LARGE SCALE UTILITY CFB TECHNOLOGY IN WORLDS LARGEST GREENFIELD
100% BIOMASS POWER PLANT
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Abstract: Major incentives on wind and solar power and decreasing consumption have nearly stalled thermal power investments in Europe. While fossil fuels are facing strong political pressures there seems to be a market for CO2 neutral thermal power and heat production. Today’s market situation requires fuel flexible technologies, while maximum efficiency and economics of scale drive towards utility size solutions. The world’s largest greenfield biomass power plant in the United Kingdom is taking the Circulating Fluidized Bed (CFB) combustion technology to the 300-MWe scale with 100% biomass fuels. MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MWe combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K.. The CHP plant will be provided by one CFB boiler supplied by Amec Foster Wheeler. The power plant will utilize wood pellets and wood chips that will be sourced from sustainable forest by-products in North America and sustainable wood chips mainly from the United Kingdom. Besides providing controllable and nearly CO2 free energy by using renewable fuels, the plant will comply with the most stringent emission limits set for the traditional (SOx, NOx, dust) as well as previously unlimited pollutants, such as NH3, Hg, HCl and HF. High-efficiency biomass power plants need to utilize advanced steam parameters and in Tees Renewable Energy Project (REP) they are 176 / 43.8 bar(a), 568 / 568 °C. With sufficiently clean biomass and state-of-the-art design, such high steam parameters can be applied while maintaining high availability and acceptable lifetimes of boiler pressure parts. When this CHP plant enters commercial operation in January 2020, it will introduce the world’s largest and most advanced 100% biomass fired CFB based power plant. This paper presents the key technical features in large scale biomass CFB-boiler technology.

1 INTRODUCTION
MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MWe combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K.. Reaching this stage required technical performance, such as fulfilling the new BREF emission limits covering multiple pollutants, meeting high efficiency energy production target and adapting the design to the variable properties of biomass from international sustainable sources.

Construction is taking place under an EPC contract with a joint venture of Tecnicas Reunidas and Samsung C&T, and it is scheduled to take approximately 3.5 years. The project will receive revenue fundamentally from the sale of electricity under a combination of a market price power purchase agreement (PPA) and a contract for difference (CFD), which provides a variable top-up between the market price and a fixed strike price.

The Tees Renewable Energy Plant will be the world’s largest CFB plant firing only biomass with a single unit producing 299 MWe. Also the steam parameters will be taken to a new level in this fully biomass-fired greenfield power plant, paving the way toward higher efficiencies. Technical readiness exists to even double the unit size if new opportunities come up, and further increases in efficiency are required.

This paper presents the key technical features and performance estimates of the high-efficiency process and state-of-the-art CFB boiler based power plant.

PROJECT OVERVIEW [1]
The Tees REP power plant in Teesside, UK is a 299 MW biomass project with combined heat and power (CHP) located in Teesport in England’s north east, near Middlesbrough. The project is located at the brownfield site near Teesport port facilities. The site has a long-term lease agreement with PD Ports. Construction is scheduled to last approximately 3.5 years.

Biomass Fuel [1]
The project’s primary fuel will be virgin wood pellets, as well as wood chips. The pellets will be supplied under a contract covering the majority of fuel requirements; the plant will combust more than 1 million tonnes fuel per year.

The plant is also expected to use a smaller amount of local virgin wood chips, sourced locally from UK that will be dried in an on-site chip drier before being used as fuel. No wood chipper exists on site – rather the wood chips will go through a quality inspection at delivery and oversized chips will be rejected.

Fuel will meet a sustainability threshold in terms of sustainable timber harvesting and CO2 footprint, which is guaranteed by the fuel supplier.

The plant will run from 70% to 100% on pellets with the remainder in the form of wood chips.

Pellets and chips will be delivered to the immediately adjacent quay, which is a deepwater jetty capable of handling up to Supramax size vessels (50000 dead weight tonnage, about 200 meters long). Some woodchips will be delivered by truck.

