Doosan Lentjes

DEVELOPING FUEL FLEXIBLE USC CFB TECHNOLOGY TO DELIVER LOWER COST GENERATION AND ENERGY SECURITY

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INTRODUCTION

There is an emerging requirement in Asia to utilise lower quality fuel for security of supply and drive down the cost of electricity. Pulverised coal boiler designs have been the technology of choice however development of a design that has much greater fuel flexibility at no extra capital cost needed another solution. Doosan is developing a 660MWe class USC CFB boiler concept for demonstration incorporating the proven aspects of both the Doosan Lentjes CFB combustor design and unique ash flow control technology with the Doosan Babcock patented PosiflowTM low mass flux vertical tube furnace technology to deliver the new USC CFB boiler design.
The result is expected to deliver a utility boiler with the efficiency, performance and reliability of PC boiler technology coupled with the fuel flexibility and smaller plant size of the USC CFB.
This paper presents the USC CFB development story and the boiler concept that will offer Asia the opportunity to access lower generation costs and greater energy security.

MODERN POWER PLANT CHALLENGES AFFECTING BOILER TECHNOLOGY SELECTION

Utilities and Independent Power Producers (IPP) across Asia, face a number of challenges when making their coal fired boiler technology selection for specific projects. For technology selection and assessment, the main challenges surround the fuel properties, site location factors and environmental controls.
The diet of fuel for the plant and how its properties affect the plant performance and economics are critical (e.g. affecting handling, processing, combustion, waste product and emissions management, and plant availability, maintenance and operation). Fuel diets for Asian Coal plants vary greatly where stations are designed for higher rank coals (Anthracite or world traded bituminous or sub-bituminous) typically over 5500kcal/kg on a LHV basis. A number of proposed power stations in Asia have limited access to domestic coals must consider imported coals, where economics favour a trend away from world traded 6000kcal/kg coal to lower rank sub-bituminous coals. These imported coals typically from Indonesia have lower LHVs down to 4000kcal/kg, higher volatile and moisture levels, much lower ash levels (e.g. <4%).
Apart from the operating challenges of coal blends, imported coals also bring economic challenges, where the coal price can be not only higher than domestic supplies but power tariffs in many off-take contracts have limited flexibility to compensate for price volatility with imported coals. Lack of fuel flexibility in the boiler technology selected can result in reduced operation and plant revenue or lost availability where the boiler design struggles to operate with lower quality/lower cost coals1. For specific projects where imported coals constitute the majority of their diet, there may be an opportunity to consider boiler technologies that offer greater fuel flexibility.
The site location may also impact not only the fuel sourcing and operating economics but also the plant emissions control strategy. In certain applications there has been a trend to limit airborne pollutants. In particular SOx emissions and the provision of Flue Gas Desulphurisation (FGD) equipment are being considered for pulverised coal plants to comply with environmental regulations and the permitting process. The additional capital cost of sea water or wet limestone FGD may also have an impact on boiler technology selection.
To date Super-Critical (SC) Pulverised Coal (PC) fired boilers have been the proven technology of choice by many utilities across Asia. There are conditions emerging now where fuel price volatility, changes in fuel diet and environmental considerations require closer evaluation during boiler technology selection.

PULVERISED COAL AND CIRCULATING FLUIDISED BED BOILER TECHNOLOGY APPLICATIONS

Extensive experience exists in the design, supply and installation of both pulverised coal (PC) and circulating fluidised bed (CFB) boilers with many PC plant operating at Ultra-Supercritical (USC) steam conditions[1]. To date few examples exist worldwide of CFB technology being applied at larger unit sizes (>300MWe) or at higher steam conditions (supercritical or ultra-supercritical). CFB technology has also been selected on certain projects where SOx emissions compliance has driven up the cost of PC technology.

The power market is changing in Asia. Price volatility between imported and indigenous coals has forced some utilities to consider the need for greater fuel flexibility in their coal fired boiler technology selection. Added to this there is the potential need for FGD for projects with environmental constraints. Although PC boiler technology can be designed to burn a wide range of fuels and meet more stringent emissions requirements, the addition of these design capabilities adds significantly to the plant size, footprint, auxiliary power losses and has a negative impact on capital and operating costs and new plant economics. CFB is a possible alternative solution.

