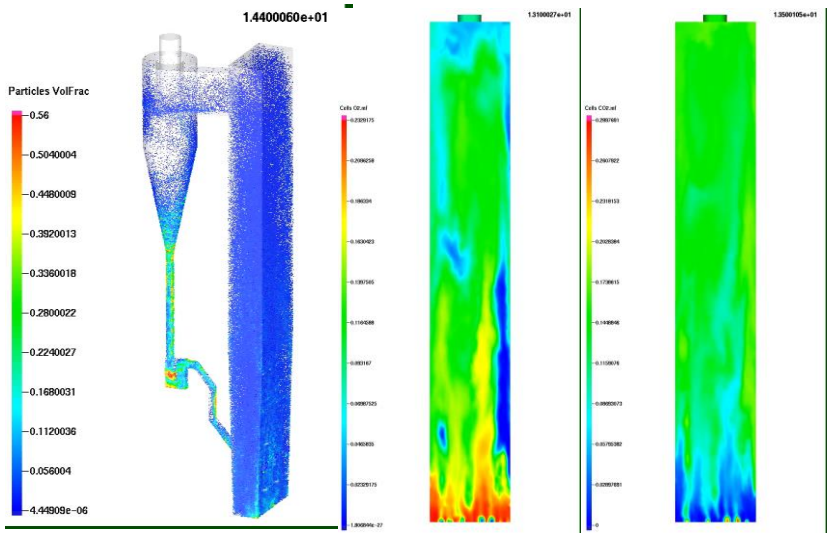
Temperature profile

Particle temperature (K)

Numerical simulation of 2 MW_e CFB boiler

2 MW_e CFB Boiler (FEP CRC)

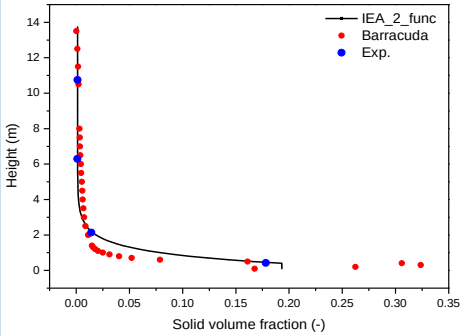
- 3D simulation results of 2 MW_e CFB boiler -

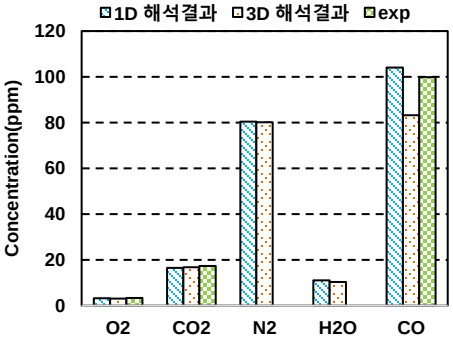


Solids volume fraction (-)

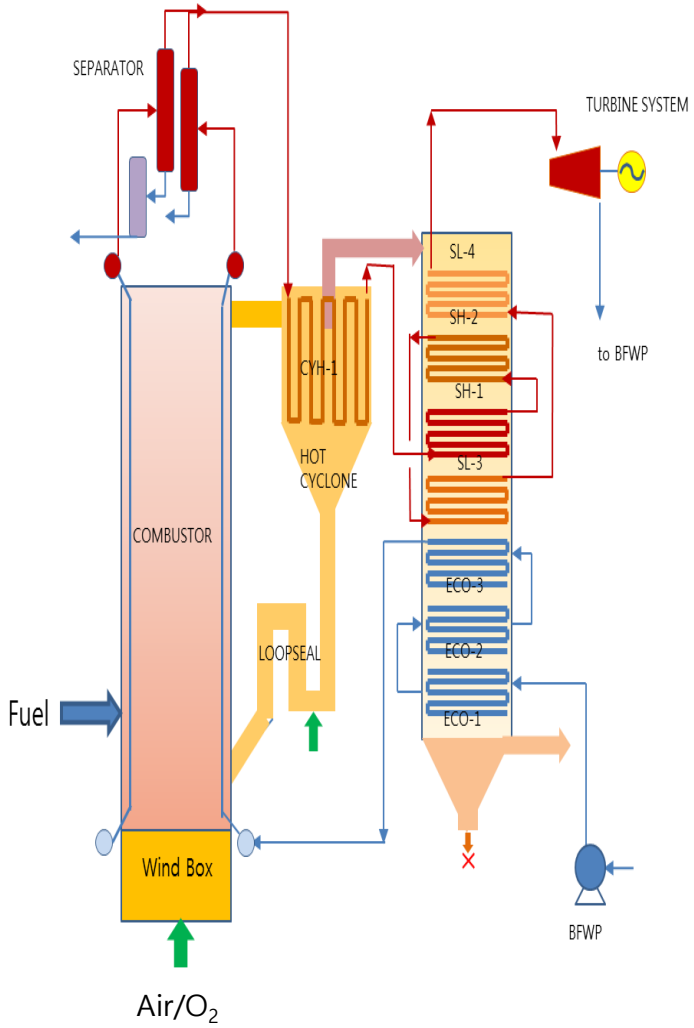
Gas composition (O_2, mass fraction)

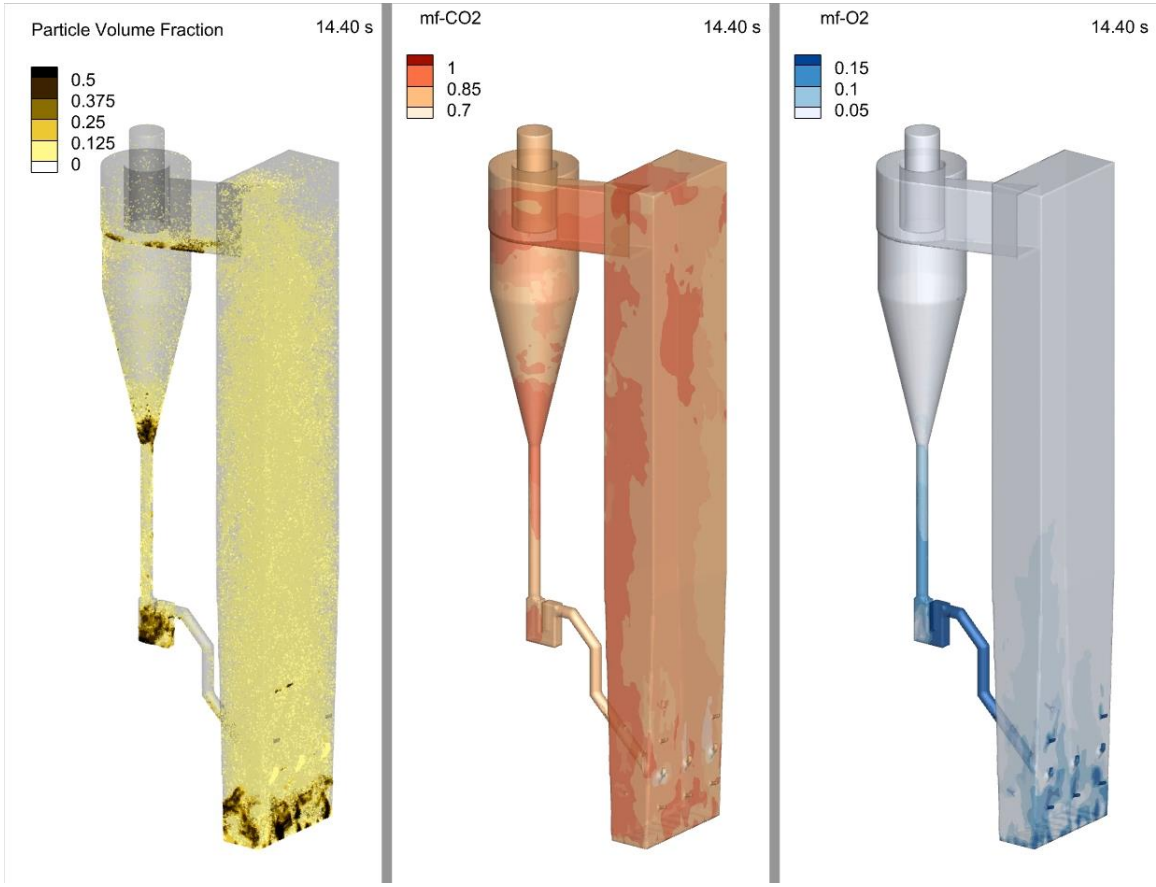
Gas composition (CO_2, mass fraction)





Numerical simulation of 2 MW_e Oxy-CFB Boiler





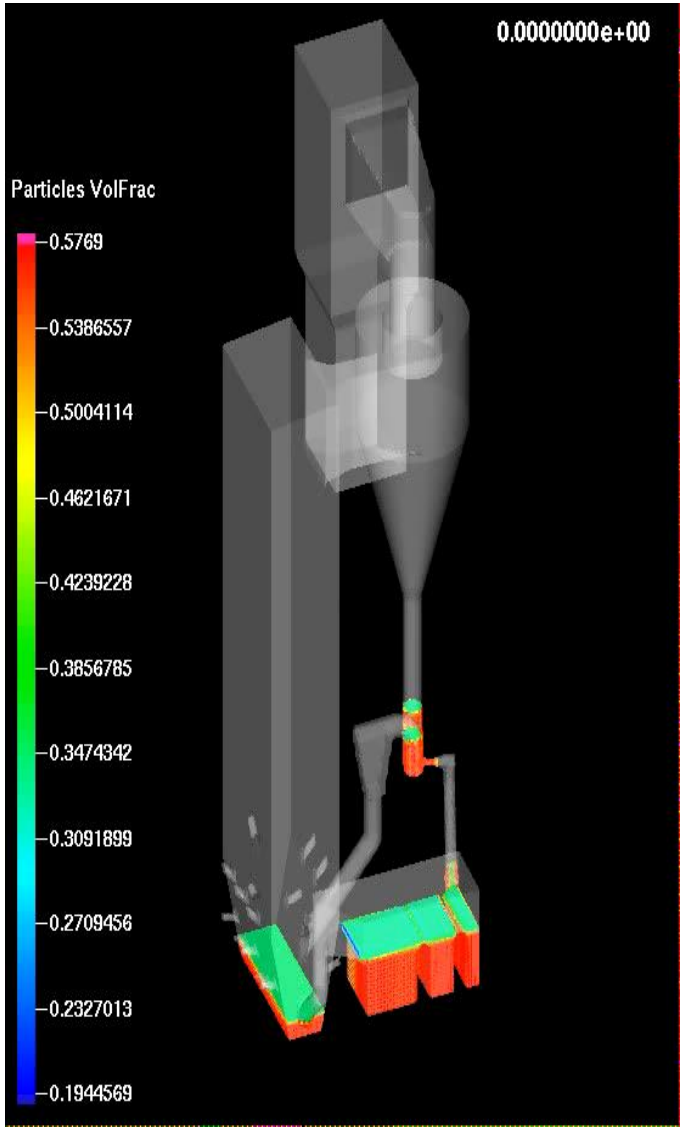
Solids volume fraction (-)

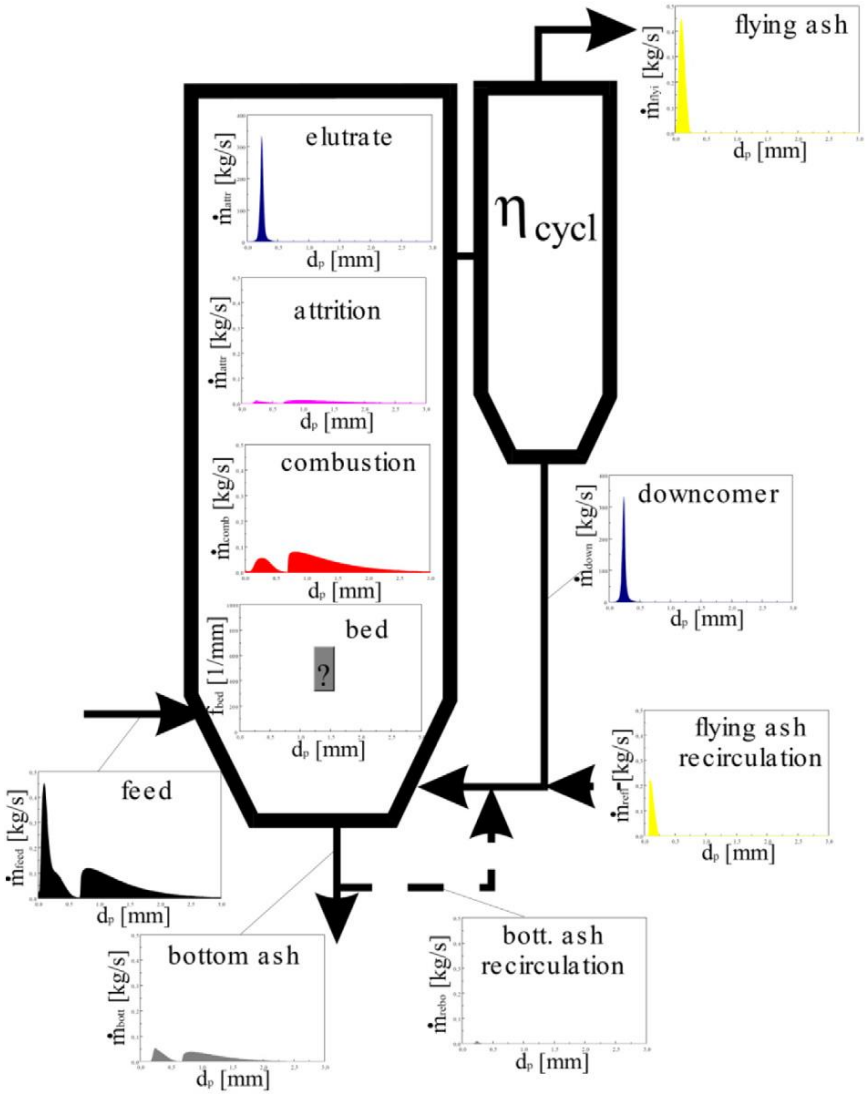
Gas composition (CO_2, mass fraction)

Gas composition (O_2, mass fraction)

Oxy combustion of 2 MW_e CFB Boiler (FEP CRC)

Correct problem definitions of CFB boiler simulations





Topology of 966MW$_{th}$ supercritical CFB boiler

Ref. : 3D simulation of a commercial CFB boiler (KITECH, Seentec)

Ref. :Hotta et. al, Experience of Estonian oil shale combustion based on CFB technology at Narva Power Plants. Oil Shale, 2005, 22(4S), pp. 381–398.

