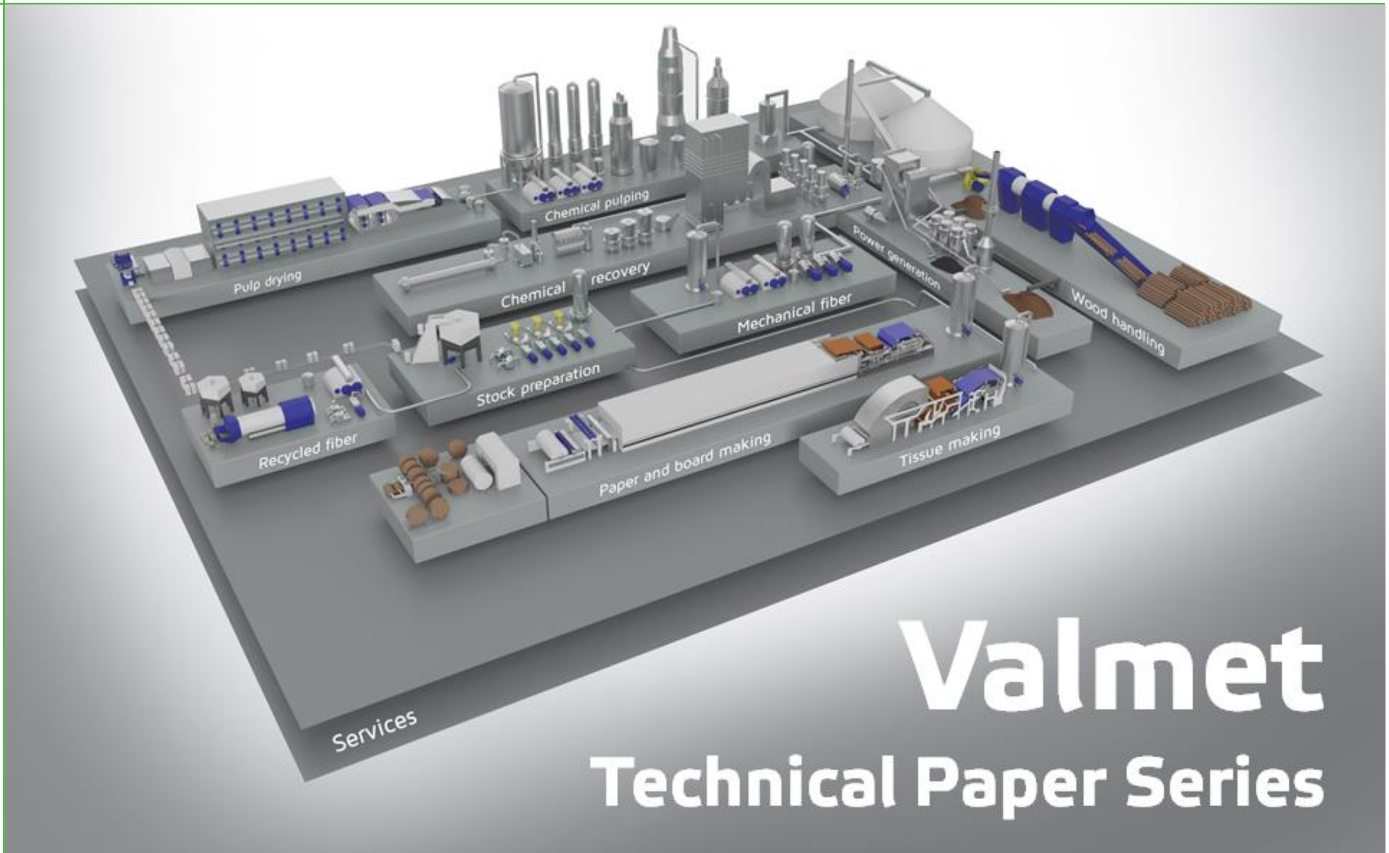

CFB's Evolution from Coal-only Boiler to Biomass – or Anything in Between

Executive Summary

Valmet and its predecessors have been developing and delivering circulating fluidized bed (CFB) boilers for more than 30 years. There has been a huge evolution in CFB technology, especially in customers' technical demands and also in emission requirements. Whereas in the 1980s CFBs were only coal firing equipment, today they are multifuel firing equipment, and sometimes even 100% biomass boilers. Also, boiler conceptual designs and mechanical structures have changed a lot since the 1980s. Back then, in a coal-fired unit, heavy refractory covered components met the requirements, but today in the world of multiple fuels, the structures are fine-tuned to meet the needs of combusting high volatile content fuels and very demanding fuel chemistry.

Valmet has delivered dozens of biomass or biomass co-firing projects during the last 25 years. This paper examines their evolution using real project examples together with lessons learned, and speculates on upcoming improvements. CFB technology has adapted to market needs over the last 30 years, from high-ash coal to low-calorific-value biomass, and from per coke with a high sulfur content to waste fuel with a high chlorine content. Boiler component design has followed customers' needs, and at the same time reliability has increased and the need for maintenance has decreased. Fuel qualities are becoming more demanding, while steam values are increasing.

Introduction

This is Valmet's overview of the evolution of CFB as a result of systematic development work as well as lessons learned in projects in a world where everyone is trying to find the most competitive fuel combination. Valmet's CFB development started in the early 1980s in the USA, Sweden, and Finland, and truly multifuel CFB development started in one Swedish project, where the customer decided to build a CFB burning coal with the option to burn some biomass. Finally, when the boiler started commercial operations in 1993, it was firing 100% biomass. Since then, there have been many improvements in CFB design, including water-cooled cyclones and loop-seals, higher steam parameters and sophisticated fuel feeding systems.

