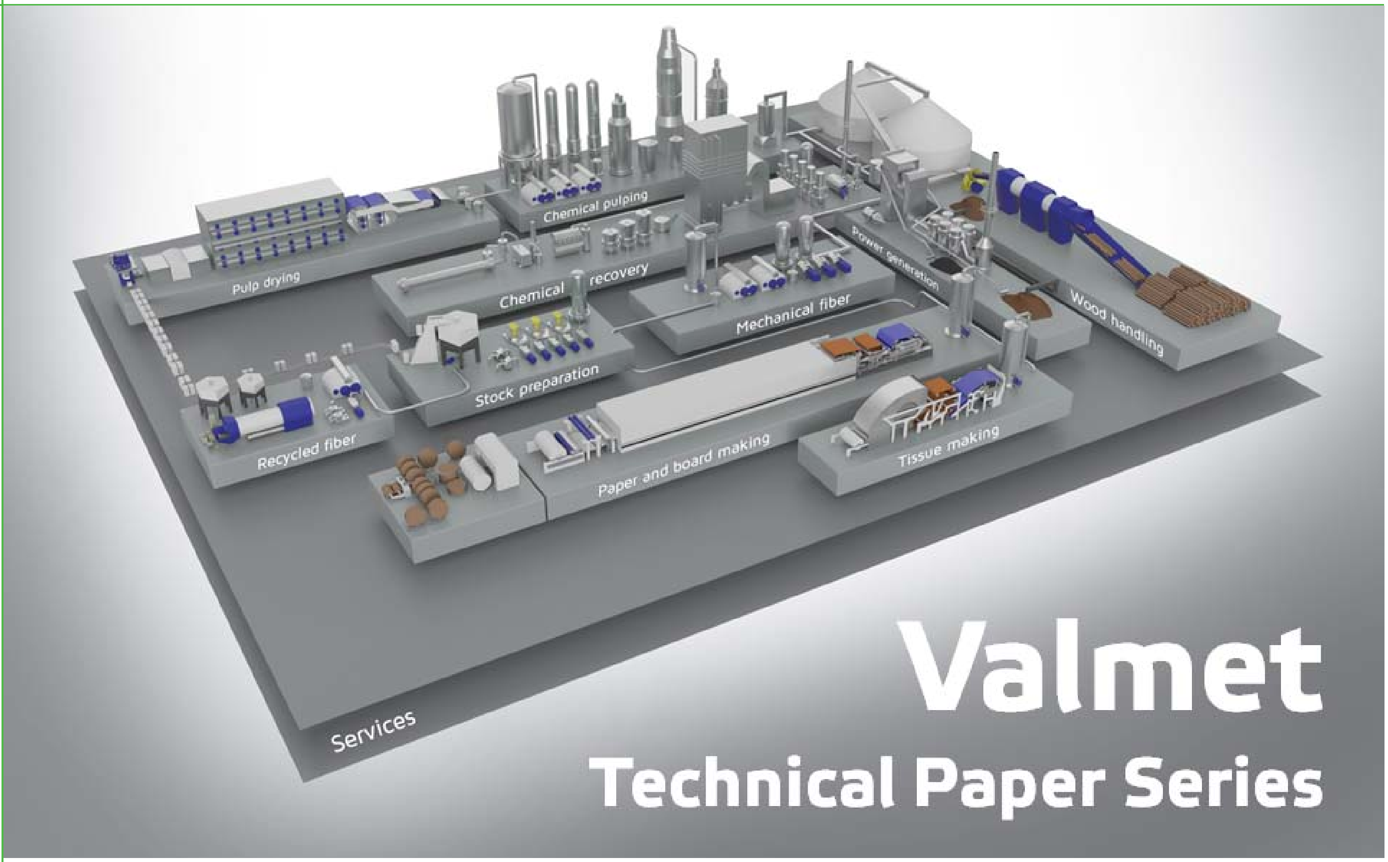


High Power Generation from Recovery Boilers - What Are the Limits?

Executive Summary

Increasing power generation from recovery boilers has been an item of interest since 2000 and really became a strong driver in the last 5 to 10 years. This trend came partly from the pulp and paper (P&P) industry desire to increase efficiency and reduce cost, but also from the legislative authorities' desire to reduce Green House Gas (GHG) emissions and their role in climate change.

Current European Union (EU) legislation gives strict limits on how much electrical power consumption of each member country must come from renewable sources by the year 2020. Since the P&P industry represents, especially in Nordic countries, a large portion of the energy generation and consumption, companies are trying to take full benefits of the available financial incentives for renewable electrical power generation and improve their environmental image by minimizing fossil fuel usage.

Although current prices for fossil fuel are coming down*, mostly due to shale oil and gas increased production, the demand for increased energy efficiency in pulp mills is a key factor in new recovery boiler projects around the world, with the goal to minimized energy purchase and maximize in-house power generation, often with the goal to generate revenue by selling excess green energy.

(* *Note: This paper was written in mid-2015. The Äänekoski mill is scheduled to come online in late 2017.*)

Introduction

So, where are we with the technology? The discussion with recovery boilers has traditionally been around the maximum achievable steam parameters (temperature and pressure). Boilers developed solely for power generation have much higher steam parameters and thus have much better steam to electricity ratio. Over the years, we have seen a steady increase of steam parameters also in recovery boilers, but current state-of-the-art is still far from power boiler figures. The limiting factors are the recovery boiler fuel/ash properties and the corrosion resistance of available superheater materials for these conditions. Since the boiler supplier's role is not to do tube material development work but to test and analyze available materials in the marketplace, their own R&D work is concentrated on identifying factors affecting the corrosion rate and finding ways to mitigate the risk of excessive corrosion. The main challenge is to avoid having ash in a molten phase close to the tube surface as no commercially available superheater tube material can resist situations where molten corrosive ash is in contact with the metal surface. A lot can be accomplished, however, with the correct superheater design in terms of arrangement, optimum material selection, steam temperature control, and controlling the sulfide carry-over. It is important to be able to optimize the superheater material selection for the given conditions in order to keep cost at an acceptable level and get acceptable financial return for the higher power generation concept.

Apart from steam parameters, the amount of steam generated from a given fuel amount has also been trending upward. The increased boiler steam generation efficiency also gives more power but with less risk of unplanned maintenance shutdowns and lost production. It should be obvious that everything in this area needs to done before stretching the envelope too much with steam parameters. The ratio of kg of generated steam per kg of liquor solids has actually gone up by more than 20 % in the last decade through techniques such as higher dry solids firing (>80%), higher feedwater temperature to maximize steam generation and the addition of heat from other external sources to the boiler (high combustion air temperature, external feedwater pre-heating).

