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CO_2 CAPTURE BY OXY-COMBUSTION IN CFB

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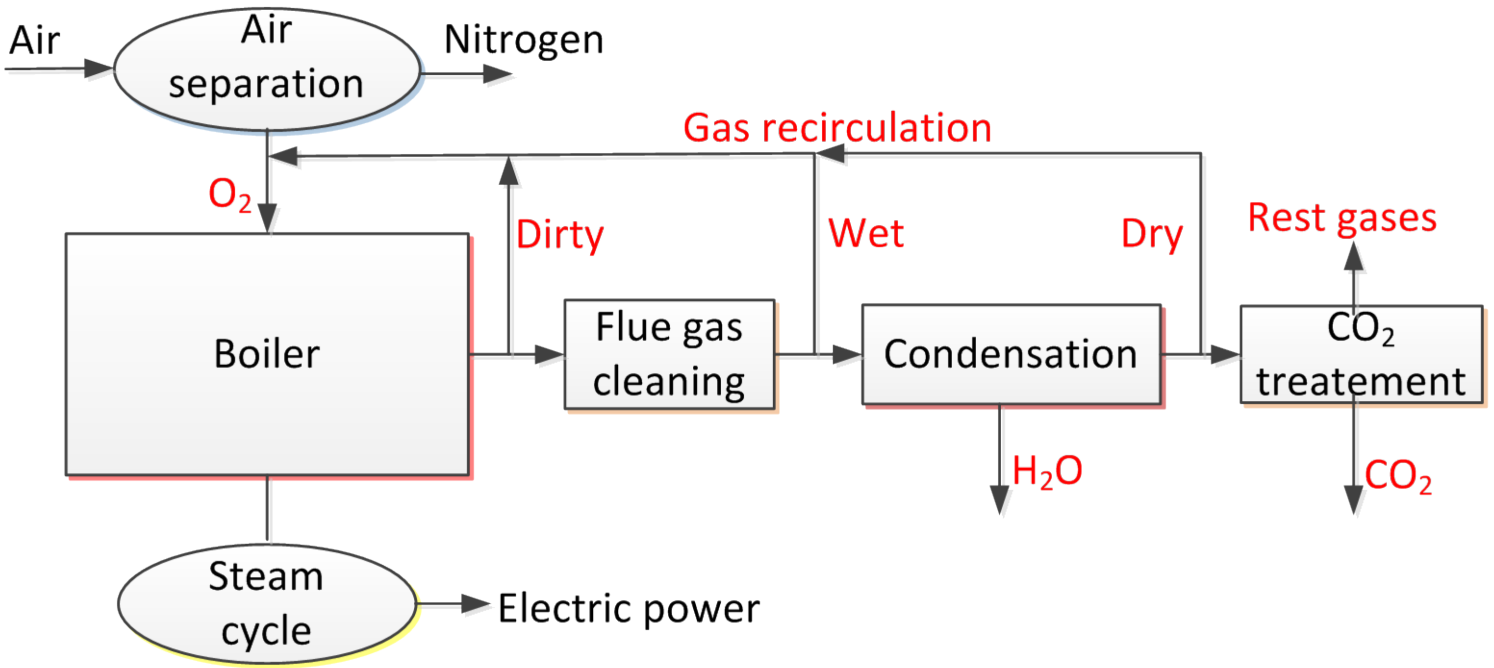
CONDITIONS

CO_2 should be removed in a pure form for deposition.

This is achieved by replacing N_2 in air by CO_2, eg by using pure O_2 diluted by CO_2 from the flue gas instead of air.

