DEVELOPMENT OF KRAFT RECOVERY BOILERS – FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

Keijo Salmenoja, ANDRITZ

Development of Kraft Recovery Boilers – From Recovery of Chemicals towards a Power Boiler Fired with Black Liquor

Keijo Salmenoja
ANDRITZ Oy

Tomlinson-type recovery boiler will celebrate its 85th birthday in 2019. Tomlinson-type recovery boiler has set the basis for modern kraft recovery boilers. Throughout its history, kraft recovery boilers have been widely developed, focusing mainly to increase safety of the operation, boiler availability, firing capacity, power production, and to decrease emissions to atmosphere.

ANDRITZ (former Ahlström) delivered its first kraft recovery boiler in 1952 to Lohja mill in Finland. The capacity of this boiler was 110 tds/d with steam production of 5.0 kg/s (18 t/h). The steam outlet temperature was 400 °C and steam pressure 45 bar. In 2014 ANDRITZ delivered the world's largest kraft recovery boiler to PT. OKI Pulp & Paper mill in Indonesia. The capacity of the boiler is 12 000 tds/d with a steam production of 582 kg/s (2 095 t/h). Steam outlet temperature is 515 °C and steam pressure 110 bar.

These two deliveries reflect very well the entire development path for kraft recovery boilers during the last 65 years; the capacity and steam production are ca. 100 times higher than 65 years ago. However, steam outlet temperature is only around 30% higher, which is mainly due to the high-temperature corrosion of superheaters. Although the power production has increased a lot from, steaming ratio of the new OKI boiler is only 7% higher than in the first boiler delivered in 1952.

In the 1960s the design starting points for new pulp lines were (1) available amount of wood raw material, wood quality, and wood logistics, (2) produced pulp quality and its markets, (3) available resources (personnel, services, utilities…), and (4) available technology. Typical capacity of a pulp line was 100 000 ADt/a corresponding to around 250 ADt daily production. At that time the main technically limiting factor was the recovery boiler and it continued to be the limiting factor till the late 1990s.

The first high-pressure recovery boiler with carbon steel wall tubes was supplied in 1961 to Äänekoski mill in Finland. The capacity of the boiler was 480 tds/d with steam temperature and pressure of 480 °C and 82 bar, respectively. Several other high-pressure boilers were also delivered during 1960s. After a short period of operation all high-pressure boilers started to suffer from rapid wall tube wastage. To find out the root cause for the wastage a national research project was started, which also led to the establishment of the Finnish Recovery Boiler Committee (FRBC) in 1964.

It was concluded that the root cause for rapid tube wastage was sulfidation corrosion by reduced gaseous sulfur compounds. The only way to prevent this type of corrosion is to use austenitic stainless steel materials. However, due to the risk of stress corrosion cracking (SCC) of stainless steels, AISI 304L could not be used as solid tube. This was solved by using a new type of tubing; composite tube. Composite tube consists of a pressure bearing carbon steel inner tube with AISI 304L cladding on the carbon steel to prevent corrosion due to sulfidation. Composite tubing with AISI 304L cladding has then been widely used for wall tubing. Composite tubes with AISI 304L cladding were also used to replace carbon steel tubes in the floor.

In the 1970s and 1980s recovery boiler capacities were steadily growing. Dry solid content of virgin black liquor was also steadily increasing. Major steps in size and development were taken in the 1990s. The first single-drum recovery boiler was realized in 1990. Also, boiler capacity of 3 000 tds/d was exceeded for the first time. This capacity was long thought to be the maximum for a kraft recovery boiler due to several different reasons.

One of the major recovery boiler capacity limiting issues was the question of air jet penetration and mixing in large furnaces. However, the development of computational fluid dynamics (CFD) simulations enabled the design of larger recovery boiler furnaces. Simulations showed that the penetration of air jets was not limiting the furnace dimensions. This encouraged the boiler suppliers to increase furnace size and the firing capacity of the recovery boilers. Today, recovery boiler size is not anymore limiting pulp mill capacity and lines with a capacity of 2.5 MADt/a (7 000 ADt/d) has been already realized.

In the 1990s high dry solids firing was taken into operation. An immediate result of high dry solids firing, which was readily observed was a significant reduction in sulfur dioxide (SO_2) emissions. It also took a long time to really understand what the reason for dramatic reduction in SO_2 emissions was. Combustion of non-condensable gases (NCGs) in the recovery boiler was also started in 1990s. Collection of NCGs and combustion in the recovery boiler furnace solved most of the odor issues of the pulp mills.

The next decade started the era of rapid increase in mill capacity and recovery boiler furnace size. The world’s largest recovery boiler with a capacity of 4 450 tds/d was started-up in 2004 in Pietarsaari, Finland. It was also the first recovery boiler outside Japan with steam outlet temperature higher than 500 ℃ (505 ℃ , 102 bar). The first boiler with a steam temperature of 515 ℃ outside Japan was start ed in Östrand, Sweden in 2006.

