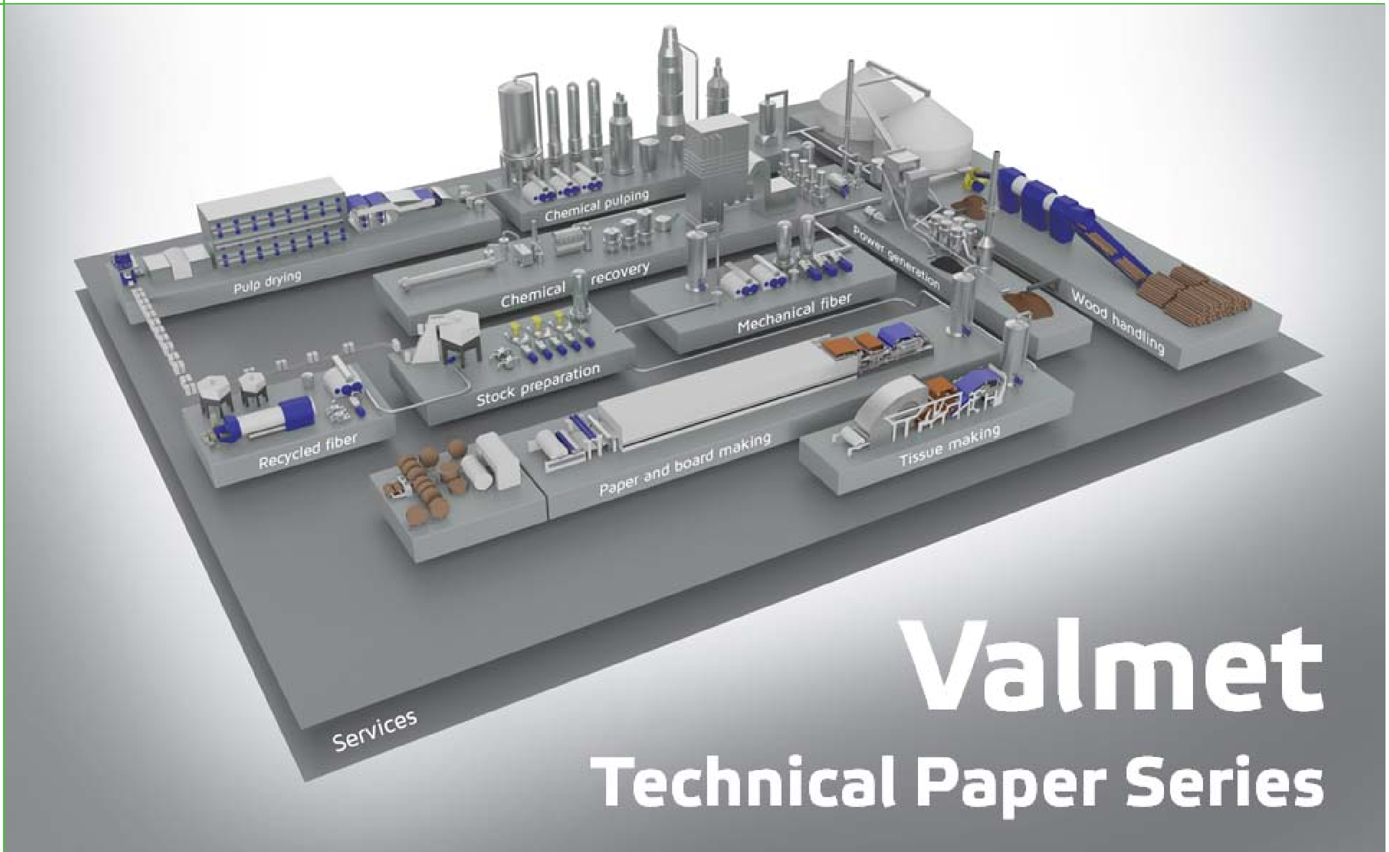

XXL size recovery boilers – present status and future prospects

Executive Summary

XXL size recovery boilers have operated since 2004, when the first XXL size recovery boiler started up in China. From the process point of view, those boilers have run extremely well, either reaching or exceeding all process requirements. The XXL size recovery boilers are typically designed for high dry solids content, high energy efficiency, low air emissions, and environmentally friendly process solutions. Those boilers burn Non-Condensable Gases (NCG) and other side streams coming from the other parts of the mill, and therefore the XXL size recovery boilers are very important in targeting for odorless pulp mills.

However, some units have encountered mechanical problems after start-up due to the large size of certain components in the pressure part. However, all those challenges have been solved and these experiences have helped to develop boilers further toward even safer operation and higher availability.

In the future, larger and larger recovery boilers will be built; therefore development work is still needed to reach even lower emissions and better availability. New recovery boilers are very typically planned to operate for at least 18 months. This creates challenges for the engineering of many process systems and components in order to meet the requirements for safety and process optimization. However, long experience with XXL size recovery boilers helps meet these new demands for longer operation periods.

Introduction

Large recovery boilers producing bioenergy have been built all over the world. This development has culminated with units that are among the largest biofuel boilers in the world. For pulp mills, electricity generation from the recovery boilers has been a secondary target; the most important design criterion for recovery boilers has been high availability. Availability is still important, but due to increased global energy demand, increased electricity price, and incentives for renewable energy, it is often profitable to maximize electricity output from recovery boilers. In recent years, many different features increasing electrical efficiency have been installed on new and existing recovery boilers.