The Company's CFB technology has been designed to operate using a wide range of fuels (anthracite/bituminous to lignite, petcoke to biomass) with a range up to 280MWe (gross) in size. In 2012 the Company commenced a feasibility study to assess the possible advantages of CFB technology and how larger scale CFB boilers at USC steam conditions may perform on a technical and economic basis.

USC CFB CONCEPT DEVELOPMENT AND TECHNOLOGY SCALE UP

The Doosan Lentjes CFB is based on a modular design concept[2]. The circulating fluidised bed process flow diagram is introduced in Figure 1 below:

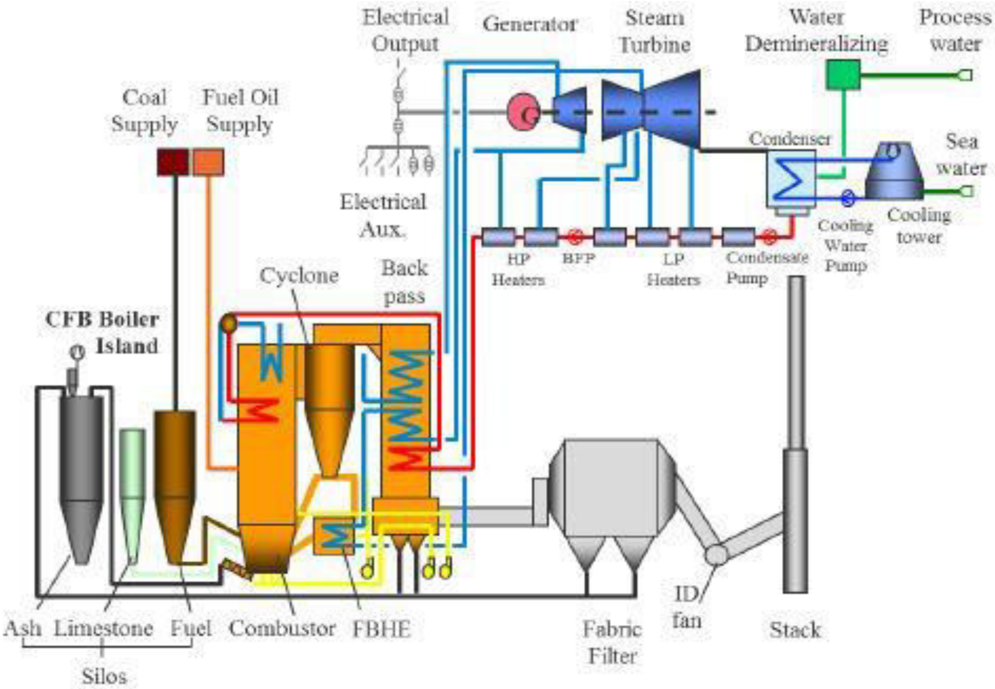

Figure 1 – CFB Process Flow diagram (Sub-critical steam cycle)

The CFB process comprises:

1) A refractory lined combustor (furnace) where fuel is fed from the coal bunker and coal crushers onto a bed of sand, which is fluidised from below by pre-heated air supplied from blowers;

2) Water or steam cooled cyclones, where the solid products of combustion and unburnt fuel are separated from the flue gas;

3) A seal pot and return chute where the solids are re-circulated back into the combustor or sent on to the FBHE;

4) The fluidised bed heat exchangers (FBHE) where a 'Spiess Valve' regulates the flow of hot solids and controls the heat transfer, thus providing the flexibility to maintain the combustor temperature in an optimum range even under part load operation and with different fuels;

5) The flue gas, from the cyclone, then travels through the convective back pass, where further heat transfer to the water/steam cycle takes place, then on to the stack.