The development of kraft recovery boilers has also been directed by external demands, both from the customers and from the authorities. Pressures to lower atmospheric emissions from pulp mills, namely SO_2 and NO_x, have strongly affected air system design and the dry solids content of black liquor in 2010s. High dry solids content is beneficial in maximizing power production and minimizing SO_2 emissions, but at the same time sets challenges to minimize NO_x. Minimizing NO_x emissions has induced a significant change in the split between primary, secondary, and tertiary air amounts. To be able to minimize

NO_x from recovery boilers, the last air should be introduced into the furnace on a level where the temperature is as low as possible.

The following decade 2020 will be the era of digitalization. The entire pulp mill is digitalized and big data and artificial intelligence will be used for process control and process optimization. With the ANDRITZ Metris brand’s digital IIoT solutions, customers are preparing for the growing digital challenges in the industrial environment. They are paving the way for digital predictability. ANDRITZ Metris technologies are aimed at digitalizing and networking machines and plants as well as developing new customer-specific solutions. Metris products are the very latest state of the art – they can be customized to suit individual customer requirements, and they make a substantial contribution towards helping customers achieve the best possible productivity and efficiency goals.

Modern recovery boilers are able to produce considerably more power than two decades ago. Interest has increased to concentrate on power production after black liquor was given a green fuel status. Thus, recovery boilers have now features that are common to the power boilers, such as the recovery of heat from the fluegases. Earlier pulp mills had large deficiencies in energy and they had to buy energy from the grid. Now the energy self-sufficiency of modern mills is over 200%. In many countries, subsidies are paid to the pulp mills, since they are producing green power with the recovery boiler. One supreme case, which could be called a “*power boiler fired with black liquor*”, is such that the recovery boiler gets black liquor from the mill and recycles green liquor back. All power produced from black liquor is sold to the grid. Internal consumption is covered by the power boilers in the pulp mill. This is only because of the high subsidies for green electricity.

The development of kraft recovery boilers will unquestionably go on and we have not seen the physical limits of the boilers, yet. Larger capacities than 12 000 tds/d are already on the design board. However, how long this will last and how long it will take before we will see capacities higher than 15 000 tds/d? This will be seen in near future. Maybe in the 60th Anniversary Conference in 2024 these will be reported.

SUOMEN SOODAKATTILAYHDISTYS
FINNISH RECOVERY BOILER COMMITTEE

Development of Kraft Recovery Boilers

From recovery of chemicals towards a power boiler fired with black liquor

Keijo Salmenoja

ANDRITZ Oy

Helsinki, Finland

June 6, 2019 55th Anniversary International Recovery Boiler Conference

CHAPTER OVERVIEW

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DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

Introduction

- Tomlinson-type recovery boiler will celebrate its 85th birthday in 2019
  - Has set the basis for modern kraft recovery boilers
- Throughout its history, kraft recovery boilers have been widely developed, focusing mainly to increase safety of the operation, boiler availability, firing capacity, power production, and to decrease emissions to the atmosphere
- ANDRITZ (former Ahlström) delivered its first kraft recovery boiler in 1952 to Lohja mill in Finland
- In 2014 ANDRITZ delivered the world's largest kraft recovery boiler to PT. OKI Pulp & Paper mill in Indonesia

	Delivery year	Capacity (tds/d)	Steam production (kg/s)	Steam temperature (℃)	Steam pressure (bar)
Lohja, Finland	1952	110	5	400	45
OKI, Indonesia	2014	12 000	582	515	110

DEVELOPMENT OF KRAFT RECOVERY BOILERS

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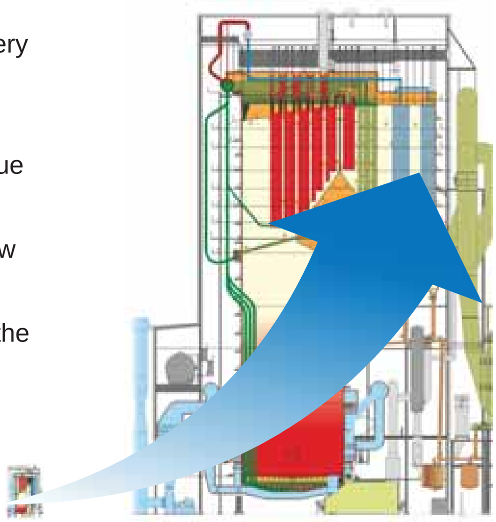
Introduction

- These two deliveries reflect very well the entire development path for kraft recovery boilers during the last 65 years; the capacity and steam production are ca. 100 times higher than 65 years ago
- However, steam outlet temperature is only around 30% higher, which is mainly due to the high-temperature corrosion of superheaters
- Although the power production has increased a lot from, steaming ratio of the new OKI boiler is only 7% higher than in the first boiler delivered in 1952
- This presentation gives an overview of kraft recovery boiler development during the last 65 years
  - Mainly based on ANDRITZ reference database and experiences
  - Reflects well the global development path for recovery boilers
  - Development trends and their effects on recovery boiler design and dimensioning