The chemical wood pulp production has grown by about 2-3 Mt/year during recent decades. This capacity increase consists of new installations, including green field mills, and capacity increases to existing recovery boilers. Most of the new projects are hardwood lines in South America and South East Asia operating with planted eucalyptus and acacia. New large mills and resultant XXL size recovery boilers are also planned for Scandinavia. Currently, one large softwood/hardwood mill with an XXL size recovery boiler is under construction in Finland.

The new XXL size recovery boilers are characterized by high black liquor firing capacity, high dry solids content, high energy efficiency, low air emissions, and environmentally friendly process solutions. One example of these eco-friendly solutions is the burning of Non-Condensable Gases (NCG) and other side streams coming from other parts of the mill. Minimizing odorous gas emissions from pulp mills is a driving force for burning these streams in the recovery boiler. The burning conditions and starting time of NCG incineration must be optimized to achieve this safely.

The "oldest" XXL size recovery boilers have operated over 20 years with good results: boiler floor loads have increased from the design values and no abnormal corrosion has been detected in the lower part of the furnace. However, some units have encountered problems, such as boiler fouling, or mechanical problems after start-up due to the large size of the components. All this feedback has helped to develop "new generation" boilers with very safe operation capabilities and high availability.

In the future, large boilers still need development in order to fulfill requirements from customers and authorities. For example, tighter NOx emission limits in some parts of the world are causing new challenges for the design of recovery boilers. Presently in many countries, NO_x is controlled by air staging, but for even lower NO_x emissions, SNCR, NO_x scrubbers, and SCR are also possible solutions in the future.

Increase of recovery boiler size during recent decades

The capacity of pulp mills and thus also recovery boilers has increased significantly during the last decades. In the beginning of the 1980s, there was a common opinion that recovery boilers had reached their maximum physical dimensions. During that time, the floor cross section was about 100 - 120 m^2. Size development has continued during recent decades and the first so-called XXL size boiler, which had a 5500 tds/d design capacity, was started up in China in 2004. That boiler has been operating for 13 years without any abnormal problems. However, some fouling problems have been observed due to extremely high K and Cl contents in black liquor (**Figure 1, next page**).

As can be seen, both K and Cl have been even at a level of 6-8% in the ESP (electrostatic precipitator) ash between years 2010 and 2012. After that, the control of ESP ash has been more effective, and the Cl and K levels have dropped to a level of 2-4%. These lower levels are of course much better from the fouling and corrosion point of view. This indicates that controlling K and Cl in the liquor circuit is very important in all boiler sizes in order to maximize boiler availability and to minimize corrosion especially in the hottest superheater stages.

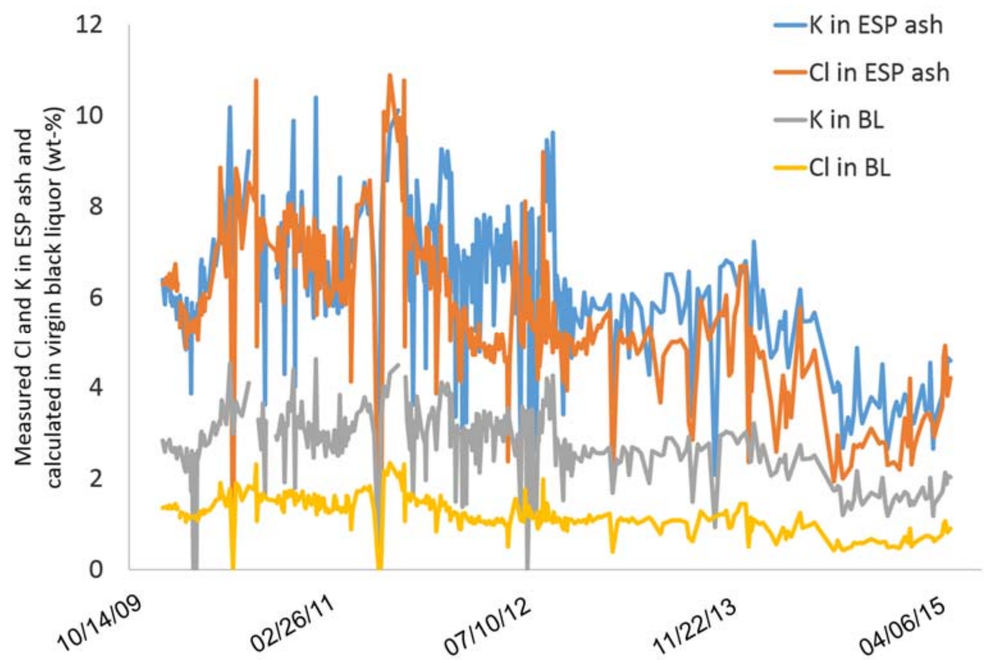

Figure 1. Measured K and Cl in ESP ash and calculated in virgin black liquor (in weight-%).

Figure 2 shows 24 recovery boilers with designed black liquor loads together with their floor loadings. Boilers shown in the figure initially had black liquor loads 3000 tds/d or higher when they were delivered.