This process offers several advantages. It is applicable for a wide range of fuels and has been consequently developed to cope especially with lower grade solid fuels. The process offers in-situ desulphurization with the help of limestone and with controlled/staged combustion the emission limits for SOx and NOx can in most cases be met without the need of external emission reduction equipment. Additional to these features the Doosan Lentjes designed CFB technology makes use of controllable fluidised bed heat exchangers (FBHE) as part of the boiler which mainly enables optimum control of the combustion temperature even under variation of the fuel quality and load range and adjustment of the boiler capacity. The "Spiess Valve" ensures safe and reliable control of hot ash flow to the FBHE. The FBHE delivers the following advantages:

- Constant combustion temperature at optimum level, even over a wide load range, resulting in
    - Thermal NOx suppression
    - Minimal limestone consumption for desulphurization
    - Excellent combustion efficiency with good carbon burn-out over the full load range
    - Avoiding sintering, agglomeration or slagging from ash with low fusion temperatures
- High fuel flexibility, i. e. use of a wide range of fuels in individual CFB boilers while showing all features mentioned above
- Highly efficient heat transfer with lower erosion and corrosion risks
- Varying fuel qualities during boiler operation
- Opportunity to place high temperature superheater surfaces into the FBHE rather than into the flue gas thus avoiding high temperature corrosion.

The modularized concept currently covers 1, 2, and 4 Cyclone Modules, where a module comprises of a cyclone, combustion section, seal pot and FBHE return. This modularized concept has been extended to the 6-8 Cyclone USC CFB class, which can be optimised and adapted depending on the project case and corresponding capacity as shown in Figure 2:

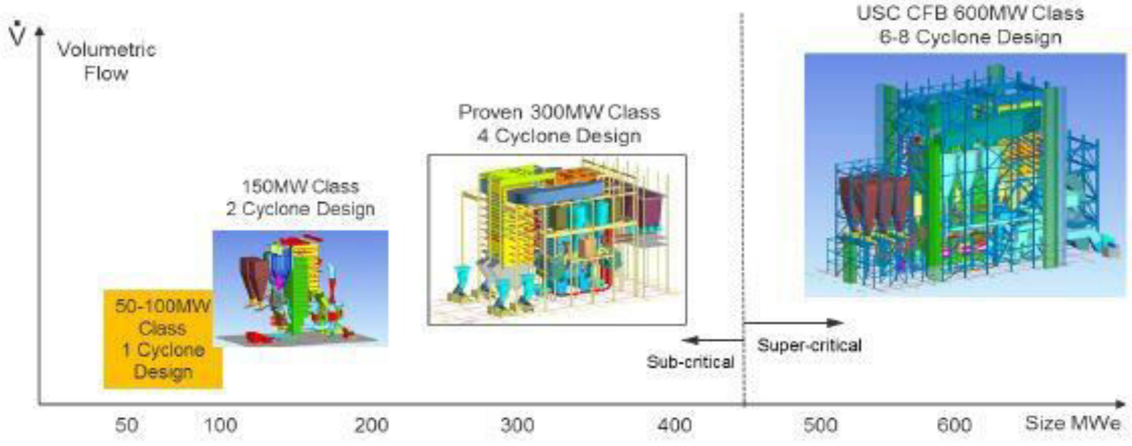

Figure 2 – CFB Module Range

The decision for the application of the right module is determined by the volumetric flow of the flue gas (V), taking into consideration the limited flue gas velocities in the combustor and the cyclone and by the maximum diameter of the cyclone. The specific volumetric flue gas flow is governed by the calorific value, the moisture content of the fuel and the ambient pressure which is dependent on the site elevation. The nominal flue gas flow at a site level of 1600 m e.g. at Mpumalanga in South Africa or in Anatolia/Turkey is remarkably higher than that at sea level. With the concept of 1, 2 and 4 Cyclone Modules we standardised the application range between approx. 70-400 MWe depending on the fuel characteristics and the site conditions.

