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Alstom Oxyfuel CFB boilers: a promising option for CO_2 capture

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Abstract

Fossil fuels will likely remain a major energy source for the foreseeable future, leading to the need for power plants including cost-effective CO_2 mitigation systems. Oxygen fired CFB boiler technology is an advanced and competitive route to offer in a relative short term commercial units addressing the CO_2 capture need.

CFB boilers in operation have shown the ability of this technology to fire a wide range of low-cost fuels. A CO_2 capture solution based on CFB technology would, hence, provide the plant with the option to utilize these lower cost fuels and as such is a promising option.

Additionally the route of plant efficiency improvement is of great interest because it leads to CO_2 mitigation together with energy sources savings and thus to operational cost reduction. Alstom has a long experience of large supercritical PC boilers and has developed a design of large supercritical CFB boilers.

Oxygen firing can be easily applicable to CFB boilers. The oxygen-fired CFB concept has already been validated in Alstom's bench- and pilot-scale test facilities.

Keywords: CO2 capture; Oxyfuel; CFB boiler; coal; supercritical.

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Introduction

Coal resources are abundant and widely distributed over the world. Coal is used to produce about one third of the world electric energy need. We can foresee that coal and other fossil fuels will still represent in the next decades the largest energy source for electricity production. The need for CO_2 mitigation will require coal power plants allowing CO_2 capture on medium term. For this type of plants it will also give an incentive for growing the use of biomass and low grade fuels, together with an increase of plant efficiency, mainly by the use of advanced supercritical steam cycles.

Oxygen fired CFB boiler technology is an advanced and competitive route in the short term to commercial units addressing the CO_2 capture need.

After a presentation of the key features of the CFB technology and its development towards large size and high efficiency boilers, this paper describes why the Alstom oxyfuel CFB boiler technology is a promising option for power generation with CO_2 capture.

CFB boiler key features

Circulating Fluidized Bed Technology (CFB) has been widely developed for about 20 years for Utility Boilers. Today, more than 900 CFB steam generators are in operation or under construction with a capacity range from 50 up to over 400 MWe. This development was remarkable in the sense that it happened in a relative short period of time for such a kind of equipment. The reason for this are the unique features offered by CFB boilers.

This technology has made the demonstration of its ability to fire a wide range of coals and other fuels while satisfying severe emission requirements.

NOx emissions are intrinsically low, due to the low combustion temperatures and a staged air injection. The long residence time of fuel particles, due to the recirculation of solids in the furnace, allows a high carbon burnout and, associated with limestone injection into the furnace at controlled temperature, allows direct sulfur capture within the combustion loop and low SO_2 emissions.

Alstom CFB boilers in operation fire lignite, bituminous coal, various international coals, anthracite, petroleum coke, coal residues and slurry, while satisfying low pollutant emissions.

Two recently commissioned CFB power plants are representative [1].

1. Sulcis 340 MWe (in Italy) : This CFB power plant began commercial operation in October, 2006. CFB technology was selected because of the local coal characteristics (high sulfur: average content 6%, high volatile: 38% and high ash: 17%) and the stringent emissions limits imposed by the local authorities. The high steam cycle parameters, 169 bars 565°C/580°C, allow a plant efficiency of 41%(LHV). The boiler is designed to burn a mixture of local coal and imported coal with addition, up to 8% of the thermal input load, of three types of biomass: wood chips, wood crops and olive pressings.

This boiler has demonstrated the ability of co-firing biomass with local or imported coals, without any difficulty, at over 8% share of thermal input load, which is forecasted to be upgraded to 16-20%.

2. Baima 300 MWe (in China) : This CFB power plant has been in commercial operation since April 2006, following the grid demand mainly between 160 and 300 MW and firing a Chinese anthracite with low volatile matter (8%), high ash content (42 to 60%), high abrasive characteristics and high sulfur content. Low emissions levels are achieved without the addition of any back end equipment. This type of coal is difficult to burn as it combines the low reactivity of an anthracite together with high ash, high abrasive characteristics. The combination of these characteristics creates a difficulty in the grinding / milling needed for achieving a good carbon burn out. CFB technology achieves lower unburned carbon than a PC boiler on these difficult fuels, due to a high solids residence time, and provides savings on coal preparation electrical consumption (crushing instead of milling) for difficult to grind fuels, resulting in coal consumption savings.