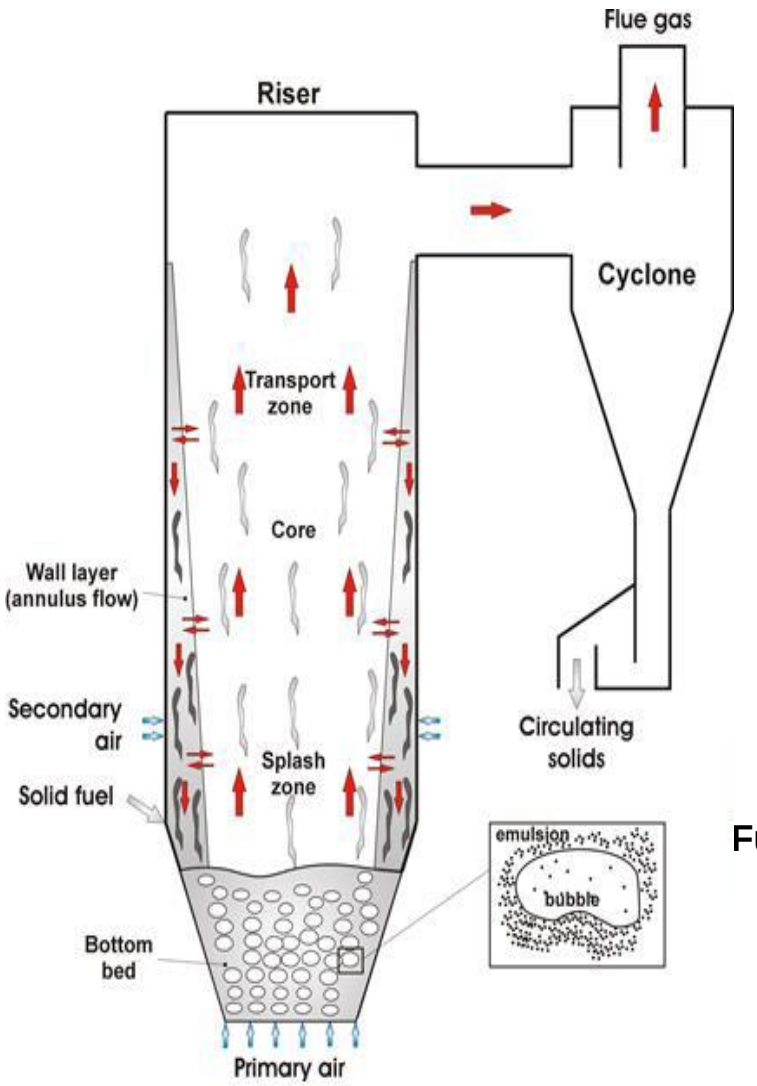
Best practices for effective modeling with Barracuda

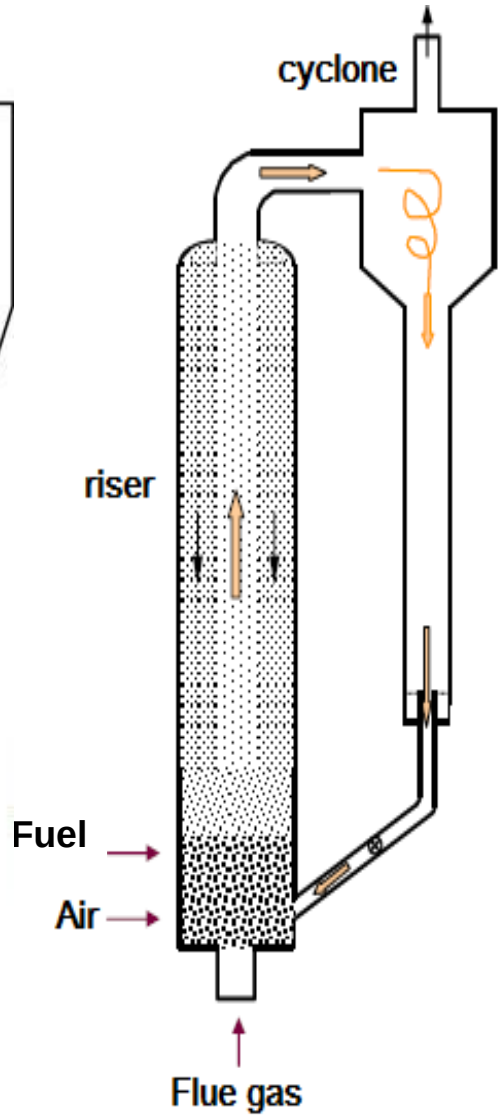
#	Tips	Details
1	Know expected fluidization	Check the Geldart particle classification and Flow regime
2	Use available data to improve particle characterization	Verify that the particle specifications are consistent with experimental data • PSD and d_{32} • Sphericity, ϕ • Close-pack particle volume fraction, εmf
3	Verify the bed mass	• history.log contains a more complete inventory of solids than the estimate from pressure drop • Understand the bed mass estimate • Place transient data points for pressure in the model to compare simulated pressure drop with Operation
4	Use a Mass and Energy balance	Mass and energy balances are important when system contains any of the following: • Complex reaction scheme / Inexact components (i.e. biomass, coal, etc) • Strongly exothermic / endothermic reactions • Verify that reactant feeds and reaction scheme can produce expected gas composition under any conditions • Inform assumptions about material thermal properties such as heat of formation and heat capacity • Determine whether any significant reactions, heat losses, inputs are missing
5	Use cyclone inlet pressure to control vessel Pressure	• Place a transient data point for pressure at the location where vessel pressure is measured. • Use SFF file for pressure BC. Initially set BC pressure to vessel pressure. • Periodically update SFF file to minimize difference btw simulated vessel pressure & target vessel pressure • Reread BC's through Interact
6	…	…..

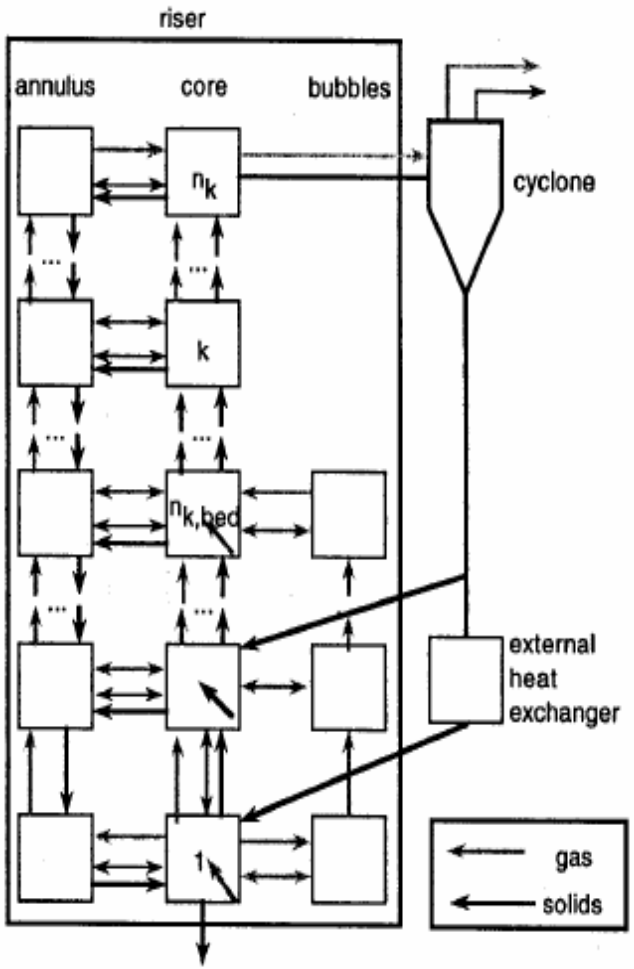
Ref. :Advanced Best Practices: Effective Modeling with Barracuda VR 2015 CPFD user's conference

- **Total amount of solid in the boiler**
- **Types and properties of particles in the boiler**
- **Size distribution of each particle**
- **What is the axial solid volume fraction in the boiler?**
- **How much solid is circulating in the boiler?**
- **What is the change in solid retention in the boiler due to load changes?**
- **How much solid is coming down in the annulus region in the boiler?**
- **Can you predict the change in the properties of solids due to the change in boiler operation time?**
- **Can you predict the boiler's performance for fuel changes?**

Characteristic flow pattern in a CFB boiler



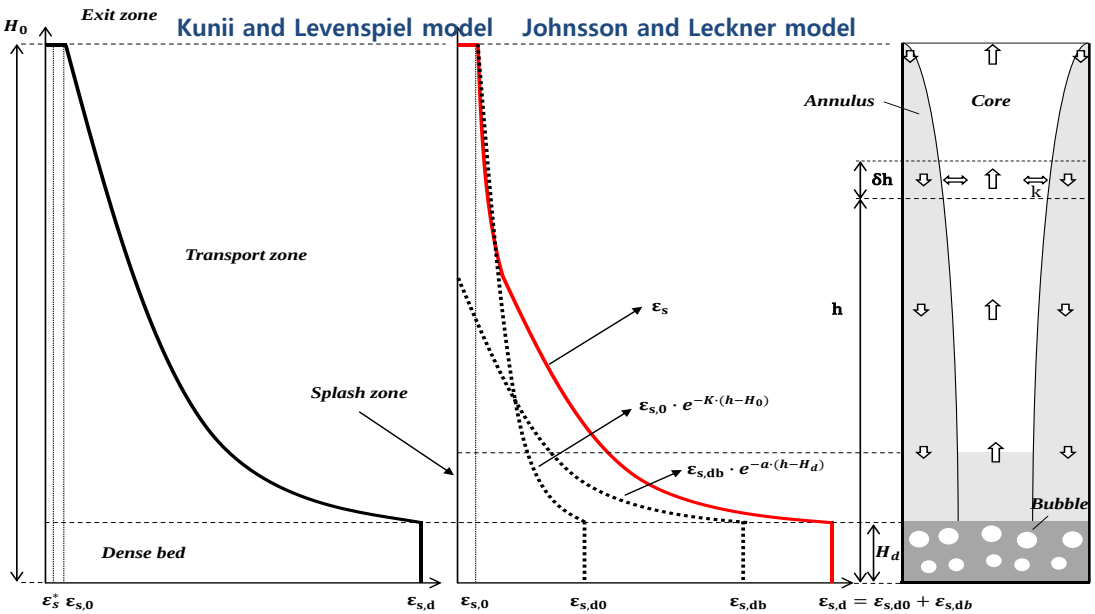


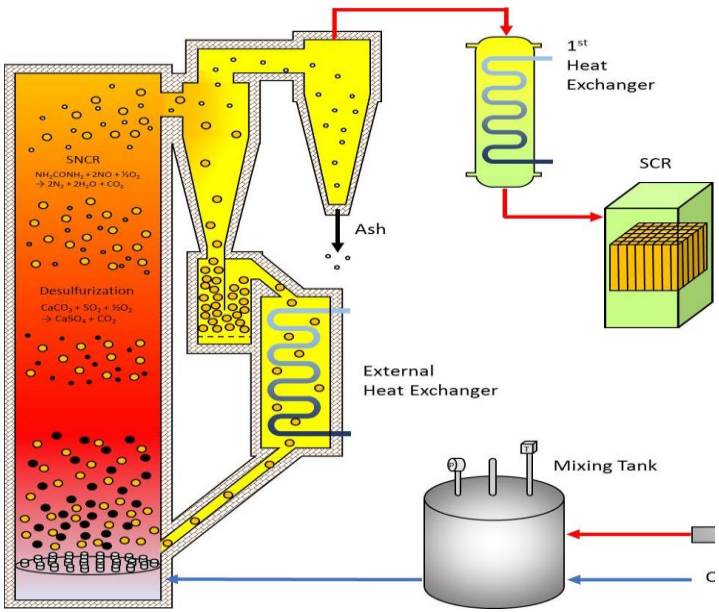


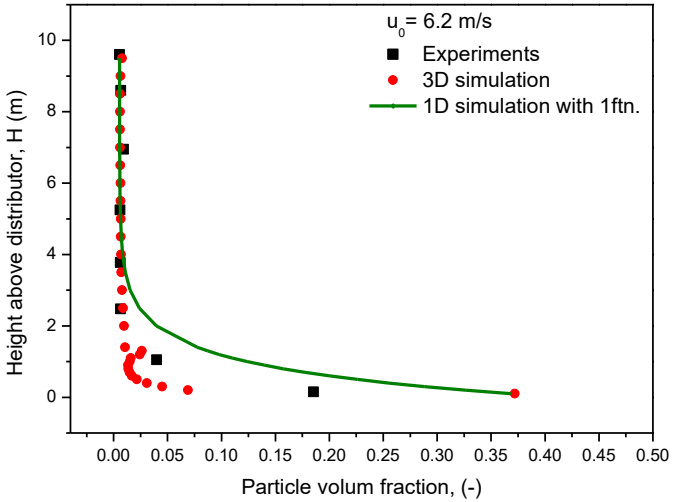
Ref. : A. Blaszczuk et al. / Powder Technology 246 (2013) 317–326