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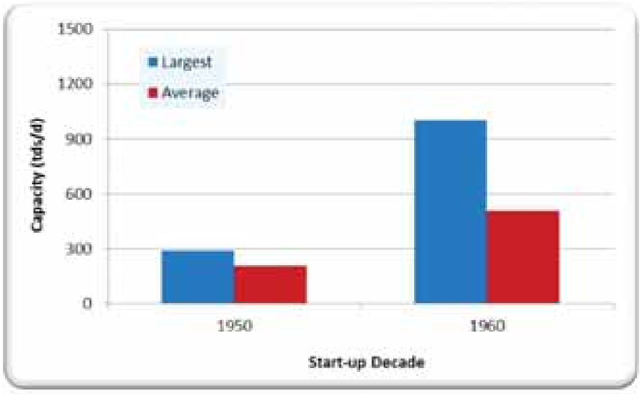
DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1950-1970

- In the 1960s the design starting points for a new pulp line were the following:
  - Available amount of wood raw material, quality, and wood logistics
  - Produced pulp quality and its markets
  - Available resources (personnel, services, utilities…)
  - Available technology
- Typical capacity of pulp mill in the 1960s was 100 000 ADt/a corresponding to around 300 ADt/d
  - The main technically limiting factor was the recovery boiler
  - A large number of unit operation suppliers
- In the 1950s small low-pressure two-drum recovery boilers with carbon steel tubing with low steam outlet temperature

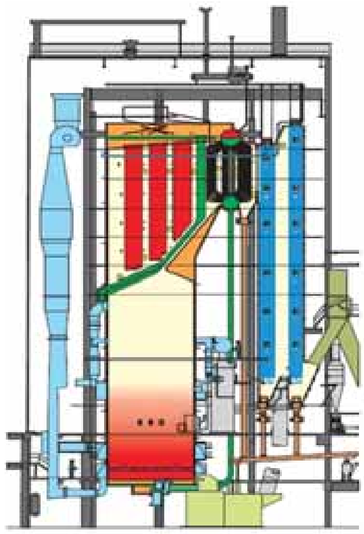


DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1950-1970

- The first high-pressure recovery boiler was supplied in 1961 to Äänekoski mill in Finland
  - Capacity 480 tds/d
  - Steam temperature 480 ℃
  - Steam pressure 82 bar
  - Carbon steel furnace
- Several other high-pressure boilers were also delivered during 1960s
- After a short period of operation all high-pressure boilers started to suffer from rapid wall tube wastage
  - All new boilers with steam pressure > 63 bar suffered from the same issue

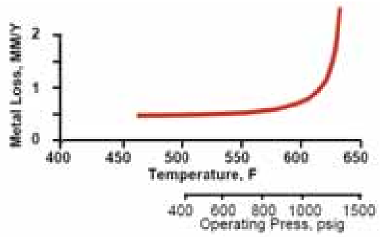


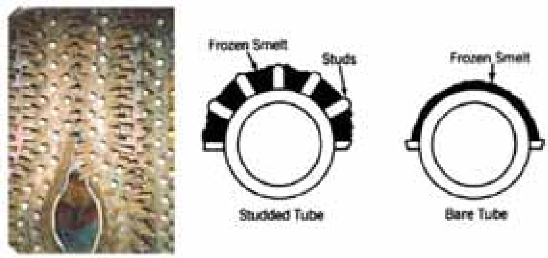
DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1950-1970

- To find out the root cause for the wastage a national research project was started
  - All Finnish pulp mills were involved by top management fiat
  - Establishment of the Finnish Recovery Boiler Committee (FRBC) in 1964
- It was concluded that the root cause for rapid tube wastage was sulfidation corrosion by reduced gaseous sulfur compounds
- The only way to prevent this type of corrosion is to use high-Cr materials
  - Stainless steel materials
  - Development of composite tubes





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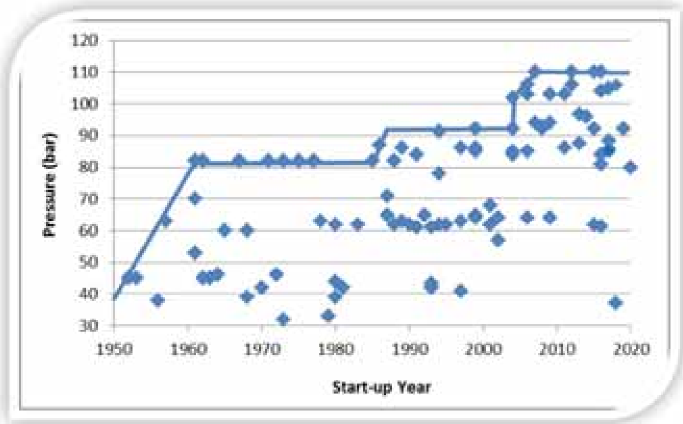
DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1970-1990