In addition to achieving full load guaranteed performance, the boiler was able to operate at 35% load without fuel oil support while maintaining the full steam temperatures (540/540°C), which represents a strong benefit for partial load operation with maintained high efficiency steam cycle.

Six more 300 MWe CFB boilers have been put in commercial operation in China utilizing Alstom licensed technology, four of which fire lignite. Due to the high amount of flue gas generated by lignite and the site locations, these boilers are presently the largest CFBs in operation in terms of physical dimensions.

There is a growing interest in China for firing waste coals. Alstom CFB technology has proven successful for burning efficiently difficult Chinese coals of high variability, with reduced emissions of all pollutants.

The CFB boilers' ability to accept a wide fuel variability has been demonstrated by Alstom since 1986 with start-up of the Kimberly-Clark CFB, burning anthracite culm, coal, pet coke and wood wastes.

In 1989, Alstom commissioned the Emile Huchet CFB boiler (France), 125 MWe, operating on coal residues, with a mixture in variable proportions of high ash coal and slurry. As another example of varying quality of fuel, the coal flow feeding the Baima boiler can vary from 130 t/h up to 210 t/h for the same power output of 300 MW in a few minutes.

In summary CFB boilers present the following key features:

- the ability to fire a wide variety of coals and other low grade fuels or wastes, which are available at low cost
- the fuel flexibility, for example a fuel change or variations in the fuels mix
- the capacity to co-fire biomass
- the ability to accept fuels with only basic preparation, e.g., coarse particles or high moisture
- the operating flexibility to meet load variations and minimum load without oil support

Efficiency improvement

The route of plant efficiency improvement is of great interest because it leads to CO_2 mitigation together with energy resources savings and thus to operational cost reduction.

Plant efficiency can be increased by minimizing the energy consumption of the power plant auxiliaries and by minimizing the heat losses of the boiler, but a real step can be reached only with advanced steam parameters in supercritical cycle power plants. The slightly higher investment cost is, at least partially, offset by a clear reduction of operating cost.

Alstom has a long experience with advanced steam cycles and is a global leader in the technology of large supercritical pulverized coal (PC) boilers. The availability and efficiency of these supercritical PC boilers have been continuously improved up to the latest commissioned power plants such as Neurath, a 1100 MWe, 295 bars, 600°C/605°C in Germany.

This supercritical boiler technology expertise is now being implemented by Alstom for our CFB boilers, taking benefit from these developments both in view of the application of materials for high steam parameters and for the design of the steam generator itself, based on once-through technology. It led previously to a design study for EDF, for a 600 MWe supercritical CFB boiler, to burn international coal with a steam cycle at 250 bar and 600°C for the superheater and reheater outlets, with a net plant efficiency around 44% (LHV). Further development work led to commercial offers in the size range 330 to 550 MWe. Currently there are no super-critical CFBs in operation in the world, but the development of this product is expected to be as remarkable as it as been for the sub-critical CFB because the unique features of the CFB will remain and high efficiency will be added.

The route for the increase of capacity to 400 up to 600 MWe is to apply the excellent operating experience gained from the CFB plants of capacity class 250 to 300 MWe to the larger plants and to accompany this capacity increase with the introduction of supercritical technology. The increase in capacity and the introduction of supercritical steam parameters in CFB plants impact some key components such as the furnace, the cyclones and the Fluidized Bed Heat Exchangers (FBHE).

Furnace

For this size a design with a dual grate (pant leg) is required in order to ensure adequate fluidisation and complete fuel combustion. Three cyclones and up to three FBHEs can be arranged on each side of the furnace. Fig.1 shows an example of the overall arrangement of a six-cyclone plant.