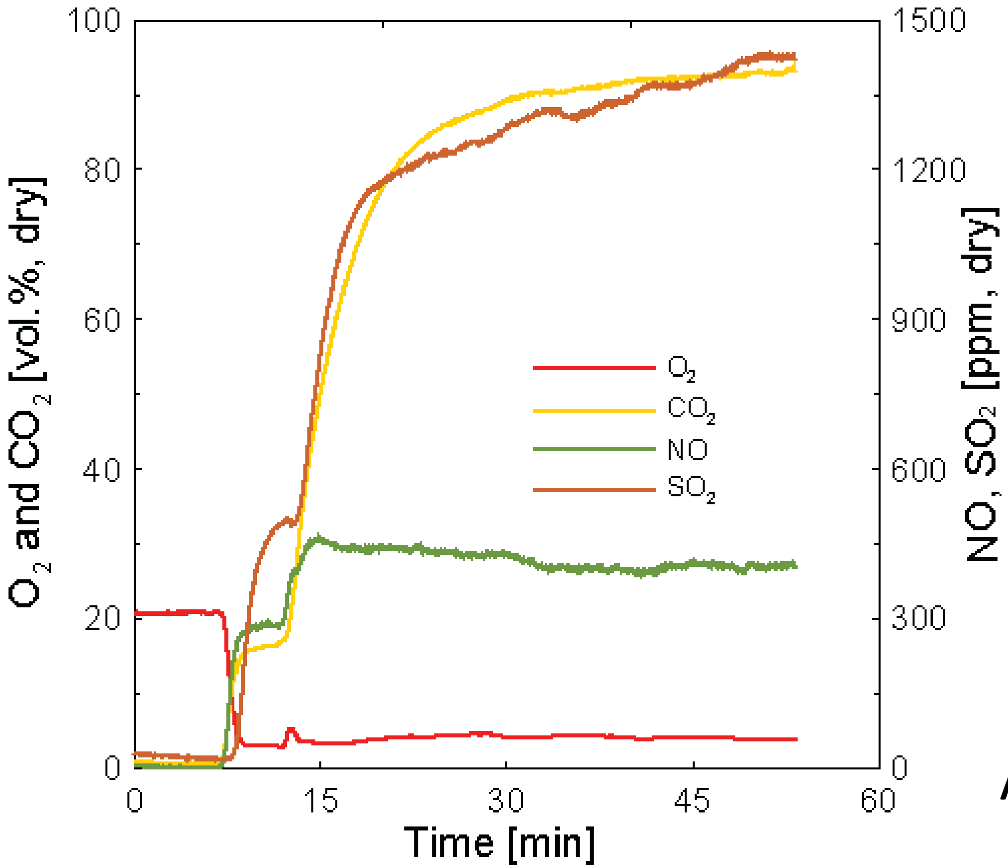
OXY-FUEL CFB BOILERS

Air (O_2+N_2) is replaced by O_2+CO_2 -----------dry recirculation
or by O_2+CO_2+H_2O ----wet recirculation .



FLUE GAS RECIRCULATION

Flue gas recirculation leads to enrichment of gases



A start-up sequence taken from flame combustion

GAS DATA

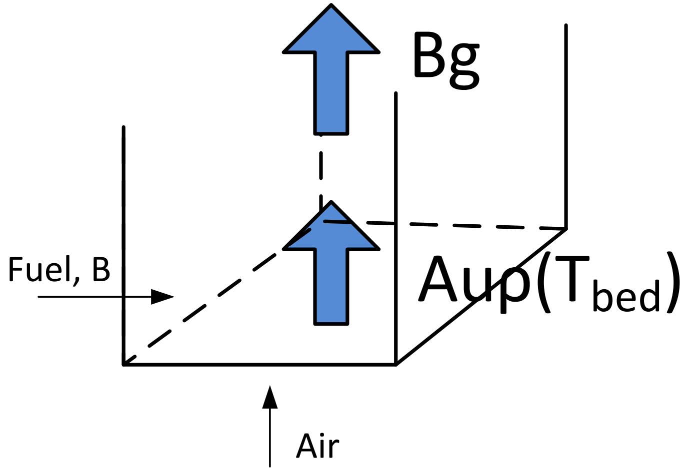
The data for the gas in the air and the oxy-fuel cases are slightly different.