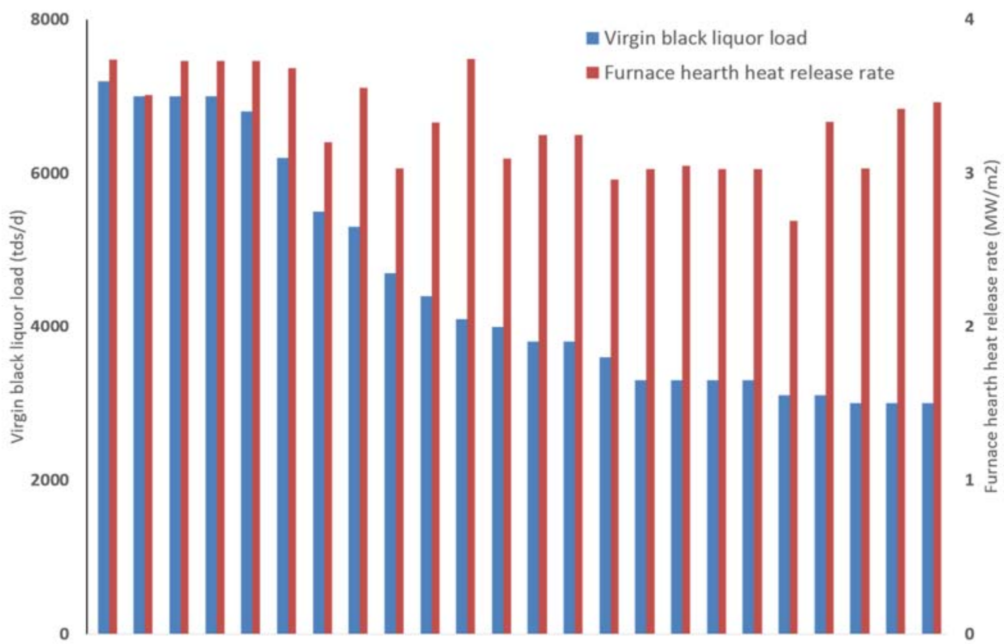

Figure 2. XL and XXL size boilers' black liquor loads and hearth heat release rates when they were delivered

As can be seen, the floor loadings have been in the range of 3.0 MW/m^2 to 3.7 MW/m^2. Very typically smaller units have had slightly lower designed floor loading than the larger ones. Floor loading is calculated by using black liquor dry solids higher heating value (HHV), black liquor load and furnace floor area. Nowadays the design of floor load in big boilers is typically about 3.5 MW/m^2 or higher. Earlier, around 20 years ago, it was 2.0 - 3.0 MW/m^2.

Many of the boilers shown in **Figure 2** are operating nowadays with higher black liquor loads than their initial design load. The updates for larger loads have been achieved, for example, by changing the air system, adding sootblowers to critical areas, or by running the boiler at the design margin used in dimensioning the furnace and the auxiliary equipment. **Figure 3** compares initial black liquor load and present load in some boilers.

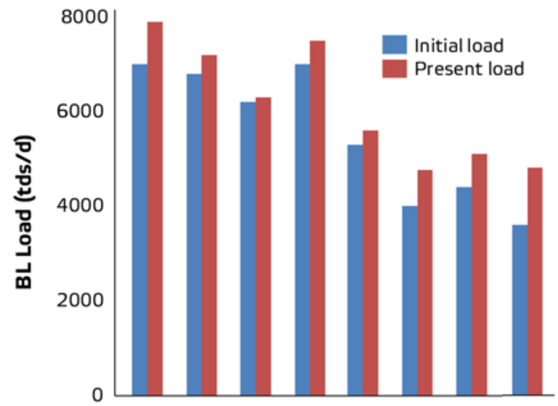

Figure 3. Initial black liquor load and present load in some boilers

Valmet's newest XXL size recovery boiler will be delivered to Metsä Fibre's Äänekoski Bioproduct mill located in Finland. The boiler will be started up in fall 2017, and it will be one of the largest boilers in the world. **Figure 4** shows some general design parameters of XXL size recovery boilers. The leftmost boiler is the first XXL boiler located in China, and the rightmost boiler is the unit to be delivered to Äänekoski.

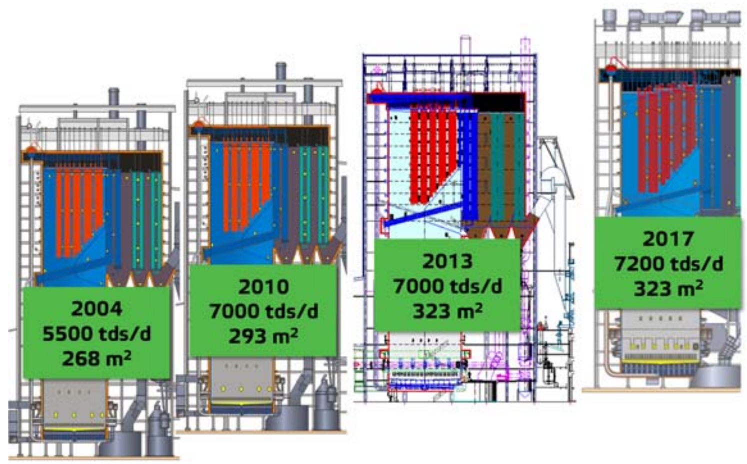

Figure 4. XXL size boilers and their black liquor loads and furnace floor areas

New XXL size recovery boiler in Finland

The Äänekoski mill is the first next-generation Bioproduct mill in the world, and the largest investment in the forest industry in Finland. The annual pulp production capacity (soft and hard wood) will be 1.3 million tons. In addition to high-quality pulp, the mill will produce a broad range of bioproducts, such as tall oil, sulfuric acid, turpentine, lignin products, bioelectricity and wood fuel. The potential new products created from the production side streams include product gas, textile fibers, bio composites, fertilizers and biogas.