- The solution to rapid wall tube wastage was a composite tube with AISI 304L cladding and carbon steel inner tube
  - The first commercial installation was made in 1972
- The AISI 304L cladding has proven to be effective against sulfidation
- Finding the root cause and solution to the tube wastage issue, encouraged to increase the steam pressures further
- Composite tubing with AISI 304L cladding has since been widely used for wall tubing
- Good experiences from wall tubing encouraged to replace carbon steel floor tubes with composite AISI 304L tubes
  - Stress corrosion cracking (SCC) of floor tubes
  - Development of SCC resistant composite tubes

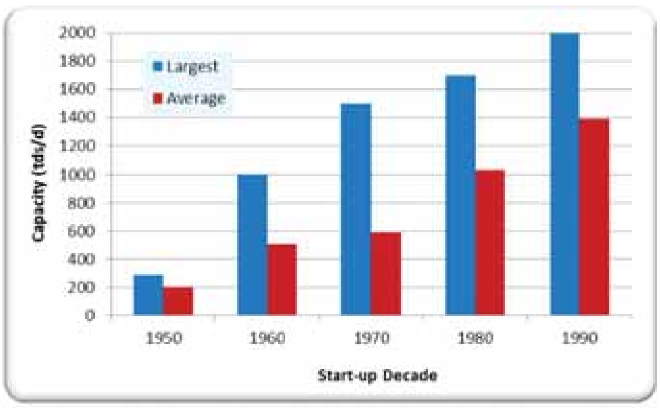


DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1970-1990

- In the 1970s and 1980s recovery boiler capacities were steadily growing
- Increase in black liquor dry solid contents up to 70-75%
- The first single-drum recovery boiler was realized in 1990
- Major steps in size and development were taken in the 1990s
  - Capacity of 3 000 tds/d was exceeded for the first time
- This capacity was long thought to be the maximum for a kraft recovery boiler due to several different reasons
- One of the major recovery boiler capacity limiting issues was the question of air jet penetration and mixing in large furnaces
- Introduction of computational fluid dynamics (CFD) simulations in recovery boiler furnace design in late 1980s



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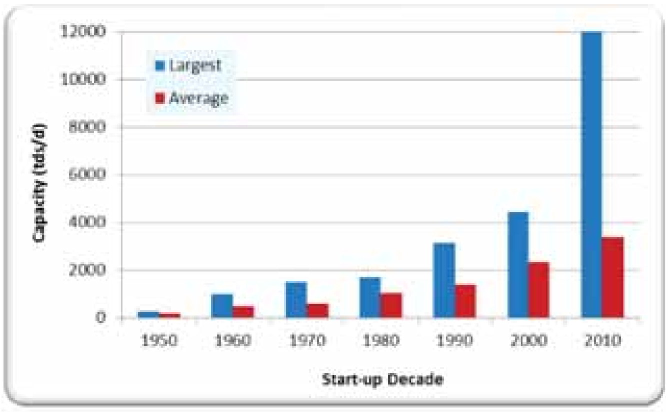
DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1990-2010

- The development of CFD simulations enabled the design of larger recovery boiler furnaces
- Simulations showed that the penetration of air jets was not limiting the furnace dimensions
- This encouraged the boiler suppliers to increase furnace size and the firing capacity of the recovery boilers
- Today, largest recovery boiler size is 12 000 tds/d capable of serving a pulp mill capacity of 2.5 MADt/a (7 000 ADt/d)