Gas	Density ρ kg/m^3 900 °C	Specific heat, C_{pg} 0°C	900 °C	Mean specific heat, C_{pgm} 0-900 °C	Molecular mass, M kg/kmol
O_2	0.328	0.917	1.100	1.025	32.0
N_2	0.287	1.041	1.200	1.098	28.0
CO_2	0.451	0.827	1.275	1.090	44.0
H_2O	0.202	2.200	2.343	2.118	18.0

THE GAS FLOW THROUGH AN FBC COMBUSTION CHAMBER

The flue gas flow and the fluidization gas flow are identical

$$Bg = Au\rho$$



B feed rate of fuel (kg combustibles/s)
g flue gas yield at a given air ratio (kg/kg comb.)
A cross section of the bed (m^2)
u fluidisation velocity (m/s)
ρ gas density (kg/m^3)

CFB: TYPICAL DATA

In all cases the same ”reasonable” CFB conditions should be maintained:

• Bed temperature	900 ^oC
• Fluidization velocity	5 m/s
• Excess oxygen	3-4 %O_2
• Fuel input (power of the boiler)	B kg combustibles/s

TWO OPTIONS FOR OXY-CFB

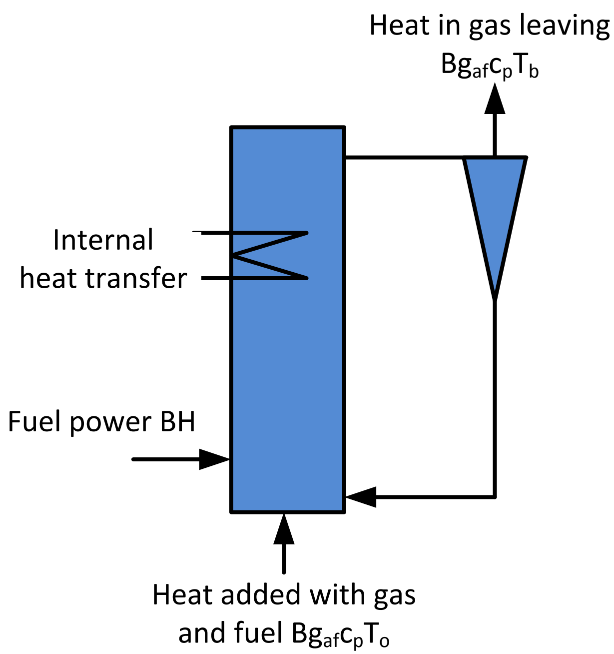
The oxy-CFB application for CO_2 capture may have two forms:

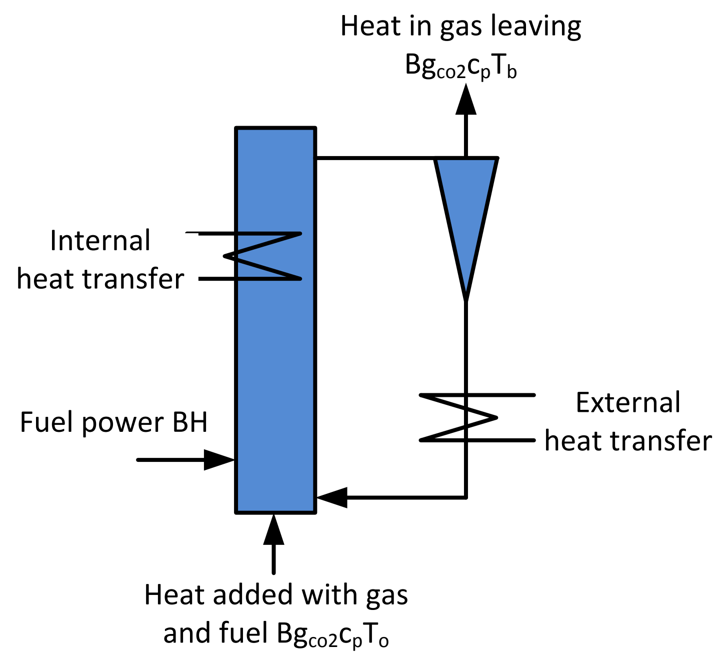
1) **”CO_2 capture ready”** → similar to present air-fired CFB boilers

2) **New development** → higher oxygen concentration

HEAT RELEASE/ABSORPTION

Exit gas temperature is equal to bed temperature.