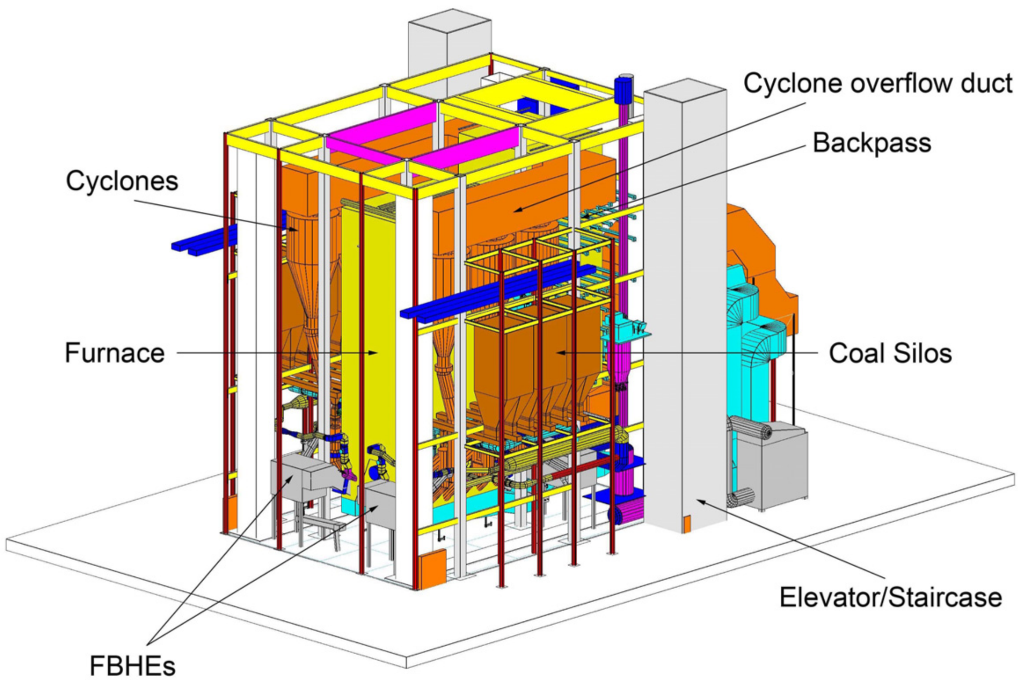

Fig. 1: Arrangement of a supercritical fluidized bed boiler for 600 MW_e

Cyclone

For supercritical steam parameters the cyclones plus inlet and outlet ducts are provided with a tubed design and a cooling by superheated steam. This leads to a minimization of the refractory lining in the cyclone area. Experience with the manufacture and erection of tubed cyclones has already been gained with sub-critical CFB plants, e.g. at Zeran B in Poland.

FBHE

For the optimum utilization of the heat input to the furnace, FBHEs can be used as a supplement to the heating surfaces in the furnace. In the FBHEs the circulating ashes are cooled by the heating surfaces which can be arranged as superheater, reheater or even as evaporator. The ash flow into the FBHE is controlled by an ash valve.

Besides the possibility of controlling the furnace and reheater temperature without spray attemperation, another advantage of the FBHE is the very high heat transfer coefficient from the ash particles to the tube banks, which leads to compact heating surfaces, particularly for high temperature heat exchangers.

By designing FBHE surfaces based on well proven tube bundle arrangements only and by utilizing a modular approach, technical scale-up risks are mitigated and an increase in unit size can be accommodated without developing a new FBHE design. With increasing boiler size the number of FBHEs is increased up to 6 for 600 MWe.

Evaporator surfaces

The once-through technology associated with advanced steam parameters implies some critical constraints on the evaporator design in order to ensure a sufficient cooling of the evaporator tubes in any operating condition and to minimize the temperature differences between the tubes. Regarding this design aspect, the CFB boilers offer the advantage of a homogenous heat absorption due to the thermal homogeneity in the furnace or FBHEs, thanks to a high solids inventory and a strong mixing, and to the absence of slagging or fouling. Therefore, a lower mass flow density, compared to PC, of the evaporator walls is sufficient for cooling and for temperature differences minimization.

In response to the growing interest for the 600 MW supercritical CFB boiler technology, Alstom has recently adapted this design to difficult coals in order to be able to satisfy the specific needs of this market.

Oxyfuel CFB

The basic concept of oxyfuel power plant is to replace combustion air with a mixture of oxygen and recycled flue gas (Fig. 2). The resulting flue gas is composed mainly of CO_2 and steam, thus eliminating most of the atmospheric nitrogen. Subsequently, the flue gas is dried and processed to produce a high concentrated CO_2 stream, which is then compressed for storage or industrial use.

