Reactor type for CaO looping cycle – Bubbling bed or fast bed, that is the question –

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Reaction in the present process

CO_2 removal from flue gas by CaO

$CaO+CO_2 \rightarrow CaCO_3$ at 873K (P_{CO2}=0.004 atm)

Exothermic reaction → Steam generation

Regeneration of CaO from $CaCO_3$

$CaCO_3 \rightarrow CaO+CO_2$ at 1223K (P_{CO2}=1.9 atm)

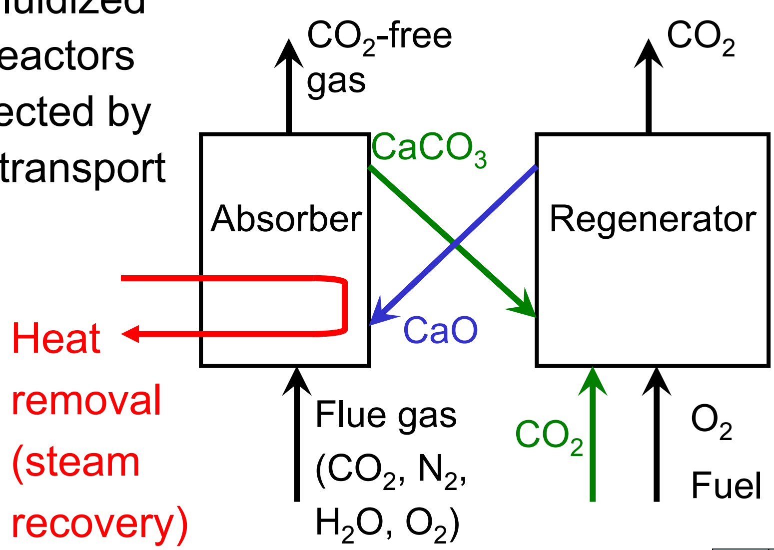
Endothermic reaction → Combustion of fuel by O_2

CaO and $CaCO_3$: solids

Two fluidized bed reactors connected by solid transport lines.

Carbonate looping cycle

Two fluidized bed reactors connected by solid transport lines.



Possible combination

Now we are planning to make an experimental apparatus of this process.

Both bubbling fluidized bed and "fast" fluidized bed are available for reactors. Four possible combinations are:

Carbonation reactor	Regenerator(Calciner)
Bubbling	Bubbling
Bubbling	Fast
Fast	Bubbling
Fast	Fast

Importance of heat removal

CO$_2$ removal from flue gas by CaO

$CaO+CO_2 \rightarrow CaCO_3$ at 873K (P_{CO2}=0.004 atm)

Exothermic reaction

→ Heat removal is necessary to maintain reactor temperature.

Often reactor size is determined not by reaction rate but by arrangement of heat transfer surface.

Heat removal scheme and required heat transfer surface area

Present system

Based on basic design by present authors
(Shimizu et al., Trans. Inst. Chem. Eng. , 77, 62, 1999).

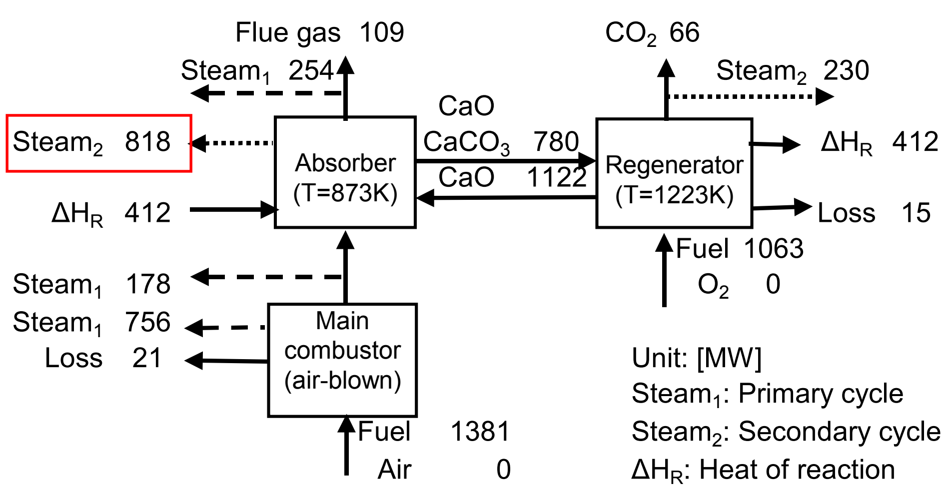
1000 MWe gross output (original concept)
→ 350 MWe gross (this work)

CaO circulation / captured CO_2 = 10

Subcritical steam from CO_2 capture process
(170 atm, 566^{o}C, with reheater)