The project will deploy continuous ship unloaders for discharge of pellets along with a substantial conveyor system and 16 separate storage silos. The plant is able to be fed from any silo and this allows separation of different cargoes along with fuel blending.
HIGH-EFFICIENCY WATER-STEAM CYCLE [1]

The plant design is based on a regenerative steam cycle with reheat. It includes the boiler itself, one three pressure two body condensing steam turbine-generator (STG) with reheat, condensate extraction pumps, a feedwater tank with integral deareator, steam driven boiler feedwater pump and an electrical driven feedwater pump (back-up of the previous one) as well as feedwater heaters. An air cooled condenser is used to cool and condense the turbine exhaust steam.

The configuration of the system, the definition of the steam parameters and the sizing of the equipment have been selected and optimized in order to achieve a high efficiency of the plant and also to comply with the high reliability required by MGT.

The steam from the CFB boiler supplies the high pressure (HP) steam to turbine at 174 bar(a) and 567 °C. The exhaust of the HP body is returned to the boiler at around 46 bar(a) and 363 °C and after passing through the boiler reheaters is another time led to the intermediate pressure (IP) turbine at around 42 bar(a) and 567 °C.

In order to comply with these frequency response requirements, the HP steam header pressure must be controlled over the natural sliding pressure value so that the HP steam header can have enough back-up pressure upstream of the turbine control valves, which can let a quick increase of power when the turbine control valves open. This quick power increase requirement (primary response) happens when there is a grid frequency drop scenario.

The CFB boiler will be able to respond with the load ramp with overfiring as required to meet the steam conditions necessary to comply with the primary and secondary response requirement. Moreover, the steam turbine will be able to respond with the power generation output within the required time to meet all the grid code requirements.

FUEL STORAGE AND HANDLING SYSTEM [1]

Another key feature of the plant is the design of the fuel storage and handling system, which is one of the largest in the world for a biomass power plant. The system includes a ship unloader of 1600 ton/h of rated capacity, conveyors to take the fuel from the quay up to the boiler feeding, and a storage of about 260000 m3 of capacity by means of sixteen circular silos 27 m in diameter and 30 meters in height, and is capable to operate with both fuels (wood pellets and wood chips) and a mixture of them. The system is designed to supply to the boiler wood pellets and chips at a rate of 660 tons/h.

The silos will include a sloped bottom to
accommodate the vibrating floor, necessary for the correct reclaiming of the fuel from the silos. Laboratory tests of the flow ability of the fuels have been carried out to optimize the slope of the belts and to avoid any future problem during operation.

The risk of fire on this kind of plants is a strong concern for project developers and owners. In the design, the fire risk of this kind of fuel has been considered from the beginning, and the system includes features to minimize the level of dust release, the root cause of the fire risk, by the use of high performance filters in the areas where dust creation is possible (transfer points mainly). Also separate surveys have been made to achieve the maximum level of protection against fire by an extensive study of the potential areas where an explosive atmosphere could be created and with a detailed analysis of the active and passive protection systems and also fire suppression for each case.

TEES CFB BOILER DESIGN [1]

Large Scale CFB for Biomass Combustion – ABC Technology

The Amec Foster Wheeler ABC (Advanced Bio CFB) technology not only addresses the fuel issues related to biomass firing, but also adopts plant requirements and optimizes the investment factors. Plant requirements include the type of the boiler i.e. utility or industrial boiler, capacity, operational load range, steam data, emission limits and other requirements set by legislation. Investment factors include plant availability, fuel flexibility requirements, the investment costs and operation costs. Consequently, economical boiler designs have been developed to fire easy-to-burn biomass, while more robust solutions are implemented as the biomass quality degrades and becomes more challenging to burn reliably.

Key design features of the ABC technology are summarized in Figure 4.

The well proven ABC technology forms the basis also for the new concept with higher steam parameters in the Tees Renewable Energy Plant described in the next chapter.