<u>Air-fired case (CO_2-capture ready)</u>. Combustion heat is transferred to gas and internal heat transfer surfaces.

<u>60% oxy case</u>. Smaller furnace with external heat exchangers, cooling the circulating particles and so the combustion chamber.

THE HEAT BALANCE (Equation 1)

Heat supplied: $BH =$

Heat spent:

$Bgc_p\Delta T_{bed}$ on heating of air and fuel (=heating of combustion gas)+

+heat absorption by furnace heat transfer surfaces+

+and by external heat transfer surfaces $AFc_{ps}\Delta T_{ext}$ (if any)+

+losses (neglected)

1) THE CO_2-CAPTURE-READY CASE
a) HEAT BALANCE (Equation 1)

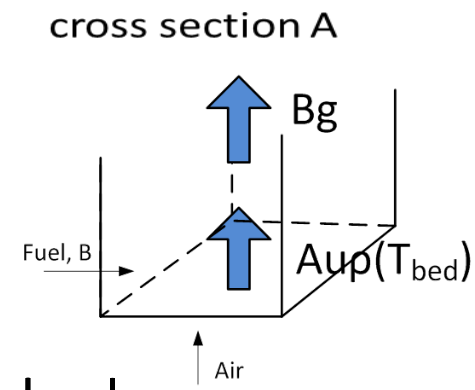
At constant temperatures and heat transfer, the heat balance becomes $\left[B g_{af} \overline{c}_{p,af} \Delta T_{bed} \right] = \left[B g_{co2} \overline{c}_{p,co2} \Delta T_{bed} \right]$ and

$$g_{af} = \frac{hM_{H_2O}}{2M_h} + \frac{cM_{CO_2}}{M_c} + \frac{1-y_o}{y_o} \ell_o M_{N_2} + w/b$$

$$g_{CO2} = \frac{hM_{H_2O}}{2M_h} + \frac{cM_{CO_2}}{M_c} + \frac{1-y_{o,co2}}{y_{o,co2}} \ell_o M_{CO2} + w/b$$

are equal at the oxygen concentration of

$y_{o,co2}=0.28$ in the dry case and about the same in the wet case (Simplified calculation without excess air).



a) GAS BALANCE, u=const

Gas produced by combustion= gas fluidizing the bed

$$Bg = Au\rho(T_{bed}, gas) \ [kg/s]$$

The gas density is ρ= 0.29 kg/m^3 in the air case and 0.45 in the CO_2 case. The remaining quantities in the gas balance should be constant in the air and oxy-fuel case, which is not possible.

Instead, optimization between T_{bed} and u is needed (ρ and heat transfer), supported by the choice of primary/secondary air (affecting the local u).

2) THE NEW-DEVELOPMENT CASE

The design is about equal to a conventional CFB

Unchanged: Operation conditions, u and T_{bed} ,
and so the heat transfer coefficient bed-to-surface (same bed suspension density (ρ_{bed}(u)) and circulation rate F(u)).

Changes: Oxygen concentration: between 0.21 and 1.0 (0.60 is chosen as a maximum)

- The corresponding flue gas recirculation (CO_2,H_2O)
- The corresponding heat release per x-section area MW_{fuel}/m_2.

