SP4 Public Summary Report

Based on the Del. 4.2.4.: 455 MWe CLC boiler / plant feasibility report and recommendations for the next step

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The aim of ENCAP's SP4 is to develop the concept of Chemical Looping Combustion - an entirely new combustion technology with no contact between fuel and combustion air – featuring the inherent separation of CO_2 and avoidance of nitrogen oxide formation. In WP 4.2 a specifically dedicated new architecture was established for the design of a CLC-process suitable for solid fuels, based on Circulating Fluidized Bed technology. A conceptual design for a greenfield advanced chemical looping circulating fluidized bed (CFB) coal-fired power generation plant has been developed for capture of CO_2 by ALSTOM Power Boilers. This concept of CO_2 capture technology takes benefit of no Air Separation Unit (ASU) need, is using current CFB technology and allows a direct production of CO_2. Due to the inherent fuel flexibility associated with CFB boiler, multiple fuels can be used such as coal, petroleum coke, biomass and a range of opportunity fuels.

Chemical Looping CFB technology

The CLC integrates air separation into the combustion process and produces a separated CO_2/H_2O flue gas stream for CO_2 capture. The principle is to separate the fuel oxidation process from the air stream by carrying oxygen to the fuel in the form of a metal oxide.

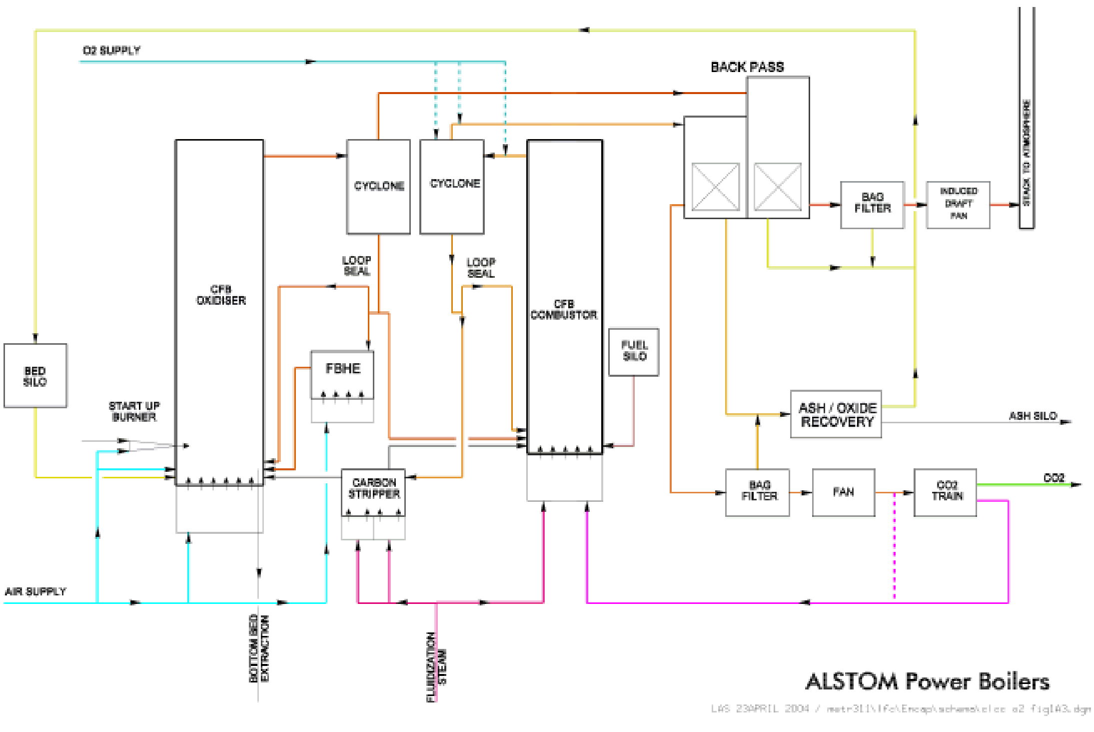

Figure 1: Scheme of CLC CFB for solid fuels

The considerable parts of the CLC boiler are the interconnected Air Reactor (AR) and Fuel Reactor (FR) using fluid bed technology.