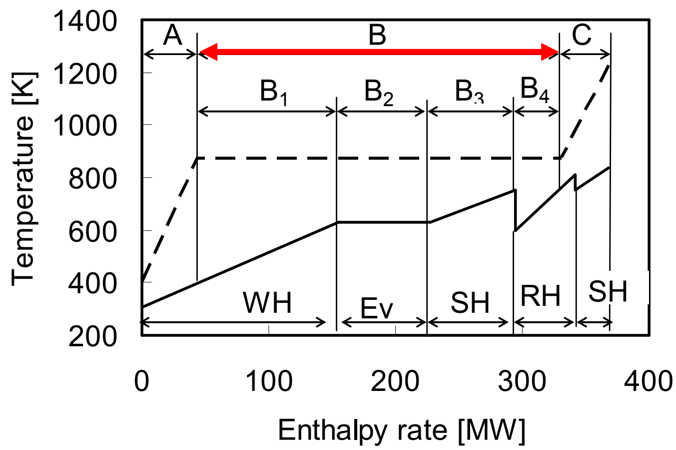
Heat balance for 1000 MWe(gross) system

Heat removal requirement is very severe.



Steam recovery from CO_2 capture

Heat source: Carbonation reactor (B) and hot CO_2 from regenerator (A and C). Estimation of heat transfer surface area is conducted.



Heat transfer surface design

	Bubbling	Fast
Heat transfer surface	tube	flat panel
Bed-surface HT coeff.	258 W/m^2K	250 W/m^2K
Gas velocity	1.38 m/s	6 m/s

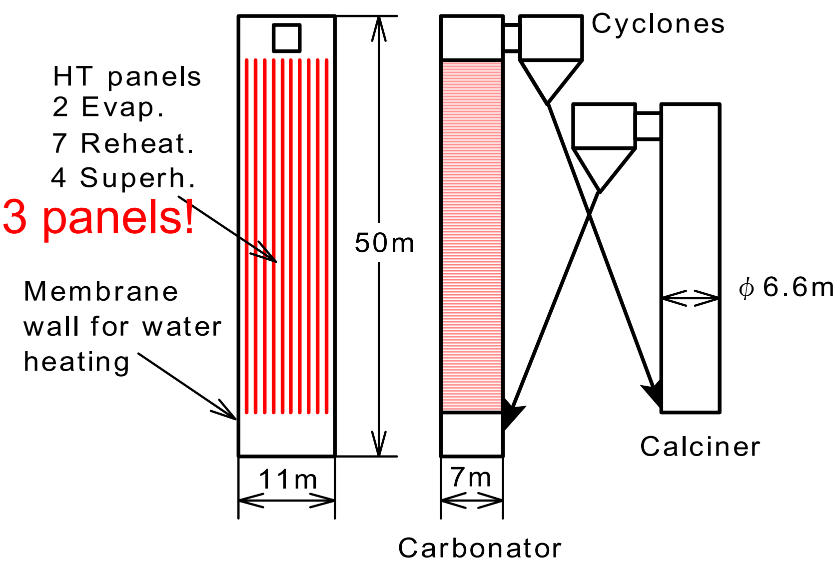
From heat transfer rate, heat transfer coefficient, and temperature difference, required heat transfer surface area of each section was calculated.

RESULTS AND DISCUSSION

Reactor design to satisfy heat removal requirement.

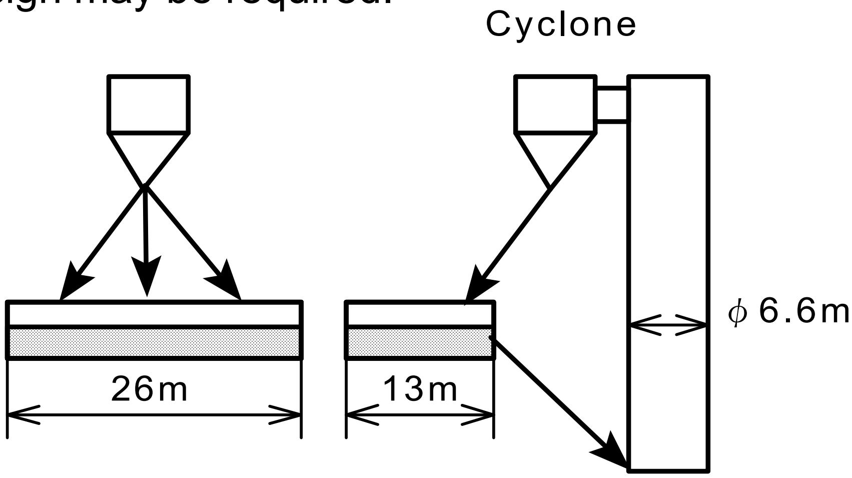
Fast-fluidized bed carbonator

13(!) HT panels in 11m-width are required.