This paper will present, discuss and compare the current possibilities to increase recovery boiler power generation using the recovery boiler currently under design for the first next-generation bioproduct mill, Äänekoski, as an example. A review of the technical and financial impact of various alternatives to improve power generation and their associated return on investments will be reviewed.

Äänekoski bio-product mill

The Äänekoski mill was originally built in 1985 and, upon start-up, it was one the biggest and most efficient single-line pulp mills in the world with about 350.000 tons of annual pulp production capacity. Special attention was paid in the design of the mill to make it as environmentally friendly as possible. Thirty years later, in spring 2015, Metsä Fibre announced an investment decision for a new 1.3 million ton bioproduct mill to be built at the same location and again the target was set high. Nothing less than high energy efficiency, maximum amount of bioelectricity generated, low emissions and minimal specific water consumption were accepted. Calling it a bioproduct mill means basically that all the raw materials and side streams will be utilized as products and bioenergy. Mill planning also takes into account future bioproduct possibilities, e.g. lignin separation.

Energy efficiency got a special emphasis when choosing the equipment and machinery. The most advanced energy technologies in the recovery boiler and lime kiln equipment solutions were applied and will make the Äänekoski bioproduct mill the world's most energy-efficient pulp mill, and the first to operate 100% fossil fuel-free. The lime kiln will use biogas generated from bark and other wood residues, and the recovery boiler will have several advanced design features to maximize bioenergy production.

The EU dictates that each member country increase the share of renewable sources in energy production. The target for Finland is to raise it from 28.5% (1990) to 38% (2020); this individual Metsä Fibre bioproduct mill investment will contribute by approximately 2 percentage points toward that target. The mill will not only be electricity self-sufficient, but actually generate 2.5 times more than it will consume. To put it into perspective, the annual production 1.8 TWh of electricity represents 2.5% of the electricity produced in all Finland. It should be also noted that the sales of energy and other new bioproducts could contribute up to 20% of the mill's total revenues and provides a nice buffer for the sometimes-volatile pulp market.

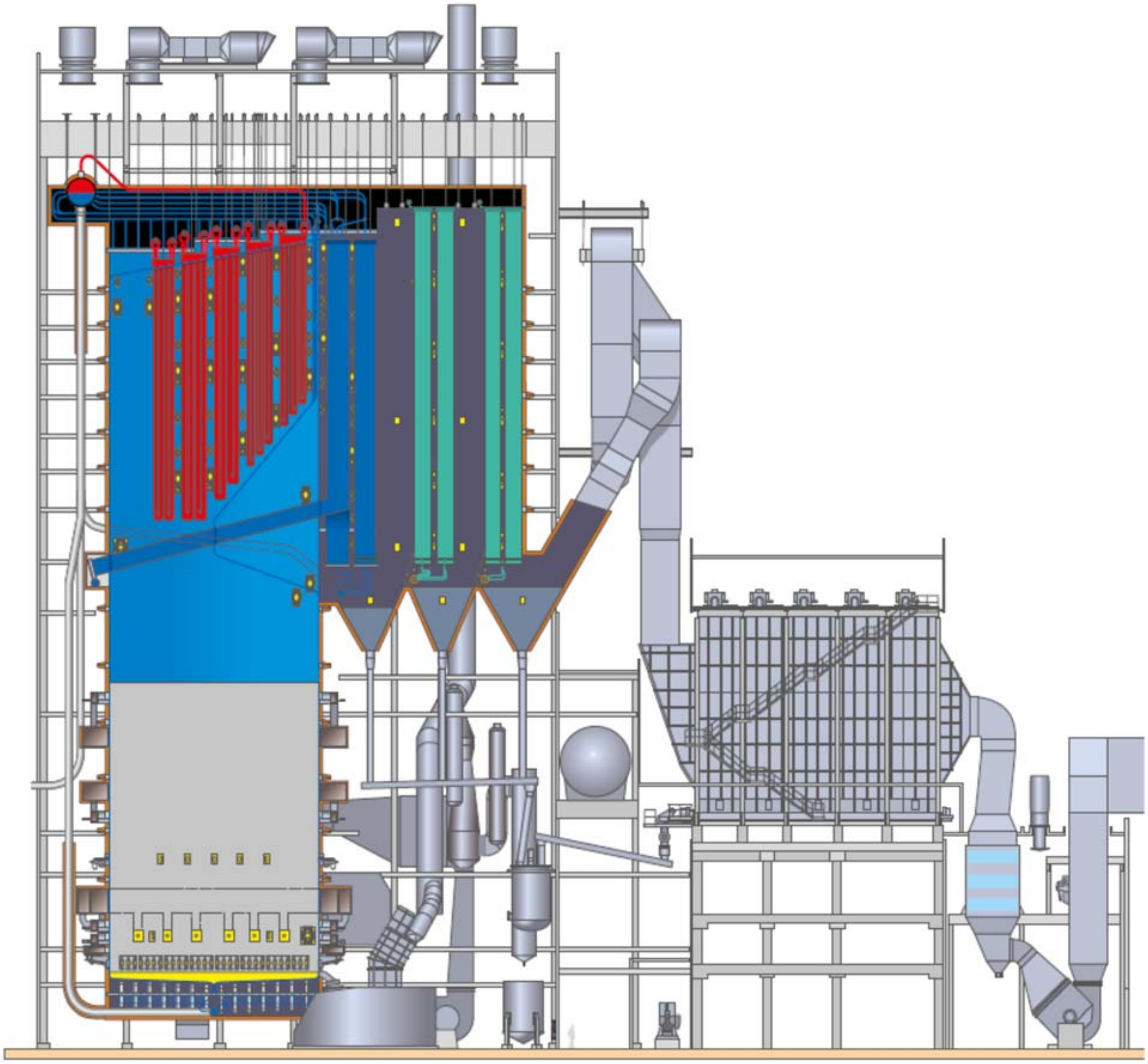


Figure 1. Side view of Äänekoski recovery boiler

High power features used in Äänekoski

The most common high power features are presented in **Figure 2** and will all be included in the upcoming Äänekoski recovery boiler. Starting from the right, the boiler feedwater, which comes from mixed demineralized water and turbine condensates, is heated in a tube condenser (1) which uses the heat available in the vent gases from the dissolving tank. The feedwater is then further heated in a flue gas cooler (2) where some of the heat left in the flue gases after the economizers is recovered. Both of these features decrease the amount of low pressure steam needed in the feedwater tank. [2]