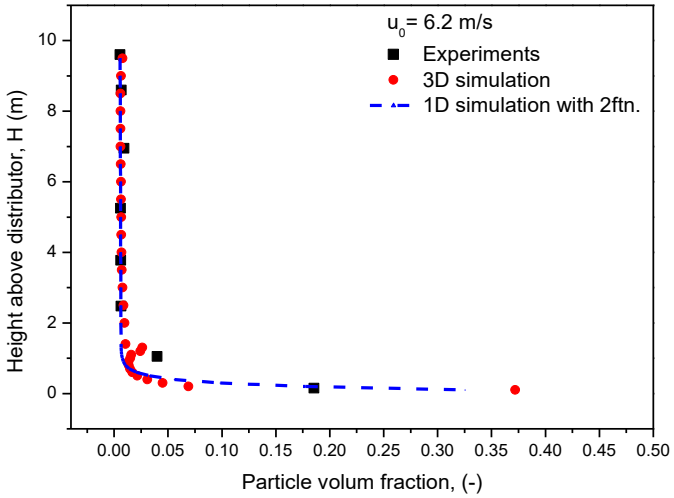
Ref: Hannes J, Mathematical modelling of circulating fluidized bed combustion, Thesis, University of Delft (1998)

Estimations of axial solid volume fraction in a riser



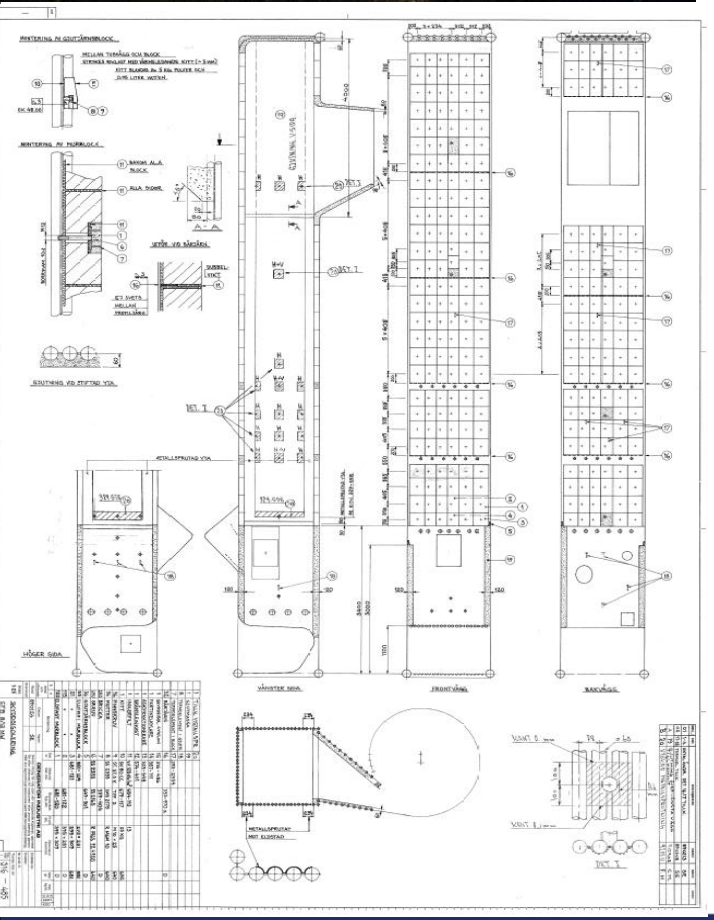


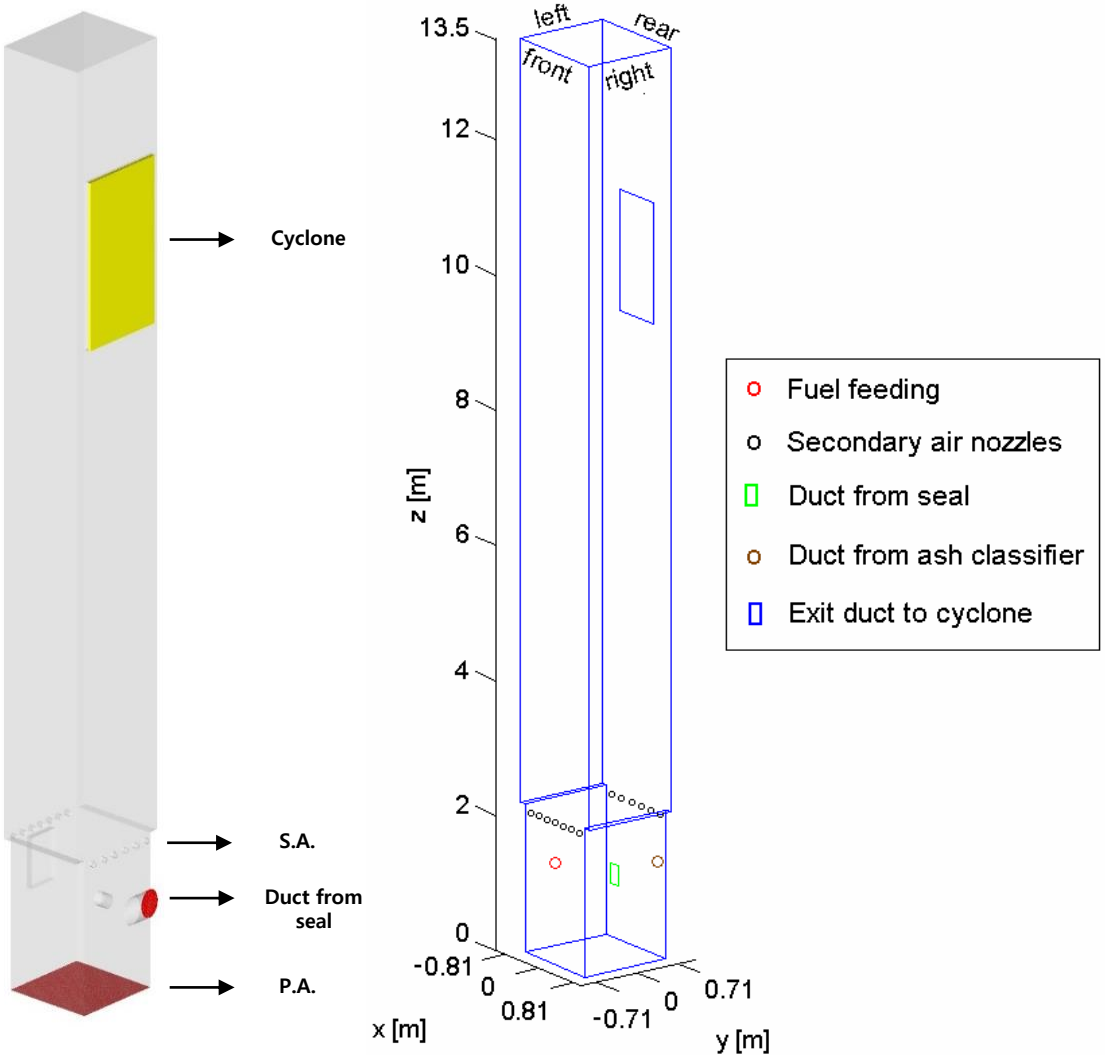




Ref: C Yang, J Jeong, Y Kim, B Bang, U Lee, Powder Technology 393, (2021) 786-795

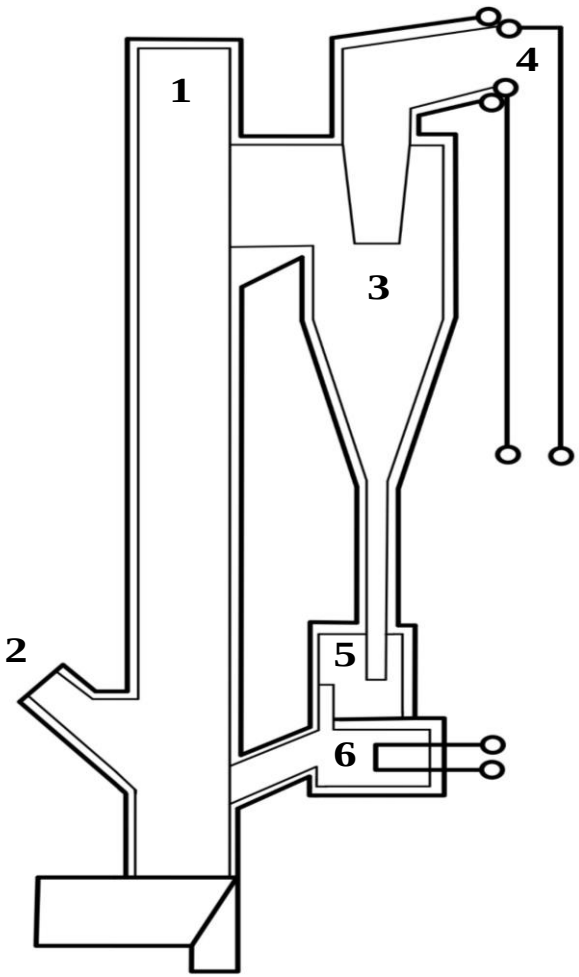
12MW$_{th}$ CFB boiler of Chalmers Univ. of Tech.





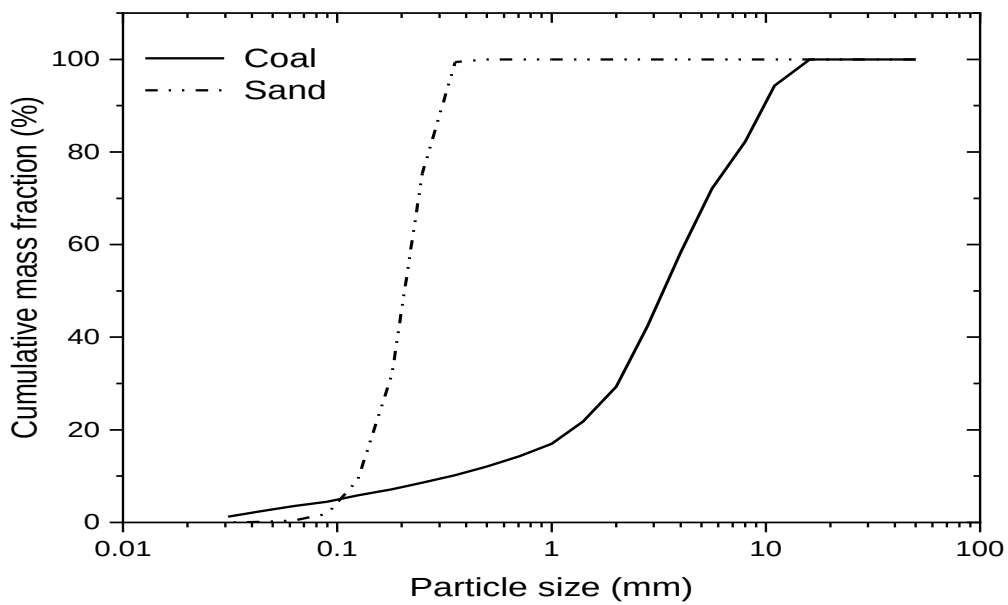
Chalmers Boiler geometry

Operating conditions of the CUT 12MW$_{th}$ CFB boiler



Schematic of the CUT 12MW$_{th}$ CFB boiler

Coal feeding rate (kg/s)	0.27
Primary air (Nm^3/h)	2.26
Secondary air (Nm^3/h)	none
Superficial velocity (m/s)	4.7
Pressure drop (Pa)	9,500
The average diameter of coal particle (mm)	0.79
The average diameter of sand particle (mm)	0.22