Figure 4. Key features of the ABC technology.

Tees Boiler Design

General [4, 5]

CFB boilers operating on biomass only have typically used steam temperatures of approx. 540 °C and live steam pressures up to about 140 bar. Besides historical reasons – previously biomass was burned in relatively small units – the steam parameters have been limited due to commonly identified corrosion issues in combustion of biomass and waste derived fuels, attributed to the ash forming elements that largely define the degree of challenges in combustion, such as halogens (notably chlorine), alkali metals (mainly sodium and potassium), phosphorous and heavy metals (e.g. lead, zinc). Although higher steam parameters have been applied to some extent in smaller industrial boilers, it has become more important in large utility size boilers firing biomass. Reaching such high steam temperatures without major corrosion issues already calls for austenitic superheater and reheater materials, and applying these heat exchangers as fluidized bed units such as INTREX™.

Utility size biomass plants are aiming at maximum steam cycle efficiency, therefore live steam parameters in the order of 170 bar, 570 °C were selected for the Teesside boiler with clean biomass. Biomass in this case may be virgin wood pellets or chips, the origin varying in a wide range. With sufficiently clean fuel such a high steam pressure, which is about the maximum applicable in natural circulation boilers, is considered feasible with normally applied waterwall materials. Correspondingly, acceptable SH/RH lifetimes can be achieved with clean biomass. With clean woody biomass sand not only acts as circulating material but also serves as alkali getter, binding and purging away potassium with ashes. With more challenging type biomass, additives such as kaolin and elemental sulfur may be fed into combustor to control bed agglomeration, fouling and hot corrosion; the additive type and feed rate depending on fuel quality.

Fuels [3]

The design fuel is a mixture of virgin wood pellets (70 wt-%) and virgin wood chips (30 wt-%), therefore the moisture is quite low, but the mixing ratio is highly variable and the boiler is capable of burning up to 100 % pellets at full load. This means that the design shall be able to adapt to wide variations in heat value, and also in the chemical properties as a result of international fuel sourcing. Generally, boilers sized to handle the modest amounts of flue gas from dry pellets may have difficulties managing the considerably larger volumes of flue gas from wet chips. Conversely, furnaces designed to handle the moderate heat from wet chips may suffer overheating from drier and more calorific biomass and residue [2].

Biomass properties vary considerably depending on their biological origin, location, seasonality, farming and harvesting practices, and ultimately their preparation and processing. This leads to broad variations in chemical composition and physical properties across different biomass types and even within the same type. The related issues such as agglomeration, fouling and corrosion have been discussed in [2] and [3].

The fuels specified for the Tees project, in spite of being virgin woody biomass, may have elevated chlorine contents (max. 0.1 %dry). Such fuels have been characterized with various methods mentioned in [2], ranging from laboratory tests to pilot tests. Numerous challenging biomass fuels have also been burned in existing CFB (and BFB) boilers, and studied with in-house models.

Water-Steam Circuitry

The Tees CFB boiler features the following design parameters: approx. 650 MWth, 230/207 kg/s, 568/568 °C and 176/43 bar, a.

Figure 5 describes the water – steam circuitry of the Tees biomass CFB boiler. The feed water is led to a
series of conventional feed water heaters that use steam extracted from the turbine. Next, the feed water stream enters the boiler at a temperature of about 260 °C for preheating in a bare tube economizer. Thereafter water is taken to the drum; the boiler is of natural circulation type. From the drum water is led via downcomers and distribution headers to the evaporator (furnace) walls. The water is heated in the evaporator wall tubes, turning partly into steam at constant temperature and the water-steam mixture is taken from the evaporator outlet to the drum where water and steam are separated.