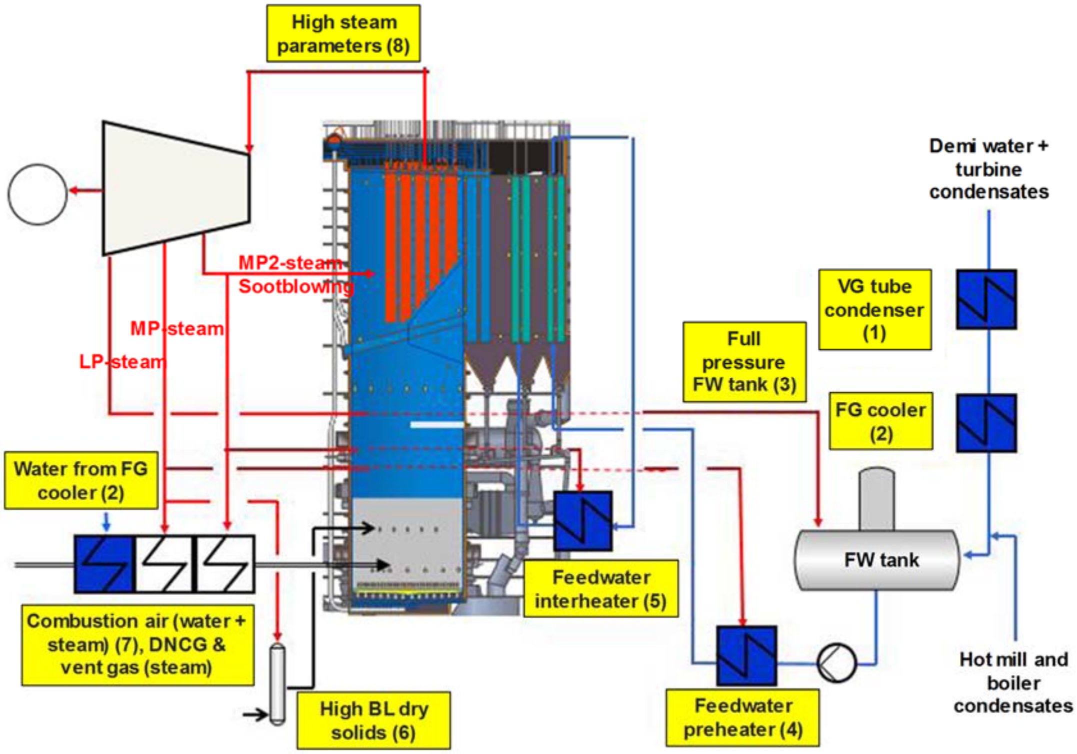


Figure 2. High power features in recovery boilers

Then there are five features that increase main steam flow. The full pressurized deaerator / feedwater tank (3) means that pressure losses from the turbine LP steam extraction to the feedwater tank are minimized, leading to as high an operating temperature as possible. After the feedwater tank, the feedwater is preheated in two additional steps: first with a feedwater preheater (4) and between the economizers with an interheater (5), both using medium pressure extraction steam. Higher feedwater temperature results in higher steam generation from the recovery boiler. Using turbine extraction steam to preheat feedwater is a well-known approach in the power generation industry to increase cycle efficiency as it reduces heat loss to the condenser.

With high dry solids content (6) in the liquor, less heat energy is required to evaporate the moisture in the furnace and more steam is generated. Also, using high combustion air temperature (7) increases the heat input to the furnace and leads to an increase in the main steam flow. Low pressure steam consumption is decreased further by replacing the first stage of air preheating with a heat exchanger using the heat from a flue gas cooler (2). Finally, electricity generation is improved by having high main steam parameters (8), 515°C and 111 bar (a) With higher main steam parameters less main steam is generated as the same amount of heat is transferred from flue gases to steam. [2]

One important parameter describing the energy efficiency of a recovery boiler is the ratio of steam generation and black liquor dry solids. Basically, it tells how much steam is produced by kg of black liquor solids combusted. **Figure 3** shows typical values for conventional recovery boilers as well as a few high power recovery boilers. For Äänekoski this ratio is 4.35, which is clearly higher than the others and actually will be the highest for any recovery boiler, even though high steam parameters decrease the steam generation.

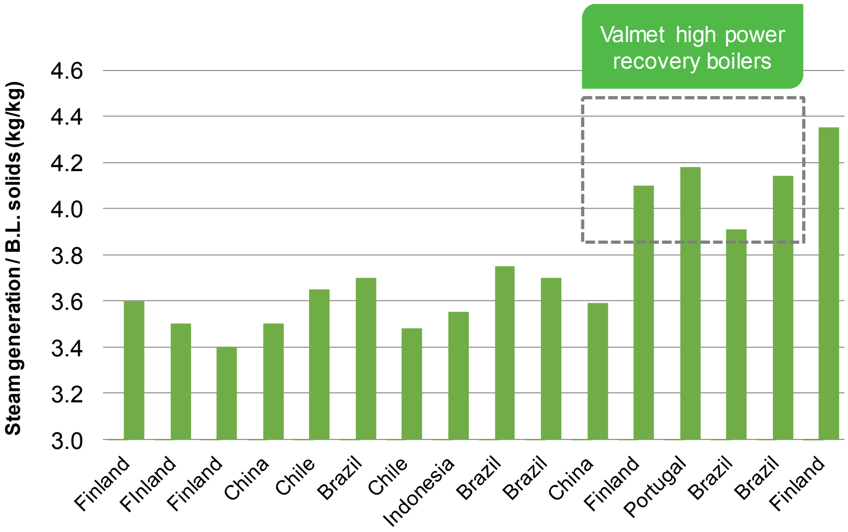


Figure 3. Steam generation / black liquor solids

Significant improvements have been accomplished with the high power features during the past decade and, in the Äänekoski case, the full capacity of each feature has been utilized as well as possible. However, there is still some room for improvement, especially in increasing the steam parameters. Before going into details, it is important to understand the factors limiting the steam parameters.

Role of ash composition in recovery boiler design

When designing a recovery boiler, everything starts from the black liquor composition, which depends on wood species and quality used in the pulp mill, cooking yield which is affected by cooking method and operation parameters, spent acid amount from the chemical plant and other miscellaneous chlorine inputs. Knowing the higher heating value (HHV) and the amount of black liquor available, it is possible to calculate the dimensions of the boiler and determine how much heating surface is needed. However, in order to be able to select the appropriate superheater materials, one needs to know the ash composition and more specifically the potassium and chlorine contents (also called as non-process elements, NPE), since these have a major role in corrosion and fouling phenomena. Ash treatment systems have been developed in order to control the potassium and chlorine balances; they have now become almost standard equipment in pulp mills.

In the following sections corrosion and fouling phenomena are discussed more in detail, and ways to control the ash composition with the help of ash treatment technologies are presented.