The next big development in CFB design took place when demanding biomass fuels with high chlorine and alkali metal levels entered the fuel portfolio. Corrosion minimization had to improve significantly due to these fuels.

Valmet as technology provider

One very efficient way to fire demanding fuels, such as fuels with a high ash or moisture content, is fluidized bed technology. The existing fluidized bed technologies are bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). Valmet has been manufacturing fluidized bed boilers since the 1970s. Initially, we built BFB boilers for low-calorific biofuels. In the 1980s, Valmet's product offering expanded with CFB boilers for fossil fuels and biomass in any combination. To date, Valmet has delivered over 290 fluidized bed boilers for different kinds of fuels and fuel mixtures.

Valmet is the leading global developer and supplier of process technologies, automation and services for the pulp, paper and energy industries. Valmet aims to become the global champion in serving our customers.

Valmet has received approximately EUR 3.1 billion in orders in 2016. Our 12,000 professionals around the world work close to our customers and are committed to moving our customers' performance forward – every day. Valmet's head office is in Espoo, Finland, and our shares are listed on the Nasdaq Helsinki.

Valmet has its own fluidized bed technologies for BFB and CFB, and is actively developing these technologies. The brand name of Valmet's CFB boiler is CYMIC, and the BFB boiler is called HYBEX. Valmet's Research Center in Tampere, Finland provides excellent possibilities to test new fuels. It has three different sizes of test reactors for fuel testing, and the main focus during the last fifteen years has been to utilize renewable fuels and low-cost fossil fuels.

The CFB process in a nutshell

CFB technology (**Figure 1**) was originally developed to burn a variety of different kinds of low-grade fuels that are not suitable for pulverized coal (PC) or grate-fired boilers. A large amount of inert bed material involved in the process allows a lot of variation in fuel properties or changing fuels on-line without any significant disturbance in the process. Circulating solids improves heat transfer and

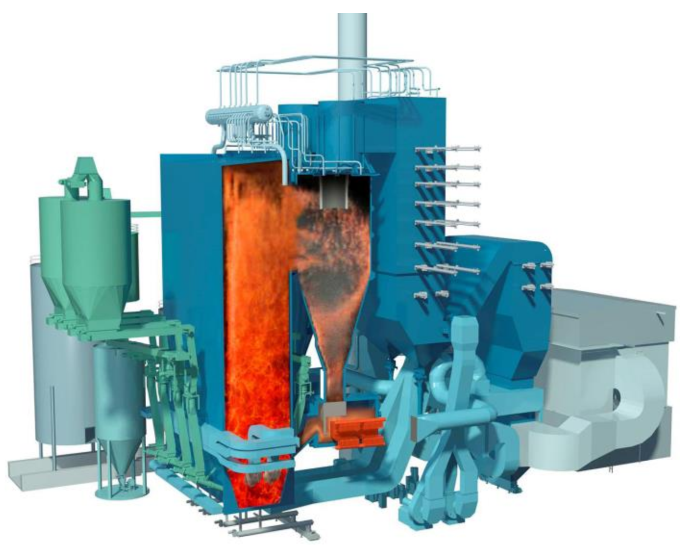

Figure 1. CFB process overview

makes it possible to burn high-calorific-value fuels while keeping the combustion temperature in the range 850–900 °C. The low combustion temperature minimizes fouling and slagging of heat surfaces, since ash melting and softening points are much higher than combustion temperature in a CFB. The low temperature also makes emission control quite easy. The solids circulation in CFB provides a long residence time for the fuel and limestone particles, meaning high combustion efficiency and low sorbent consumption.

Excellent performance of the cyclone is key to efficient combustion and low limestone consumption. Limestone is used for removing sulfur. Cyclone performance also determines the split between fly ash and bed ash. The long combustion time and low combustion temperature mean that very different types of fuel can be burned in a CFB boiler. For instance, coal qualities with a very high ash content can be burned efficiently with CFB while a pulverized coal (PC) boiler cannot.

Customer demand as a driver in development

CFB design in the1980s – low-grade coals

Wider use of CFB boilers was started in the 1980s (**Figure 2**). In most cases, the fuel was coal. The reason why CFB was able to beat prevailing technologies, such as stoker and pulverized coal boilers, was the capability to burn coal qualities with a very high ash content. The reasonably low combustion temperature prevents any slagging and fouling, even with a very high ash content. Many of Valmet's first CFB references were firing waste coal – culm and gob. Culm is anthracite waste (ash content 65% or higher), and gob is bituminous coal waste (ash content around 50%). The driver for using these fuels was their low price, and naturally the plant was built next to the mine.

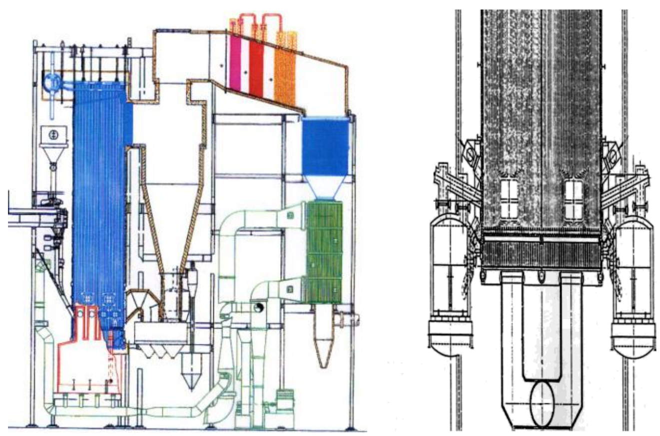

Figure 2. Left: Wheelabrator Frackville Energy Inc., PA, USA CFB boiler. Fuel: culm. Start-up: 1988. Steam values: 51 kg/s, 90 bar, 513 °C. Right: external bed ash cooler design in the 1980s.