A 6-8 cyclone design was defined for the USC CFB feasibility study where the unit size was set at 600MW gross based on the demonstration project requirement in South Korea. Doosan Lentjes undertook the basic process design, heat transfer surface sizing/arrangement, thermal performance and mechanical arrangement/3D visualisation. In addition to this the product development roadmap and basic design schedule were outlined. In parallel to this Doosan Babcock were engaged to identify the USC boiler design features for integration into the final basic design and materials requirements. The following technical challenges are part of the development programme:

1. Scale up of the combustor and introduction of PosiflowTM vertical furnace tubing with once through ‘Benson’ technology to improve furnace performance and auxiliary losses, simplify construction, and optimise cost
2. Validation of analytical results of combustion behaviour and gas/solid flow pattern
3. Adoption of approach used in integrated design for 150MW CFB class.
4. Design optimization for maximized fuel flexibility value and reliability

The outline design requirements for the South Korean USC CFB Boiler concept are presented in Figure 3 below:

Requirement	Target Value
Unit Size (MWe gross)	600
Main Steam Temperature (°C)	610
Main Steam Pressure (barg)	280
Reheat Steam Temperature (°C)	621
Fuel – Indonesian LRC – LHV/HHV (kcal/kg)	3896/4250
Location/ Arrangement	Coastal/ Sea Water cooled 6 Cyclones
Boiler Thermal Efficiency (%HHV)	>85
Boiler Availability (%)	>90
Outlet SOx (ppm@6%O_2)	50
Outlet NOx (ppm@6%O_2)	50
Outlet Dust (mg/Nm³@6%O_2)	15

Figure 3 – South Korean Demonstration Project Requirements

USC CFB DESIGN CONCEPT FOR THE ASIAN MARKET

The USC CFB Design concept offers an advantage over pulverised coal technology where greater fuel flexibility can deliver fuel cost savings and lower cost generation. CFB technology has been demonstrated to cover a broad range of fuels. Figure 4 below presents the extensive range of fuels for which Doosan Lentjes has experience and references. As originally stated the primary design consideration for a USC CFB boiler design in Asia begins with understanding the fuel properties and the likely impact they will have on key design parameters.

Fuel Experience	Carbon %	Sulphur %	Ash %	Moisture %	HHV MJ/kg [kcal/kg]
Biomass	20	0.03	2	40	15.00 [3583]
Oil Shale	13.8	0.4	73.7	5	4.95 [1182]
Anthracitie Culm	44.8	0.8	45.1	15	6.85 [1635]
German Brown Coal	27.2	1.7	7	52.8	9.17 [2190]
Gujarat Lignite	43.3	2.5	19	24	16.50 [3940]
Kentucky Coal	63.7	4	12.9	4.7	20.05 [4790]
Anthracite	59.6	1.8	25.2	10	20.70 [4945]
Coal containing Chlorine	80	6.2	0.1	10	31.40 [7500]
Petcoke / Texas	82	4.5	2.7	7.3	31.80 [7595]

Figure 4 – Doosan Lentjes Fuel Range Experience

The USC CFB design concept for Asian market has been based on the following assumptions (with key parameters and target values in Figure 5):

1. The optimal USC CFB unit size for application by IPPs and state utilities in Asia is up to 660MWe (gross) unit.
2. 600°C main steam and reheat to deliver optimal pressure part life utilising existing proven materials (however higher steam conditions can be utilised).
3. It is expected that the cycle efficiency, boiler thermal efficiency, boiler availability levels and part load points would be comparable to USC PC units under the same fuel and site conditions.
4. Although there would be a fuel arbitrage opportunity with domestic coals it is considered that units with a need to use fuel flexibility to control imported coal costs would benefit the most. On this basis the concept design is based on an USC CFB with a coastal location burning Indonesian Low Rank Sub-bituminous coal (HHV 4250kcal/kg).
5. Depending on permitting requirements and fuel availability it is possible to develop a more environmentally sustainable solution with the inclusion of biomass co-firing. The impact on cost and performance would be subject to co-firing level and fuel properties.
6. The coal specified sets the size of the plant to a 6 cyclone unit with an estimated footprint of ~4950m^2 versus a similar USC PC unit @ ~5440m^2 (includes 900m^2 for FGD). If poorer quality coals are to be burnt an 8 cyclone configuration may be employed.
7. The USC CFB will achieve SOx emissions control through addition of limestone to the bed, whereas FGD will be required on any equivalent PC plant.