Corrosion and fouling

Figure 4 shows how ash appearance changes as a function of temperature. In a certain temperature ash starts to melt and this is called the first melting temperature T_0. Molten ash is highly corrosive. It is therefore very important that the temperature at the surface of the superheater tube does not exceed T_0 or molten phase corrosion will occur. Because no known material can withstand the molten phase corrosion, it is

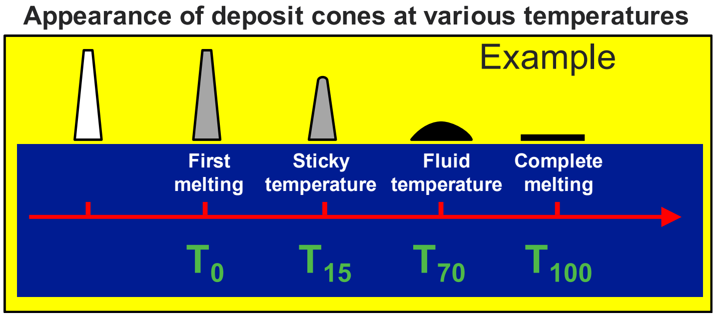


Figure 4. Ash melting deformation temperature

very crucial to operate the tube surface temperature under T_0 where only solid phase exists in the ash on the tube surface.

Figure 5 shows how superheater materials are selected in order to avoid molten phase corrosion. When there is a large enough temperature difference between superheater tube surface (T_m) and T_0, a thick protective layer is formed which keeps the superheater tube safe from molten phase corrosion (A). In such a case carbon and low chrome alloy steel materials can be applied. For thin frozen layer (B), stainless-steel material must be used to provide better corrosion resistance. When the surface temperature T_m is the same as T_0 (C) and due to the lack of protective frozen layer, the tube surface will corrode heavily, even for stainless-steel materials.

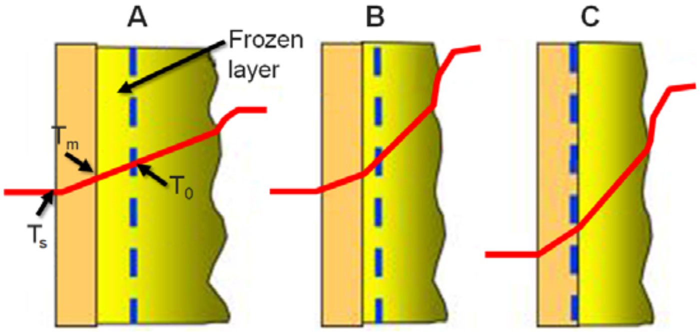


Figure 5. Ash layer influence on SH material selection

Besides molten phase corrosion, superheaters must also be protected from carryover and chlorine induced corrosion mechanisms. Carryover droplets contain unburned carbon and Na_2S which can create local reducing conditions making the ash more corrosive. Sulfides may also decrease T_0 by up to 50 °C. Therefore, having an excess amount of carryover may cause corrosion even though the previously mentioned superheater material selection principles have been applied. Chlorine induced corrosion occurs only when alkali chlorides (NaCl, KCl) are present, which is always the case in recovery boilers, and for superheater tube material temperature above a certain threshold temperature. Under such conditions, chlorine reacts with Fe in the alloy, forming volatile iron chlorides, which are oxidized and then release chlorine back to the process continuing the corrosion mechanism.

Typical amounts of stainless and carbon steel materials used in recovery boiler superheaters with modern steam parameters are illustrated in **Figure 6**. Primary superheaters are usually made entirely from carbon and low chrome alloy steel. Low chrome alloy steel materials are also used in the secondary and tertiary superheaters, but since they are visible to the furnace and to possible carryover, it is necessary to protect the lower bends with stainless-steel. Quite often the last tubes of the hottest superheater are made from stainless-steel since the steam temperature is highest in this location and carbon and low chrome alloy steel material would corrode due to molten phase corrosion.

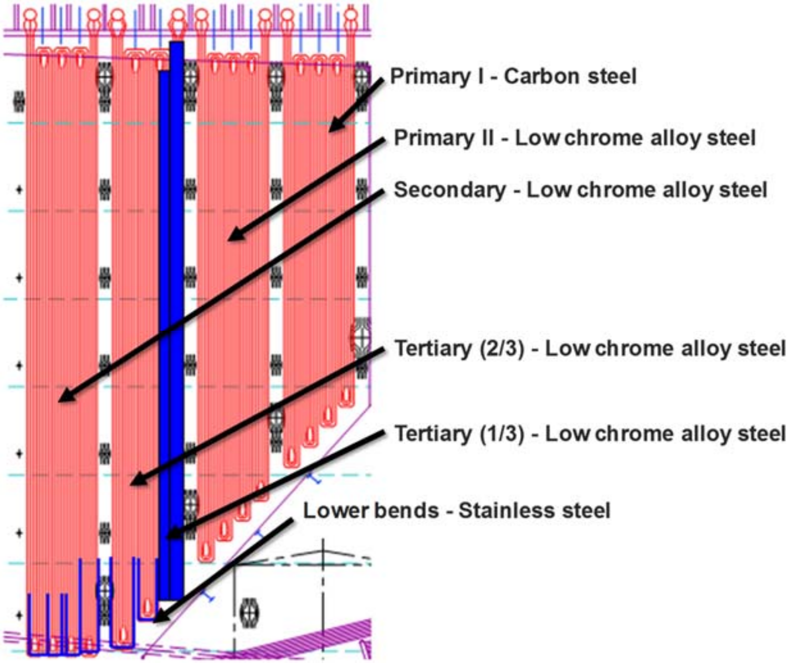
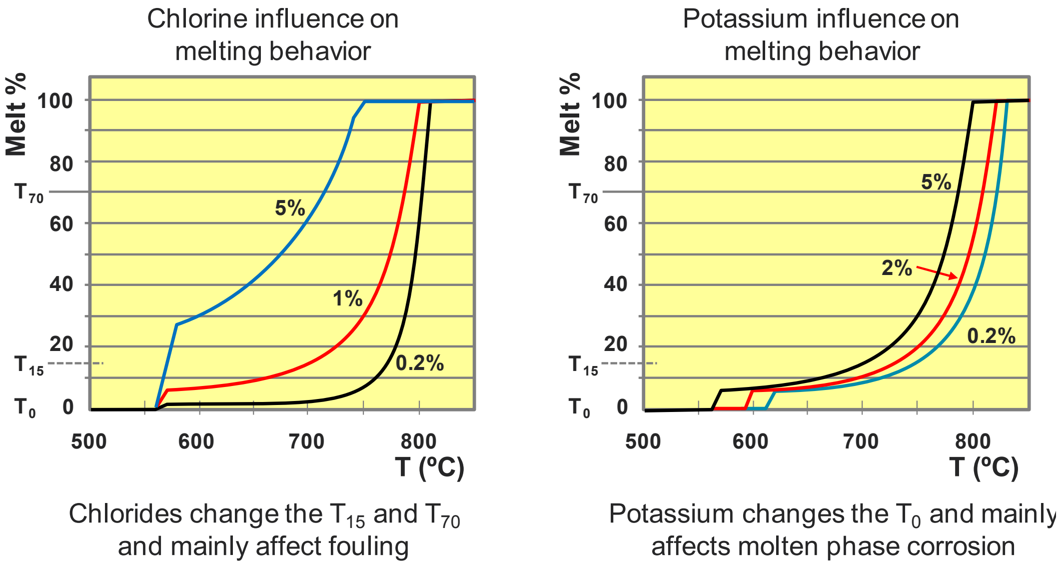