Valmet delivers the following equipment to this new pulp mill (**Figure 5**):

- XXL size recovery boiler
    - Smelt spout robot
    - Valmet's own four chamber ESP (five electrical fields)
- Gasification plant
- Lime kiln
- Pulp drying machine
- Sulfuric acid plant
- Automation system for all equipment at the mill

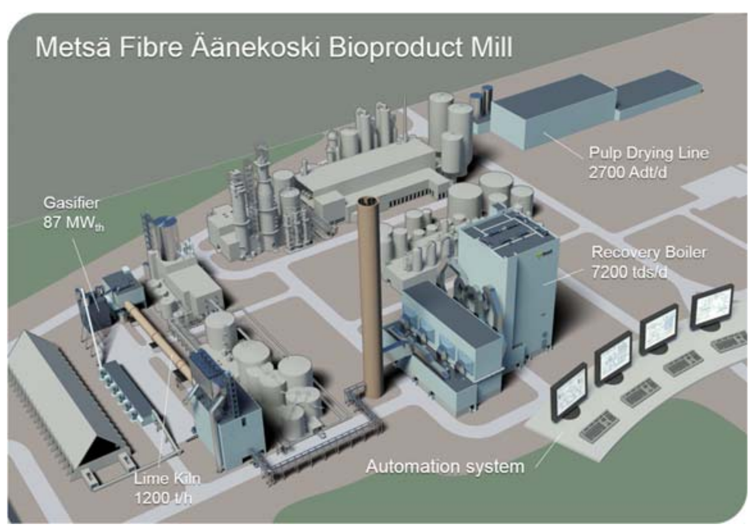

Figure 5. Valmet's deliveries to the new pulp mill in Finland

The new recovery boiler has many interesting design features regarding material selection, safe boiler operation, high-power features and NCG burning for targeting odorless pulp mill. **Figure 6** shows the main design parameters of this new recovery boiler.

Figure 7 shows this new boiler building compared to the new Torni hotel in Tampere, Finland.

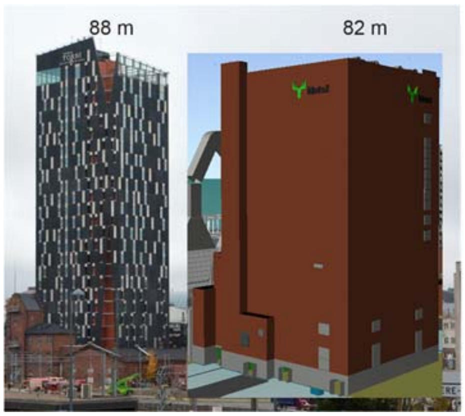

Figure 7. Äänekoski recovery boiler (right) compared to the Torni hotel (left) located in Tampere

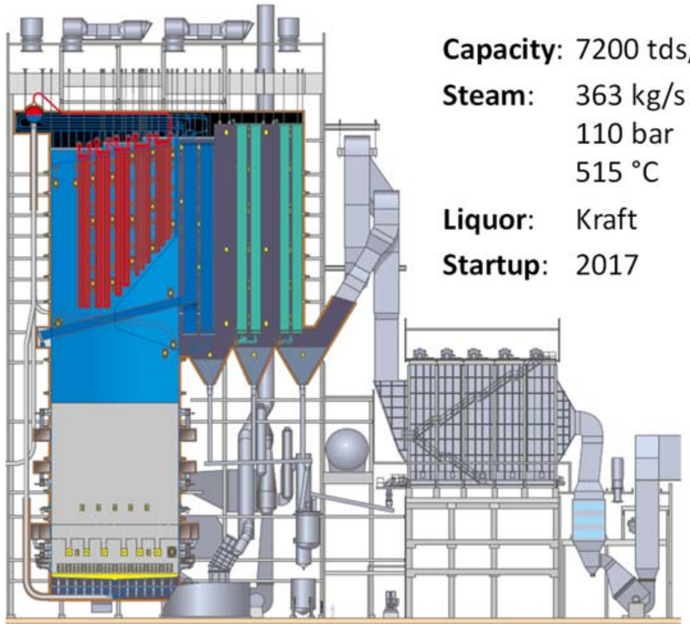

Figure 6. Main design parameters of Äänekoski new recovery boiler

The amount of steam generated in the new boiler is extremely high because of many high-power boiler features (**Figure 8**).

The following technical solutions increase the steam generation in the Äänekoski boiler compared to "traditional" recovery boilers:

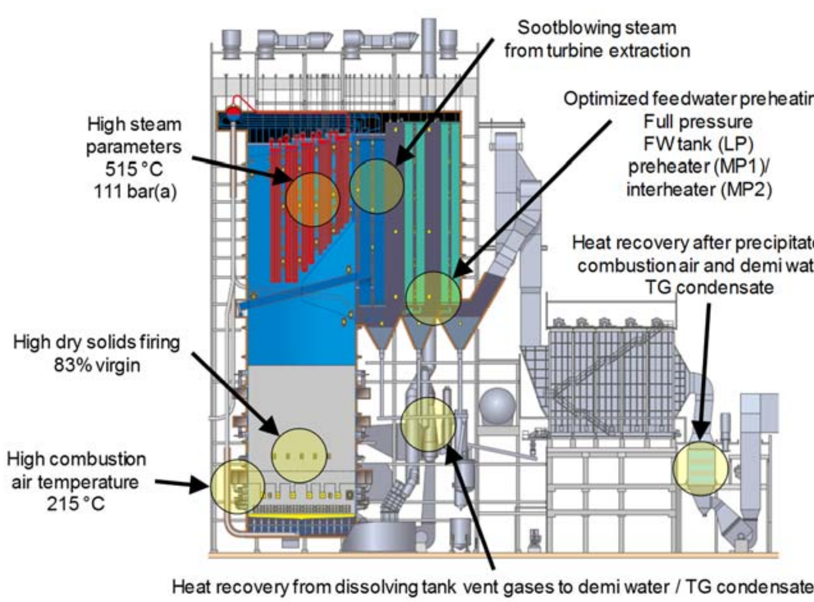

Figure 8. High-power features in new recovery boiler in Äänekoski

- High dry solids firing
- Flue gas outlet temperature optimized together with feed water preheating concept; after flue gas cleaning (ESP) further cooling to 130 °C in flue gas coolers
- Feed water preheating
- Full LP pressure feed water tank at 143 °C
- Water preheater before economizer (MP1 steam) (to 185 °C)
- Interheater between economizers (MP2 steam)

With high-power features, the boiler can generate much more steam than traditional recovery boilers.