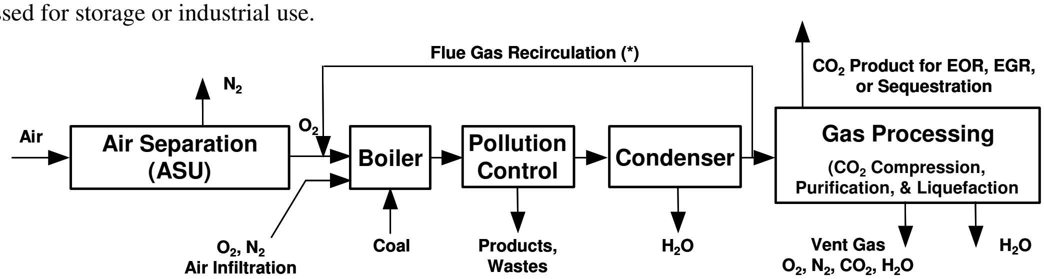

Fig 2 : Oxy combustion process diagram
(*) Several options for the position of the FGR loop

The needed oxygen is produced by a conventional Air Separation Unit and the gas processing is simplified as the inlet gas is already concentrated, and consists of cleanup and compression of the CO_2.
The impact of oxygen firing on the boiler concept and design is mainly due to the differences in the thermal and radiative properties between CO_2 and N_2. This impact can be easily moderated by adapting the flow rate of recycled flue gas. Thus the furnace temperature is maintained within the limits imposed to avoid slagging and fouling and corrosion of the furnace surfaces.
The CFB technology offers an additional degree of freedom. At a given flue gas volume, the furnace temperature can be controlled and adjusted with the Fluidized Bed Heat Exchangers (FBHE), through the ash valves' control of solids flow. So, that gives an additional control means of combustion and emissions performances, particularly useful to adapt to fuel variations.

The oxygen-fired CFB concept has been validated in Alstom's bench-scale and pilot-scale (3 MWth) test facilities [2].
It results that this technology can be easily developed from conventional CFB boilers, so that a medium scale oxy-fired CFB demonstration plant could be developed on short term, followed on medium term by larger scale commercial plant at relatively low risk. The design is based on proven, reliable, commercially available boiler technology. Oxygen can be produced by commercial air separation units, and CO_2 processing can be scaled-up from existing sub-systems.
It should be emphasized that oxy firing technology can also be implemented to retrofit existing power plants, provided that sufficient space is available on site to install the additional equipment for oxygen production and for CO_2 processing.

A power generation technology with CO_2 capture based on oxy-fuel CFB will take direct benefit from the large fuel range and flexibility, widely experienced in Alstom operating CFB boilers. The ability to fire low cost fuels or wastes in co-firing will allow our customers to be less dependant on expensive high rank imported coal, and thus, to have a unique solution to reduce the Cost of Electricity using cheaper fuels. Furthermore, the capability of biomass co-firing will allow additional CO_2 credits.

A further reduction of CO_2 production is achieved by plant efficiency improvement, which also yields fuel savings and Cost of Electricity reduction. The oxy CFB technology offers intrinsic efficiency advantages:

- The strong mixing in the furnace, the long residence time due to the recirculation of solids allow a good carbon burnout.
- The reheat temperature can be controlled by a specific FBHE, then avoiding a reheat spray, which is detrimental to the cycle efficiency.
- On the long term, the design of oxy-fuel CFB could be improved even more by the reduction of flue gas recycling, thus reducing the size of some equipments and the auxiliaries consumption. This would be possible using the already mentioned CFB specific control of furnace temperature by means of the FBHE heat pick up adjustment, allowing an oxygen-fired CFB boiler to operate with a much lower flue gas recycling rate compared to that needed for equivalent air operation. This reduced flue gas flow yields significant size reduction in the combustor and all the equipments on the flue gas stream, leading also to cut in heat losses and fans power consumption.

But clearly a valuable step in efficiency is obtained by advanced steam cycle parameters. The impact of oxyfiring being absorbed by the specific features of CFB technology, i.e. the high ash loading, the furnace relative homogeneity and the temperature control by ash recirculation through the FBHE, the oxyfiring technology can easily be implemented in advanced supercritical CFB boilers, leading to high efficiency power plants.

Conclusion

The oxygen fired CFB technology is an advanced and competitive route in the short term for commercial power plants addressing the market needs for CO_2 mitigation. The oxygen-fired CFB concept has been validated in Alstom's bench- and pilot-scale test facilities.

The next step for Alstom will involve a demonstration of this technology at a medium scale facility from 100 MWe.

Alstom's roadmap entails the following next steps, which are needed before supercritical Oxy-CFB plants can be offered commercially: (1) Building and operation of a large supercritical air-fired CFB plant; (2) Demonstration of first-of-a-kind commercial-scale subcritical Oxy-CFB plant; and (3) Demonstration of first-of-a-kind commercial-scale supercritical Oxy-CFB plant.

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