Figure 6. Typical amount of stainless and carbon steel in superheaters

As shown in **Figure 4**, when 15 wt-% of the ash is molten, ash becomes sticky and it tends to accumulate and stay on superheater surfaces. Ash remains sticky until the ash melt fraction is more than 70 wt-% after which it is fluid enough to flow off the superheater elements. Therefore, the sticky area region determined by T_{15} and T_{70} should be before the second pass where spacing between tubes is smaller than in the superheater area. Two ways to improve the situation are to treat ash or add superheater area.

T_0, T_{15} and T_{70} all depend on the ash composition - mainly potassium and chlorine contents. It can be seen from **Figure 7** that potassium changes T_0 and chlorides affect T_{15} and T_{70}. Higher potassium content decreases T_0 and higher chlorine decreases T_{15} and T_{70}. The first impression can easily be that high potassium content leads to corrosion issues and high chlorine content increases fouling problems. Unfortunately, it is not that simple; chlorine is needed in the molten phase corrosion mechanism and its effect on corrosion has been extensively studied during the past decades with more research ongoing. In addition, potassium has an effect on T_{15} and T_{70} and furthermore, carbonates and sulfides change T_0 but the effect is smaller than potassium [1].



Chlorides change the T_{15} and T_{70} and mainly affect fouling

Potassium changes the T_0 and mainly affects molten phase corrosion

Figure 7. Effect of K and Cl on corrosion and fouling

Low potassium and chlorine contents in the black liquor lead to a narrow sticky area, and this area is located far enough from the second pass, as shown in **Figure 8**, image A. Image B represents a situation where potassium and chlorine contents are high and therefore the sticky area is wide and located in the second pass - leading to fouling problems.

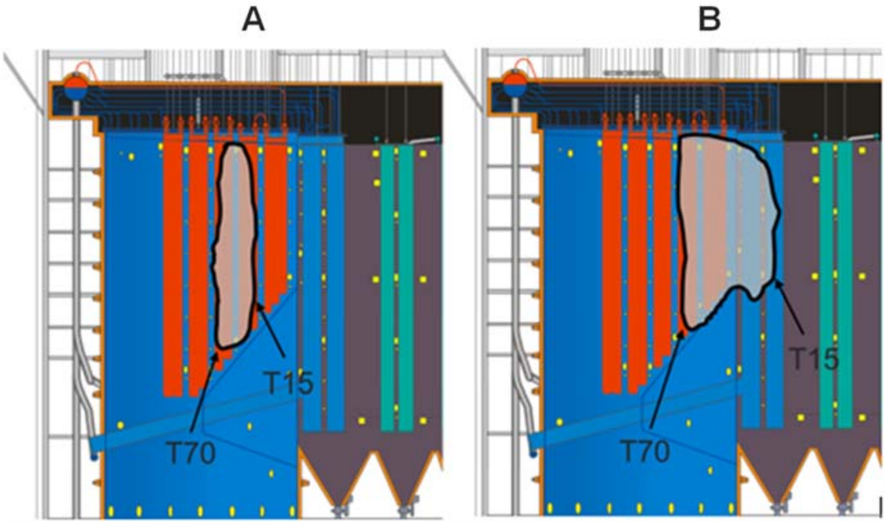


Figure 8. Sticky area location with different K and Cl contents

At this point it is good to mention that excluding high steam parameters, high power features do not affect corrosion. Some of the features can slightly change the flue gas temperature field across the superheater, but the influence on the fouling region is marginal. However, they might affect some other boiler parameters such as the main steam flow, the total boiler attemperation, the temperature difference between the drum and sweet water condenser/last economizer, the flue gas exit temperature and the drum pressure. [2]

Ash treatment methods

The harmful substances potassium and chlorines can be controlled by treating the ash. Two technologies are offered for this purpose: ash leach and crystallization. Both technologies are able to remove these non-process elements from the liquor cycle at significantly lower sodium and SO_4 losses compared to purging of boiler ash.

Ash leaching has a lower capital and operating cost, but also a lower removal efficiency, resulting in a higher chemical loss. Crystallization is becoming more popular, especially for larger mills, for its higher Na recovery efficiency and lower associated chemical losses.