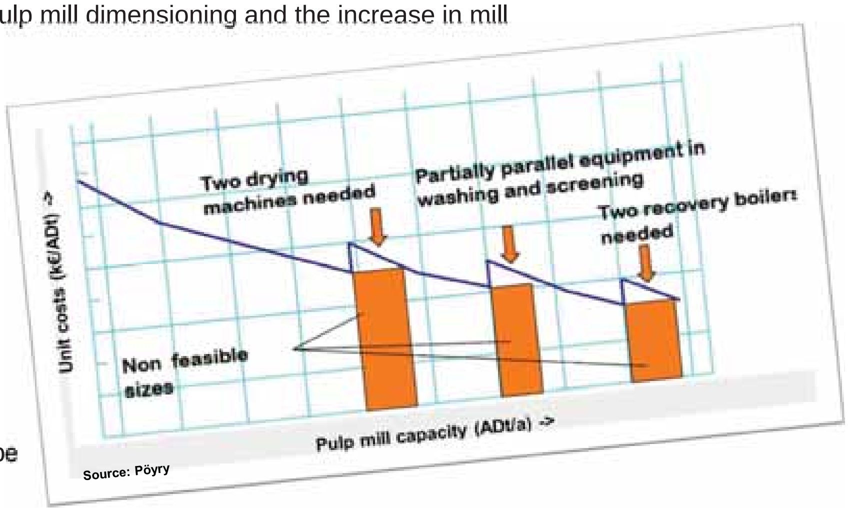


DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1990-2010

- Recovery boiler size was not anymore limiting pulp mill dimensioning and the increase in mill capacities started to be realized
- Economy of scale was taken into use in pulp mill dimensioning and design
- It seems that the optimum single-line mill capacity would be around 2.3 MADT/a
  - Two drying machines
  - One digester
  - Single evaporation train
  - One recovery boiler
  - One lime kiln
- It was speculated that two recovery boilers will be needed beyond some capacity point

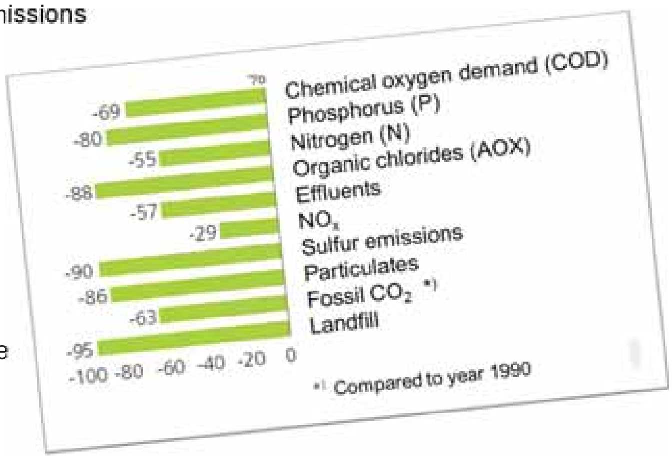


DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

1990-2010

- The 1990s was a decade of intense R&D and the reduction of emissions
- Major steps were taken to improve the combustion process in recovery boilers
  - High dry solids firing was taken into operation (ds ca. 80%)
  - Combustion of non-condensable gases (NCGs) was started
- A direct result of high dry solids firing was an immediate reduction of sulfur dioxide (SO_2) emissions
- It was not understood why the SO_2 emissions were reduced
- Collection of NCGs and combustion in the recovery boiler furnace solved most of the odor issues of the pulp mills
- Significant progress also in effluent handling



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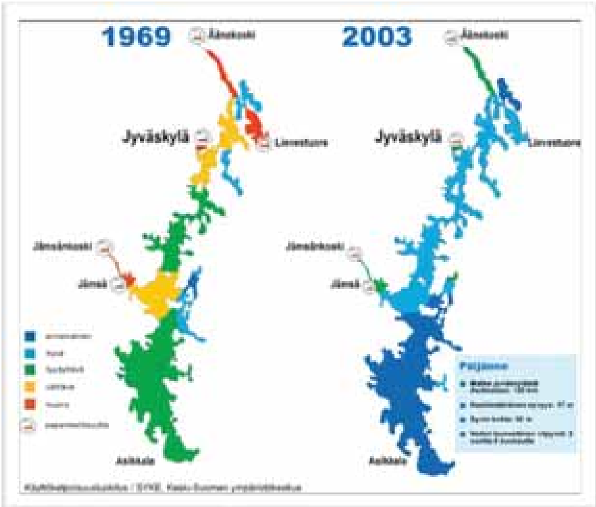
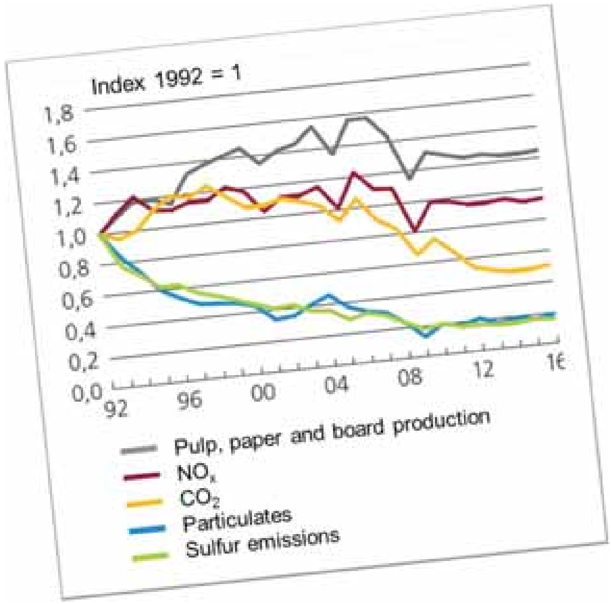
1990-2010