Figure 9 shows how boiler steam generation has increased compared to traditional recovery boilers with the following parameters: air preheating 150/30 °C, feed water temperature into the economizer 130 °C, no high-pressure feed water preheaters and interheaters, black liquor dry solids content 70-75%, and flue gas exit temperature 180 °C.

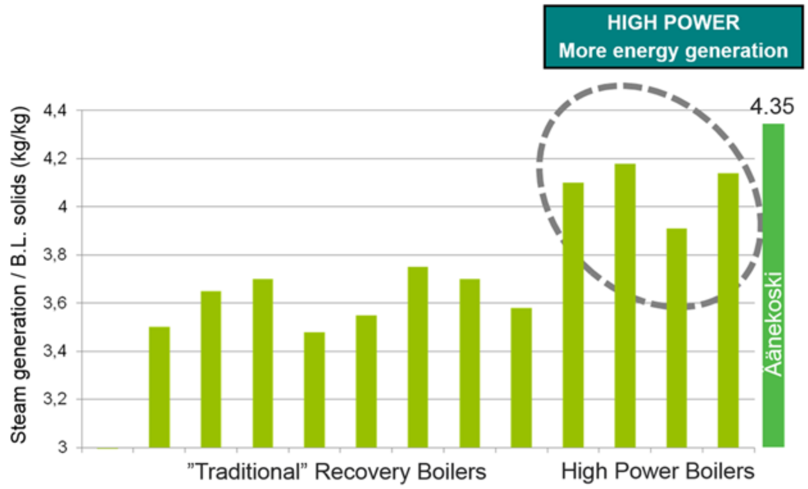

Figure 9. Steam generation ratio in different types of recovery boilers

As can be noticed, the traditional recovery boilers generate typically 3.5 kg steam/kgds. Steam generation in high-power boilers is easily higher than 4.0 kg steam/kgds and for example in Äänekoski's new recovery boiler, this ratio is 4.35 kg steam/kgds. If the new boiler had traditional recovery boiler features with the same black liquor load, then its steam generation would be 7200 tds/d x 3.5 = 292 kg/s. The high-power boiler is therefore generating 20-25% more steam. This steam generation difference also means about 40 MW difference in power generation, for about 340,000 MWh per year. When using the electricity price of 50 €/MWh, this leads to 17 M€ extra income per year from electricity.

Recovery boiler as a multi-fuel boiler

The XXL size recovery boilers are multi-fuel boilers, and they have been designed for the purpose of an odorless pulp mill. This means that all NCG and vent gases from the different sources around the pulp mill are burnt in the recovery boiler. For example, DNCG, dissolving tank and mixing tank vent gases are typically introduced into the high secondary air level where they are mixed with fresh air, whereas CNCG and methanol or turpentine are burnt in a dedicated burner which is typically located on the furnace front wall at the secondary air level. **Figure 10** shows the possible fuels in recovery boilers.

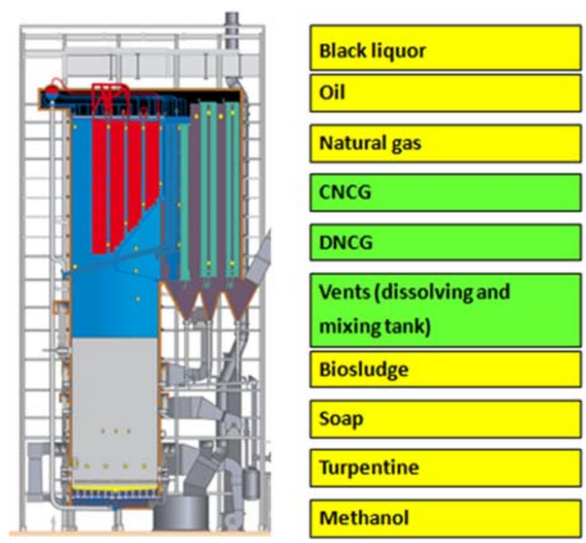

Figure 10. Recovery boiler as a Multi-fuel boiler

As **Figure 10** shows, it is possible to burn many types of fuels in the recovery boiler, but when is it possible to start to burn NCG gases? This is a very important topic which has been discussed in many mills. Very typically mills want to introduce NCG gases into the furnace as soon as it becomes possible from a safety point of view. Some national recommendations cover these starting pre-conditions, such as recommendations by BLRBAC (Black Liquor Recovery Boiler Advisory Committee) and the Finnish Recovery Boiler Committee (FRBC). For example, BLRBAC states that DNCG gases can start to be burned in the boiler when the boiler steam load is above 30% of MCR load. Of course, there are also other permissive starting conditions, like DNCG gas temperature after condensing stage, etc. In the FRBC recommendations the corresponding load limit is 15% for DNCG and dissolving vent gases, but this limit should be determined case by case.

For CNCG burning to start, BLRBAC requires that the firing liquor flow is stable or the steam flow is greater than 50% of the boiler's MCR steam flow. Moreover, the igniter must be on at least for one minute before CNCG firing can be started. During CNCG burning, the igniter or support fuel must always be on when CNCG gases are burnt. On the other hand, FRBC says this for CNCG burning: Boiler Furnace heat loading is above 0.7 MW/m^2. For using the support flame, FRBC says: Boiler furnace heat loading is below 1.5 MW/m^2. However, in both cases, the limit should be determined case by case. Many large boilers now follow the recommendations of FRBC for burning NCG gases. Typically, that 0.7 MW/m^2 heat load means about 30-40% of MCR steam generation.