A high ash content naturally decreases the calorific value of the fuel, but on the other hand the ash content does not vary much. Combustion is very stable due to the huge amount of circulation material. The first CFB boilers were equipped with water-cooled membrane furnaces, but the cyclone was always a hot cyclone with a very thick refractory layer. Some suppliers applied a plate design for the lower furnace as well.

High-ash fuel also means that the material handling systems are very important parts of the boiler design, i.e. fuel in and ash out. The bed ash system design is especially important; if the bed ash is removed without any cooling (850–900 °C), the heat losses are quite significant, and handling the ash is also very challenging. Valmet's first-generation bed ash cooler was a refractory covered vessel, and the ash was cooled using combustion air. The ash drain pipe from the lower furnace brings the hot material into the cooler, and the air connection feeds hot air back to the furnace as secondary air.

Connecting boiler pressure parts together with uncooled refractory covered plate casing components means many expansion joints in order to compensate for differential thermal movements. Hot expansion joints were typically in cyclone inlets, with a loop seal return back to the furnace and a cyclone outlet duct connection to the second pass.

CFB design in the 1980s fit its purpose reasonably well, but the need for maintenance was quite high and reliability quite low compared to competing technologies. Thick refractories and expansion joints in the hot loop caused much additional maintenance every year. A major overhaul for a refractory also took quite a long time, and shutdowns could last several weeks.

New fuels changed CFB design in the 1990s – high volatile content fuels

The benefits of the CFB process were better understood once more units were operating around the world. There were small, biomass-fired CFB boilers already in the 1980s, mainly in Sweden. Most of those were hot water boilers providing district heating to cities.

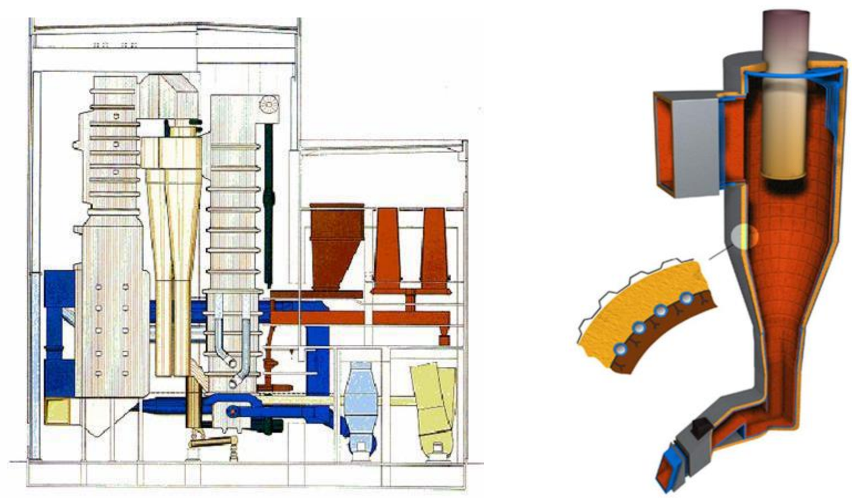

Figure 3. Left: Örebro 165 MWth CFB boiler with water-cooled cyclone. Start-up: 1990. Fuels: biomass, peat and coal. Right: principle of water-cooled membrane cyclone.

The real biomass boom started in Sweden in the 1990s. One of the first larger-scale biomass CFBs was built in Örebro, Sweden (**Figure 3**) by Valmet's predecessor Götaverken. This boiler started up in 1990. Today it is owned by E.ON Sverige. This boiler is also one of the world's first CFB boilers to have water-cooled membrane cyclones. The boiler capacity is 165 MWth, and it was designed for 100% biomass, 100% bituminous coal, or any combination in between. After the investment decision, there have been many changes in regulations in Sweden, resulting in biomass replacing coal almost completely. Thanks to fuel flexibility, CFB owners have survived. Fuel combinations have been over 60% biomass, 30% peat, and a few percent of coal. Coal is mainly a support and back-up fuel. The biomass comes from several sources and some comes crushed, but part of the biomass is crushed at the site. The biomass can be wood chips, forest residue or sawdust.

The Norrkoping boiler (**Figure 4**), also owned by E.ON Sverige, is about the same age as the Örebro boiler, having been in operation since 1993. The steam capacity of the boiler is 125 MWth, and this boiler is also equipped with cooled membrane cyclones because of its biomass fuel.

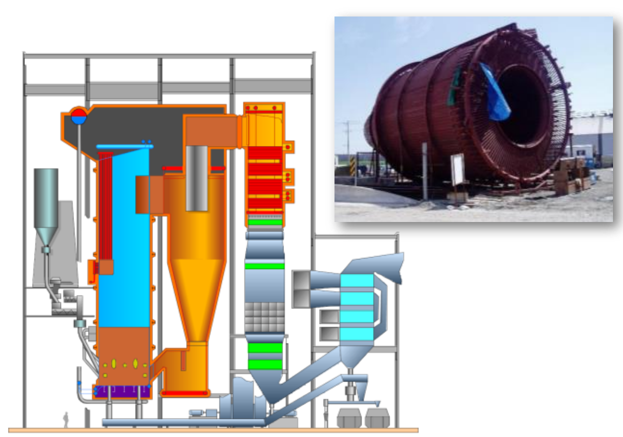

Figure 4. Norrkoping CFB boiler – in operation since 1993.