Initial particle size distribution of coal and sand

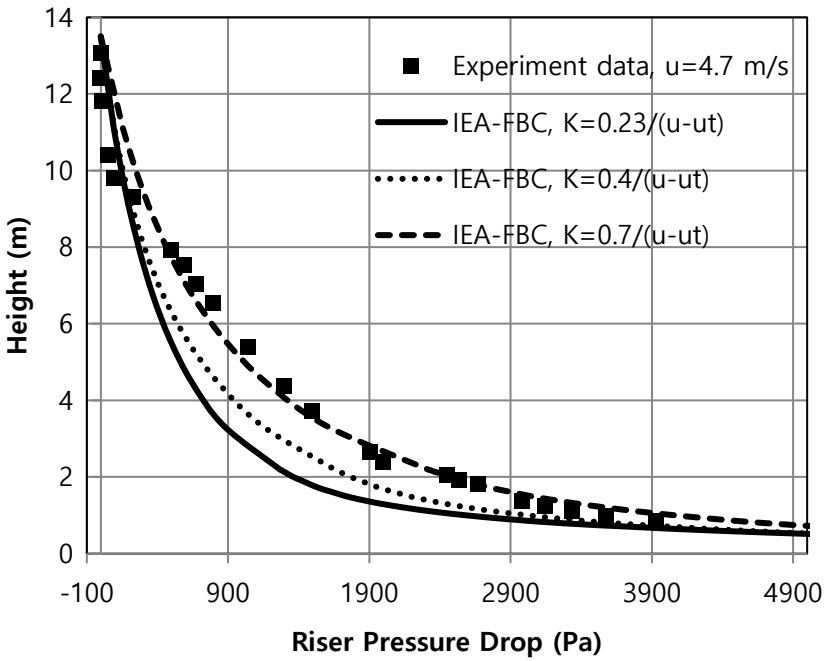
1D simulation results (Whole sample PSD profile)

- The 1D simulation was conducted with varying decay constant 'K'.

Operating conditions	Run 1*
Coal feeding rate (kg/s)	0.2722
Primary air (Nm^3/h)	2.255
Secondary air (Nm^3/h)	-
Superficial velocity (m/s)	4.7
Pressure drop, Pa	9,500
Particle mean diameter, mm	0.32

*Johnsson and Leckner, 1995

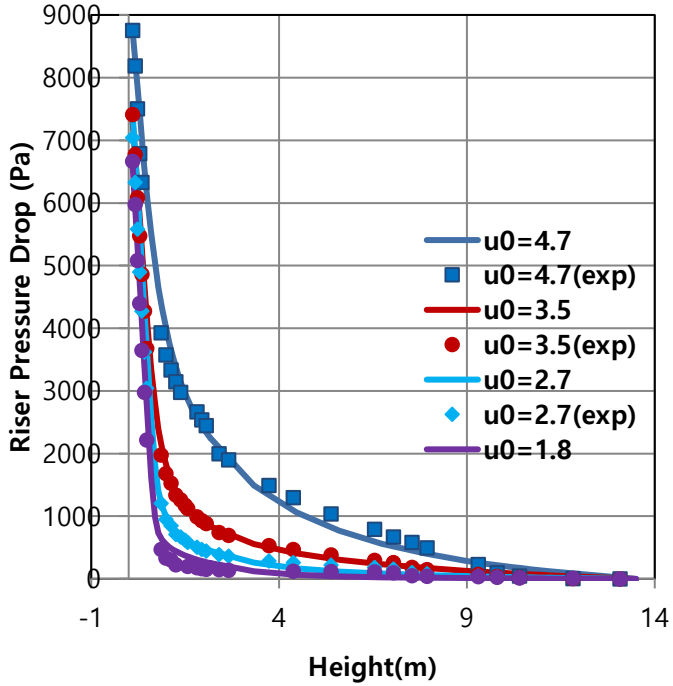
Operating conditions of the Chalmers CFB boiler



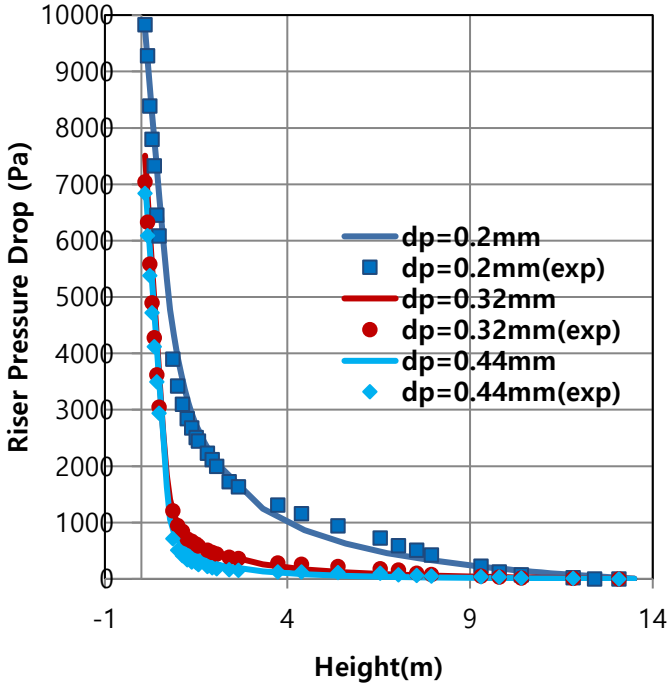
Improvement of 1D simulation with two decay functions

<Chalmers CFB boiler(12 MW_{th})> Comparison of 1-D simulation with experimental value

1) Different gas velocity(mean particle size : 0.32 mm)



2) Different particle size (gas velocity : 2.7 m/s)



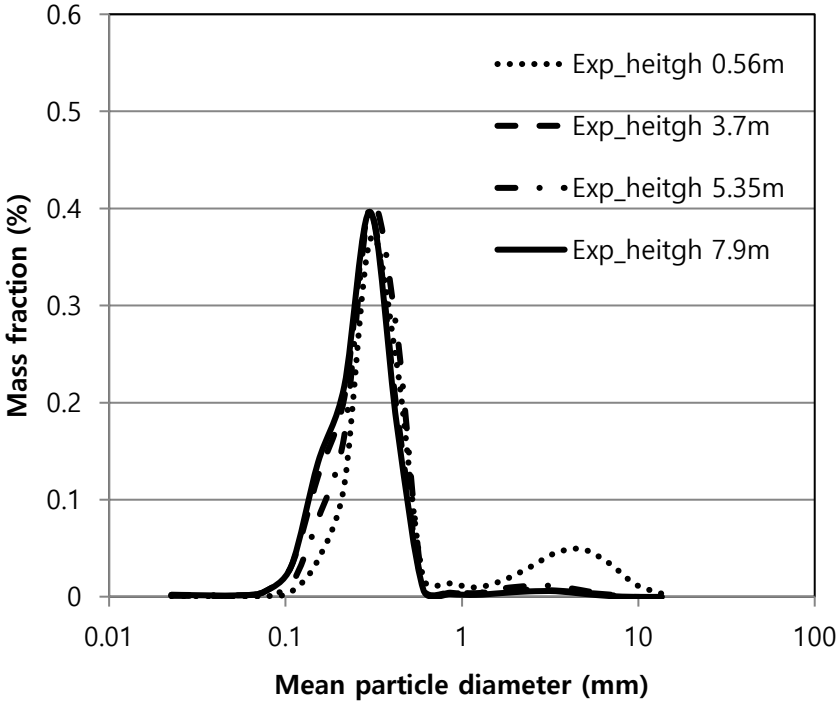
- Calculation condition

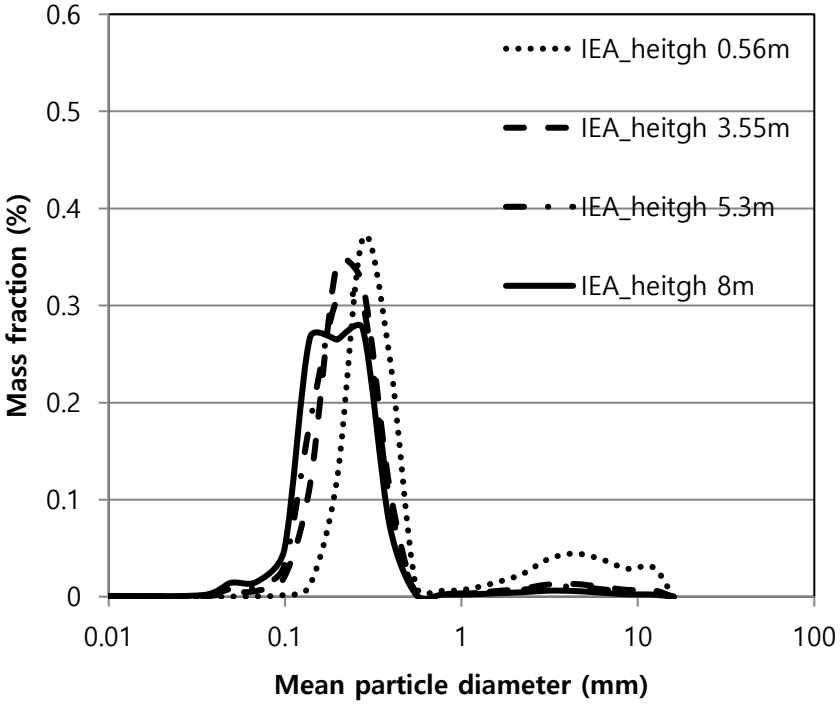
Gas velocity(m/s)	4.7	3.5	2.7	1.8
Riser pressure drop(Pa)	9500	8200	8500	7700
a	4	4	8	12
K	0.7	0.15	0.23	0.023
Feed inert(kg/s)	0.05	0.06	0.09	0.09

Mean particle size(mm)	0.2	0.32	0.44
Riser pressure drop(Pa)	10500	8500	8000
a	4.5	8	12
K	0.23	0.23	0.023
Feed inert(kg/s)	0.05	0.09	0.05

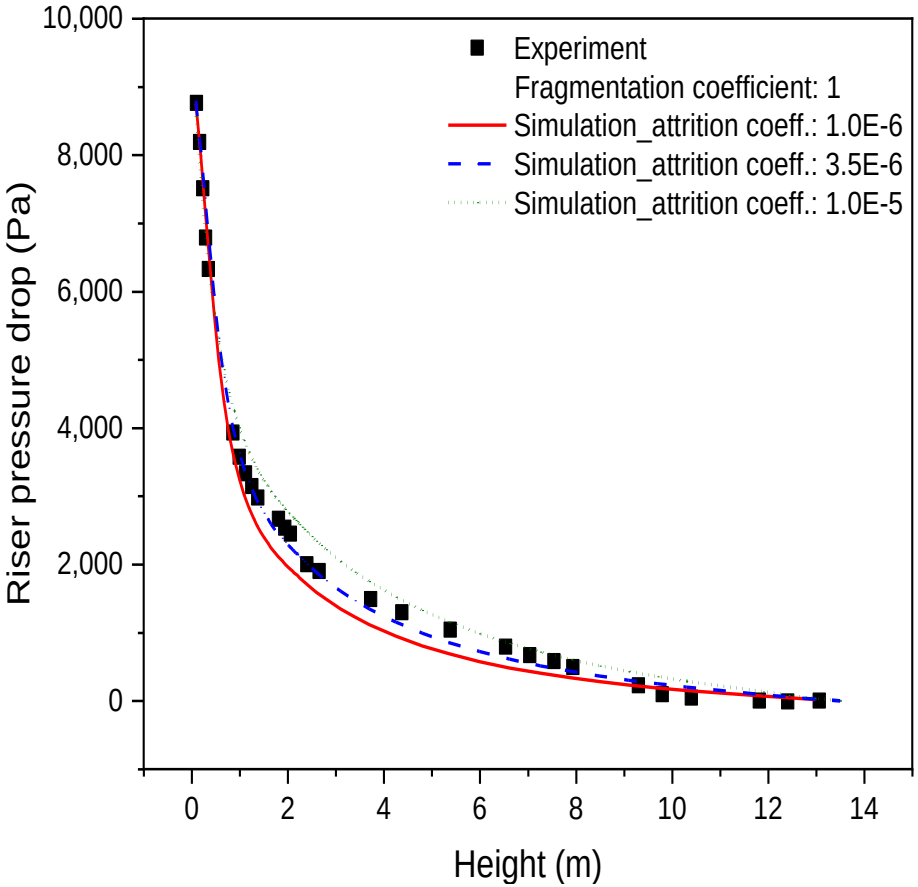
1D simulation results (Whole sample PSD profile)

- The whole PSD (char + sand) profiles in CTH have a almost same peak and the peaks are shifted toward fine particle sizes with increasing furnace height.
- In the 1D results, these peaks also are shifted to fine particle sizes and the mean particle diameter has changed along the height.