In many mills, methanol production has been so high that a separate methanol lance has been installed to an existing start-up burner meaning that methanol is not only burnt in the CNCG burner. This separate methanol burner makes it possible to distribute heat into the furnace more evenly.

	Boiler A	Boiler B	Boiler C	Boiler D	Boiler E Finland	Boiler F Finland
Black liquor	X	X	X	X	X	X
Biosludge			X	X	X	
Oil	X	X	X	X	X	
Diesel			X			
Natural gas	X				X	
Tall oil pitch						X
Methanol			X	X	X	X
Turpentine					X	
CNCG	X	X	X	X	X	X
DNCG	X	X	X	X	X	X
Mixing tank vent gas	X	X	X	X	X	X

Table 1. Burnt "fuels" in different recovery boilers

Table 1 shows fuels that are burnt in different boilers. As can be seen, nowadays the NCG gases are incinerated in XXL size recovery boilers in all cases. Also, methanol burning starts to be a very common practice and its amount has typically increased in many mills. **Table 1** also shows that an interesting fuel, tall oil pitch, is replacing oil in the start-up burners in that new boiler in Finland. Moreover, incineration of biosludge (secondary sludge) has been done successfully at multiple recovery boilers in Europe.

Material selection in XXL size recovery boilers

The XXL size recovery boilers have principally the same materials as other recovery boilers. The lower furnace walls have been made using the composite material of AISI 304L/SA-210 A1. This material has been used for nearly 40 years.

Floor tubes are typically made of carbon steel, which is possible because the tubes are protected by a frozen smelt layer during boiler operation. Even some high-pressure boilers have carbon steel material on the floor tubes. When the floor middle part is made from carbon steel material, the front and rear wall corner bends on the floor have been manufactured from Sanicro 38 material. The 304L composite is completely avoided in furnace floors. Sanicro 38 is nowadays also a typical material in the bended tubes in primary airport openings.

Some boilers have a floor manufactured completely from Sanicro 38 composite tubes, such as the new Äänekoski recovery boiler. The cut point of Sanicro in that boiler is above the primary airport openings. **Figure 11** shows the rear part of Sanicro 38 furnace floor in this boiler.

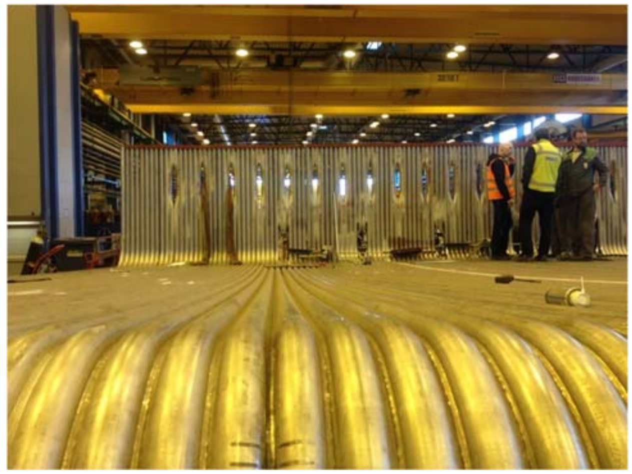

Figure 11. Sanicro 38 furnace floor during manufacture

Material selection of superheaters

As boiler steam parameters become higher and higher, controlling the Cl and K content in black liquor has become very important. This kind of development has caused special challenges for superheater material selection and the prevention of sudden corrosion. For example, in Äänekoski's new recovery boiler, there are about 135 km of superheater tube materials in all five superheater stages. It is easy to imagine what could happen if the tubes corroded suddenly due to uncontrolled K and Cl contents and not optimized material selection.

Project	K (%)	Cl (%)	SH steam temperature (°C)	Stainless steel material in hottest stages	Ash handling
Boiler 1	2.0	0.15	505	8/T	Yes
Boiler 2 & 3	2.4	0.6	480	N/A	Yes
Boiler 4	0.5	0.6	480	4/S & 4/T	Yes
Boiler 5	2.6	0.55	485	1/T	Yes
Boiler 6	1.2	0.4	487	2/Q	Yes
Boiler 7	1.1	0.25	487	1/T and 4/Q	Yes
Boiler 8	1.5	0.4	492	1/Q	Yes
Boiler 9	2.2	0.4	490	1/T & 4/Q	Yes
Boiler 10	0.9	0.4	515	3/T & 6/Q	Yes

Table 2. Recovery boiler references with stainless steel materials in superheaters

Table 2 shows recovery boiler references with stainless steel material selection in superheaters. Stainless steel has typically been either Sanicro 28, AISI 347L or overlay welded tubes. In **Table 2** also shown are the steam outlet temperature and how many tubes have stainless steel material. Code S means secondary superheater, T tertiary superheater and Q quaternary superheater. The table shows whether ESP ash is handled or not for controlling K and Cl in black liquor and ESP ash. It also shows what have been the design values for K and Cl in black liquor.

Molten phase corrosion is a corrosion phenomenon in superheater tubes and it may be very severe in the hottest superheater stages. It occurs when an ash particle or deposit melts on the tube surface. This type of corrosion is controlled by the First Melting Temperature (FMT) of the deposit. The FMT is the temperature at which the first melt appears in the deposit (also known as T0). The main contributor to FMT is potassium (K), whereas Cl increases the amount of smelt in the deposit. A high amount of carbonates (CO_3), i.e. carryover, also lowers the FMT of the deposits. Moreover, even small amounts of sulfides (0.1 wt-%) in the deposits lower the FMT by about 50 °C, and thus increase the risk for superheater corrosion.