Like the Örebro boiler it is involved in co-generation of electricity and district heating. The design fuels were originally 100% biomass and 100% coal, and the expectation was to have the fuel mixture clearly on the coal side when starting up. Finally, due to taxation changes in Sweden, the boiler ended up firing 10-15% coal and the rest was biomass. Soon after that it was

100% biomass. The biomass feedstock is prepared from whole trees, including roots, branches and tops. The biomass is crushed at the site. There was also a unique feature in this boiler – for the first time ever in a fluidized bed boiler firing biomass, there was a selective catalytic reduction (SCR) system for NOx control. Unfortunately, knowledge of how catalysts operate with biomass was not at a sufficiently high level, and heavy fouling and catalyst poisoning forced the owner to remove the catalyst after a trial lasting a couple of years. Luckily, a selective non-catalytic reduction (SNCR) system gave the same NOx-reduction performance.

The fuel mixture has changed over the years. In a certain time period, this boiler fired 20– 25% of TDF (tire-derived fuel), with the rest being biomass. TDF is chipped into 25 mm pieces, and the main wire ropes are removed before crushing. Biomass quality is also getting worse all the time. The huge demand for biomass in the market has led to the situation where the fuel price has increased and quality has fallen. By firing some part of the fuel mixture with TDF with a high heating value (around 32 MJ/kg), it is possible to accept lower-quality biomass and maintain the original performance.

The lesson learned from using demanding biomass is that maintenance challenges are different than in coal firing. By having forest residue as a fuel – especially when crushing it at the site with all the rocks – fuel feeding system maintenance is continuous. Rocks in the fuel are very abrasive, so the biomass silo screw discharger must be hard-welded during every outage.

Multifuel approach in the late 1990s

Approaching the end of the 1990s, customer demand changed again. In Scandinavian countries, taxation favored the use of biomass, but one challenge was the availability of reasonably priced biomass qualities. This lead to a situation with a wide design fuel portfolio. A very good example of this kind of project is Alholmens Kraft's CFB project in Pietarsaari, Finland (**Figure 5**).

Alholmen started up in 2001, when it was physically the largest CFB boiler in the world; it is still the biggest CFB capable of burning 100% biomass. The design basis was to maximize the use of domestic fuel (biomass and peat), and also to secure operations by having 100% coal back-up. This CYMIC boiler was originally designed to burn peat, wood, and bituminous coal in any fuel combination. The steam data in this reheat unit are 194/179 kg/s, 545/545 °C, and 165/40 bar, meaning an electrical capacity of 260 MWe. The fuel mixture has varied year by year, for many reasons. In some years, biomass availability has been poor, and in some years, peat quality and availability have been very bad due to the rainy summer. Then, the mixture has been balanced with more coal.

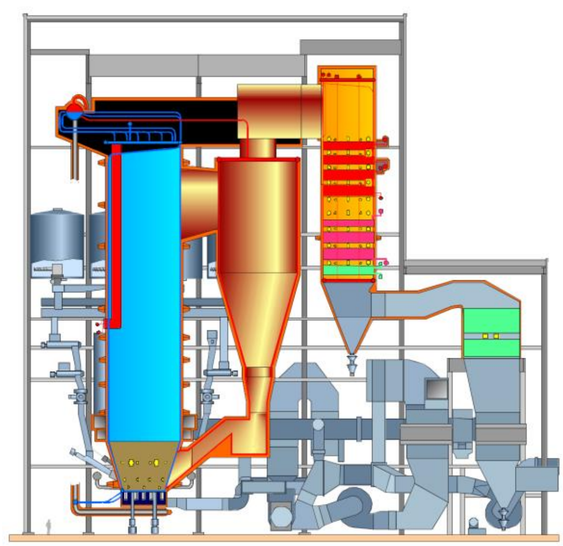

Figure 5. Alholmen 260 MWe multifuel CFB.

When starting to design this boiler, Valmet already had years of experience of using biomass in CFB. The new lessons learned were related to some new biomass qualities, like stumps. The challenge comes when stumps are crushed at the site, including all the soil and gravel.

When stones are crushed, the result is very sharp, small stones, which also go into the boiler. Abrasive particles caused wear in the primary air nozzles and in the cyclone target area refractory. Primary air nozzle wear was solved by developing a new nozzle with a new material (high chromium cast) that can withstand very abrasive conditions. The type of refractory was changed in the target area to prefabricated tiles, and the lifetime of the refractory increased dramatically.

Petcoke boom in the early 2000s

There was a brief boom of petcoke (petroleum coke) and high-ash coal projects, especially in the US market, at the beginning of this millennium. CFB development actions had been more on the biomass and multifuel side throughout the 1990s, but now the need was to combine 1980s coal design with 1990s biomass design to meet modern boiler requirements. The only feature that petcoke and biomass share is a very low ash content. Petcoke has a high heating value (usually 32 MJ/kg) and a high sulfur content (6%), which means that a lot of limestone is needed to keep SO_2 emissions below given limits. Since the ash content is low, the bed is mainly limestone. Good cyclone performance is important in order to minimize limestone consumption. When the cyclone performs well, there is more bed ash than fly ash, and bed ash must be removed from the furnace. The bed ash must be cooled down before removal from the boiler, like with high-ash coals.

One of the petcoke plants from that time is the Manitowoc Public Utilities 60 MWe CFB plant (**Figure 6**), with steam values of 60 kg/s, 103 bar and 541 °C. It is designed to burn either 100% bituminous coal or 100% petcoke, or any mixture in between, and it started up in 2005. This boiler is equipped with a water-cooled cyclone and a water-cooled integrated bed ash cooler, which were new features for a coal-fired design.