Requirement	Target Value
Unit Size (MWe gross)	660
Location / Cooling / Arrangement	Coastal / Sea Water cooled, 6 Cyclones
Fuel – Indonesian LRC – HHV (kcal/kg)	4250
Main Steam Temperature (°C)	600
Main Steam Pressure (Barg)	280
Reheat Steam Temperature (°C)	600
Boiler Thermal Efficiency (%HHV)	>85
Boiler Availability (%)	>90
Outlet SOx (ppm@6%O_2)	<50
Outlet NOx (ppm@6%O_2)	<50
Outlet Dust (ppm@6%O_2)	<15

Figure 5 – USC CFB Concept Design for Asia

USC CFB VERSUS PC TECHNOLOGY - BENCHMARKING VIETNAM

Techno-economic benchmarking was undertaken to evaluate the advantages USC CFB may have when benchmarked against Pulverised Coal plant technologies. The benchmarking exercise was completed using benchmark state of the art Wall fired and Downshot PC fired plant operating in Vietnam. This country was chosen because the power sector in Vietnam is presented with economic challenges regarding security of supply of fuel sources and the growing dependence on imported coals. The analysis first established the representative fuel diets currently being utilised and the boiler designs selected. PC technologies have historically been selected, with Downshot employed on the very low volatile indigenous supplies of Anthracite coal and Wall fired PC technologies being used for imported Sub-bituminous and Bituminous coals. CFB technology has been utilised where some fuel flexibility is envisaged and experience exists in country for a range of coals, but more importantly applied to sources of opportunity fuels like lower cost Anthracite coal slurries[3]. Both Downshot and Wall Fired PC required seawater FGD to meet environmental requirements[4]. Figure 6 presents the benchmark USC CFB plant conditions and fuel range.

Design Benchmarked	Once-Thru Ultra-Supercritical CFB, Coastal / Sea Water cooled, 6-8 Cyclones
Capacity	2x 600MWe
Steam Conditions	SH 600°C, 280Barg/RH 600°C
Fuel Range	Bituminous, Sub-bituminous, Anthracite and Anthracite Slurry (LHV= 4061 – 6000kcal/kg)
Ash Range	3 - 38%
Volatile Range	3 - 35%
Moisture Range	4 - 30%
Boiler Thermal Efficiency	>85 (%HHV) *as per ASME PTC4*
Boiler Target Availability (%)	>90
Outlet SOx ($mg/Nm^3@6\%O_2$)[4]	<273
Outlet NOx ($mg/Nm^3@6\%O_2$)[4]	<210
Outlet Dust ($mg/Nm^3@6\%O_2$)[4]	<84

Figure 6 – Benchmark USC CFB plant conditions and fuel range

Our proprietary techno-economic model was used to determine 25 year Levelised Cost of Electricity (LCOE) and Net Present Values (NPV) for USC CFB, Wall fired PC and Downshot PC technologies. The design input conditions were set for each plant configuration, with unit and plant sizes set to 600MW and 1200MW Gross for all cases respectively. Fuel diets were defined as follows:

1. For USC CFB – Bituminous (LHV 6000kcal/kg), Sub-bituminous (LHV 4443kcal/kg), Anthracite (LHV 4471kcal/kg), Anthracite Slurry (LHV 4061kcal/kg). Slurry only assessed blended with Anthracite (40% Slurry/60% Anthracite)

2. For Wall Fired PC - Bituminous (LHV 6000kcal/kg), Sub-bituminous (LHV 4443kcal/kg)
3. For Downshot PC - Anthracite (LHV 4471kcal/kg) only.

Plant performance levels (e.g. boiler and plant cycle efficiencies, auxiliary losses, availability) were derived by proprietary plant cycle analyses for each design/fuel case or taken from known plant data where available. The life of the plant has been assumed as 25 years. CAPEX levels were set from proprietary analysis and inputs for the OPEX side of the model (Fuel cost, limestone cost, Operating and Maintenance costs) were set using a range of proprietary and public sources. Fuel costs ranged from an estimated $17/mt for Anthracite/Slurry to $80/mt for imported Bituminous coal.