When designing new recovery boilers, it is very typical to determine the maximum K and Cl values for black liquor or ESP ash. Those values can be controlled to desired levels by ash treatment systems, such as Ash Leaching or Crystallization processes, and also with ash dumping. One alternative for minimizing corrosion risk is to use better materials in the critical parts (hottest stages) of the superheaters. This better material means higher alloyed tubes. For example, overlay welded tubes are used in many large recovery boilers. Also, Sanicro 28 composite material is commonly used in recovery boilers. Feedback from many XXL size recovery boiler references together with theoretical and empirical corrosion knowledge are also very important when selecting superheater materials.

As has been discussed and illustrated already in **Figure 1**, it is very important to follow the Cl and K levels in the ESP ash. **Figure 12** shows as an example, how one mill in East Asia is following the components, and what is the acceptable range for Cl and K in their boiler.

When using the measured values in **Figure 12**, the average K content (4%) in ESP ash corresponds to about 1.6-1.8% of potassium in virgin black liquor. Correspondingly, the average Cl content (1.6%) is about 0.3% of chlorine in black liquor.

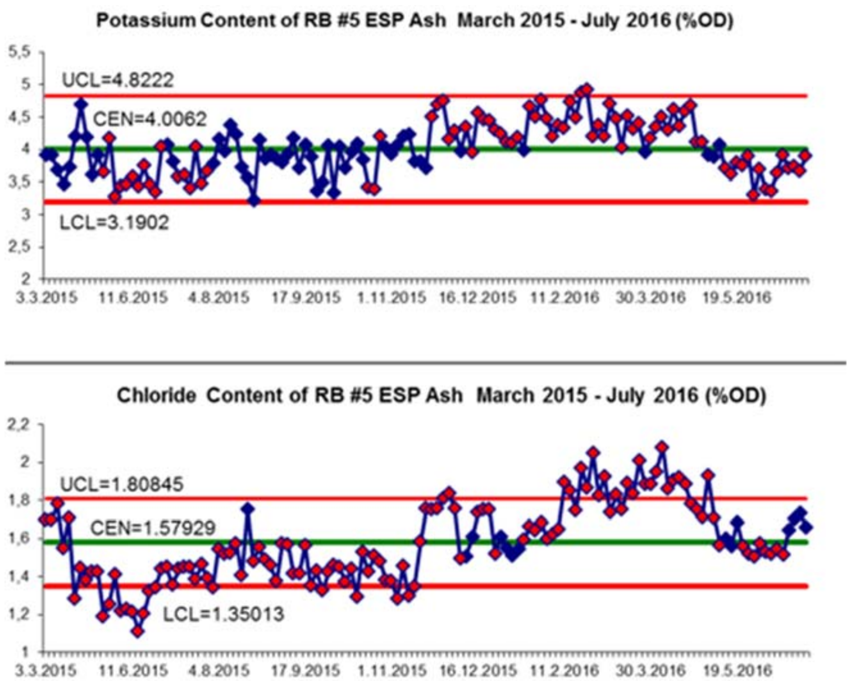

Figure 12. Measured Cl and K in ESP ash in one mill in East Asia

Although the mill has tried to control the Cl and K levels, the boiler has faced slight corrosion in the last tubes of the tertiary superheater, beside the sootblower cavity (**Figure 13**). This is an interesting finding, because the steam outlet temperature in that stage is relatively low, 440-450 °C.

One possible reason for corrosion is that the tertiary superheater is located in the radiation zone, which increases tube surface temperatures and thus the risk of corrosion. Interesting in this case is that the hottest superheater stage, quaternary superheater, is intact, although its steam outlet temperature is 480 °C.


Figure 13. Corroded tertiary superheater tubes.

Moreover, there is no stainless-steel material in the vertical tubes of the hottest superheater. However, there is no indication of abnormal corrosion in the lower bends either.

Emissions of XXL size recovery boilers

Flue gas emissions are very low in large recovery boilers, and SO_2 and TRS are very typically at a level of zero. Eucalyptus and Acacia mills typically have relatively low sulfidity levels, 30-35%, which together with high dry solids firing helps to reach low SO_2 emissions. In Scandinavian mills, the sulfidity level is typically 38-40%. However, SO_2 is still not causing problems in large boilers if the dry solids content is at a level of 80%. **Figure 14** shows an example of TRS and SO_2 emissions from one XXL size recovery boiler.