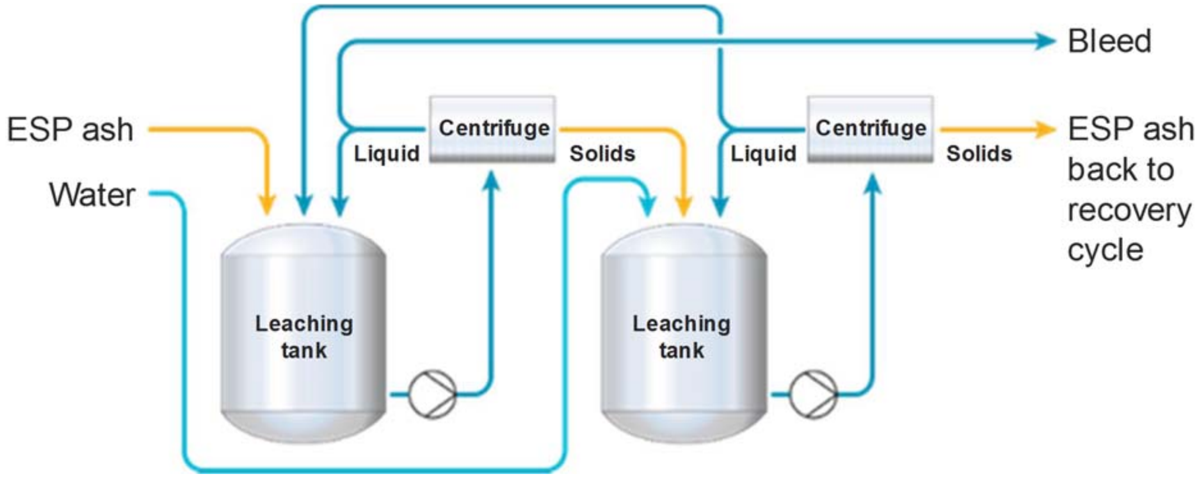


Figure 9. Ash leaching operation principle

Figure 9 illustrates the operation principle of a two-stage ash leach system. ESP ash is mixed with warm water in the agitated leaching tank where slurry forms. As the solubility of Na_2SO_4 is significantly lower than the solubility of NaCl and KCl and other potassium and chlorine salts, most of the potassium and chlorines dissolve in the water while the main part of Na_2SO_4 remains solid. From the leaching tanks the slurry is pumped to centrifuges where the liquid phase is separated from the solid phase. The solid phase is recovered back to the black liquor cycle and the chlorine and potassium rich liquid is partly purged as a reject and partly recirculated back to the leaching tank. A single stage system can be used if the carbonate content of the ash is fairly low (<5%) or if the carbonate can be converted to sulfate through sulphuric acid addition. Where the sulphur balance of the mill does not allow the addition of sulphur acid, a two-stage system is used. The presence of carbonate in the ash makes it more difficult to separate the solid and liquid phases.

The crystallizer operation principle is a bit more complex as shown in **Figure 10 (next page)**. Instead of dissolving potassium and chlorine salts from the Na_2SO_4 rich ash, sodium salts are crystallized in a flashing stage. ESP ash is first dissolved in the ash dissolving tank and then it is pumped to the crystallizer circulation loop. Before entering the crystallizer tank, the solution is heated by flash steam taken from evaporator effect 1, after which it flashes in the crystallizer tank. Sodium based salts are crystallized in the flashing process before potassium and chlorines which mainly stay in the remaining solution and the flashed saturated steam is returned back to the evaporator. The crystals and the potassium and chlorine rich solution are then led to a thickener where the slurry density is increased by decanting the solution, following which the crystals are separated from the solution in the centrifuges. The purified ash crystals are then dissolved in intermediate black liquor in a separate crystal dissolving tank and the remaining solution, which is now called the mother liquor, is returned back to the crystallizer circulation loop. Potassium and chlorine rich bleed is purged from the crystallizer tank in order to remove the non-process elements from the black liquor cycle.

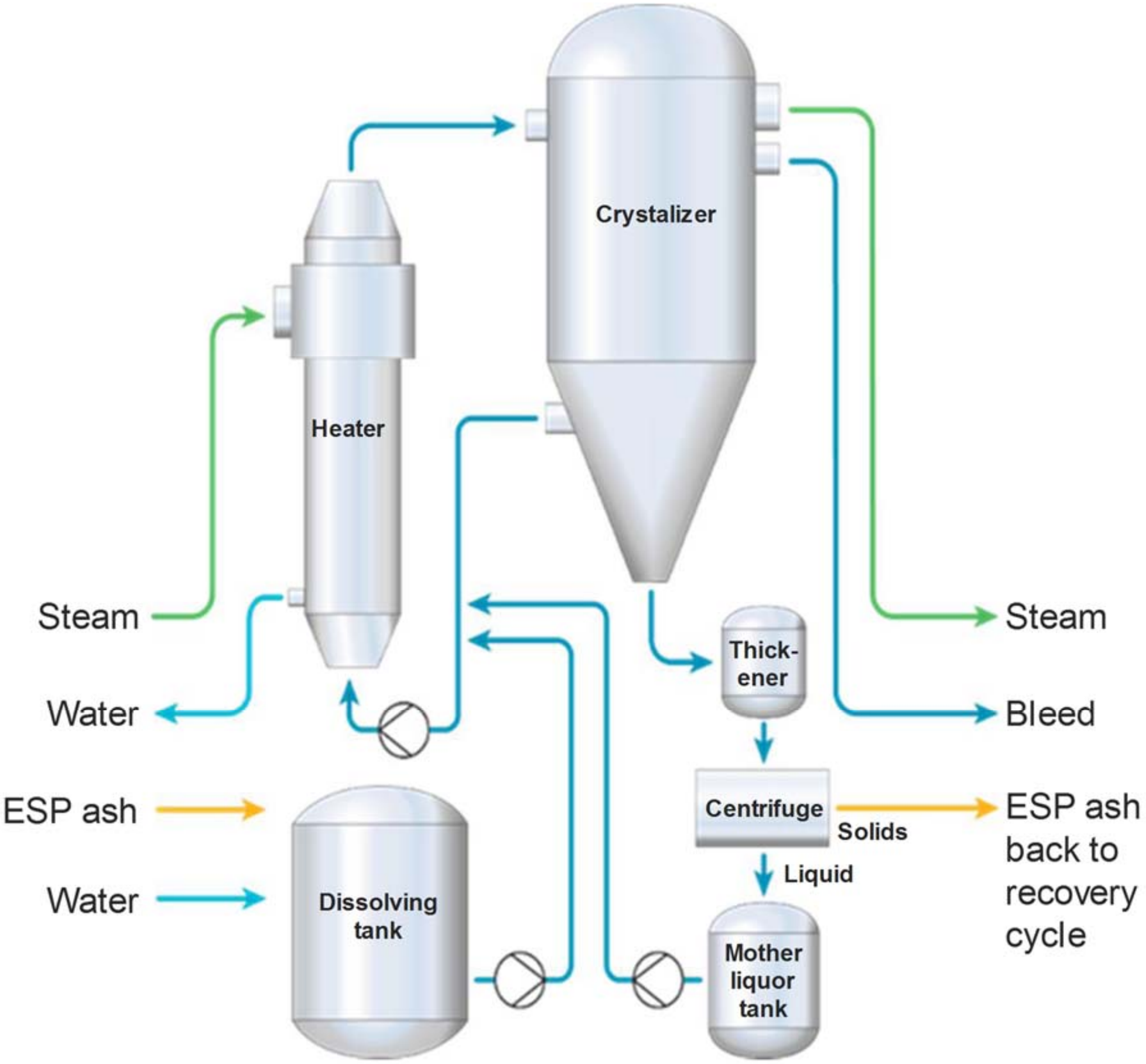


Figure 10. Crystallizer operation principle

Maximizing steam parameters

As stated earlier, the superheater material surface temperature must be lower than T_0 in order to avoid molten phase corrosion. The required temperature difference between T_0 and superheater material temperature depends on whether stainless-steel is applied or not. By treating ash and removing potassium and chlorine from the liquor cycle, it is possible to increase T_0, but at the same time some of the valuable sodium is lost. Basically, when increasing steam parameters it is a trade-off between optimizing investment cost (superheater materials and ash treatment equipment) against operating cost (gains in electricity production and losses in sodium make-up chemical costs).