Bubbling-fluidized bed carbonator

Bed height is 2.5 m + jet region (0.3 m). Compact but needs more cross-sectional area. Stacked design may be required.



To reduce heat transfer area in carbonation reactor

Higher reaction temperature
→Limitation of equilibrium (< 923 K)

Lower steam temperature
→Decreased turbine efficiency

Simple steam cycle without reheating
→Problem with turbine

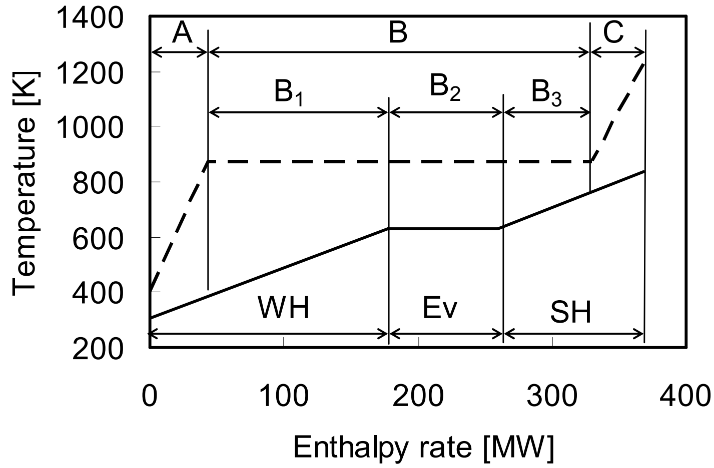
Integration of steam cycle with air combustor
→Increased construction cost

Steam recovery from CO_2 capture

Simple superheating without reheating.

→More heat recovery by WH and EV.

→

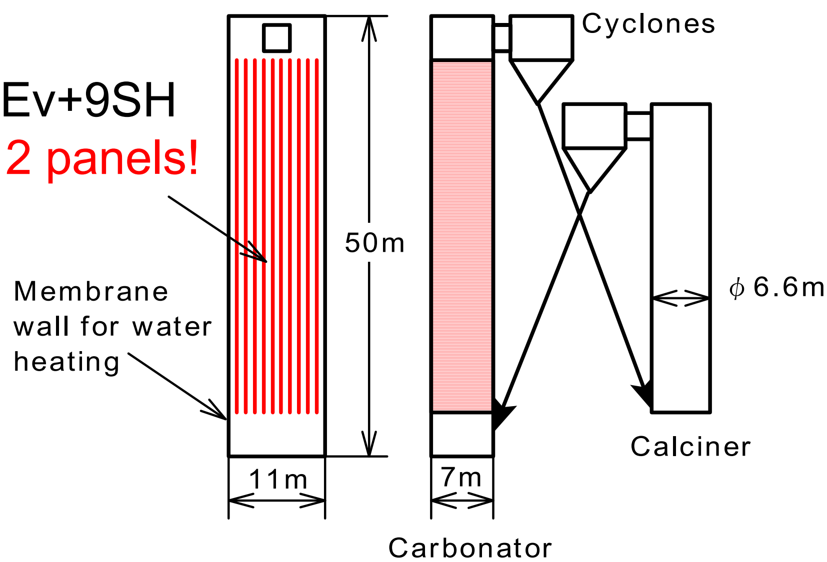


Fast-fluidized bed carbonator

12(!) HT panels in 11m-width are required.

3Ev+9SH

=12 panels!



RESULTS AND DISCUSSION

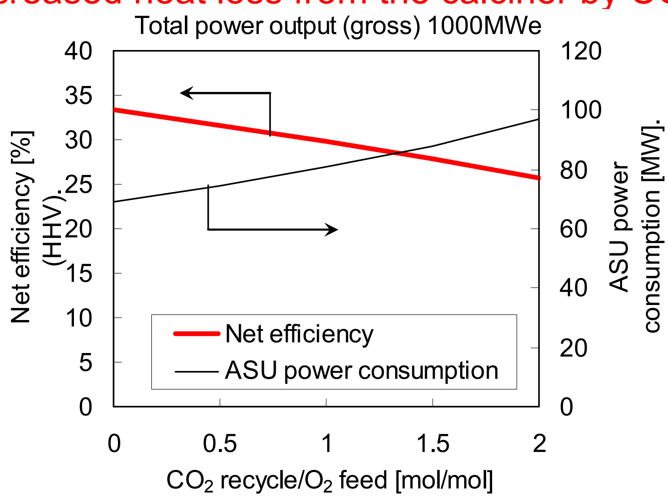
Reactor design to minimize O_2 consumption.