The main steam temperature is controlled with feed water sprays. Steam after the high-pressure turbine is brought back to the boiler for reheating. The first stage reheater is located in the convection pass and it is equipped with a steam side bypass used for reheating steam temperature control. At higher loads part of the reheat steam bypasses the RH I, which reduces the heat pick-up and hence the inlet steam temperature to RH II is decreased. With this patented reheat steam control method spray control is normally not required on the reheat side, and therefore the related decrease in plant efficiency is avoided. Also the second stage reheater is located in the convection pass, and it is followed by the DSH (that is normally closed). Final reheating (RH III) is performed in two INTREX units on opposite sides of the furnace below the separator(s) [3].

Figure 5. Water-steam circuitry of the Tees CFB boiler.

The Tees CFB boiler is designed for sliding pressure operation in order to maximize the efficiency within the load range; besides base load operation the boiler shall be capable of rapid load changes.

Dynamics [3]

Load change flexibility of thermal power plants can be maximized by joint operation of the boiler (steam generator), the turbine system and the balance-of-plant (BOP) system; e.g. condensate throttling. The performance of the boiler depends on the type of steam generation process (drum or once-through boiler), the operation mode (constant or sliding pressure), and the thermal (combustion) capacity of the plant. The constant pressure drum boilers are capable for 3 – 4 %/min ramp due to the large throttling reserve of the turbine valve and the large stored energy.

The dynamics of the steam generation can be further improved by over-firing the boiler; i.e. the maximum heat input to the boiler temporarily exceeds that of the nominal MCR. The load change capability of the Tees 299 MWe unit is demonstrated by dynamic simulation in Figure 6; a 10 % step change in the generated power in 10 seconds is achievable. This quick change is due to the large storage capacity of the steam generator. The recovery time of the main steam pressure – which is the

long term operation – was improved by the over-firing of the boiler. Note, that the initial pressure drop is independent of the combustion capacity.

Figure 6. Improved performance by over-firing the boiler; steam mass flow to the turbine and main steam pressure.

Furnace Design

Figure 7 shows a 3D view of the CFB boiler's furnace and back pass area. The furnace has a single water-cooled fluidizing grid with combination of AmecFW step grid and novel design grid nozzles. It is provided with refractory protection on the upper side, and bottom ash discharge openings distributed across the grid ensure efficient removal of bottom ash and foreign material from the grid. The single continuous fluidizing grid ensures simple control as well as a stable and uniform operation of the furnace.

Figure 7. Tees 299-MWe biomass CFB boiler.

The lower furnace is refractory-lined and tapered so that the grid area is smaller than that of the upper furnace cross section, which provides high internal turbulence of the fluidized bed and enables efficient mixing of fuel and secondary air. Secondary air nozzles provide approx. half of the combustion air.

The flue gas side furnace design is based on extensive analysis of the fuels that are going to be used. This has given the required data for the design models to make predictions for circulating material particle size distribution, solids densities and finally the heat transfer and gas temperatures within the entire load range and specified range of fuels.

From the top of the furnace, through openings in the front and rear wall the flue gas flows into four steam-
cooled high-efficiency solids separators, two on each side. Separated solids are discharged from the bottom via non-mechanical gas seal into INTREX units, one below each separator. Two INTREX units serve as the final SH, and the other two as the final RH stage [2].

Table 1 shows a comparison of the design steam parameters of the Tees 299-MWe biomass CFB boiler, the GDF Suez Energia Polska S.A. Polaniec CFB boiler (205 MWe, gross) that has been successfully operated since 2012, the Kaukas 125-MWe (152 MWsteam, 110 MWDH) CFB in Finland that entered commercial operation in 2009, as well as the Samcheok (4 * 550 MWe, gross) CFB boilers designed to fire moist, low-ash, high-volatile Indonesian coal and biomass.

Table 1. Scale-up of biomass CFB vs. the largest utility-size CFB.