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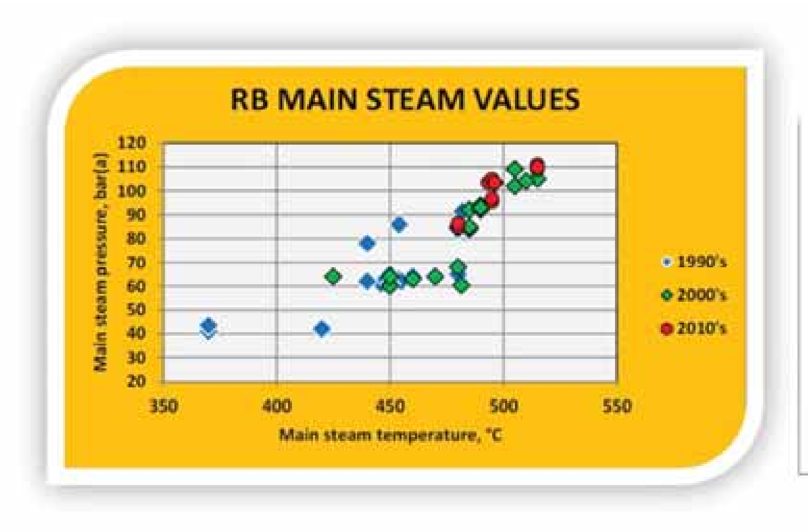
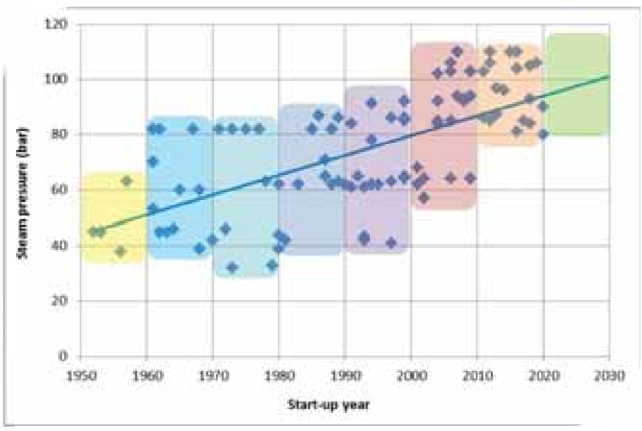
FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

2010-2030



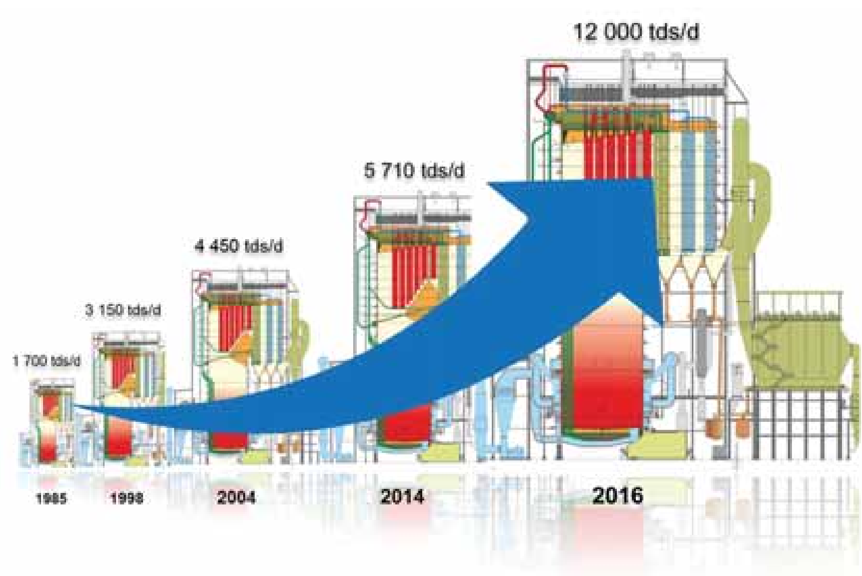


DEVELOPMENT OF KRAFT RECOVERY BOILERS

FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

2010-2030

- The era of rapid increase in recovery boiler capacity and power output
- The first recovery boiler outside Japan with steam outlet temperature of 505 ℃ (102 bar) was started-up in 2004 in Pietarsaari, Finland
- Largest recovery boiler in the world, capacity 4 450 tds/d
- The first boiler with steam temperature of 515 ℃ was started in 2006 in Östrand, Sweden
- The world's largest recovery boiler in OKI, Indonesia was started-up in 2016