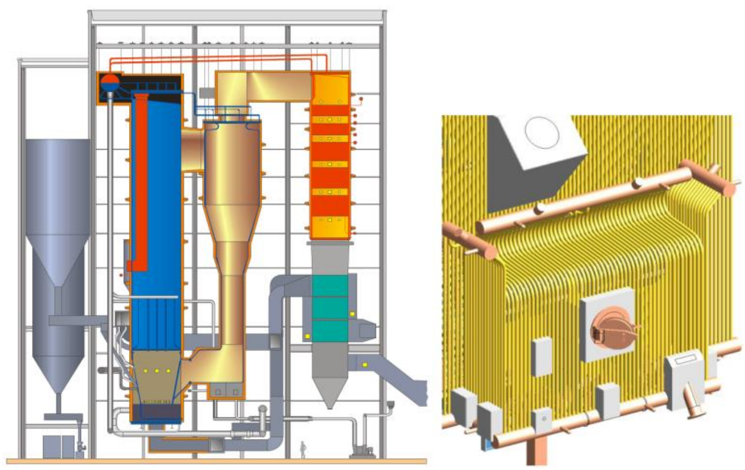

Figure 6. Left: Manitowoc 60 MWe petcoke-fired CFB boiler. Right: integrated bed ash cooler.

The integrated bed ash cooler seen in **Figure 6** (**right**) is constructed using the furnace membrane side wall, and the actual cooling is done by air fluidization: Air is taken from the primary air system. It goes through the ash bed, and after that it goes into the furnace as secondary air through air nozzles located in the upper part of the bed ash cooler (BAC). The BAC has an inlet opening from the furnace at one end and an ash removal chute at the other end. The design basis for the BAC is that ash is cooled from the bed temperature (850–900 °C) to 200 °C. Differential heat goes back to the furnace with the air, markedly reducing the heat loss.

Lessons learned from Manitowoc related to bed chemistry. A limestone bed with practically no inert material together with a very high SO2 content can lead to very fast sulfation and agglomeration in locations where fluidization is poor. One place that this can happen is the cyclone dip leg and loop seal. This risk can be mitigated by adding some inert material to the process, such as sand. The conclusion from Manitowoc is that blending 93% petcoke and 7% coal without adding sand is the economical optimum. Emission performance was excellent: a 97% SO_2 reduction was achieved with a Ca/S molar ratio of around two.

Toward increasingly demanding fuels

Waste fractions and agro-biomass fuels were the next new fuels for CFBs, either co-fired with other fuels, or fired alone. The trend for having more and more design fuels in one boiler continued. Waste fuels and agro-biomass have some similarities, like high chlorine and alkali metal contents.

A good example of waste co-firing with other fuels is Porin Prosessivoima's CFB boiler (**Figure 7, left**), which started up in 2009. Refuse-derived fuel (RDF) is very cost competitive – sometimes having a negative price – but it also makes the fuel chemistry much more challenging. In the Pori boiler, the entire fuel portfolio is wood-based biomass, peat, coal and RDF. RDF is limited to 10% of the fuel mix, and the other fuels in the mixture burned are based on cost and availability. The steam data of the boiler are 67 kg/s, 84 bar, and 522 °C. With 10% RDF content, the chlorine content in the fuel mixture is about 0.1%. In order to minimize the risk of high-temperature corrosion, the finishing superheater is located in the cyclone loop seal inside the bed material, and convective superheaters are in a parallel flow with flue gases in the second pass. Having the finishing superheater in the loop seal was a new design with a completely different loop seal design than previous boilers. In this design there is a double lock toward the furnace, but also toward the cyclone. This minimizes any flue gas entry into the superheater chamber. The experience at Pori is that there has not been any corrosion on any superheater surface.