Attractive financing conditions (Debt/Equity Ratio 70%/30%, Cost of Debt 0.5%, Loan Term 25 years) and local economic taxation and inflation levels were assumed the same for all cases. The results of the techno-economic analyses are presented in Figure 7 below:

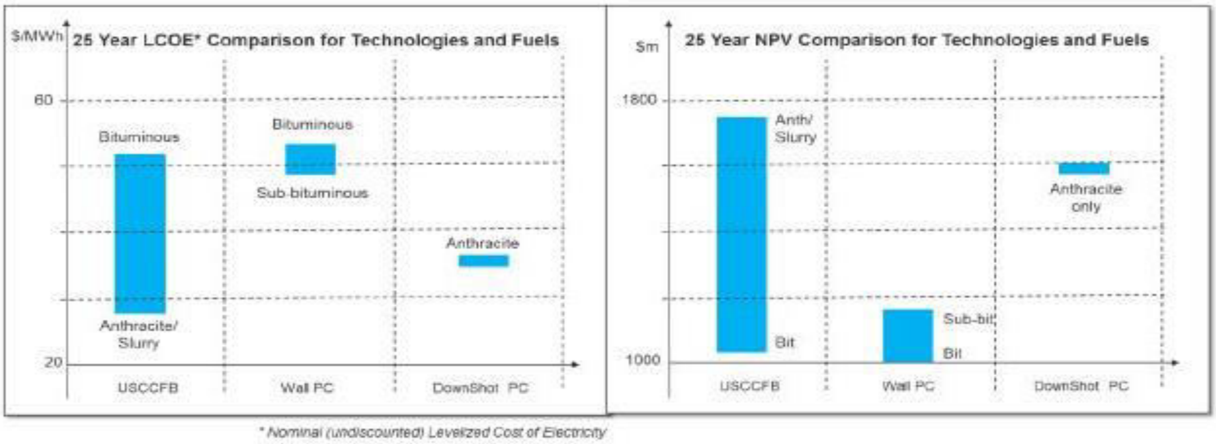

Figure 7 – Techno-economic Analysis of USC CFB Versus Wall Fired and Downshot PC

The results in Figure 7 demonstrate that USC CFB returns marginally better Levelized Cost of Electricity and Net Present Value on Bituminous coal when compared to wall fired PC technology, which is due in part to current PC solutions in Vietnam being at slightly lower supercritical steam conditions. However the true advantage of USC CFB fuel flexibility is shown in the range of LCOE and NPV where USC CFB out performs both Wall Fired and Downshot Fired PC solutions by being able to burn all coal types down to the lowest cost local Anthracite slurry blends. The result being that USC CFB operators will be able to achieve better returns on investment by utilising low cost opportunity fuels to mitigate fuel price volatility.

The NPV levels may appear much better than some project developers' experience, however this is due to the current low price of imported coals and the low finance and inflation levels applied across all cases (0.5% and 1.8% respectively). The actual numerical results may vary from project to project depending on the location, design requirements, fuel and other fixed/variable costs, environmental legislation, specific tax and inflation levels and project finance conditions. In certain countries co-firing of low cost biomass (e.g. Palm oil industry waste) will also offer economic advantages with a USC CFB.

The results of this techno-economic analysis was key in helping the Company commit to investing in the USC CFB development programme that will deliver a basic design for demonstration from 2016 onwards. The development programme was started in 2014 and key component and technology development work packages are well advanced ensuring the basic design integrates the combined capabilities from,

1. Doosan Lentjes on CFB Combustor and FBHE design and
2. Doosan Babcock USC PosiflowTM furnace design, USC materials experience.

CONCLUSIONS

1. The Company is currently scaling up its CFB boiler capability to 600MWe class for demonstration in South East Asia with target steam conditions at Ultra-Supercritical levels.
2. The plant design will couple CFB combustion design with proven supercritical boiler design for Pulverised Coal technology.
3. The USC CFB design for Asia will target unit sizes up to 660MWe with application to coastal locations where whole life cost savings from fuel arbitrage and FGD avoidance delivers lower cost generation.
4. Benchmarking USC CFB against other technologies for application in Vietnam confirmed the design's advantage in fuel flexibility accesses lower cost fuels and offsets the impact of imported fuel price volatility on LCOE and project NPV.
5. The USC CFB design for Vietnam can also accommodate biomass co-firing, supporting a more environmentally sustainable power plant solution with greater energy security.

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