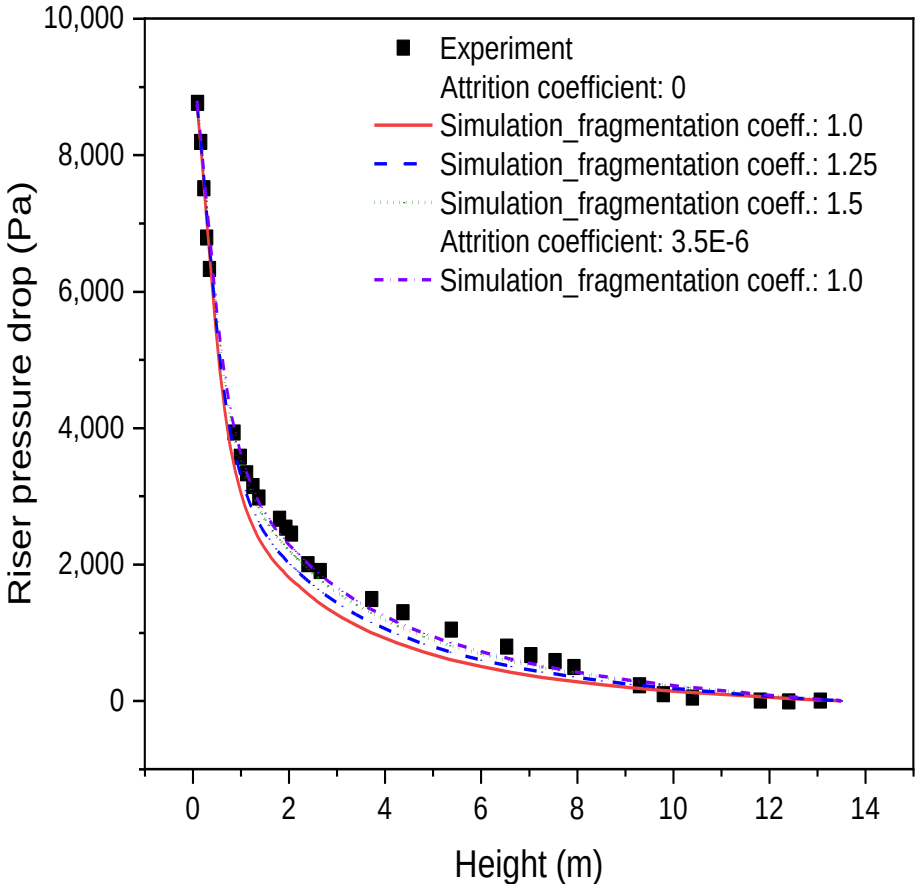




Comparison of axial pressure profile between experiments and 1D simulation results

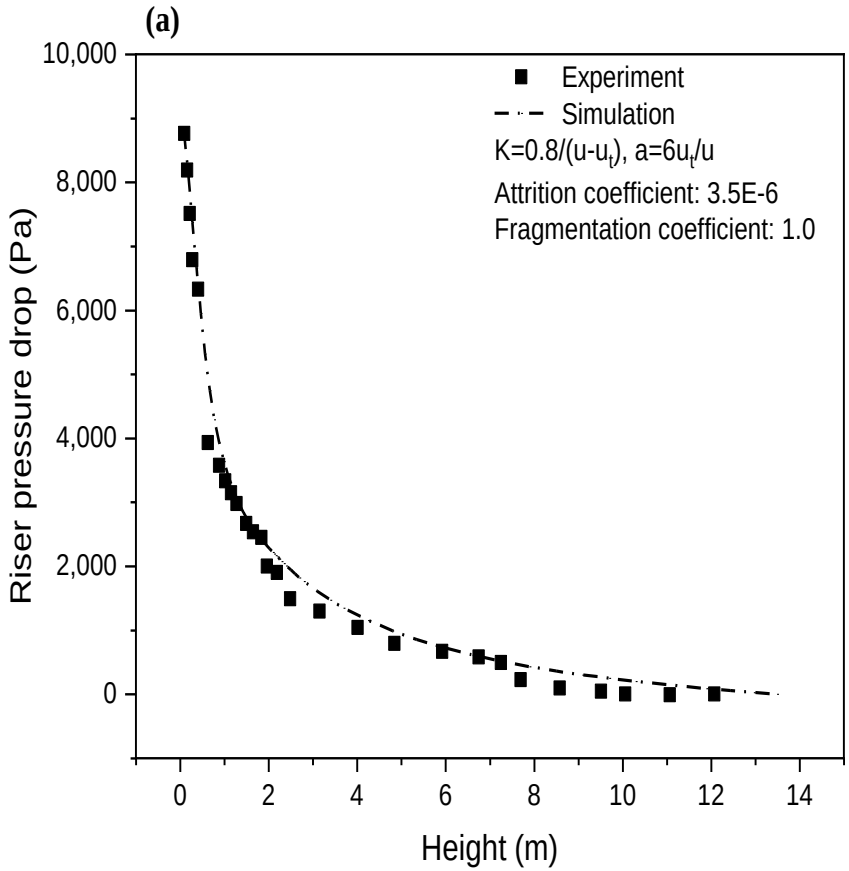


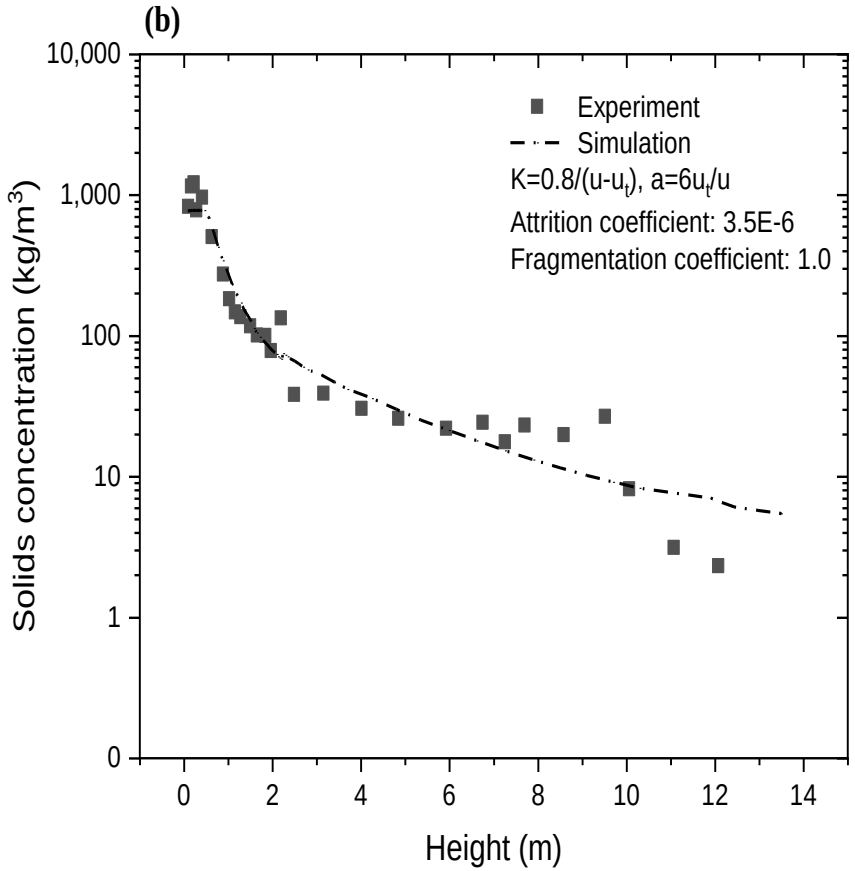
Effects of sand attrition coefficients



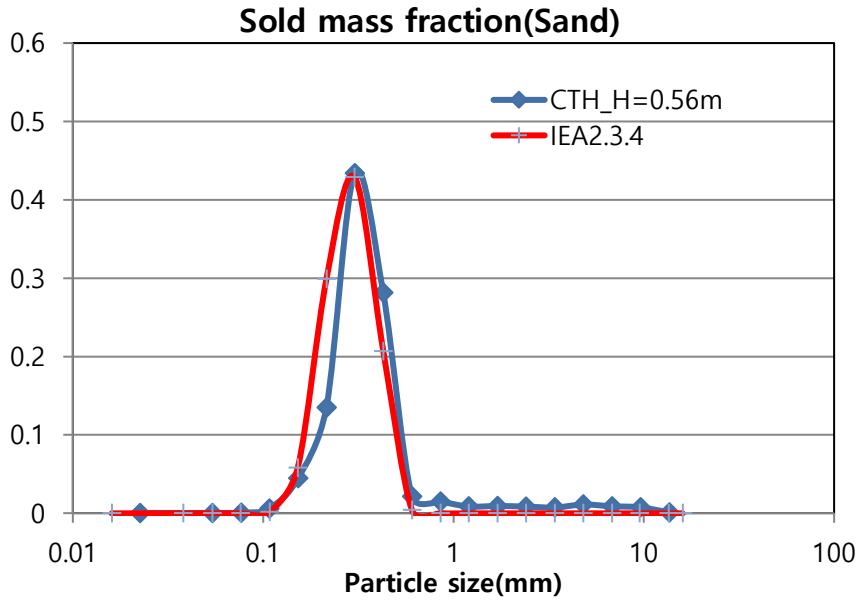
Effects of fuel fragmentation coefficients

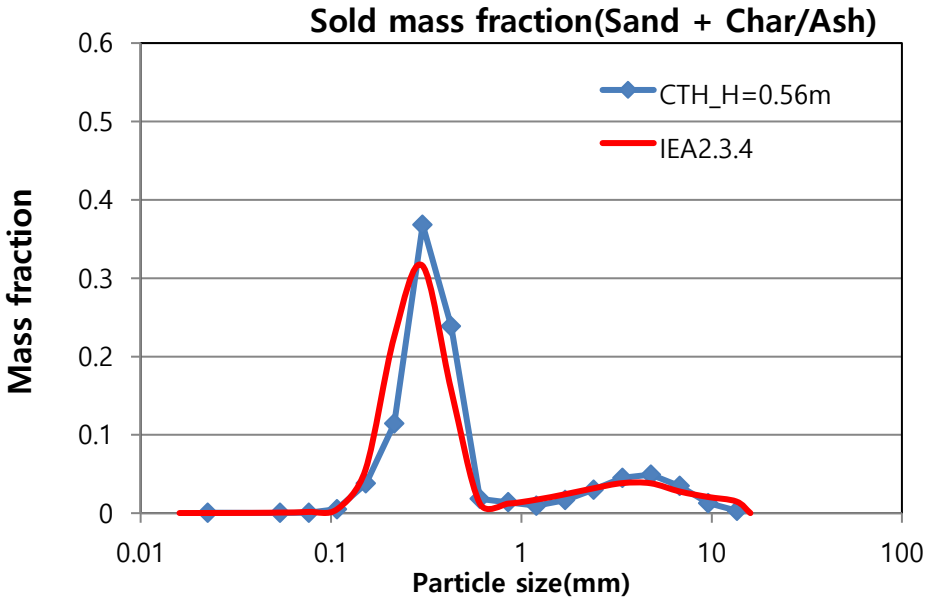
Distribution of axial pressure drop (a) and solids concentration (b) along the height