<table>
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<tr>
<th>Parameter</th>
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Layout of the Boiler Island [1]

Figure 8 shows a 3D view of the boiler island. The boiler is located in a closed building. After the convective heat exchangers and catalyst, the flue gas stream is divided for the rotary air preheater (RAPH) and an additional heat exchanger called bypass economizer, which heats up part of condensate extracted from the turbine island, thereby reducing need for turbine steam extractions. These parallel streams are joined before the flue gases are cleaned in a high-efficiency baghouse. Between ID fans and stack, further cooling of gases takes place in a Heat Recovery System (HRS). At the HRS, gases are cooled down to a potentially corrosive temperature, nevertheless far above water dew point, in a corrosion resistant flue gas water heat exchanger provided with plastic tubes. A closed cooling water circuit transfers heat into combustion air upstream of the RAPH, replacing auxiliary steam normally needed in the first stage of air preheating. As a result of lower flue gas exit temperature, lesser steam extractions and auxiliary steam consumption, the boiler efficiency and overall process efficiency are improved. A similar system has been in operation e.g. at the 458-MWth biomass CFB boiler in Jyväskylä, Finland since 2010.

Figure 8. View of the boiler island.

Emissions Control [1]

The emission limits set for this project are in line with the new IED and anticipated LCP-BREF requirements. The controlled pollutants include sulfur dioxide/trioxide (SOx), nitrogen oxides (NOx), dust, carbon monoxide (CO), ammonia (NH3) slip, mercury (Hg), hydrogen chloride (HCl) and fluoride (HF). The CFB combustion technology provides inherent mechanisms to reduce various pollutants to a low level; however the strict limits based on BREF call also for additional measures. Several technologies are available for control of acid gases (SOx, HCl, HF) and heavy metals (Hg), e.g. CFB scrubbers and spray dry sorbers (SDA), but in biomass combustion the simple and proven dry sorbent injection (DSI) technology is considered more economical.

In DSI, powdered sorbent is pneumatically injected into the flue gas, acid gas is adsorbed onto the sorbent and dry waste product is removed via a particulate removal device. It is a simple system with low capital cost and also low operation cost when the required level of acid gas removal is moderate. DSI provides efficient control of the acid gases HCl, HF and SO3 and acid dew point by calcium hydroxide or sodium bicarbonate sorbents, but limited SO2 removal capability. By injecting also powdered activated carbon (PAC), also mercury and dioxins and furans can be absorbed.

The emissions control concept selected for the Tees project includes the following gas clean-up facilities:

- High-efficiency fabric filter combined with DSI to control Particulate matter
- DSI with hydrated lime for control of acid gases (SO2, SO3, HCl, HF) (not needed with normal clean biomass but could be required with some high-S biomass)
- Activated carbon injection (if required) for Hg control
- Selective non-catalytic reduction, SNCR, i.e. ammonia injection into separators and/or into furnace depending on load, for NOx control
- A slip catalyst in-between two economizer stages to minimize NH3 slip while utilizing SNCR for DeNOx [3].

SUMMARY

Today's market situation for thermal power in Europe calls for CO2 neutral and fuel-flexible technologies capable of grid control, while maximum efficiency and economics of scale drive towards utility size solutions. Conventional thermal power generation has an increased role to compensate for the variation of renewable power generation. Simultaneously, tightening emission regulations also sets new requirements for thermal power project developers and technology vendors. Amec Foster Wheeler has continued the development of its innovative circulating fluidized bed (CFB) combustion technology as well as back end emission control systems and combinations of those in order to meet the increasing challenges.

Reflecting the above-mentioned trends in power production, MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MWe combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K. The Tees Renewable Energy Plant is taking the Circulating
Fluidized Bed (CFB) combustion technology to the new 299-MWe scale with 100% biomass fuels. The steam parameters (SH/RH 176 / 40.4 bara, 568 / 568 °C) will rise to a new level in fully biomass-fired greenfield power plants, which together with an optimized process design will enable high efficiency in power production. Technical readiness exists to even double the unit size if new opportunities come up, and further increases in efficiency are pursued.

This paper presents the key technical features and performance estimates of the high-efficiency process and state-of-the-art CFB boiler based power plant.

REFERENCES