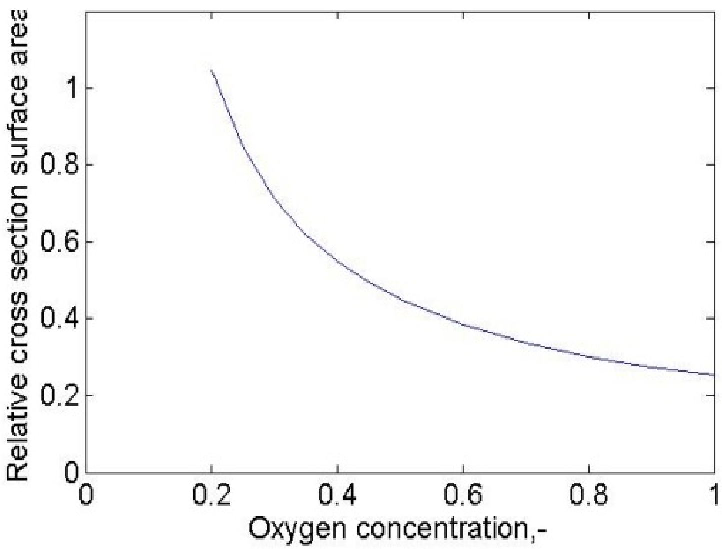
Consequences: x-section surface A is reduced, and additional heat removal (in the return loop) is needed.

THE FURNACE CROSS-SECTION AREA

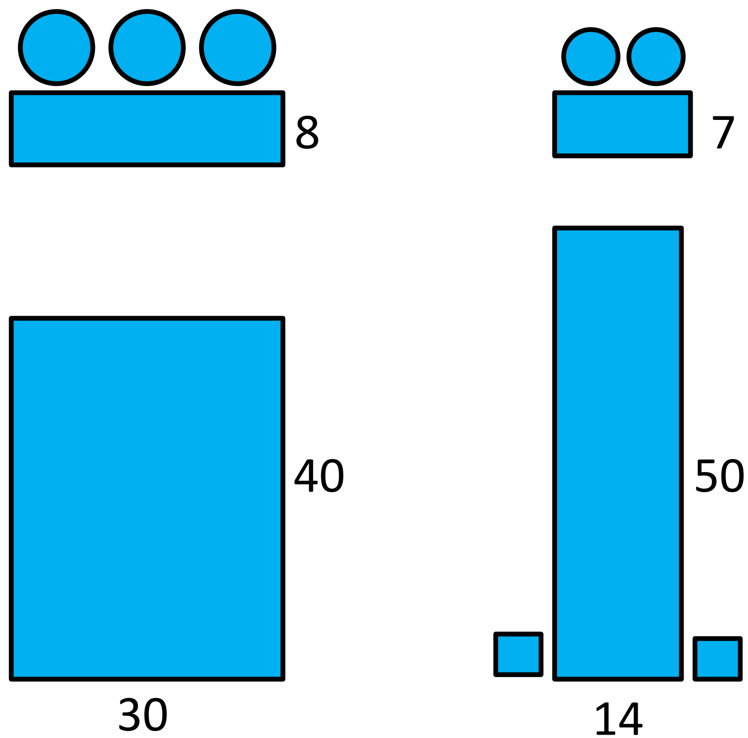
Gas yield from combustion ***Bg***= Fluidization gas $uA\rho_{gas}(T)$

B fuel feed rate (kg fuel/s)--given
u fluidisation velocity (m/s)--given
ρ_{gas} gas density (kg/m^3)---given @ given temp

$$A_{co2}/A_{af}=(g_{co2}/g_{af})_{volume}$$



AIR-FIRED BOILER OF SIZE 300 MW_e COMPARED WITH AN OXY-FIRED @ 60% O_2 (Dimensions in m).



The volumes of the two furnaces
$V_{af} = 9600\ m^3$
$V_{co2} = 4900\ m^3$

The air fired boiler has $A_{af} = 240\ m^2$ and g_{af} (y_o=0.21, N_2).
The oxy-fired one has A_{co2}=98 m^2 and g_{co2} ($y_{o,co2}$=0.60, CO_2)

HEAT BALANCE CALCULATION (Equation 1)

The air-fired case (no external heat exchangers):