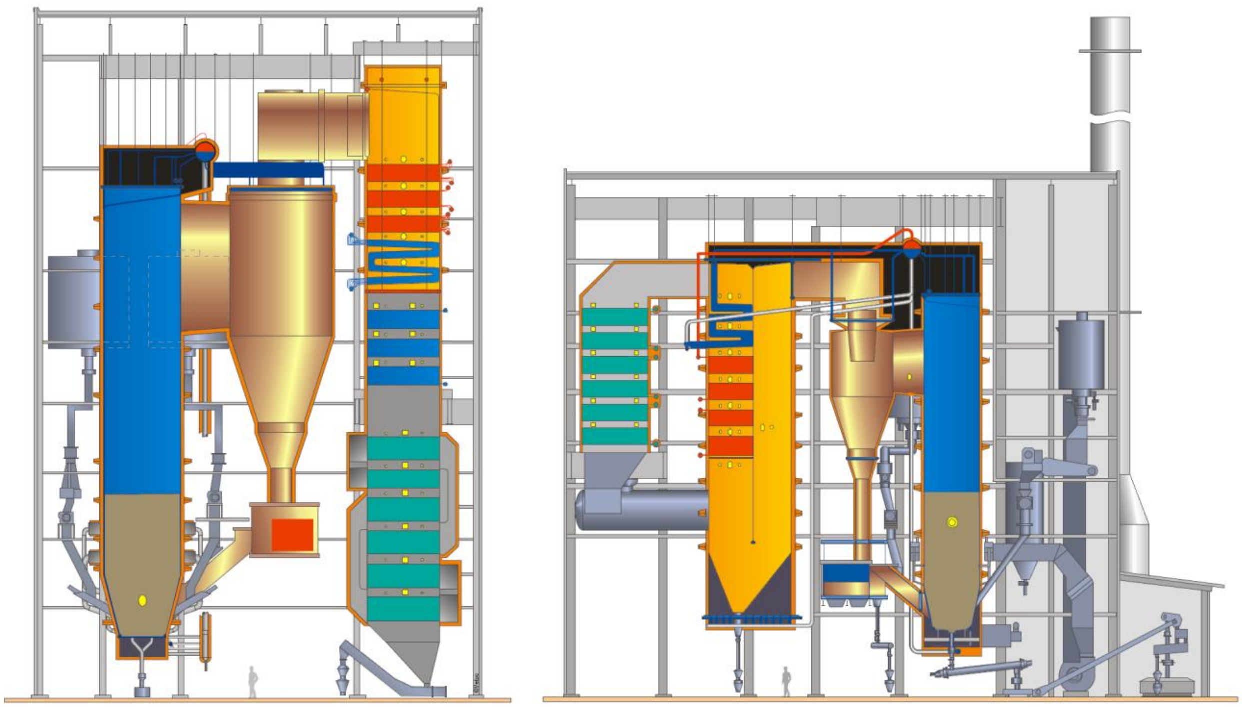

Figure 7. Left: Porin Prosessivoima 60 MWe waste co-firing CFB. Right: Langerbrugge 40 MWe waste-fired CFB boiler.

If waste is the main fuel (100%), the boiler design is again different. Waste fuel has a chlorine content of more than 1% and an alkali (Na, K) content much higher than in biomass. The CFB boiler at Stora Enso's Langerbrugge mill (**Figure 7, right**) uses RDF as the main fuel, and so the technical concept is much different than the Pori boiler. The steam values are usually a little lower with waste firing; in Langerbrugge, they are 45 kg/s, 475 °C and 60 bar. The biggest difference in these two concepts is the empty pass before the convective superheaters. In the empty pass, the flue gas temperature is decreased to 600 °C using water sootblowers in order to keep the empty pass surfaces clean. The lower flue gas temperature minimizes fouling in the convective superheaters, minimizing the risk of corrosion on those surfaces. The construction of the finishing superheater is also different than in Pori. The superheater is located in the loop seal in both cases, but in the waste design, a double tube design is applied for the superheater itself. This means that the surface temperature of the outer tube is so high that no fouling occurs, since all the harmful ash components evaporate.

The boiler has been operating since 2010, with very high annual reliability figures. It is unusual for a waste-fired boiler to be the main boiler at a paper mill. In this case, it is not a problem, since boiler reliability has been 99.3% of requested time on average over the last four years, and it has operated for an average of 8,300 hours a year.

Valmet's fuel experience

The previous project examples offered a nice overview of what CFB can do with different kinds of fuels. But CFB can do even more; in today's modern CFB boilers, it is possible to fire several fuels (**Figure 8**) with different characteristics, either at the same time or separately. This feature enables always using the most economical fuel combination. Naturally, there are some limitations to the properties of the fuel. In Valmet's experience, the extremes are as follows:

- Calorific value from 6.5 MJ/kg for biomass to 32 MJ/kg for petcoke
- Moisture content of up to 60% in biomass
- Ash content of up to 65% in waste coal
- Sulfur content of up to 6–8% in petcoke

Figure 8. Some fuels used in Valmet CFBs. Top, from left: wood biomass, recycled wood, RDF, agro-biomass, and sludge. Below, from left: bituminous coal, peat, lignite, petcoke, high-ash coal (ash >50%).

Usually, the boiler can achieve full capacity with all the design fuels, but in some cases, it is not feasible to design a 100% load for the worst fuel, since that may increase the size of the boiler too much.

Milestones in Valmet CFB design

The previous chapters have provided a picture of the market drivers in the power business during the last three decades. Different customer needs have affected CFB development a lot. This section explains more about technical breakthroughs in CFB design – why they were made and what the improvements are.

Water-cooled cyclone

In the 1980s, almost all cyclones used an uncooled plate design, meaning that the furnace and cyclones have differential thermal expansion, and movement had to be compensated for with expansion joints. Expansion joints located in a hot loop caused much additional maintenance work. The heavy refractories (300 mm insulation and 100 mm of erosion resistance) required a lot of maintenance when damaged. A thick refractory is sensitive to temperature gradients and tends to crack when it encounters temperature differences. The cracks fill with bed material, preventing movement, resulting in that piece of the refractory falling off. After that, heat damages the plate casing, and the resulting deformation means more of the refractory detaches. This also happened when biomass with high volatile content began to be used to fire CFBs as well. CFBs had a very poor reputation at that time due to the high need for maintenance.

Valmet started developing water-cooled cyclones in the 1980s. The first project with such a cyclone was the Bodens Torvvärme CFB boiler in Sweden in 1985. Then came Örebro and Norrköping at larger scales (introduced in an earlier chapter of this paper).

A membrane cyclone (**Figure 9, left**) can also be connected tightly to the furnace without any expansion joints. The cyclone is in natural circulation, and there is no thermal expansion between the furnace and cyclone. The thickness of the refractory is only 80–90 mm, with only one refractory material, which is typically a low-cement, low-heat conductive, erosion-resistant refractory. A water-cooled cyclone can be insulated on the outside, decreasing heat losses to the boiler building.

Figure 9. Left: water-cooled membrane cyclone before installation of insulation. Right: cyclone vortex finder before installation.

Cyclone geometry has changed several times based on research work. In the first units, the manufacturing of the cyclone partly determined its shape. Today, after dozens of water-cooled cyclone deliveries, there have been huge developments in cyclone performance and in manufacturing technology. Scaling-up of the membrane cyclone has been very successful; today, a 90–100 MWe CFB can be constructed with only one cyclone.