The Fuel Reactor (the CFB combustor in figure 1) is a circulating bed fully lined with refractories and fluidized by steam and recycled CO_2 with SO_2 traces possibility.

Solid fuel (coal and/or pet coke) is introduced into the fuel reactor and oxidize by contact with oxygen carrier. An almost pure CO_2 stream is obtained when H_2O is condensed. Particles of the oxygen carrier are transferred to the air reactor where they are regenerated by contact with air. Carbon strippers remove selectively the carbon inventory in metal oxides extracted from the fuel reactor. This carbon is recycled to the fuel reactor.

In the Air Reactor (the CFB oxidiser in figure 1), the oxygen carrier oxidation and the heat transfer to the reactor walls and in-reactor surface are a result of fluidization of the bed. The location of the secondary air along the front and rear walls creates conditions to control the upper reactor solids loading and external solids circulation to the FBHE (Fluidized Bed Heat Exchanger) and the Fuel Reactor. It should be mentioned that the Air Reactor is much simpler since there are no gas-phase reactions which, if not complete will give emissions of unburned gases, and no NO_x formation to be consider. The reaction with the metal oxide only consumes oxygen without giving rise to any gas phase pollutants. The flue gas at air reactor outlet is composed of N_2 and some unused O_2. Thus, proper operation is only dependent on sufficient solids inventory and contact between gas and solids and gas residence time/gas mixing do not need to be considered.

The Cyclones separate the entrained oxide particles from the oxygen depleted air leaving the Air Reactor. Their efficiency impacts the capture rate of the fines fraction of the oxides entering the cyclone. This in turn affects the allowable oxide particle size distribution which should be as fine as possible for heat and mass transfer purposes.

The FBHE has the role of cooling recirculated oxides coming from the cyclones, before re-injection in the air reactor bottom.

The Back pass has similar role with two channels of flue gas cooling, one stream of CO_2/H_2O and the other stream of oxygen depleted air. Complete tightness between the two channels is required to avoid CO_2 stream dilution by oxygen depleted air.

Increasing the steam cycle efficiency is needed to significantly contribute to the reduction of CO_2 to be stored. Elevated feedwater, superheater and reheater outlet temperature are then selected to operate with an ultra supercritical steam cycle. The non corrosive air depleted stream in a CLC boiler is extremely well suited to these supercritical steam conditions by non corrosiveness.

455 MWe Chemical looping CFB design and costing

The design and costing of a 455 MWe CLC CFB plant have been performed.

Design data

As shown in figure 1 the CLC CFB boiler island consists of:

- Two CFB reactors with interconnected solids transfer lines
- Conventional solids loop for the CFB reactors: reactors, cyclones, loop seals
- Carbon stripper Fluid Bed installed on the solids transfer line from the Fuel Reactor to the Air Reactor

- LP steam for Fuel Reactor, carbon stripper and loop seals fluidization
- Air for Air Reactor, loop seals and for FBHE's fluidization
- FBHE's and in furnace heat exchangers to perform the required heat duties on Air Reactor
- Conventional back pass (splitted for CO_2/H_2O and Depleted Air streams)
- Air Heaters (regenerative, tubular) for cooling the depleted air leaving the AR back pass down to 90 ^oC and for cooling the Fuel Reactor flue gas leaving the FR back pass to 195 ^oC
- The last cooling step, down to 25 ^oC, is performed without heat recovery by the cooling water of the plant in the Flue Gas Condenser
- Integration of once through circulation for the water/steam side with evaporation achieved in one pas furnace.

Technical data summary

An overview of the main technical data for Chemical Looping CFB operating with bituminous coal and petcoke are illustrated in the annexes A1 and A2.

Economic data

Investments costs including costs of all equipments on the side to the fence (excluding harbor and mining facilities but including coal yard for 30 days storage and coal handling equipment) and operating costs have been determined.