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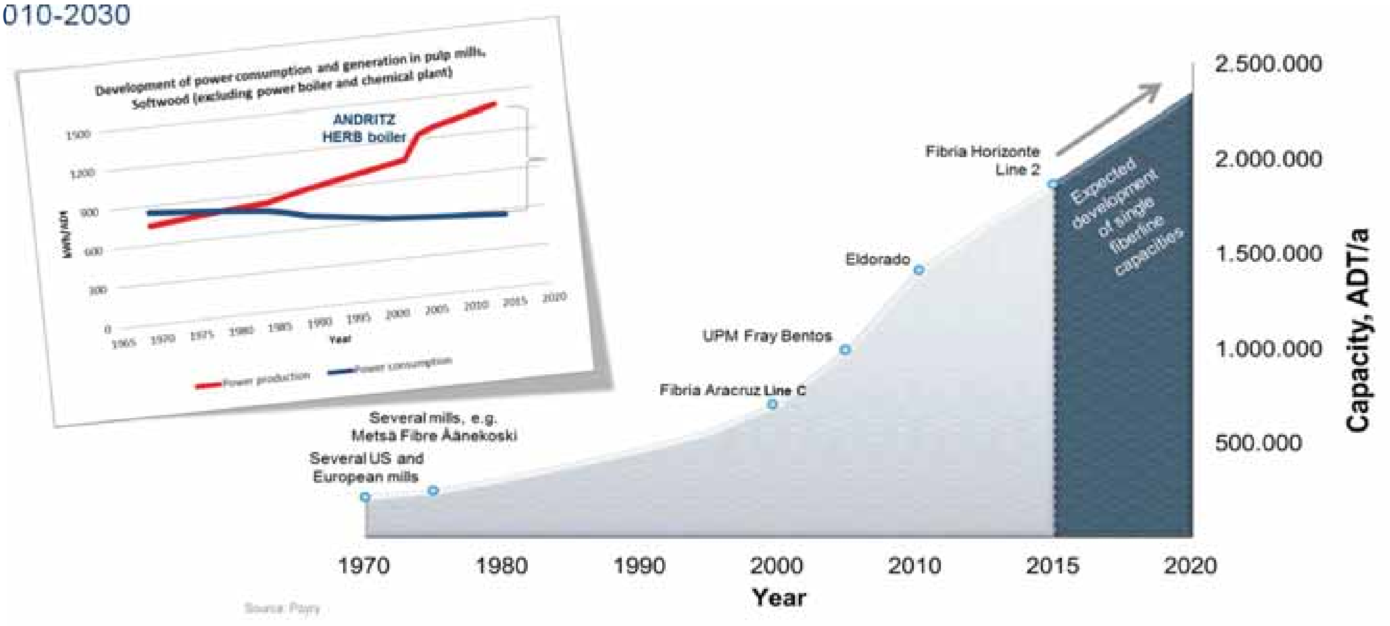

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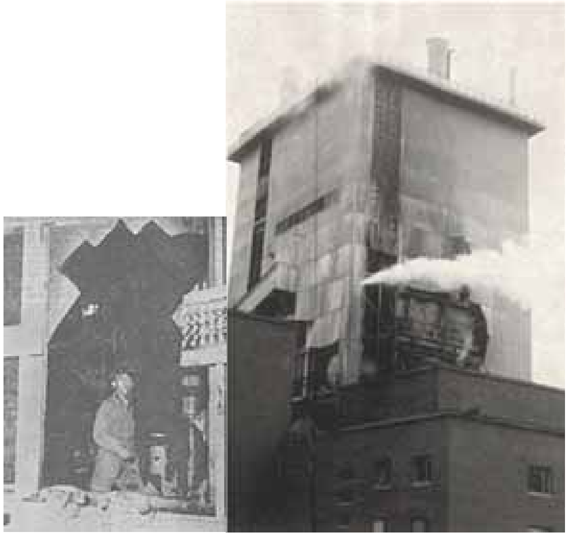
FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

Safety

- Safety and safe operation of recovery boilers have been #1 priority in the design
  - Development of features increasing the safety
  - Interlocking systems
  - ESP and rapid drain procedures
- Despite the rapid increase in furnace size, the number of incidents has decreased significantly
- Thus far, the last fatal recovery boiler explosion occurred 1965 at Äänekoski mill, in Finland
  - Smelt-water explosion***** due to a leakage in furnace screen tube
  - Four fatalities and four injured
- FRBC has also promoted the safe operation of the recovery boilers by several recommendations and guidelines



* **1.0 kg of H_2O ~ 0.5 kg of TNT**

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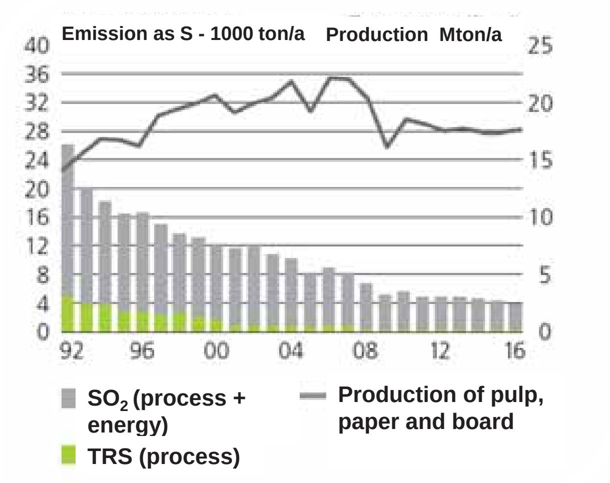
FROM RECOVERY OF CHEMICALS TOWARDS A POWER BOILER FIRED WITH BLACK LIQUOR