Thick refractory and expansion joints were the weak points in early cyclone design. One component that has been developed to have a better lifetime is the vortex finder (**Figure 9, right**) in the cyclone (the flue gas exit pipe from the cyclone). When the cyclone size increases, naturally the vortex finder dimensions also increase, and damage occurs after a couple of years. The length and shape have been modified again based on research work, and the most important improvement was at the location where it is supported; that point must always be at a constant temperature. With all these improvements, the lifetime of the vortex finder has increased from a couple of years to more than ten years, regardless of the fuel used.

Fuel feeding for multifuel CFB

The change from coal only to multifuel boilers changed the fuel feeding system completely. In a 100% coal design, the layout involved coal silos at the front wall, with each silo having one or two gravimetric feeders and fuel chutes to feed coal into the furnace. Coal could be fed into the furnace using only a few feeding points, but biomass must be distributed more evenly, since the combustion is almost immediate due to their high volatiles content. So, the feeding system layout had to be changed. The volumes fed were also much higher than for coal only.

The fuel feeding system examples in **Figure 10 (next page)** are from the Alholmen 260 MWe plant and the Naantali 142 MWe plant. At Alholmen, the maximum fuel flow is 800–1,000 m3 an hour with biomass only, and 110 m3 an hour with coal only. Coal and biomass have separate silos, but after that the fuels are mixed and fed through a common system. At Alholmen, there are 11 feeding points. At Naantali, the maximum fuel flow is 460 m^3 an hour and the feeding system consists of 6 feeding points.

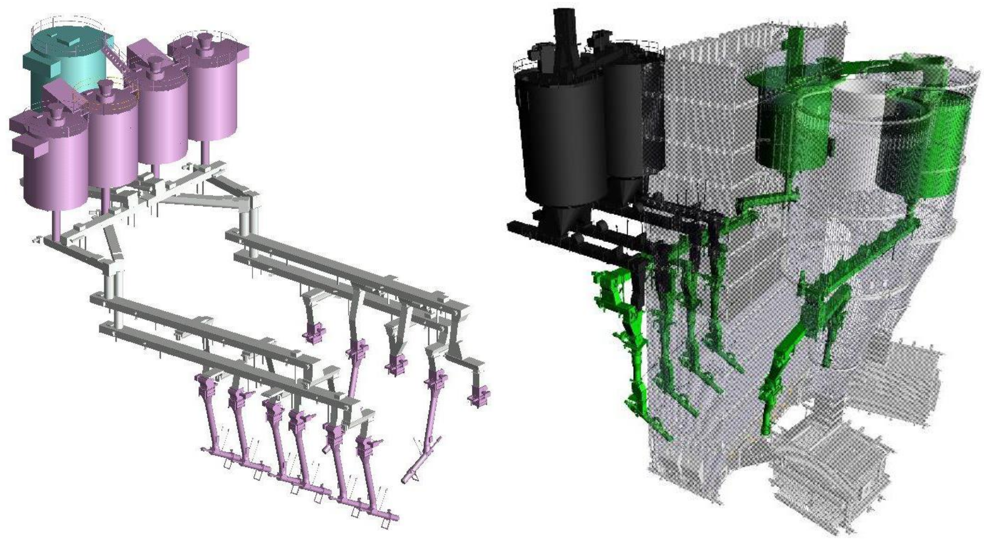

Figure 10. Left: fuel feeding system for 100% coal and 100% biomass case (260 MWe). Right: fuel feeding system for five different fuels (142 MWe).

Primary air nozzles for multifuel and waste

Primary air nozzles (**Figure 11**) are a small part of the boiler design, but they can cause big trouble for boiler operation if poorly designed. Impurities in biomass fuels cause a lot of wear in primary air nozzles designed for coal, which soon leads to air leakages, and finally, bed material back-sifting into the primary air wind-box. All this can lead to shutdowns. Valmet faced many wear challenges when forest residue and stumps started to be used as fuels in the late 1990s. Several designs were tested at full scale, but finally, a high-Cr cast nozzle was found to be robust enough to manage with all types of biomass.

Using waste as fuel also requires a very special design for the primary air nozzle. The chemistry is very demanding in waste firing, and there is no material that can withstand the combined corrosion and erosion forever. Waste has even more impurities than in biomass, increasing the mechanical wear on the primary air nozzles. The nozzles (**Figure 11, bottom**) are directed so that the air pushes impurities toward the bottom ash chute in the middle of the furnace. The nozzle material is a cast, high-chromium material, like with biomass.

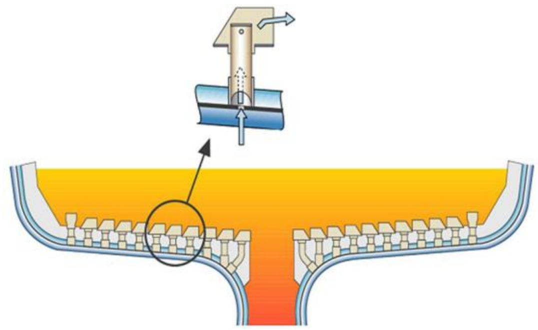

Figure 11. Top: primary air nozzle for biomass. Bottom: primary air nozzle for waste.

Integrated bed ash cooler

The first-generation bed ash cooler was introduced previously in this paper. That equipment generated a large amount of heat loss, and the refractory and expansion joints also needed significant maintenance work. An integrated BAC was developed at Valmet for high-ash fuels – and also for high-sulfur fuels. The idea was to connect the ash cooler as close to the furnace as possible. Cooler cells are formed by bending both the furnace side walls to form chambers for cooling the ash. There is simply an ash inlet opening at one end of the BAC and an outlet opening at the other end (**Figure 12, middle & right**). Air outlets back to the furnace are located in the upper part of the BAC (**Figure 12, middle**). When the furnace and ash cooler beds are fluidized, the bed level sets at the same height. Ash removal is controlled by a slide gate valve at the outlet chute (temperature 200 °C), and the ash temperature in each cell is measured.