According to these costs, some preliminary evaluation leads to:

- CO_2 avoidance cost: 7 to 10 €/ton CO_2 depending on the type of fuel
- Cost of electricity: 30 €/MWh

The CO_2 avoidance cost is under ENCAP target figure of 20 €/ton.

Conclusions

This work is demonstrating that chemical looping fired CFB is a feasible concept, close to the conventional CFB process with existing proven components. For the boiler island, there is no foreseen degradation of availability, resulting from the process simplicity. The CO_2 trains, mainly compressors, are proven units. No availability degradation is expected.

Some aspects of the technology remain to be addressed:

- The part load behaviour
- The implementation of a 700 ^oC steam cycle appears quite easy
- The Air Reactor back pass and the FBHE bundles are particularly attractive for locating high temperature exchanges with very high heat transfer coefficient
- The evaluation of oxygen carrier manufacturing processes for simplification and life cycle assessment.

A. ANNEXES

A1. Overview of the main technical data for Chemical Looping CFB operating with bituminous coal

Design case - Bituminous Coal		Reference power plant	CO2 capture power plant	comment no
Overall energy balance				
Gross el. capacity	MW	445,00	454,7	
Auxiliary power demand	MW	41,80	67,5	
Net capacity	MW	403,20	387,20	
Fuel mass flow	kg/s	36,50	36,98	
LHV	kJ/kg	25174,00	25174	
Net efficiency	%	43,88	41,59	
CO2 balance				
CO2 "input"				
C content of fuel	%	66,52	66,52	
Total theoretical CO2 input via fuel	kg/s	89,38	90,13	+ CO2 from limestone injection for ref case
CO2 input via air	kg/s	0,20	0,16	
CO2 "output"				
Flue gas mass flow (to atmosphere)	kg/s	408,00	264,2	
CO2 content flue gas	%	21,42	0,685	
CO2 emissions	kg/s	87,40	1,81	
CO2 to storage	kg/s	0,00	87,56	
CO2 "loss" due to unburnt carbon, etc.	kg/s	2,18	0,92	
CO2 capture performance				
Spec. CO2 emissions (C from fuel)	g/kWh	778,59	15,34	+ CO2 from limestone injection for ref case
CO2 avoidance rate (based on reference)	%		98,03	
CO2 capture rate (ENCAP design target)	%		98,15	

		Guidelines	CO2 capture power plant	comment no
CO2 conditions				
CO2 delivery pressure	bar	110	110	
CO2 delivery temperature	°C max	30	25	

A2. Overview of the main technical data for Chemical Looping CFB operating with petcoke

Design case - Pet Coke		Reference power plant	CO2 capture power plant	comment no
Overall energy balance				
Gross el. capacity	MW	445,00	454,7	
Auxiliary power demand	MW	41,80	67,1	
Net capacity	MW	403,20	387,64	
Fuel mass flow	kg/s	30,00	30,05	
LHV	kJ/kg	30928,00	30928	
Net efficiency	%	43,46	41,71	
CO2 balance				
CO2 "input"				
C content of fuel	%	81,32	81,32	
Total theoretical CO2 input via fuel	kg/s	96,58	89,54	+ CO2 from limestone injection for ref case
CO2 input via air	kg/s	0,20	0,16	
CO2 "output"				
Flue gas mass flow (to atmosphere)	kg/s	411,80	263,6	
CO2 content flue gas	%	22,94	0,68	
CO2 emissions	kg/s	94,47	1,79	
CO2 to storage	kg/s	0,00	86,98	
CO2 "loss" due to unburnt carbon, etc.	kg/s	2,31	0,93	
CO2 capture performance				
Spec. CO2 emissions (C from fuel)	g/kWh	841,67	15,16	+ CO2 from limestone injection for ref case
CO2 avoidance rate (based on reference)	%		98,20	
CO2 capture rate (ENCAP design target)	%		98,16	

		Guidelines	CO2 capture power plant	comment no
CO2 conditions				
CO2 delivery pressure	bar	110	110	
CO2 delivery temperature	°C max	30	25	