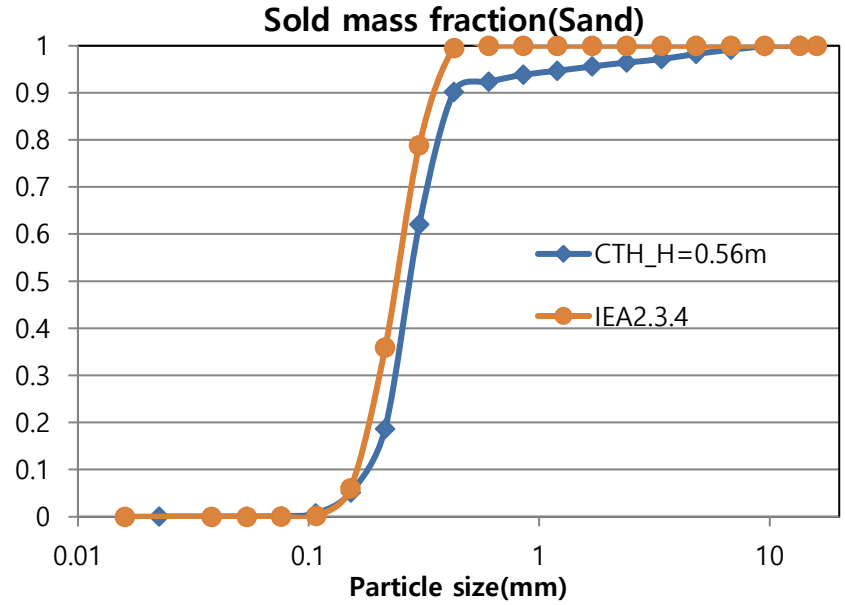


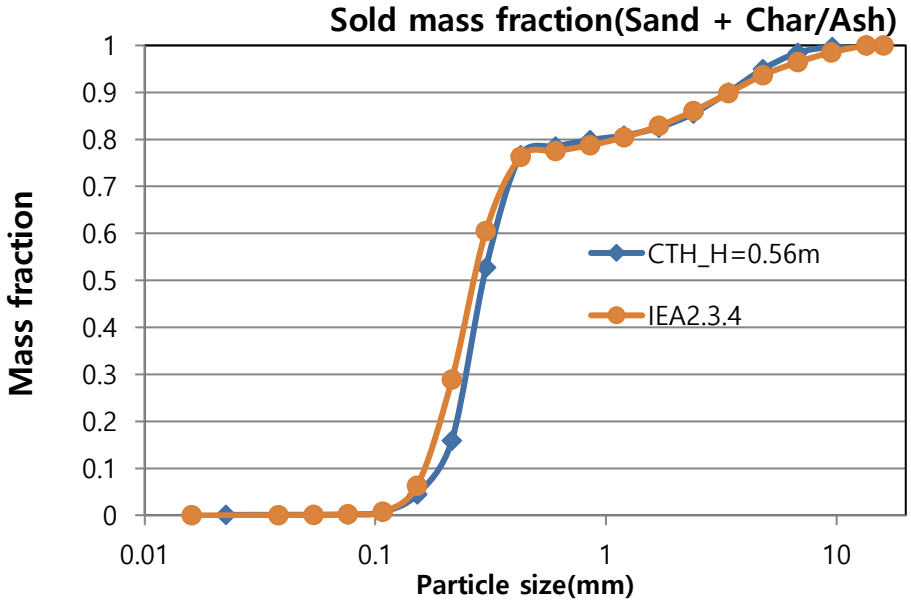


PSD of inert (silica sand only) and whole bed materials

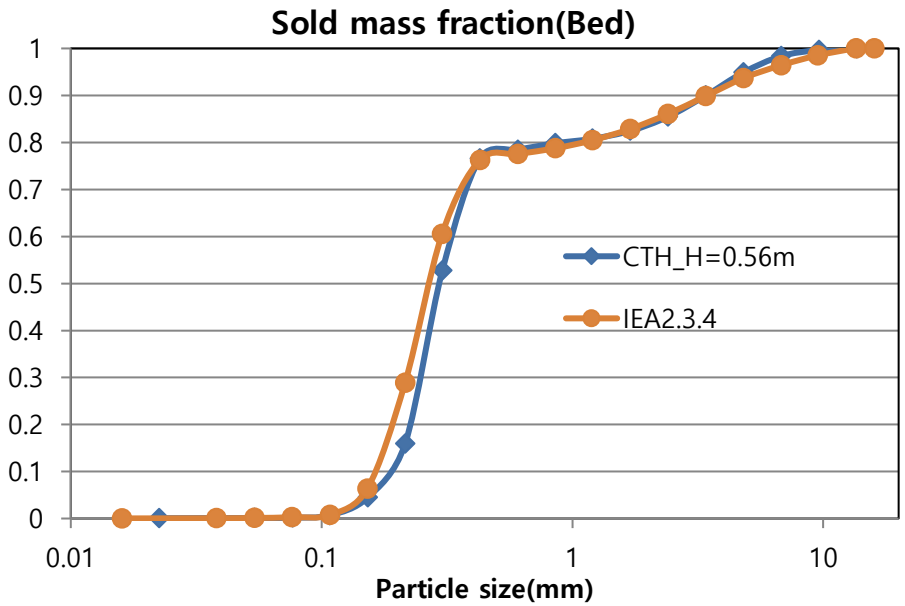


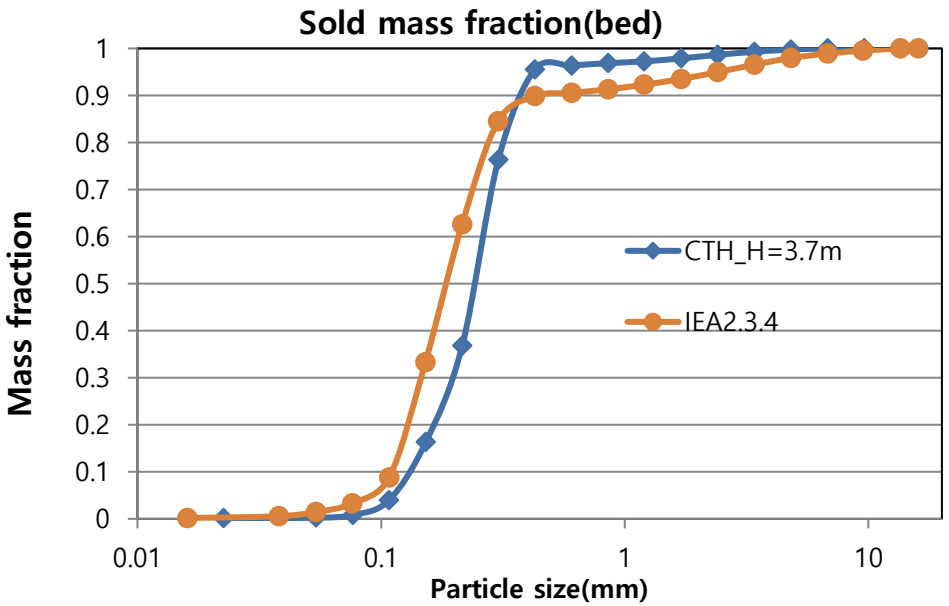


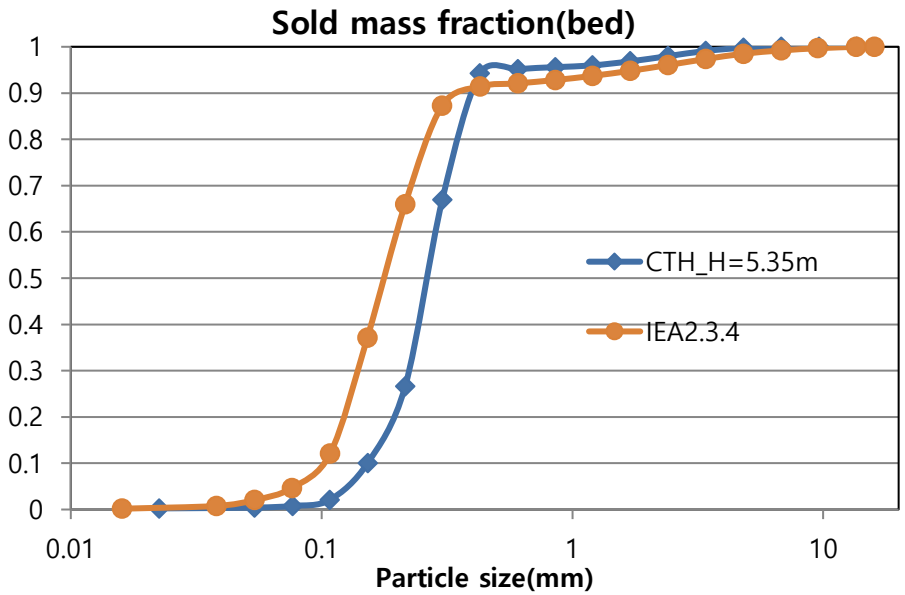


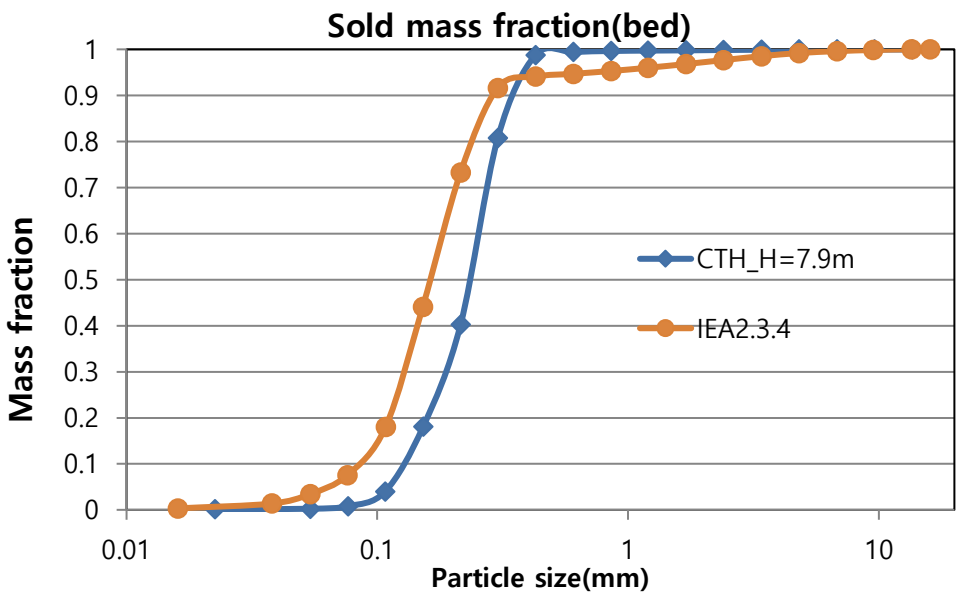


Change of PSD along with the height of the riser

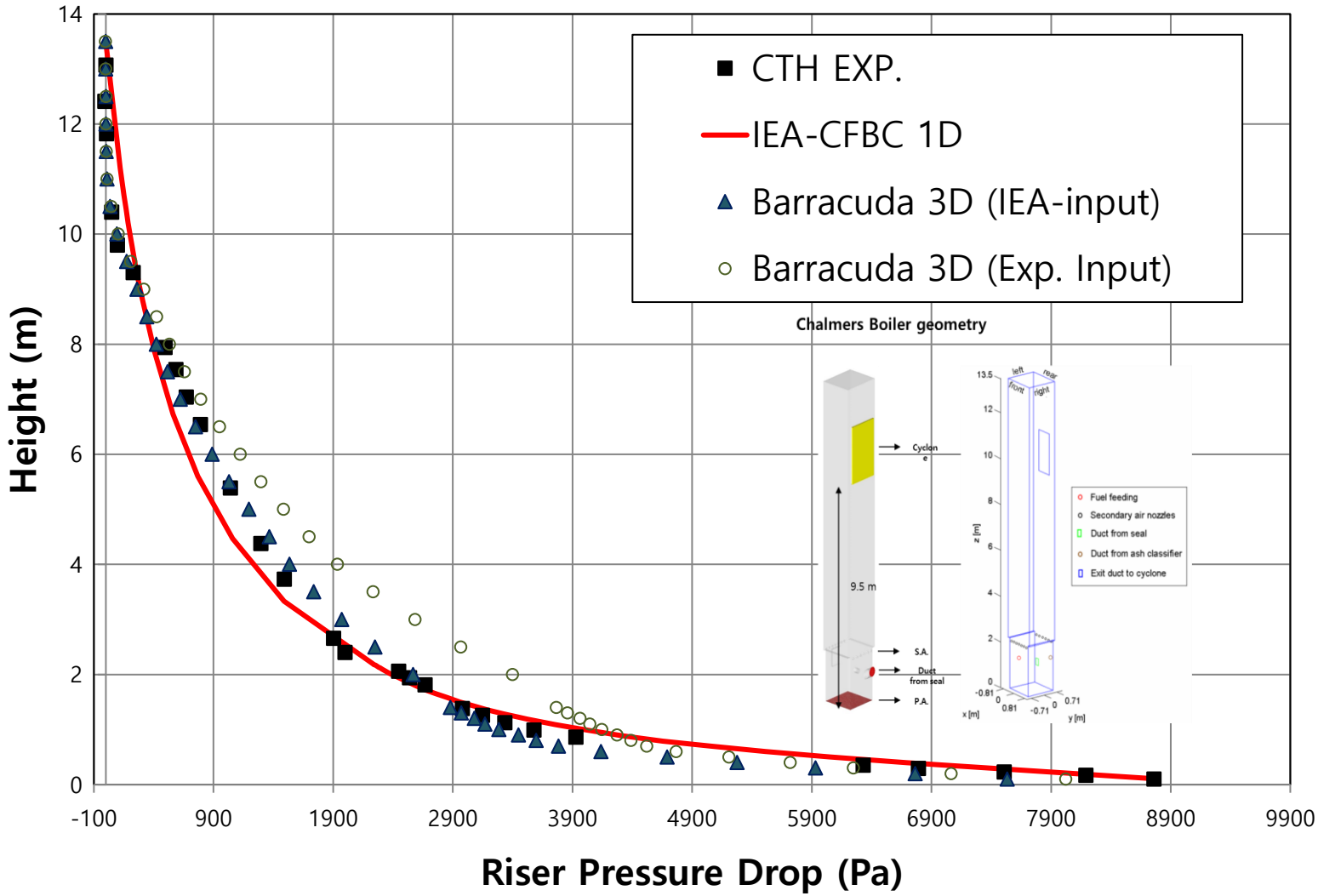






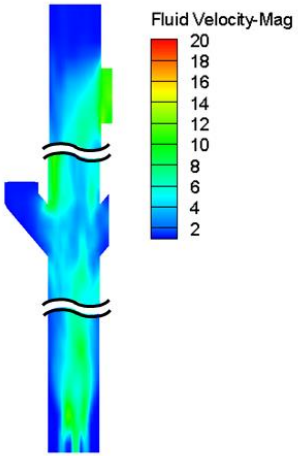


Axial pressure drop of Chalmers boiler (Experiments, 3D CFD results with different inputs)