Figure 12. Left: One of the BAC cells. Middle: BAC air and ash connections as seen from the furnace. Right: the BAC from the outside.

The biggest benefit of this design is that no moving parts or expansion joints experience high temperatures. The design has been very reliable, with little need for maintenance.

CFB design for waste-to-energy

A big challenge in waste-fired CFB design has been the reliability of the plant. Improving this has been a clear development target in Valmet's waste CFB design (**Figure 13**). High-temperature corrosion in all superheaters, furnace erosion-corrosion, and wear in the primary air nozzles have been the biggest challenges. The primary air nozzles have been covered in the previous section.

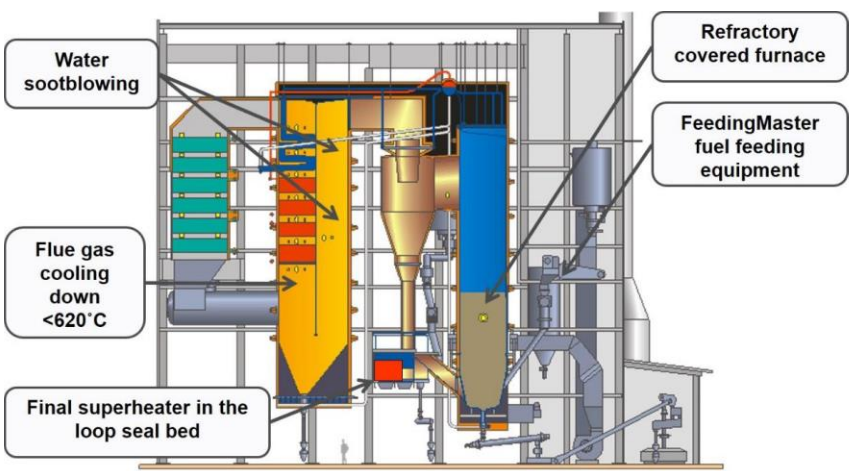

Figure 13. Valmet waste-to-energy CFB concept

For furnace corrosion, the corrective improvement was to cover the whole furnace water-cooled membrane walls with a thin, heat-conducting refractory. In waste firing, the furnace must be covered with a refractory to quite high elevation in any case, in order to maintain a high enough combustion temperature in all conditions. Convective superheaters withstand high temperature corrosion much better when the temperature of the flue gas is below the ash softening point (about 650 °C). That is done by having an empty pass with water-cooled walls and water-gun type sootblowers to keep surfaces clean.

Finally, the biggest improvement has been in the lifetime of the finishing superheater in waste firing. With a conventional design, a lifetime of one year was quite normal, but with a double tube design lifetimes of 3–5 years have been achieved. The outer tube is made of a heat-resistant material, and the surface temperature is above the evaporation temperature of harmful ash components, meaning that the surface stays clean. The inner tube carries the pressure, as in a conventional design. This design (**Figure 14**) is good for steam temperatures of up to 500–520 °C steam temperatures with 100% waste fuel.

Figure 14. Finishing superheater with double tube design

What is next in CFB development?

The fuels used in CFBs have changed quite a lot over the last 30 years, from coal to petcoke, and later to biomass together with waste fractions. The trend recently has been multifuel design. Having three to five design fuels for the same boiler is quite normal today. This decreases the price and availability risk of fuels with a very small additional investment. Right now, most renewable incentives have disappeared from solid fuels, and at the same time coal is not favored; many governments are even targeting entirely fossil-free power production in the near future. What the right fuel will be in the future is unclear.

Coal is not going to disappear from the CFB fuel portfolio, but most likely it will go to a very large capacity with high efficiency, most likely more than 300 MWe scale and supercritical steam values.

On the biomass side, more and more demanding fuel qualities must be accepted. Wood-based biomass is not available everywhere, and where it is available, there is competition for it because it is a raw material for many industries. The biomass that will be burned in boilers will be residues which are not used anywhere else, such as wood-based residues like forest residue and stumps, agro residues such as straw, or oil palm residues like palm kernel shells or empty fruit bunches. This means the boiler must ready for high-alkali and -chlorine fuels with higher and higher steam temperatures.

The amount of waste will continue to increase. Big cities globally have to consider waste as a source of energy instead of only incinerating it. CFB technology will get its share of this as a high-efficiency waste-firing technology.

The biggest benefit of CFB technology is the fuel flexibility. Regardless of what the future fuel portfolio will be, CFB is already on its way toward it.

Summary

This white paper shows how CFB technology has adapted to market needs over the last thirty years, from high-ash coal to low-calorific-value biomass, and from petcoke with a high sulfur content to waste fuel with a high chlorine content. Boiler component design has followed customers' needs, and at the same time reliability has increased and the need for maintenance has decreased. Fuel qualities are becoming more demanding, while steam values are increasing. CFB technology has proven its capability to adapt to changing technical requirements.

This white paper combines technical information obtained from Valmet personnel (Ari Kokko) and published Valmet articles and papers.

Valmet provides competitive technologies and services to the pulp, energy and paper industries. Valmet's pulp, paper and power professionals specialize in processes, machinery, equipment, services, paper machine clothing and filter fabrics. Our offering and experience cover the entire process life cycle including new production lines, rebuilds and services.

We are committed to moving our customers' performance forward.