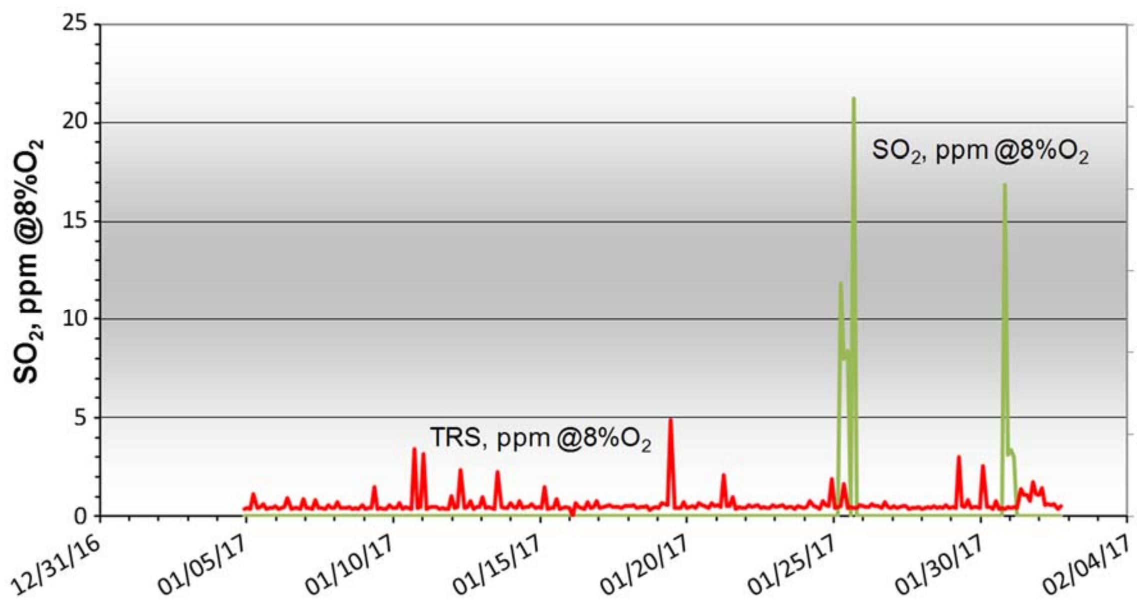

Figure 14. SO2 and TRS emissions in one XXL size recovery boiler

In contrast to SO_2 and TRS, the most "interesting" emission nowadays is NO_x, especially in certain parts of the world. In South America, all the large boilers have tertiary air level as the highest air level, except for one boiler which also has a quaternary air level for NO_x control. In those boilers with the tertiary air level as the highest air level, the NO_x emissions are at a level of 230-250 mg/Nm^3 (dry gas 6% O_2). In the Äänekoski new recovery boiler, there will be a quaternary air level in order to reach the BAT value of 200 mg/Nm^3 in dry gases (6% O_2). **Figure 15** shows an example of NO_x reduction vs. quaternary air flow.

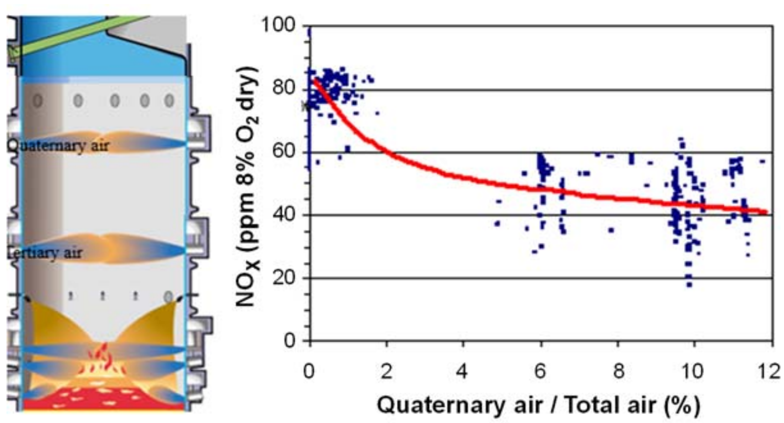

Figure 15. NOx reduction as a function of quaternary air flow

An additional challenge for NO_x emissions is the burning of various fuels in recovery boilers. For example, NCG and methanol contain ammonia compounds which tend to increase NO_x emissions. Therefore, when XXL boilers are designed and NO_x emissions are guaranteed, it is very important to estimate what the NO_x emission increase could be when those streams are burnt.

Future trends in large recovery boilers

Even though the first recovery boilers were designed and built over 100 years ago, there is still a lot to be developed and improved. Recently, development work has been carried out around topics such as decreasing NO_x emissions and Advanced Process Control (APC) systems.

There have been indications especially from China and some European countries that NO_x emissions below 100 mg/Nm^3 (6% O_2) need to be achieved in the near future. This is not possible with the primary method of air staging when the N-content in the black liquor is around the typical 0.1 w-% value. Instead, SCR (Selective Catalytic Reduction) has been considered for use in recovery boilers after the electrostatic precipitators (ESP). In the SCR system, ammonia (NH_3) is injected into the flue gases where it reacts with NO_x forming N_2 and H_2O. The catalyst enables NO_x reduction in relative low temperatures. Challenges for SCR in the recovery boiler environment are related to achieving appropriate flue gas temperatures together with low SO_2 and dust levels.

APC systems often comprise combustion control modules where air distribution, liquor droplet size and boiler load are controlled so that emissions and carry-over can be managed. Additionally, bed management, superheated steam temperature control, leak detector, TTA control and adaptive sootblower optimization modules have been installed with good results. The latest innovation is a reduction rate control system which controls the boiler operation with the feedback information from an online reduction rate analyzer so that high and steady reduction rate is achieved during the entire boiler operation period.

Summary

Valmet has delivered many boilers with the capacity of 4000-5000 tds/d. Experiences from those references have been extremely important when developing larger boilers, such as the XXL units. The latest achievement is the delivery of a new XXL size high-power recovery boiler to Äänekoski, Finland.

The XXL size recovery boilers have operated quite well and their availability has been good. These boilers are able to burn many kinds of fuels without increasing their emissions. The XXL size boilers have large furnaces, modern air systems, and high black liquor dry solids, and therefore the sulphur emissions have been well under control. From the process point of view, no setbacks have been experienced. However, K and Cl must be controlled very accurately in order to maximize boiler cleanability and to minimize the risk of superheater corrosion.

This white paper combines technical information obtained from Valmet personnel (Kari Haaga, Aino Vettenranta (Leppänen) and Jarmo Mansikkasalo) and published Valmet articles and papers.