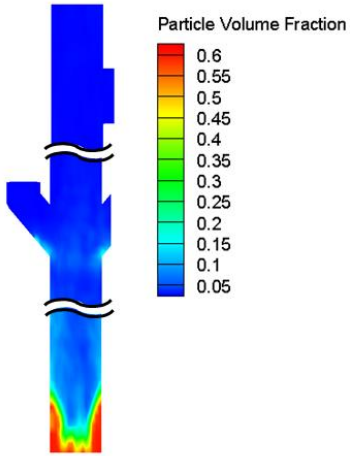


0.1 MW_{th} test-rig simulation results

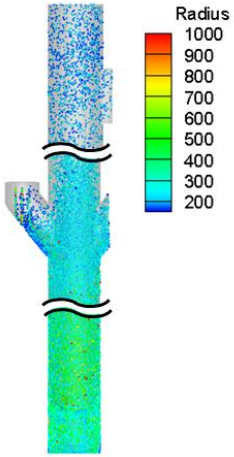
❖ Result – Hydrodynamic characteristics



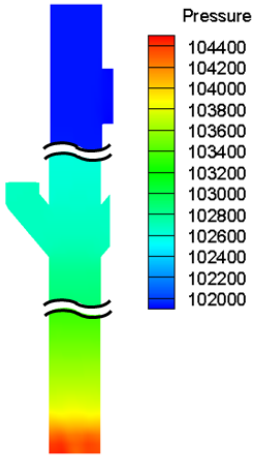
< Fluid velocity contour (m/s) >



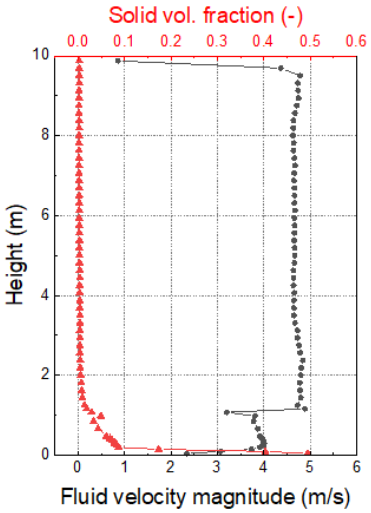
< Solid volume fraction contour >



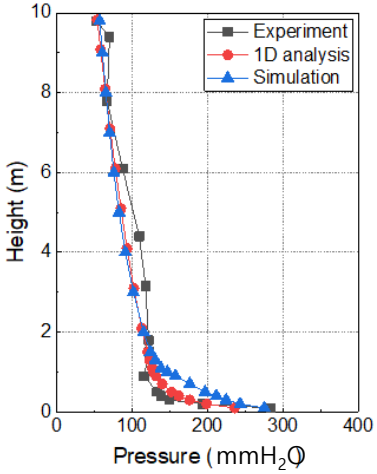
< Particle size (radius) contour (μm) >



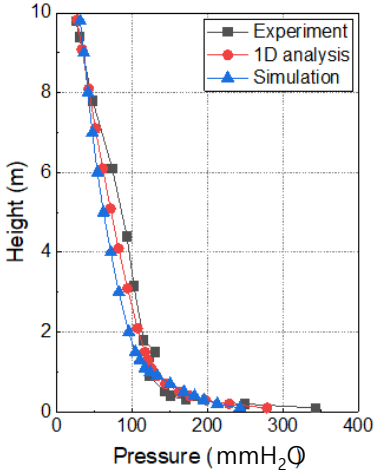
< Fluid pressure contour (Pa) >



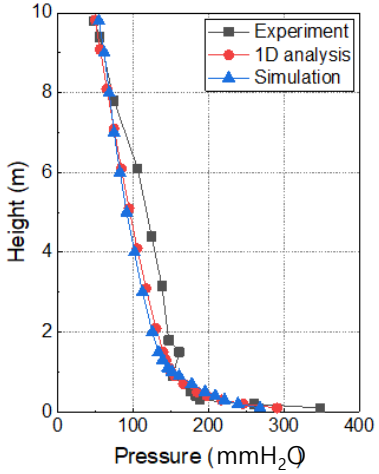
< Fluid velocity & Solid vol. fraction >



< Pressure profile (oxy-40%) >



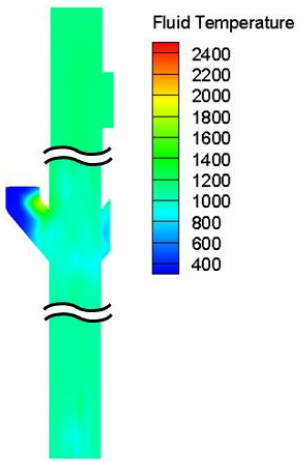
< Pressure profile (oxy-50%) >



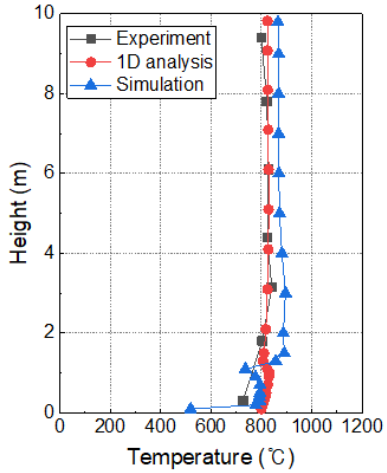
< Pressure profile (oxy-60%) >

0.1 MW_{th} test-rig simulation results

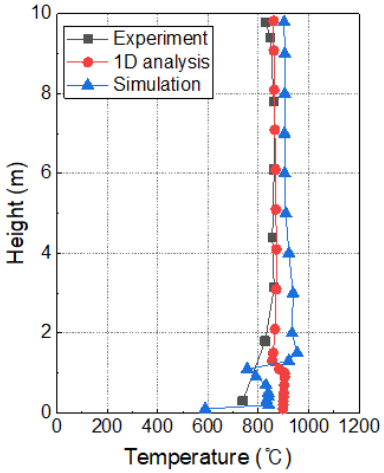
❖ Result – Temperature & combustion gas compositions



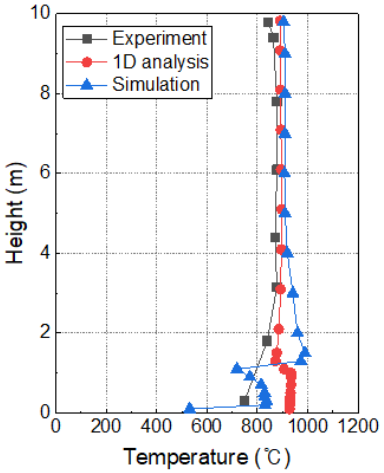
< Fluid temperature contour (K) >



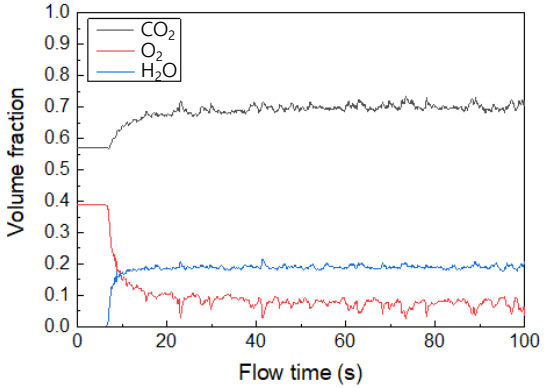
< Temperature profile (oxy-40%) >



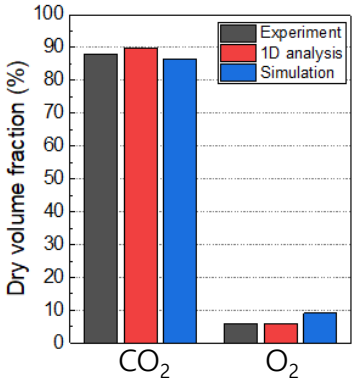
< Temperature profile (oxy-50%) >



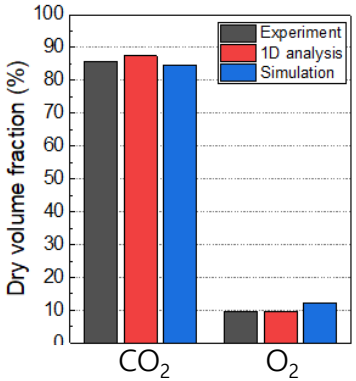
< Temperature profile (oxy-60%) >



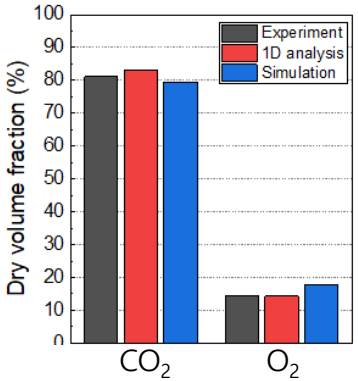
< Flue gas compositions through flow time >



< Flue gas compositions (oxy-40%) >

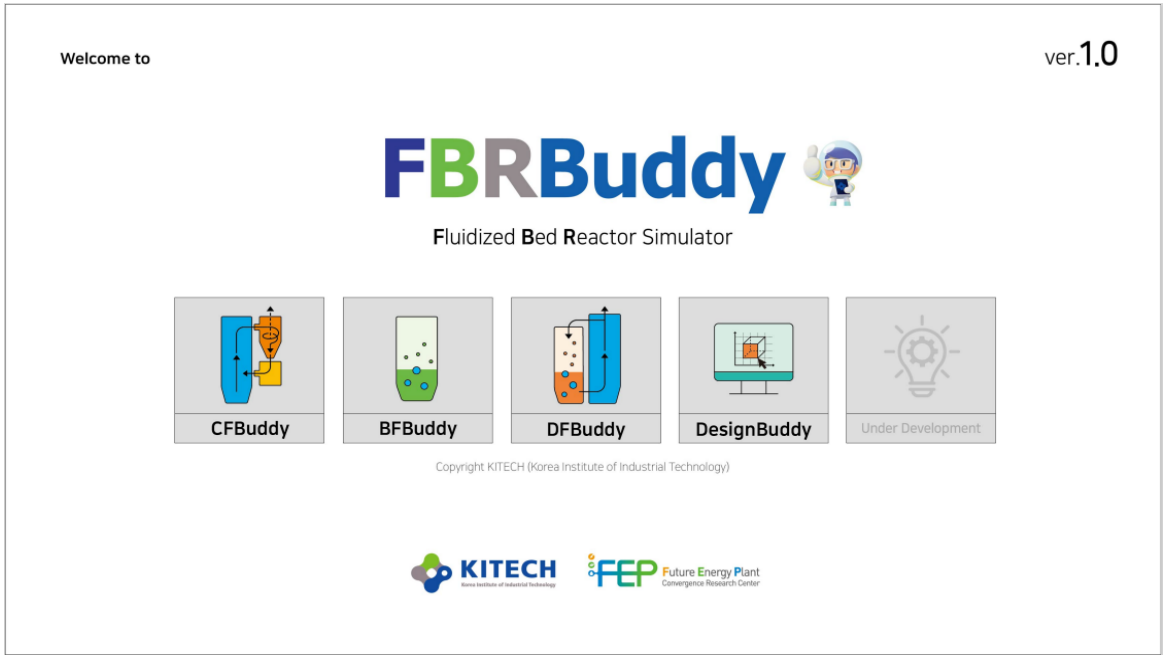


< Flue gas compositions (oxy-50%) >

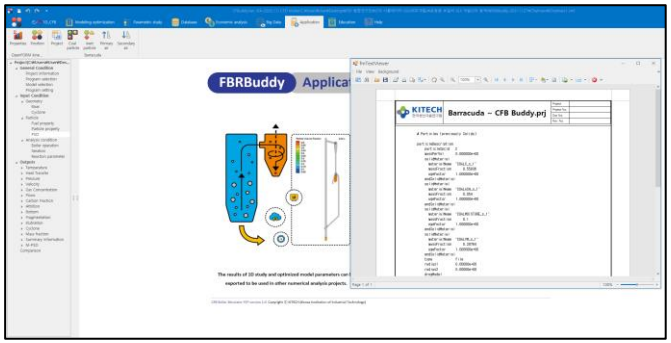


< Flue gas compositions (oxy-60%) >

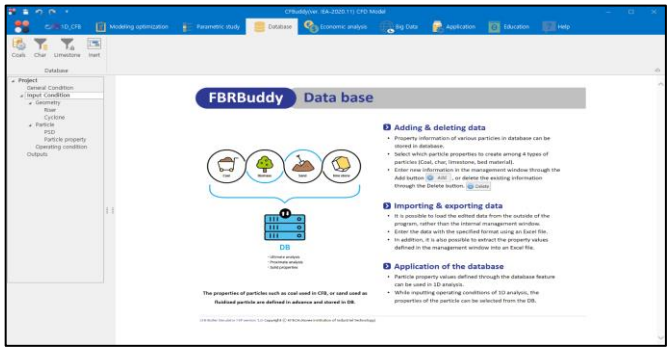
Comprehensive fluidized bed simulation SW