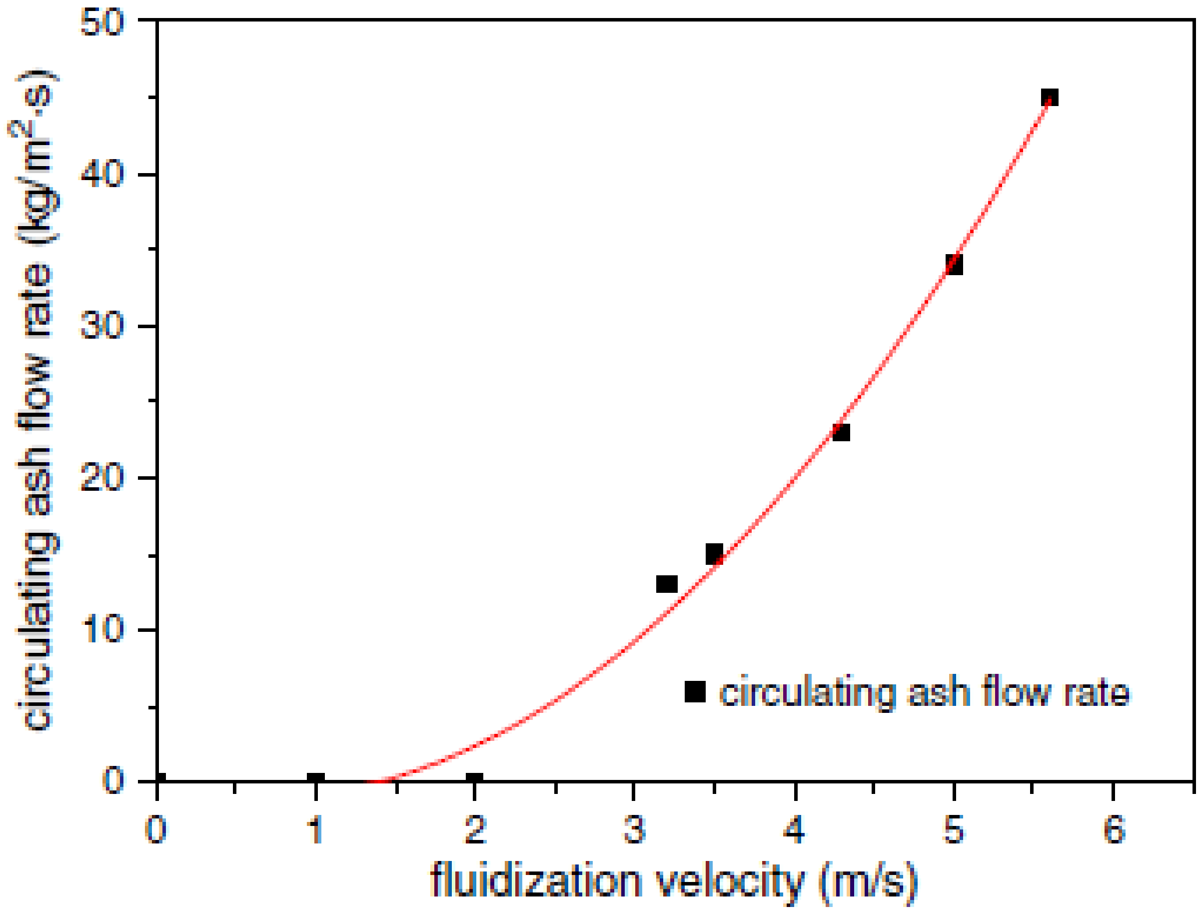
$$\textit{Internal heat transfer} = BH - Bg_{af} c_{paf} \Delta T_{bed}$$

The oxy-fired case, including external heat exchangers

$$AFc_{psolids} \Delta T_{external} = BH - Bc_{pco2} g_{co2} \Delta T_{bed} - (V_{co2}/V_{af})(BH - Bg_{af} c_{paf} \Delta T_{bed})$$