To better show how to conduct this analysis, calculations using the Äänekoski case as an example are shown in the following text. Some of the input data has been changed, but the as-sold Äänekoski recovery boiler is used in the following calculations. The assumptions behind the calculations are presented first.

Assumptions

Potassium (1.3 kg K/Adt) and chlorine (0.2 kg Cl/Adt) inputs to the mill have been modified so that they represent typical Scandinavian softwood pulp mill values. Without any ash purging or treatment and including only natural losses, the potassium and chlorine contents in the virgin black liquor are 3.5 wt-% and 0.5 wt-%, respectively. For example, in South America non-process element inputs are substantially higher, typically 2 kg K/Adt and 1 kg Cl/Adt, meaning that the higher steam parameters are more difficult and expensive to achieve.

All of the sodium make-up requirement is assumed to be handled with NaOH and the price of 400 €/t is used. Sulphur losses are ignored since quite often the sulphur balance can be adjusted with an excess amount of free or very cheap sulphur available, for example sulphur rich spent acid from the chemical plant. Use of Na_2SO_4 as a make-up chemical in addition to NaOH in order to match the sulphur balance would not change the following calculation results if the price of Na_2SO_4 is assumed to be 200 €/t.

A crystallizer is used as an ash treatment technology and the Na and SO_4 recovery efficiencies are assumed to remain constant regardless of the ash composition. Also, Cl removal efficiency is kept the same, but the removal efficiency of K is decreased quite drastically when the K content in the black liquor approaches 2%. From the energy balance point of view, it has to be noted that the crystallizer consumes saturated 1.7 bar(a) steam coming from evaporation effect 1 and the formed condensates are then flashed and returned back to the evaporator steam cycle. The crystallizer also produces saturated 0.78 bar(a) steam which is used in the last evaporator stages. In other words, the energy amount consumed by the crystallizer must be compensated in the evaporation plant by low pressure steam taken from the turbine extraction whenever the crystallizer is used. This has been taken into account when performing the electricity balance calculations.

An electricity price of 50 €/MWh has been used and operation time has been assumed to be 8500 hours in a year. When steam parameters are increased, pressure is selected so that steam quality at the condensing turbine outlet remains constant. Higher steam pressure also means higher design pressure of pressure parts. A rule of thumb is that a tube's wall thickness increases in the ratio of the (drum) pressures. In this case pressure part weight is increased by 10% (corresponding drum pressures to live steam pressures of 111 bar(a) and 119 bar(a) are 124 bar(a) and 136 bar(a)). Therefore, the 10% price increase of pressure parts has been included when calculating the investment costs.

In the following calculations, investment costs are for European market using EN code and include the following:

- Materials
- Equipment
- Manufacturing
- Installation
- Freight
- Profit margin

However, all equipment (e.g. steam turbine) outside a typical recovery boiler battery limit are ignored.

Calculation cases and results

Five cases have been calculated and **Table 1 (next page)** shows the changes in operational and investment costs of the boiler and crystallizer as well as the payback time of the required extra investment. In case 1, which is also the reference case, steam temperature is 515 °C and a sufficient amount of ash is treated to get to the typical amount of stainless-steel material required in the superheater (as in **Figure 6**). In practice, this means that 140 t/d of ash needs to be treated in the crystallizer. In a way, case 1 represents the Äänekoski recovery boiler, but with a slightly different black liquor composition due to differences in K and Cl inputs to the mill. Therefore, the treated ash amount also does not correspond to the Äänekoski balance.

	Case 1	Case 2	Case 3	Case 4	Case 5	
K in virgin BL	1.6	3.5	0.7	1.6	2.2	%
Cl in virgin BL	0.1	0.5	0.04	0.1	0.13	%
Ash amount to be treated	140	0	450	140	110	t/d
Additional make-up cost (NaOH)	ref.	-1.15	+2.91	0.00	-0.27	M€/a
Steam temperature	515	505	515	525	525	°C
Steam pressure	111	111	111	119	119	bar(a)
Difference in steam generation	ref.	3.3	0.0	-2.4	-2.4	kg/s
Difference in power generation	ref.	-0.82	-0.39	+3.83	+3.88	MW
Additional profit from power generation	ref.	-0.35	-0.16	+1.63	+1.65	M€/a
Decrease in operational costs	**ref.**	**-0.80**	**+3.07**	**-1.63**	**-1.93**	**M€/a**
Extra investment cost	**ref.**	**1.46**	**3.89**	**7.59**	**7.07**	**M€**
Payback time of the extra investment	**ref.**	**1.8**	**neg.**	**4.7**	**3.7**	**a**

Table 1. Calculation cases and corresponding changes in operational and investment costs

Case 2 represents a situation where no ash is treated leading to a higher degree of stainless-steel usage and more expensive superheaters. Since the crystallizer is not needed, the increase in the investment cost is compensated and additionally annual savings of 1.15 M€ in the make-up chemicals can be achieved. However, due to the low temperature margin between T_0 and the steam temperature 515 °C, even stainless-steel material will not be enough to protect from the molten phase corrosion. In order to maintain a safe margin, the steam temperature has to be lowered down to 505 °C, decreasing the electricity output. Taking also into account that no steam is needed for the crystallizer, the electricity output is decreased by 0.82 MW, which corresponds to an annual deficit of 0.35M€. Furthermore, because of high chlorine and potassium contents, one additional superheater (secondary superheater 0, SSH0, located in front of the secondary superheater) is needed in order to keep the sticky area far enough from the second pass, thus increasing the investment cost. Compared to case 1, the annual operational cost is 0.80 M€ lower but the investment cost is 1.46 M€ higher leading to a payback time of 1.8 years. It is important to notice that since steam temperature was lowered but pressure was held constant, steam quality after the condensing turbine decreases. Therefore, this case is not totally comparable to the other cases. Since it is not sensible for a boiler manufacturer to take a stand on the effect on the turbine, case 2 can be made comparable by lowering the steam pressure to 105 bar(a). As a result, the steam quality is the same as in other cases. This decreases the electricity output substantially leading to 0.28 M€ higher annual operation cost compared to case 1, leading to a negative return on investment compared to case 1.