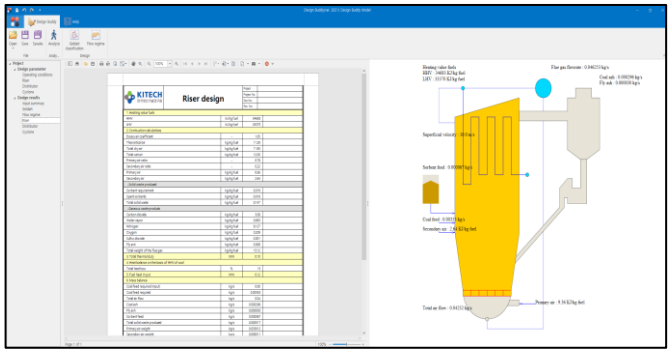
Operating conditions and pre-calculation



Fuel Data Base Management

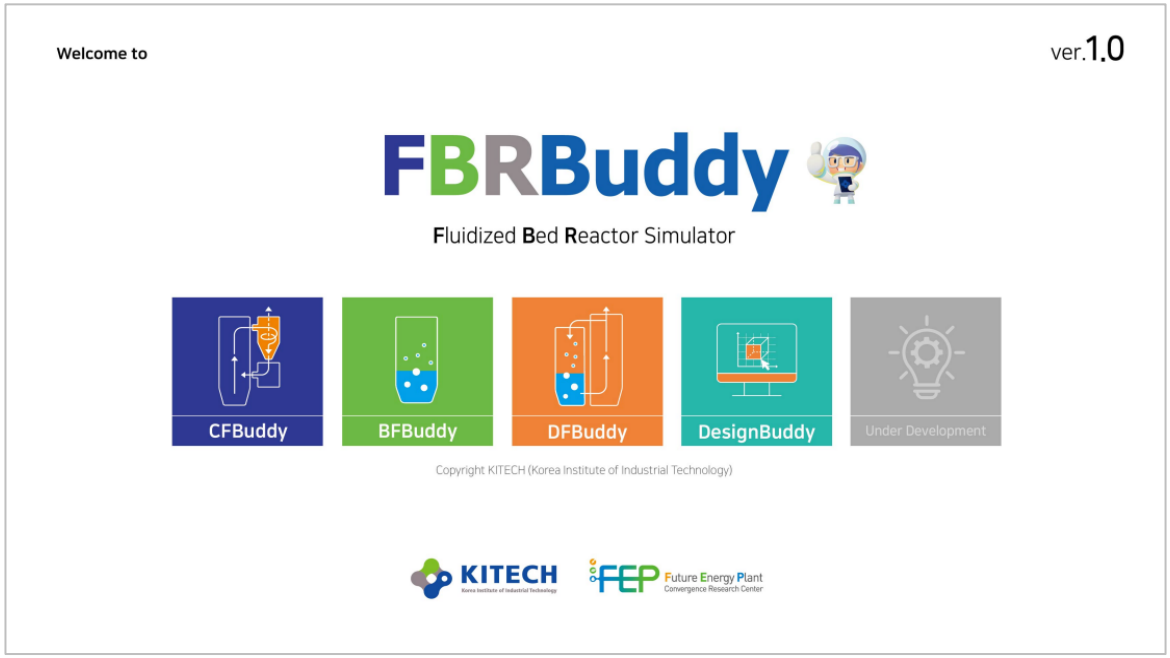


Derivation of reactor design data

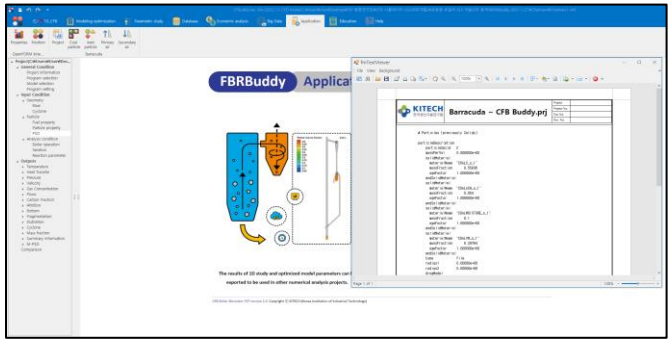


- **CFBuddy: Numerical simulation of CFB reactors**
- **BFBuddy/DFBuddy: Numerical simulation of BFB and DFB reactors**
- **DesignBuddy: Conceptual design of a fluidized bed**

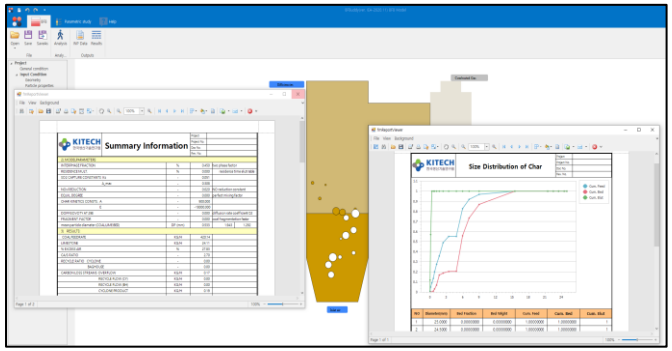
Comprehensive fluidized bed simulation SW



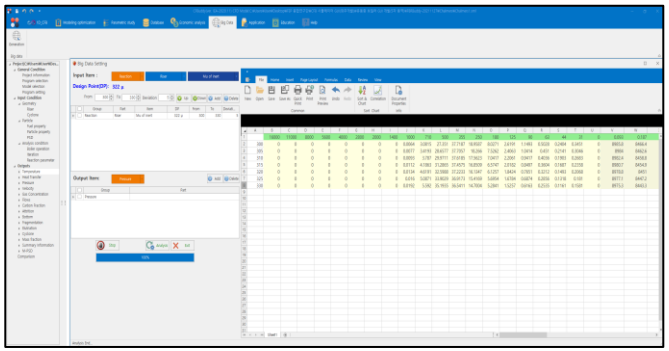
Problem definition for a 3D simulation (Barracuda/OpenFoam)



Numerical simulation of a BFB reactor

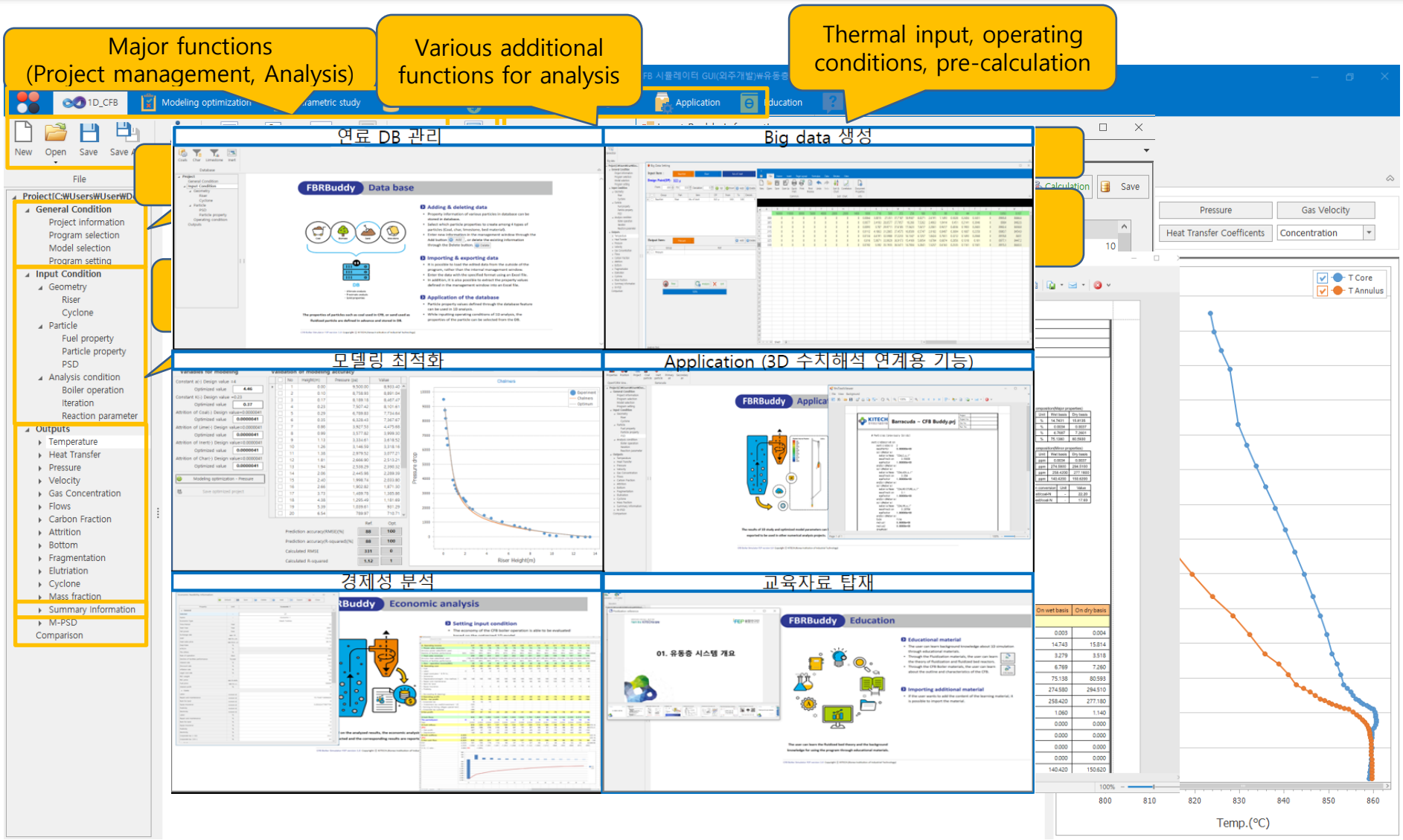


Big data generation and management



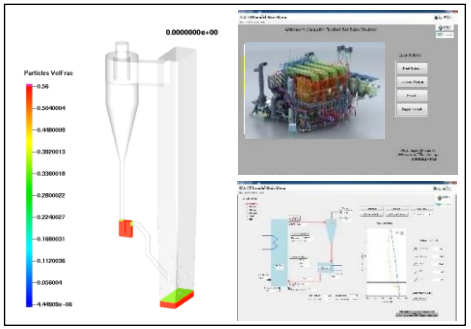
- **CFBuddy: Numerical simulation of CFB reactors**
- **BFBuddy/DFBuddy: Numerical simulation of BFB and DFB reactors**
- **DesignBuddy: Conceptual design of a fluidized bed**

Important features of CFBuddy

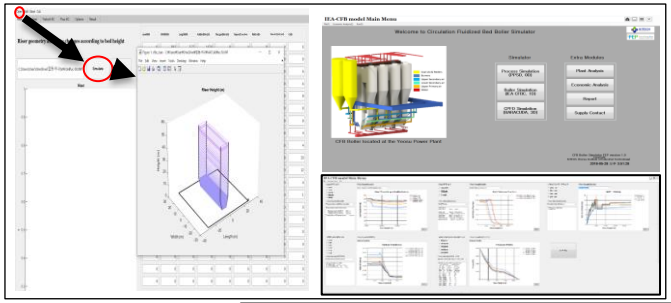


Prospects on using 1D simulation tool

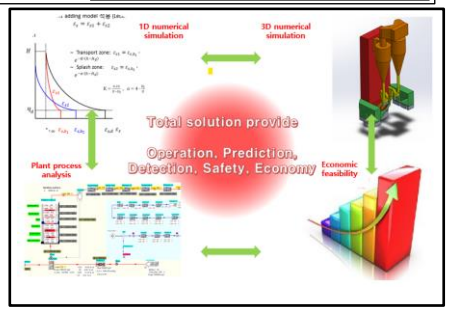
1. Interactive online CFB boiler manual based on CFD
   - Interactive guide for design and operation
   - Boiler performance check & improvement
   - Training of operator-linking with existing simulator
   - Smart boiler management system



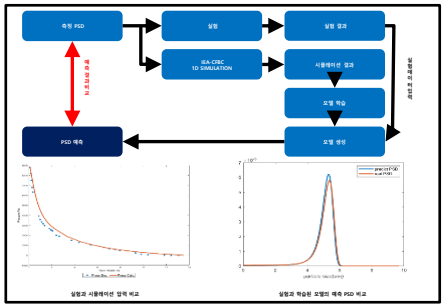
2. CFB boiler design S/W based on simulation
   - Conceptual/Basic design verification
   - Preliminary design for bidding



3. Operation support based on multidimensional simulation
   - 1D CFB simulator with GUI
   - 1D-3D CFD co-simulation for fluidized bed systems



4. Machine learning-based CFB boiler optimization
   - Big data generation
   - Correlation of big data from operation and CFD



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Thank you for your attention

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