With a circulation flux of F=35 kg/m^{2}s this gives $\Delta T_{external}$ =90 K

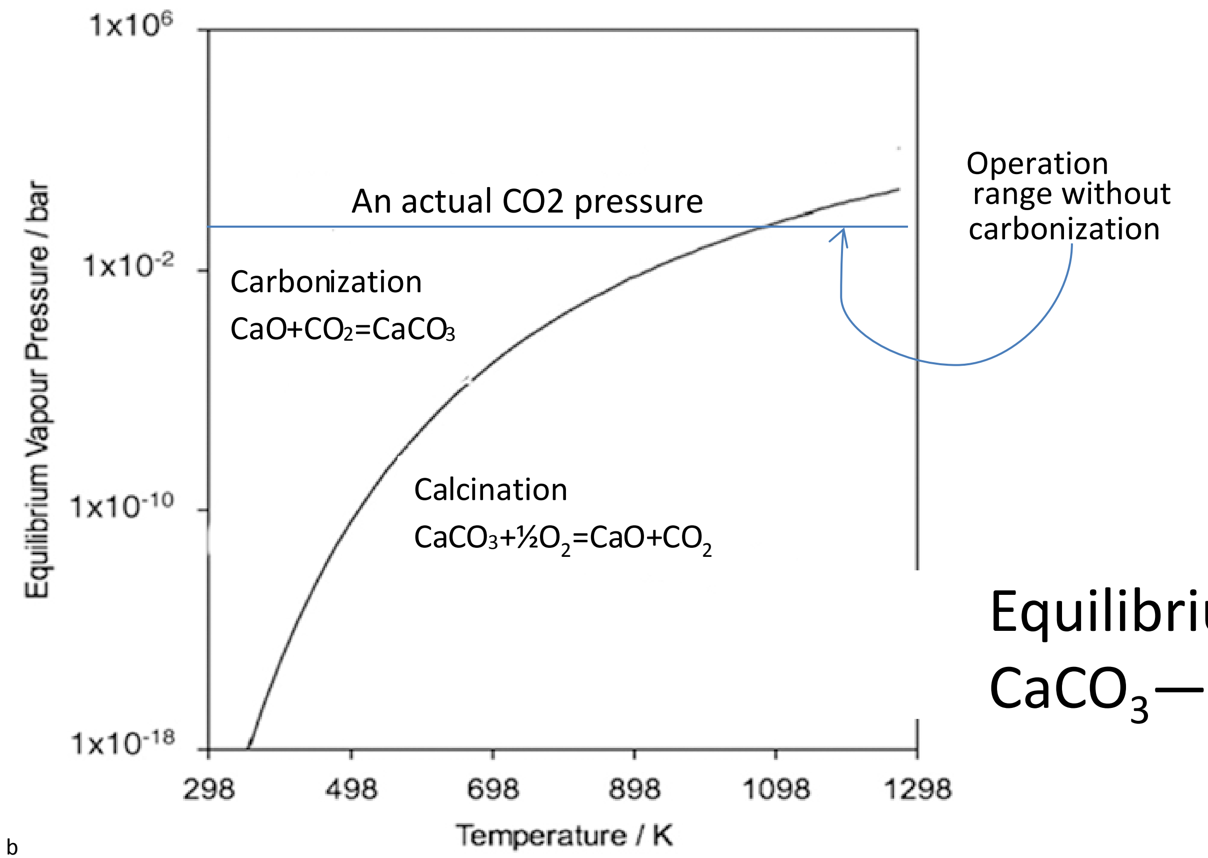
CIRCULATING FLUX VS VELOCITY MEASURED ON 300 MW_e CFB BOILERS



WuHaibo, ZhangMan, SunYunkai, LuQinggang, NaYongjie, ,Research on the heat transfer model of platen heating surface of 300 MW circulating fluidized bed boilers, Powder Technology 226 (2012) 83–90

CONSEQUENCES OF EXTERNAL HEATING

Even considering the uncertainty of the recirculation rate, the cooling of the external particle flow is moderate, but with limestone in the bed recarbonization may occur.



Equilibrium diagram $CaCO_3$—CaO—CO_2

SUMMARY ON OXY-CFB DEVELOPMENT

At present there is no commercial oxy-CFB in operation.

The heat balance cannot be satisfied at the same time as u=const in the CO_2-capture-ready case. Some (minor) adjustment is needed.

The maximum oxygen concentration that can be used is unknown at present.

The moderation of temperature by the bed material in oxy-CFB boilers is an advantage compared to oxy-PC.