The other extreme is represented by case 3 where all of the ash is treated leading to a 450 t/d crystallizer. As potassium and chlorine contents are low, no stainless-steel material is needed in the superheaters due to molten phase corrosion. Because of the risk of chlorine induced corrosion, some stainless-steel is used in the last quaternary tubes. The lowest bends are also stainless-steel to give protection from the possible carry-over induced corrosion. It is also good to note that there is a lot of margin from the fouling point of view and long operation without any water washing can be achieved. The drawbacks are higher investment cost (3.89 M€) and - since Na losses are high and a large crystallizer requires more steam than in case 1 - annual operation costs are 3.07 M€ higher. In other words, treating all the ash does not pay off, at least based on the given assumptions.

Case 4 describes a situation where the steam parameters have been increased to 525 °C and 119 bar(a) resulting in 10% heavier pressure part, as described earlier. The same amount of ash is treated as in case 1 so that no additional make-up costs occur. One additional superheater (SSH0) is needed as higher steam enthalpy requires more heat energy to be captured in order to reach the same superheating. This has been included in the investment cost calculations. Since steam temperature is 10 °C higher, more stainless-steel material is required in the superheaters. Due to higher steam parameters, more electricity is produced and therefore the annual operational cost is 1.63 M€ less than in case 1. The extra investment cost is 7.59 M€ higher and it is pays off in 4.7 years.

In case 5, the steam parameters correspond to case 4 but less ash is treated. As a result, 0.27 M€ annual make-up savings are achieved and also power generation is a bit higher than in case 4 because the crystallizer demands less steam and therefore operational costs are the lowest, 1.93 M€/a less as compared to case 1. Payback time of the extra investment is 3.7 years.

Sensitivity analysis

The calculation results shown in the previous paragraphs depend on the assumptions made and therefore it is worthwhile to investigate the sensitivity of these payback calculations. Two interesting parameters are NaOH and electricity prices. **Figure 11** shows the effect of NaOH price on payback time and it can be seen that the payback time of case 2 is the most sensitive to this value. The cheaper the make-up chemical is, the longer the payback time is compared to case 1. Regardless of the NaOH price, the case 3 operation costs are higher than in case 1, meaning that the extra investment in case 3 never pays off. The payback time does not change in case 4 in relation to case 1 since the amount of NaOH needed in both of the cases is the same. That's why case 5 payback time also does not depend so much on NaOH price as the treated ash amount is almost the same as in case 1.

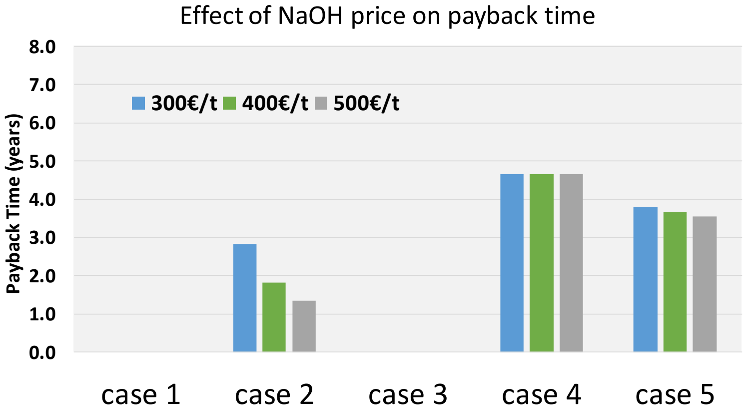


Figure 11. Effect of NaOH price on payback time

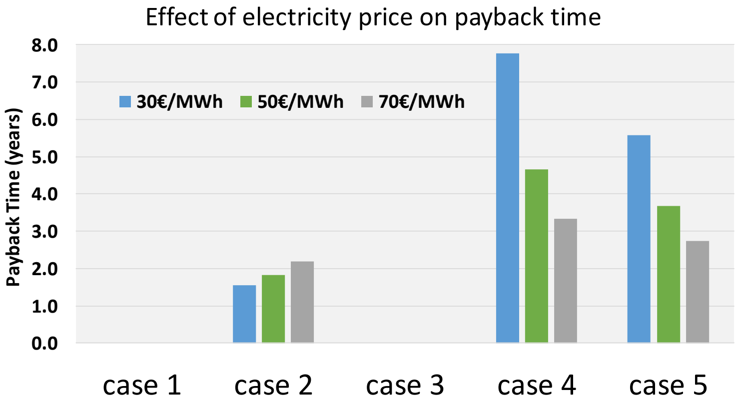


Figure 12. Effect of electricity price on payback time

The effect of electricity price on payback time is presented in **Figure 12**. Case 2 payback time against case 1 increases with higher electricity price as the lower steam temperature generates more deficit in operation costs. Case 3 is not feasible, no matter what the electricity price is.

Cases 4 and 5 benefit from high electricity price as they generate more electricity through the higher steam parameters. The payback time roughly halves when electricity price is doubled.

Conclusions

The energy efficiency of modern recovery boilers, such as Äänekoski, can be improved by introducing the following high power features to the boiler: higher black liquor dry solids, air preheating, a fully pressurized feedwater tank, feedwater preheating, heat recovery from vent gases, heat recovery from flue gases in a flue gas cooler and higher main steam parameters.

Ash composition, especially potassium and chlorine contents, have a significant impact on recovery boiler design through corrosion and fouling phenomena. There are three types of superheater corrosion mechanisms: molten phase, carryover and chlorine induced corrosions. Molten phase corrosion mainly determines the superheater material selection, but carryover and chlorine induced corrosions also have to be included in the design. The most important parameter describing corrosion is the first melting temperature T_0. The fouling region is determined by partial ash melting temperatures T_{15} and T_{70}.

Ash composition can be controlled by using an ash treatment system such as ash leaching or crystallizer. Having low potassium and chlorine contents decreases the need for expensive stainless-steel material in superheaters, but at the same time valuable sodium losses are higher. In other words, it is an optimization between investment and operation costs and the optimum solution has to be determined case by case.

Based on the assumptions made in the paper, it seems that from an economical point of view, it is not feasible to treat all ash. If no ash is treated, steam temperature must be lowered, leading to a deficit in electricity production. However, investment cost is less since no ash treatment system is needed. Lower steam temperature also leads to a decrease in steam quality after the condensing turbine, making that case not totally comparable to other cases. Assuming that lower steam quality does not significantly affect the turbine investment leads to a short payback time. If the steam pressure needs to be decreased in order to reach the same steam quality, then the case is not feasible. It seems that the best solution is to treat an appropriate ash amount which allows increasing the steam parameters without losing too much valuable sodium. The appropriate ash amount of course depends on the given input values and the optimization must be done case by case. Based on the study presented in this paper increasing steam parameters is feasible and the required extra investment pays off in a relatively short time.

References

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