Emissions

- The development of kraft recovery boilers has also been guided by external demands
  - Customers and authorities
- Pressures to lower SO_2 and NO_x emissions have strongly affected the design of the air system and increased the utilization of high dry solids black liquor
- High dry solids content is also beneficial in maximizing power production and minimizing SO_2 emissions
  - Sets challenges to minimize NO_x at the same time
- Minimizing NO_x emissions has induced a change in the air split
  - To be able to minimize NO_x, the last air should be introduced into the furnace to as low temperature as possible



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Emissions

- Lowering NO_x from present level sets major challenges
  - NO_x increases with increasing dry solids content
  - Low NO_x requires a high furnace height
  - Maximizing power output benefits from low furnace height to assure high steam outlet temperature
- New BAT-BREF document sets guidelines for national environmental regulations
  - Both concentration based (mg/m³n) and specific (kg/ADt) emission limits
  - Daily and yearly averages

Decade	SO_2 (mg/m³n)		TRS (mg/m³n)		Dust (mg/m³n)	NO_x (mg/m³n)
1970	100-4000		0-500		50-1500	Not measured
1990	100-800		0-50		10-200	120-260
2010	0-100		0-50		5-190	120-250
BAT-BREF	10-70	5-25	1-10	1-5	10-25	120-200

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Metris
ANDRITZ Digital Solutions

Digital Transformation

IT Enabled Recovery Developments

Foresee digitally

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Digitalization

- The following decade 2020 will be the era of digitalization
- The entire pulp mill is digitalized and big data and artificial intelligence will be used for process control and process optimization
- With the ANDRITZ Metris brand's digital IIoT solutions, customers are preparing for the growing digital challenges in the industrial environment
  - They are paving the way for digital predictability
- ANDRITZ Metris technologies are aimed at digitalizing and networking machines and plants as well as developing new customer-specific solutions
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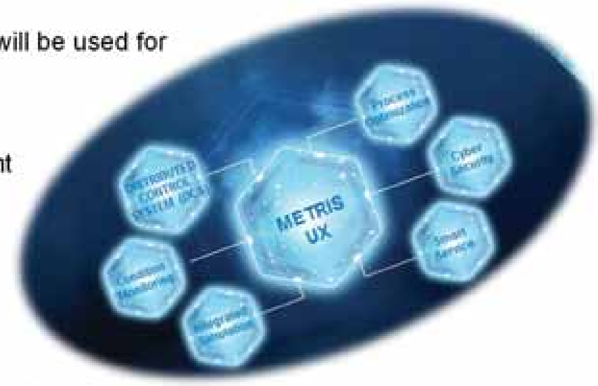

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Digitalization

- From single machines to Smart factories
- Complete functionality on premise or optional cloud based enterprise solutions
- All in one - Full integration between all apps
- For plant performance, production- and maintenance management
- Artificial intelligence based apps

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DEVELOPMENT OF KRAFT RECOVERY BOILERS

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Summary

- Development of kraft recovery boilers has led to:
  - Increased safety
  - Lower emissions
  - Longer operation periods
  - Less maintenance
  - Higher power production
- Modern recovery boilers are able to produce considerably more power than two decades ago
- Recovery boilers have now features common to the power boilers
  - Recovery of heat from the fluegases
  - High steam temperature and pressure
- Earlier pulp mills had large deficiencies in energy and they had to buy energy from the grid
  - Now the energy self-sufficiency of modern mills is over 200%

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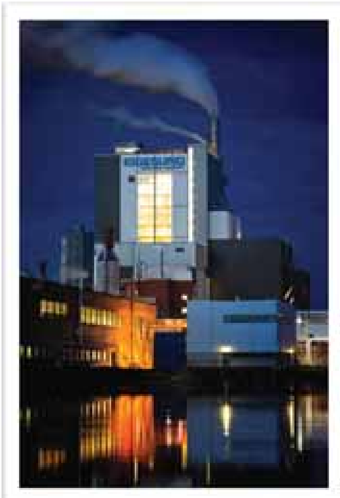
Conclusions

- ANDRITZ has delivered 94 new recovery boilers since 1952
  - Latest delivery to Klabin, Brazil
- ANDRITZ is the forerunner in the field of increasing power production from recovery boilers
  - First 505 ℃ recovery boiler started-up in 2004
  - First 515 ℃ recovery boiler started-up in 2006
- ANDRITZ has built two world’s largest recovery boilers
  - 12 000 tds/d OKI in Indonesia
  - 8 250 tds/d Suzano Horizonte II in Brazil
- Physical limits of kraft recovery boilers have yet not been seen
  - Even higher capacities on design board



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