Regenerator (calciner)

Combustion in O_2/CO_2 atmosphere

→Prevention of hot-spot

→Increased heat loss from the calciner by CO_2



Regenerator (calciner)

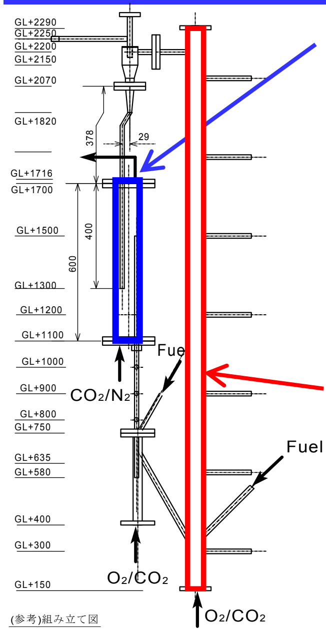
To suppress hot-spot formation under high O_2 partial pressure conditions,
→"fast" bed may be advantageous, but
→ loss of sorbent by attrition may become a problem. (Synthetic sorbent may be a solution though the cost will be higher than natural limestone.)

Conclusion

To remove heat from carbonation reactor, quite large heat transfer surface area is required. "Fast" beds require considerable number of heat transfer panels. Bubbling beds need large cross sectional area (or stacked design).

For regeneration (calcination), low CO_2/O_2 ratio is favorable, thus vigorous mixing of solids will be necessary to prevent hot-spot under high O_2 partial pressure conditions.

Research in Niigata Univ. (under preparation)



Carbonator: BFB

ID 9.3 cm, bed height 0.3 m

Gas vel. 0.22 m/s at 600 ^{o}C

Expected CO_2 removal 78%

(assumed max conv. = 0.1)

Calciner: Fast bed

ID 2.2 cm, height 1.93 m

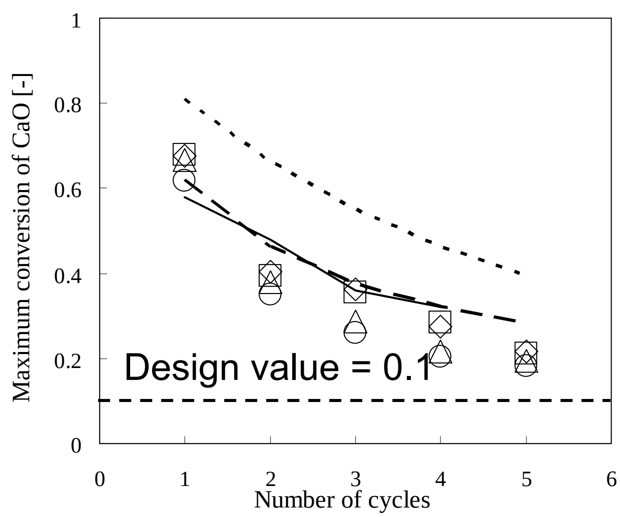
Gas vel. 6 m/s at 950 ^{o}C

CO_2/O_2 = 1

Ongoing research in Niigata Univ.

<u>Deactivation and attrition of calcined limestone</u>

Deactivation occurred after repeating cycles.

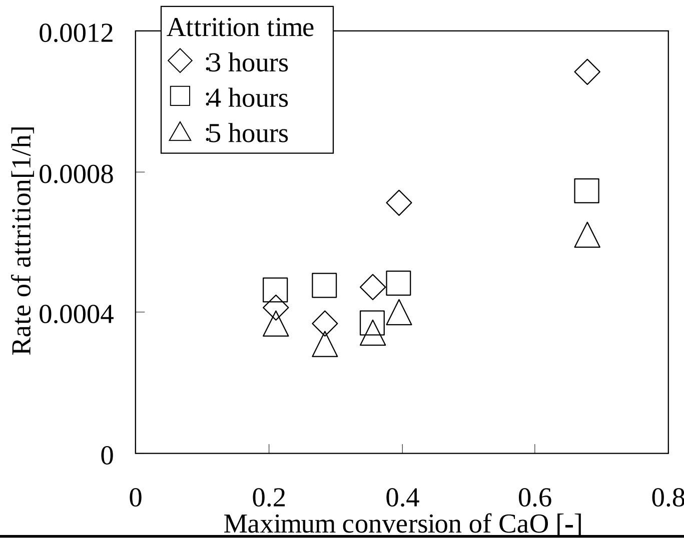


Miyairi, K., Shimizu, T., 15th SCEJ Symp. on Fluidization and Particle Processing, 2009

Ongoing research in Niigata Univ.

Deactivation and attrition of calcined limestone

Attrition rate decreased with deactivation.



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